Analysis of California Hourly End-Use Residential Electricity Load Shapes[1]

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ABSTRACT

The impact of demand-side management programs on residential hourly electrical loads is a major issue for the development of integrated resource plans. Historically, end-use hourly and peak demand models for this task have been constrained only by the availability of high quality load data. This paper reports the results of an analysis of recent sub-metered residential end-use load data for use by such models.

Sub-metered end-use load data for more than 700 Pacific Gas and Electric, 300 Southern California Edison and 50 San Diego Gas and Electric residential customers were analyzed to develop representative daily hourly load shapes by season for refrigerators, cooking, freezers, clothes dryers, dishwashers, and clothes washers. Central and room A/C, and heating loads were represented by fitting empirical observations with an analytical expression that relates energy use to the hour of the day and the weather occuring during that hour.

[1] This work was supported by the California Energy Commission through the University of California Universitywide Energy Research Group and the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

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INTRODUCTION

The impact of demand-side management programs on residential hourly electrical loads is a major issue for the development of integrated resource plans. Historically, end-use hourly and peak demand models for this task have been constrained only by the availability of high quality load data.

The major purpose of the work reported here was to use available measured end-use hourly data to develop new load shapes for the California Energy Commission (CEC) residential peak model. The CEC has developed and used a peak model to forecast electric load growth separately for each utility planning area in the state [CEC 1987]. The model calculates hourly loads for a system peak day based on end-use specific daily load shapes and seasonal allocation factors. It is one of a suite of interconnected models that are used by the Commission staff to evaluate forecasts of energy and load growth submitted by the utilities on a biennial basis.

This paper consists of 4 sections following this introduction. In section 2, we describe our utility sources for data. In section 3, we report our analysis for non-conditioning end uses. In section 4, we report our analysis for conditioning end uses. Section 5 contains our references. The basis for this paper is a longer and more detailed technical report prepared for the California Energy Commission [Ruderman, et al 1989].

DATA SOURCES

In this section, we review the major sources of end-use load data for the project. We limited our analysis to recent and readily available data from the Pacific Gas and Electric Company (PG&E), the Southern California Edison Company (SCE), and the San Diego Gas and Electric Company (SDG&E). Efforts to obtain end use residential load data from the Bonneville Power Authority's End Use Load and Conservation Analysis Program and from the Sierra Pacific Power Company were unsucessful.

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Table 1 summarizes, for each end use, the number of households monitored by each utility.

Table 1. Summary of Residential End-Use Metering Data

	Pacific Gas and Electric	Southern California Edison[1]	San Diego Gas and Electric
Central A/C	384	39	85
Room A/C	55	21	
Heat Pump		4	
Heat Pump Compressor	52		
Heat Pump Heating Strip	13		
Resistance Heat	6		
Water Heater	72		50
Refrigerator	21	62	
Freezer		28	
Stove-Range Top	91		
Stove-Range w/Oven	199	19	
Stove-Oven	28		
Stove-Range, Oven and Mircrowave	20		
Microwave		28	
Misc. Kitchen Circuit	77		
Clothes Dryer	373	30	
Gas Dryer		14	
Clothes Washer		59	
Dishwasher		17	
Television		16	
Pool Pump		9	10

1. Participation in SCE's program was increasing throughout monitoring period; maximum number of households monitored is reported.

Pacific Gas and Electric

PG&E collected residential load data as part of their Appliance Metering Project [PG&E 1987]. The residential sample consists of single-family, owner-occupied residences, which were respondents to the 1983 Residential Appliance Saturation Survey. In each of the 742 households, two end uses were metered, with an emphasis on central air conditioners, clothes dryers, and cooking equipment. The other end uses metered were room AC, heating, heat pumps (compressors and heating strip), water heaters, and refrigerators. Cooking was broken down into range top, oven, range/oven, and range/oven/microwave. The original data intervals vary, but the data were aggregated by PG&E to half-hourly loads for this project. Temperature data from PG&E weather stations were also available. Installation quality inspections were made roughly two

years after installation. Data covering the 1985 and 1986 calendar years were cleaned and validated for this project.

