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Authors
Verzhbinsky, G.
Levine, M.D.

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Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

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Gleb Verzhbinsky and Mark D. Levine

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Gleb Verzhbinsky
Mark D. Levine

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABSTRACT

We have developed a model that simulates the hourly residential electricity demand for electric utility service areas. This model is integrated with the Oak Ridge National Laboratory (ORNL)/ Lawrence Berkeley Laboratory (LBL) residential energy demand forecasting model. The most important new feature of the hourly demand model is that it is disaggregated to 12 end uses. This disaggregation, in addition to its extensive time of use and engineering/econometric data base, makes possible the evaluation of specific electric utility conservation programs and various energy conservation policies.

KEYWORDS

Peak demand model, hourly demand model, energy conservation, residential electricity loads.

INTRODUCTION

Electric utility systems design, capacity projections, financial impacts of alternative supply and demand management strategies, rate setting, and energy conservation and load management programs are all key facets of the electric utility industry. Each of these subject areas raises key issues confronting electric

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utilities today. Many of the issues relating to energy conservation and load management are assuming increasing importance to utilities in the current economic climate because of the difficulty in raising capital for new power plants.

In an effort to understand these issues and provide a quantitative evaluation of some of them, we have developed a computer model that forecasts hourly electricity demand for the residential sector. A key feature of this model is that it is disaggregated into each of the twelve major end uses. The model is based both on econometric and engineering/economic data, as well as measured data on time of use of energy demand by end use. The high degree of detail about hourly demand by end use, combined with economic information and a specification of the average efficiency of each appliance type in the house and of the thermal integrity of the house, make possible the evaluation of the potential impact of specific energy conservation and load management activities within an electric utility service area. The model has been applied to the evaluation of the likely impacts of the proposed Building Energy Performance Standards and Consumer Products Efficiency programs of the U.S. Department of Energy.

The residential hourly demand model is currently integrated with the ORNL/LBL residential energy forecasting model (Hirst and Carney, 1978; McMahon, 1981). In order to achieve this integration, selected changes were made in the ORNL/LBL model (especially in the characterization of their thermal integrity of new houses) and a utility specific data base was used as input to the ORNL/LBL model (McMahon, 1981; McMahon and Herring,1981). This approach of incorporating the hourly and average energy demand forecasting models takes advantage of the key features of the ORNL/LBL model: its treatment of socio-economic determinants of energy demand growth, and its engineering/economic data and analysis of residential end use efficiency choices. At the same time, the inclusion of hourly demand data and appropriate algorithms substantially increases the analytical capabilities of the ORNL/LBL model.

We are currently testing the residential hourly load model. Within the next few months, we anticipate completing a validation of the model results against one or two electric utility service areas, using historical data from the past five to ten years. After a full validation exercise is completed (probably requiring application to at least ten utilities), we intend to develop appropriate interfaces between the model and other utility planning tools: capacity expansion, dispatch, and financial models.

OVERVIEW OF RESIDENTIAL HOURLY DEMAND MODEL

This paper describes the structure, input data, operation, and results of the disaggregate residential hourly demand model developed by Lawrence Berkeley Laboratory with the assistance of Hittman Associates, Inc. (HAI). The model:

- projects the hourly and peak electricity demand for the residential sector of an electric utility service area
- estimates the impact of different energy conservation policies on the hourly demand curve (load shape, including peak demand in the residential sector)
- estimates reductions in fuels and capacity for electric generation, by fuel type, resulting from residential energy conservation programs.

The model considers 12 end uses divided into two groups: temperature sensitive (central space heating, room space heating, heat pumps, room air conditioning and central air conditioning) and temperature insensitive end uses (water heating, refrigerating, freezer, cooking clothes drying, lighting, miscellaneous).

The model deals with three housing types: single family, multifamily, and mobile homes; also it disaggregates the total housing stock into three groups by age of the house (and hence, by average, its thermal integrity): houses built before 1974, from 1974 to the present and homes built after the start of the U.S. Department of Energy Building Energy Performance Standards program, assumed to have its initial impact in 1982.

The model can handle as many as five climate zones within a utility service area.

The model simulates hourly electricity demand for each year from 1977 to 2005 (8760 hours each year). The total hourly demand curve is transformed into the load duration curve, which presents the number of hours where load exceeds any fixed value.

The model is part of a larger modelling effort to asses conservation impacts on utilities (CIUS) with the following objectives:

- compute hourly electricity demand profiles under a wide range of economic conditions
- evaluate and project hourly load profiles
    - -by climate region within a service area
    - -by building type (single family detached house, single family attached house, mobile home)
    - -by building thermal integrity
- evaluate the likely impacts of energy conservation programs on the hourly and peak demands of an electric utility.
- quantify the costs and benefits of energy conservation programs to the consumer

- evaluate the effect of utility conservation programs on the cost of delivered electricity and on the financial performance of electric utilities

- estimate the degree to which energy conservation will reduce demand for ail and gas to generate peak and intermediate electricity

- evaluate a range of potential load management strategies to reduce peak demand in the residential sector

- provide a quantitative basis for comparing costs and effects of investments in energy conservation programs and in increased generating capacity (including expansion of transmission and distribution systems, if required) in specific electric utility service areas.

To accomplish these long term objectives, we are working on a series of analytical tools that deal with different facets of the electric utility system. Figure 1 presents an overview of these tools and their interrelationships. This figure also describes the process of modelling conservation impacts on utilities in individual utility service areas. The resulting estimates of service area impacts, combined with regional input forecasts of appliance stock and electricity generation may ultimately be aggregated to the national level after the analysis of enough different electric utilities has been completed. This will permit the tools to be applied to the evaluation of selected national energy conservation policies.

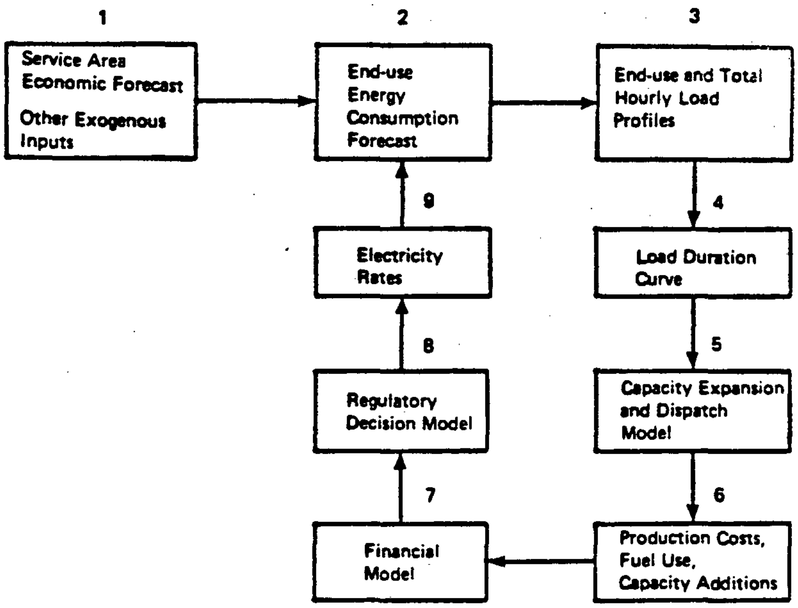

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FIG. 1 MODELS OF CONSERVATION IMPACT ON UTILITIES.

The first step is the development of economic forecasts (e.g., households, personal income, data to develop capacity expansion and dispatch schedule) and other exogenous inputs (e.g., weather) are input for the utility service area. In step 2, these data are used in the ORNL/LBL Residential Energy Model to project annual end-use energy consumption, including electricity consumption. In step 3, end-use and total hourly load profiles are projected based on the annual electricity use forecasts. Step 4 aggregates the total electric utility system load into a load-duration curve.

Step 5 develops an optimal pattern of generation capacity expansion and dispatch (generation by unit type), giving electricity production costs, fuel use, and generation capacity additions (step 6). In step 7, the generation and capacity expansion data are used to assess utility financial performance.