PG&E provided two tapes containing half hourly data for 742 houses metered during 1985 and 1986. A third tape contained demographic data from the 1983 RASS, weather data for 1985 and 1986 from 25 PG&E weather stations, and some average load shapes derived by PG&E from the AMP data. All data were in SAS format. All information that would identify individual customers were removed by PG&E and replaced by a single variable which could be used to identify households across data sets.

Southern California Edison

This monitoring project consists of single-family residences with a summer consumption of over 800 kWh/mo. Three channels were monitored in each of about 300 homes, covering 14 different end uses with a data interval of 5 minutes. Monitoring began in late 1985, and about 1.5 years of data have been recorded. Demographic data were available from hardcopy (survey forms) only.

The five-minute interval data were provided by SCE on five tapes. The data covered the period Jan. 1, 1986 through Dec. 31, 1986. The weather data on a separate tape consisted of hourly temperature data from 26 SCE weather stations.

San Diego Gas and Electric

Data are from the Residential Peak Shift Project, in which load management was investigated. Monitoring in most cases covered three years from 1982 to 1985. The data for each residence include total load and either the air conditioner, water heater, or pool pump. Demographic information was available for the households, and weather information (including smog levels) was also available.

SDG&E provided a single tape containing hourly load data and information on the maximum and minimum temperatures for each day. No demographic data was provided except for house type -- single-family, multifamily or mobile home.

NON-CONDITIONING END USES

Pacific Gas and Electric

The PG&E data tapes provided end-use load data for refrigerators, water heaters, clothes dryers, and four combinations of cooking appliances (see Table 1). After analyzing the cooking data separately, the monthly energy consumptions and daily load shapes appeared sufficiently similar to justify combining the four cooking appliance types into a single cooking end use. The resulting non-conditioning end uses were then analyzed.

Figures 1 through 4 present our results for refrigerators, water heaters, clothes dryers, and cooking, respectively.

Southern California Edison

The SCE data tapes provided end-use load data on six end uses, including refrigerator, freezer, cooking, dishwasher, clothes washer, and clothes dryer.

Figures 5 through 10 present daily load shape data for refrigerator, freezer, cooking, dishwasher, clothes washer, and clothes dryer, respectively.

San Diego Gas and Electric

The only non-conditioning load data we analyzed from the SDG&E tape was electric water heaters. Because some of the water heaters were subject to cycling on certain days, it was necessary to select a subsample containing only data for days on which no cycling strategy was employed. Figure 11 presents the daily load shape data for water heating.

CONDITIONING END USES

Our analysis of residential load data for the conditioning end uses focussed on re-estimation of the time-temperature matrices used to develop hourly load profiles for the peak day. Each time-temperature matrix relates conditioning load to the hour of the day and the weather conditions in that hour. Separate central A/C and room A/C time-temperature matrices were developed from the PG&E and SCE data, and a single heating time-temperature matrix was developed from the PG&E data.

The analysis proceeded in two steps. First, we binned and summed the hourly household conditioning loads by time and temperature for the heating end uses and by time and temperature-humidity index (THI) for the cooling end uses. Dividing the summed load by the number of households monitored at the time and temperature gave a raw value for the average load. However, the raw average load time-temperature matrices were not suitable for use in a model because of statistical fluctuations between nearby bins (see Figure 12). The second step in creating the final time-temperature matrices was to smooth the raw matrices using a statistical fitting technique especially developed for this purpose.

Pacific Gas and Electric

We developed separate time-temperature matrices for central A/C, room A/C, and central space heating from the PG&E residential load data. Figures 13 through 15 present these data graphically.

Southern California Edison

We developed separate time-temperature matrices for central A/C and room A/C from the SCE residential load data. Figures 16 through 18 present these data graphically.

REFERENCES

California Energy Commission (CEC), "California Energy Demand: 1985-2005, Volume II, Electricity Demand Forecasting Methods," CEC Publication P300-87-004, July 1987.

Pacific Gas and Electric Company, "Residential Appliance Load Study, 1985-1986," September 1987.

Ruderman, H., Eto, J., Heinemeier, K., Golan, A., and Wood, D. "End-Use Load Shapes for the CEC Residential Peak Model" LBL Report LBL-27114, 1989.