In step 8, a regulatory decision model determines electricity rates (step 9). These rates are input to the end-use energy consumption forecasting model, and steps 2 thru 9 are repeated until the rates converge, i.e., the rates are consistent with the quantity of electricity demanded.

MODEL COMPARISONS

Most utilities project system peak demand, including demand for both residential and not-residential sectors, as an aggregate demand which depends on total sales (EPRI,1977). These aggregate procedures do not develop estimates of the residential sector peak demand.

Some utilities project system peak demand, considering residential appliance (air conditioning) stock and temperature data (CEC,1978). These models also fail to estimate the residential sector peak demand.

Other utilities project peak demand for the residential sector using procedures similar to the Mathematical Science Northwest/MAI model, which estimates the number of appliances, the kw demand per appliance and multiplys and sums these terms to derive residential demand at an assumed peak hour (Consolidated Edison,1980).

A few utilities project residential hourly demand, considering the appliance stock, typical hourly load profiles, and temperature-load relationships for space heating and cooling (NEPOOL,1977). This model builds on the example of the work done by these utilities.

Table 1 presents a comparison among four peak demand models:

- the LBL/HAI electricity hourly demand model in combination with the ORNL/LBL residential Energy Model
- the NEPOOL model (NEPOOL,1977)
- the California Energy Commission forecasting model (CEC,1979)
- the Decision Focus Model. (DFI,1979)

This comparison does not reflect some of the NEPOOL refinements embodied in ELFOR (electric utility forecasting model). Both NEPOOL and ELFOR are proprietary models with restricted data bases within a proprietary computer language (NUCLEUS). However, the comparison does reveal several points regarding potential model use:

- The LBL/HAI hourly demand model is designed for conservation policy analysis; the other models require separate conservation calculations as inputs (although the ELFOR update of NEPOOL includes some conservation calculations within a single model).
- The LBL/HAI model computes savings of all fuels; the other models do not.

INPUT DATA

The model is extremely data intensive. A previous section (Model Overview) summarizes the overall data requirements of the model. The data that is most important and most difficult to obtain is the estimate of time of use of each end use. For the five weather dependent end uses (central space heating, room space heating, heat pump, room air conditioning and central air conditioning), the time of use is a function of the temperature and humidity as well as time of day.

To keep track of the data, we have followed the procedure employed in the NEPOOL model of defining time of use matricies. Initial matrices of relative fraction of capacity of individual appliances in use as a function of temperature and hour of day are input into the model. Adjustments are applied for service area, climate zone, house type, house vintage, and day type (weekday or weekend). Specification of the hourly temperature profile permits selection of relative use value from the adjusted matrices. The final set of values is normalized to the annual demand, obtained from the ORNL/LBL residential energy use demand model.

Table 1. Comparison Among Residential Peak Demand Models

Category	NEPOOL	ORNL/LBL+ HAI/LBL	CEC	DFI
Data Base	New England	10 Service Areas	CA	4 Census Regions (Energy) AL.-WDC (DEMAND)
Number of End Uses	19	12	13	6
Availability	Proprietary	LBL	Published	Published
Satuaration Determinants (ex. Space Heat)	Income	Income, Equipment Fuel Prices	Min. LCC, Fuel Prices	Exogenous
Saturation Determinants, Space Heat	Fuel Cost, Capital Cost, Promotion, Urban Single Family	Income, Fuel Prices, Equipment Price.	Min. LCC	Exogenous
Cooking Seasonal Load Profile	No	Yes	Yes	No
Appliance Load = f(Family Size)	Yes	No	Yes	No
Use/Appliance Determined by	Trend, Fuel Price	Income, Fuel Price	Lt.+Misc=f(Income, Price)	Total Use Assumed
Appliance Efficiency	AEPS	AEPS	AEPS	Constant
Appliance Efficiency Impact	Assumed	Vintage	Vintage	None
Second Homes	Explicit	Not Explicit	Not Explicit	Not Explicit
Connected Load/Home for Conditioning	AEPS	House Size, BEPS, AEPS, LCC (house & appliance)	Vintage, AEPS, (BEPS) (weatherization)	Total Use Assumed
		Income, Weatherization, Tech. Change, House Vintage		
Profiles	Total	Building Type, Vintage	Building Type	Total
Energy Projected	Electricity	All Fuels	Electricity Gas	Electricity
Housing	Endogenous	Exogenous	Endogenous	Not Included
Fuel Savings Calculated	No	Yes	No	No
Hours/Year Calculated Demand	8760	8760	12	192
Appliance Seasonal UseProfile (ex. Cooking)	Yes	Yes	Yes	No
Cost Savings from Storage Calculated	No	No	No	Yes
Load-Duration Curve Estimated (including non-residential)	Yes	Yes	No	Yes
Fuels Included	Electricity	All	Electricity, Natural Gas	Electricity
Demand Distribution Among Customers	No	Yes	No	No