Figure 1. Daily Load Shape - Refrigerator
source: LBL-PG&E

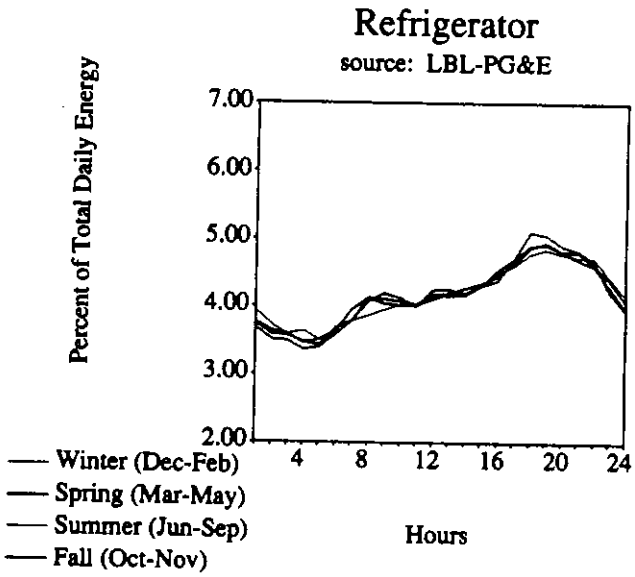

Figure 2. Daily Load Shape - Water Heater
source: LBL-PG&E

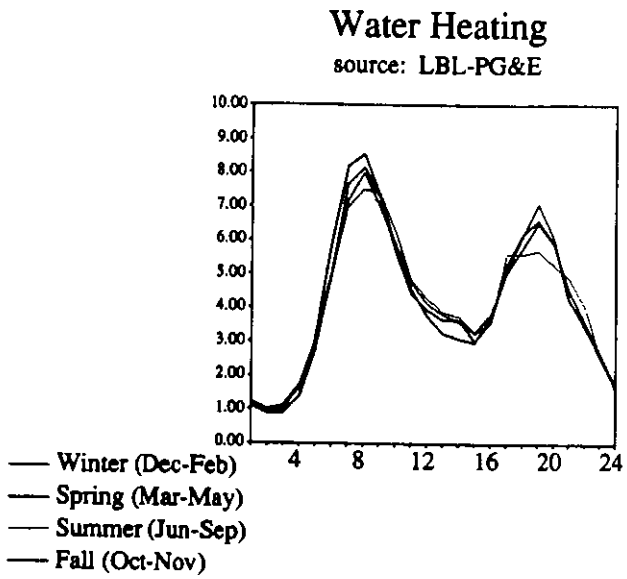

Figure 3. Daily Load Shape - Clothes Dryer
source: LBL-PG&E

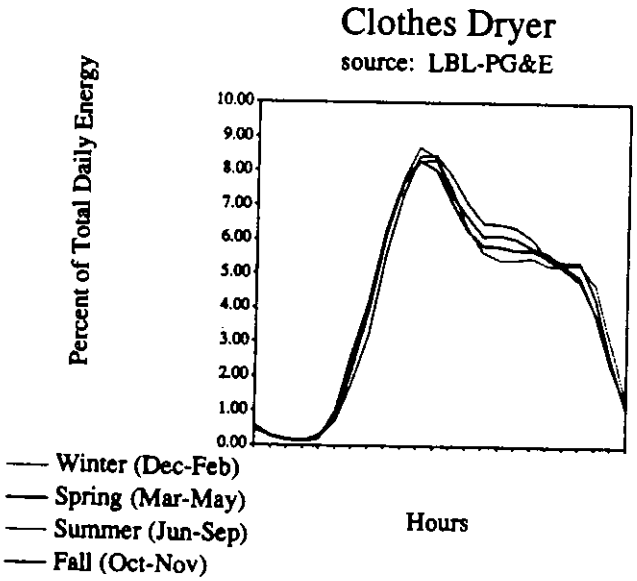

Figure 4. Daily Load Shape - Cooking
source: LBL-PG&E

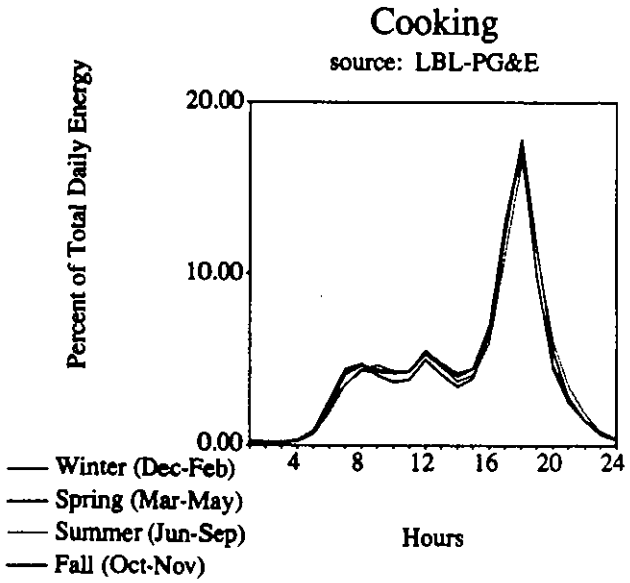

Figure 5. Daily Load Shape - Refrigerator source: LBL-SCE

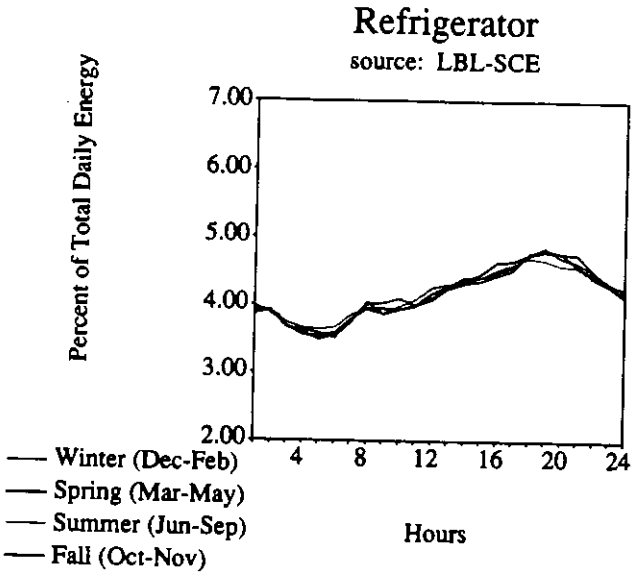

Figure 6. Daily Load Shape - Freezer source: LBL-SCE

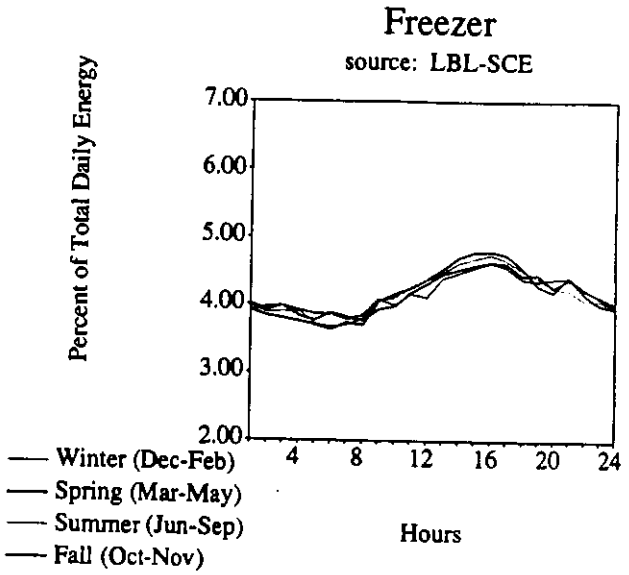

Figure 7. Daily Load Shape - Cooking source: LBL-SCE

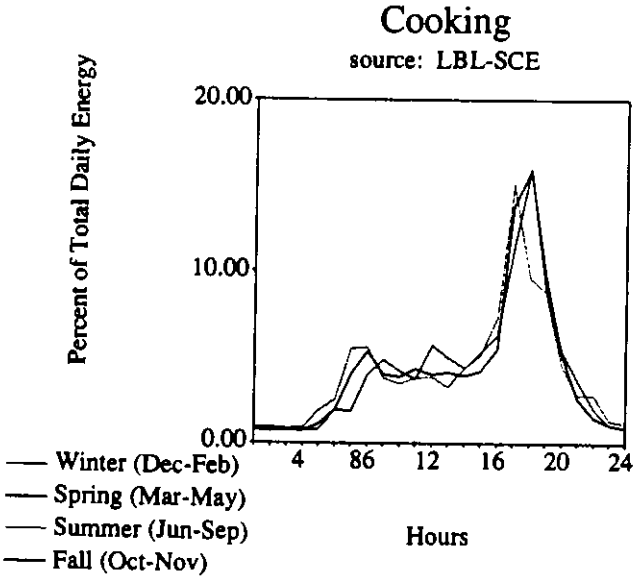