Note: LCC is life cycle cost.
AEPS is appliance efficiency standards.
BEPS is building energy performance standards.

All calculations of hourly electricity demand for temperature sensitive end uses are based on appliance use matricies(NEPOOL,1977). Each element of these matrices gives the fraction of the connected appliance that is operating at any specified temperature and time of day conditions. In other words, these matrices show the shape of hourly demand for any given hourly temperature curve.

Space heater matrices have been derived for the temperature range from -22^{o}F to $+62^{o}$F by steps of +3 degrees (28 values), so 28x24 matrices are used for a space heater. For space cooling (end uses 4,5) the temperature range is from 60^{o}F to 96^{o}F, so in this case we use 13x24 matrices. And 41x24 matrices are used for heat pumps--corresponding to the temperature range from -22^{o}F to $+96^{o}$F. These matrices depend on house type, vintage of the house and climatic zone. Usually there is only one climate zone in the service area, so the model generates 9 matrices for each temperature sensitive appliance for each service area, to account for 3 house types and 3 vintages. Greater detail is provided in the following three sections.

We now describe the adjustment procedure which is used in the model to generate these matrices from the initial inputs to the model. These adjustments are needed to translate the initial matricies, which are for single-family houses in a specific region in which measured data are available for different house types, vintages, and weather regions.

A. Space Heating

NEPOOL provides an estimate of the fraction of electric space heaters in use in existing single-family dwellings (pre-1974) for weekdays, by hour of the day and temperature. These data are used to compute its complement of heaters not in use. A Potomac Edison Company study (1963,1968) indicates that space heaters are used 3% less often in multi-family homes and 3.4% less often in mobile homes than in single-family homes. This information is expressed in the fraction not in use multiplier by building type.

Carrier Corporation (1965) provides design temperature conditions for cities, by service area, and climatic zone within service areas. It is assumed that the maximum NEPOOL fraction of heaters in use in the hour will be attained at the design temperature. For any service area, at temperature below the design temperature, the fraction of heaters in use equals the maximum NEPOOL fraction for that hour. The results of this procedure are shown in Figure 2.

For newer homes with higher thermal integrities, heaters are utilized less at a given tempeature. An LBL analysis using DOE-2.1 (building energy analysis computer program) runs (MSNW,1980) provides the relative fraction of space heaters not in use by building thermal integrity group, when combined with the Potomac results. These results are shown in Figure 3.

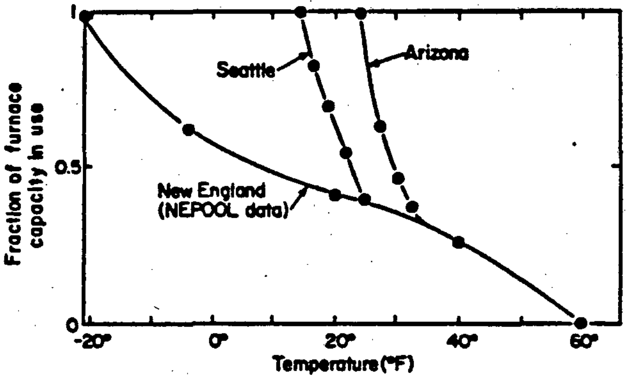

FIG. 2 ADJUSTMENT OF CENTRAL SPACE HEATING FRACTION IN USE FOR DIFFERENT CLIMATE CONDITIONS. XBL 816-937

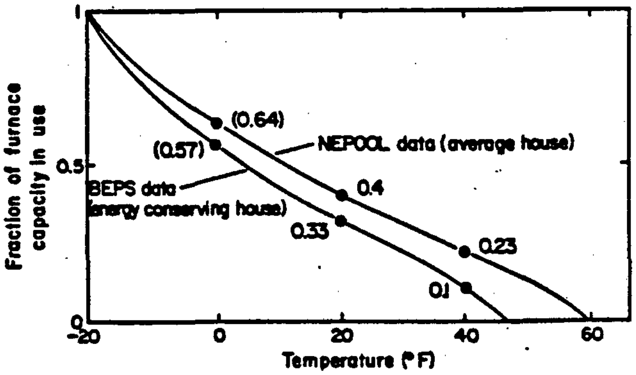

FIG. 3 DEVELOPMENT OF FRACTION OF SPACE HEATERS IN USE AS A FUNCTION OF TEMPERATURE (NEW ENGLAND). XBL 816-939

Few data are available on the usage characteristic of room space heaters. Based on the EPRI compilations (EPRI,1976), we assumed that room heaters were in use 98.5% of the central heater fraction in use, plus 1.5%. Thus room heaters are in use slightly more than central space heaters.

Assuming an electric resistance unit provides low-temperature back up, an electric heat pump fraction not in use is the central space fraction not in use times the heat pump COP (GA,1976).

B. Space Cooling

Like space heating, space cooling temperature-fraction in use by hour data development begins with the NEPOOL relationship.

Matricies relating room air conditioner use, by building type, to temperature-humidity index and hour of the day were developed by weighting similar matrices (PSEG,1961) for room units in the bedroom , living room, and multiple rooms by the prevalence of those units in building types (PPL,1979). These matricies gave kW use instead of fraction in use.

Building type-temperature/humidity index (THI) matrices were related to temperature using regression analyses of temperature-THI relationships to fill in THI data missing from the National Oceanic and Atmospheric Administration data files (e.g., missing wet bulb temperatures). The room air conditioner KW use at capacity, assumed to be at the design temperature, was derived from THI-kW relationships by building type. The difference between the NEPOOL fraction in use and the THI-based estimates was linearly interpolated to zero at +60 F.

Like space heating, the LBL analysis using DOE-2.1 runs (MSNW,1980) provides the relative fractions of air conditioners not in use by building thermal integrity group.

The central air conditioner fractions in use follow the room air conditioner derivation except that the relative hourly loads between room and central air conditioners (CPC,1979) are adjusted according to comparable hourly usage.

The heat pump fractions in use are derived from the central air conditioner values and the relative fractions not in use (GA,1976).

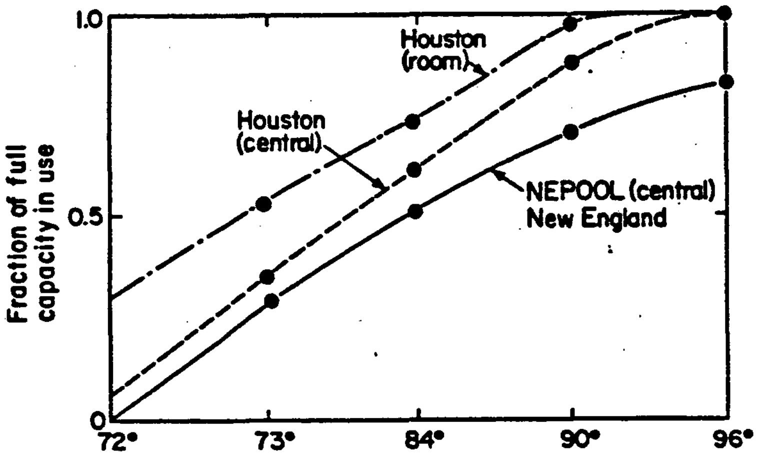

FIG. 4 ADJUSTMENT OF SPACE COOLING FRACTION IN USE FOR CLIMATIC ZONES (ROOM AIR CONDITIONERS 4 PM IN PRE-1974 BUILDINGS).
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For both space heating and cooling, fraction of units in use are limited to the 0,1 range. On weekends, the hourly usage is shifted during the morning hour to reflect later wake-up times, as shown in load studies (CPC,1979;PSEG,1963).