Figure 8. Daily Load Shape - Dishwasher source: LBL-SCE

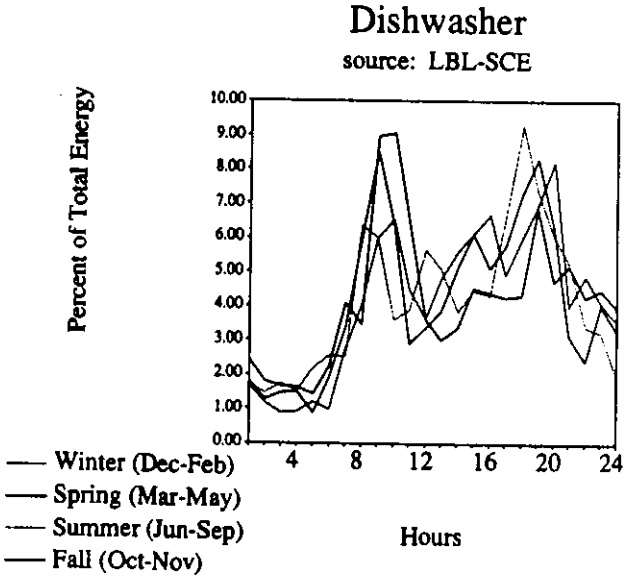

Figure 9. Daily Load Shape - Clothes Washer source: LBL-SCE

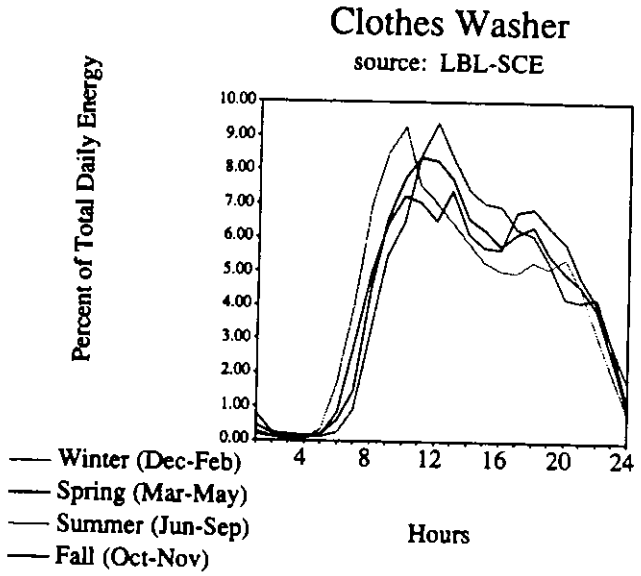

Figure 10. Daily Load Shape - Clothes Dryer source: LBL-SCE

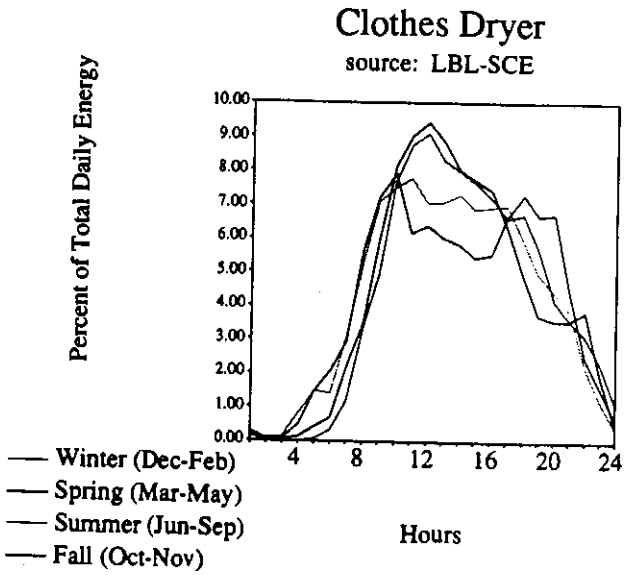

Figure 11. Daily Load Shape - Water Heater source: LBL-SDG&E