C. Temperature insensitive appliances

For temperature insensitive appliances the corresponding appliance use matrices do not depend on temperature conditions and house vintage, but instead they depend on housing type (single-family, multi-family, mobile homes), daytype (weekday/weekend), season (winter/summer), and hour of the day. The load shapes for these appliances are considered to be the same for all service areas. These matrices are provided by California Energy Commission Study (1979).

ILLUSTRATIVE RESULTS

Figures 5 and 6 show the types of results that can be obtained from the model. Figure 5 illustrates the hourly demand for electricity by each of the major end uses in a winter peaking electric utility during the peak day. Figure 6 provides the same information for a summer peaking utility. From these hourly results (available from the model for each hour of the year) it is possible to derive a wide range of information useful to the evaluation of the impacts of energy conservation and load management on electric utilities.

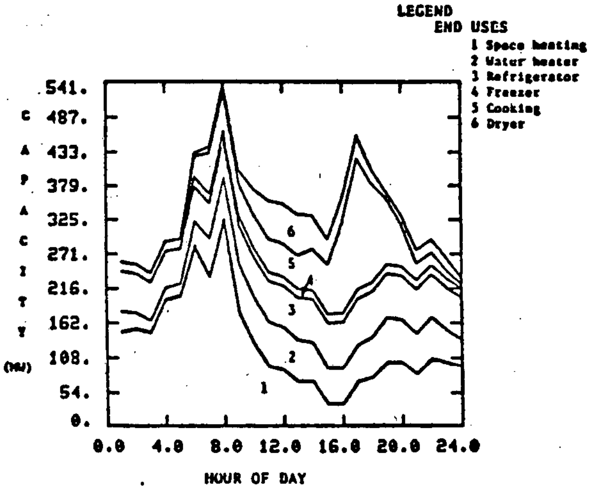

FIG. 5 PEAK DAY HOURLY RESIDENTIAL ELECTRICITY DEMAND BY END USE FOR A WINTER PEAKING UTILITY

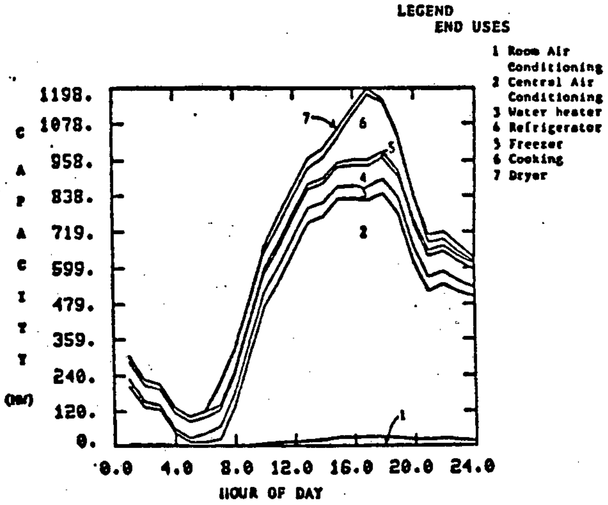

FIG. 6 PEAK DAY HOURLY RESIDENTIAL ELECTRICITY DEMAND BY END USE FOR A SUMMER PEAKING UTILITY

CONCLUSION

While this attempt to build highly disaggregated peak demand model has resulted in a new methodology being made available to the utility industry, there remain several major areas in which further research is desired.

First, the electricity demand of commercial (and industrial) customers needs to be modeled in greater detail.

Second, the model needs to be modified and extended so that the impact of some load management programs (such as time of day rate policy, customer energy storage, etc.) can be analyzed.

Third, the model needs to be implemented and tested for more utility service areas.

Fourth, it is desirable to make the model sensitive to the programs affecting utility financial performance, capacity expansion and dispatch.

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TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720