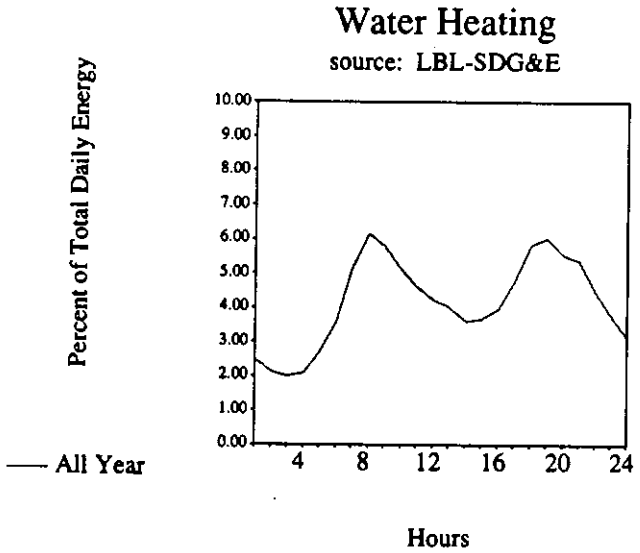

Figure 12. Raw Time-Temperature Matrix - Central A/C
source: LBL-PG&E

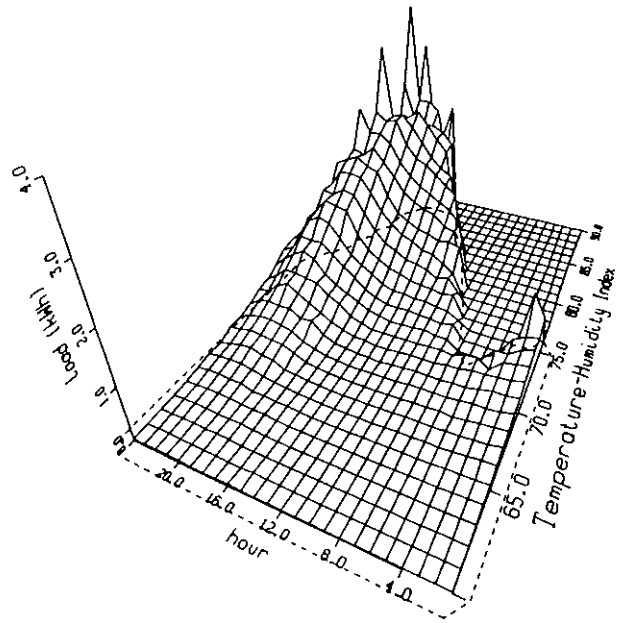

Figure 13. Smoothed Time-Temperature Matrix - Central A/C
source: LBL-PG&E

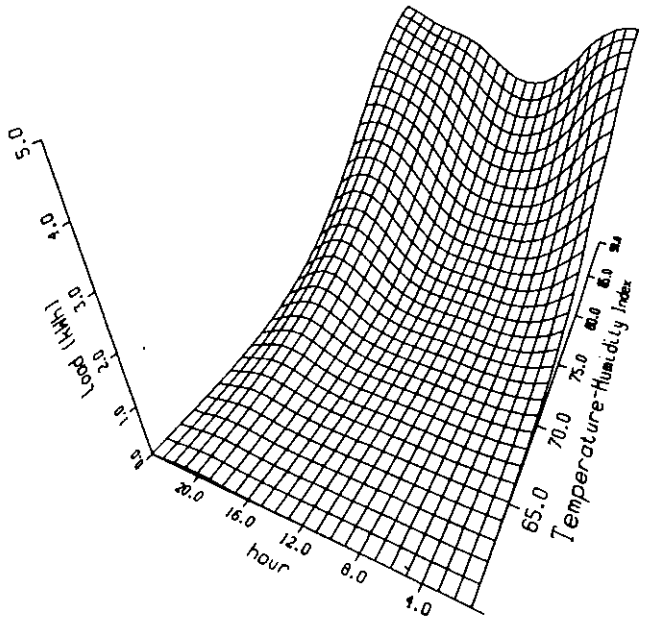

Figure 14. Smoothed Time-Temperature Matrix - Room A/C
source: LBL-PG&E

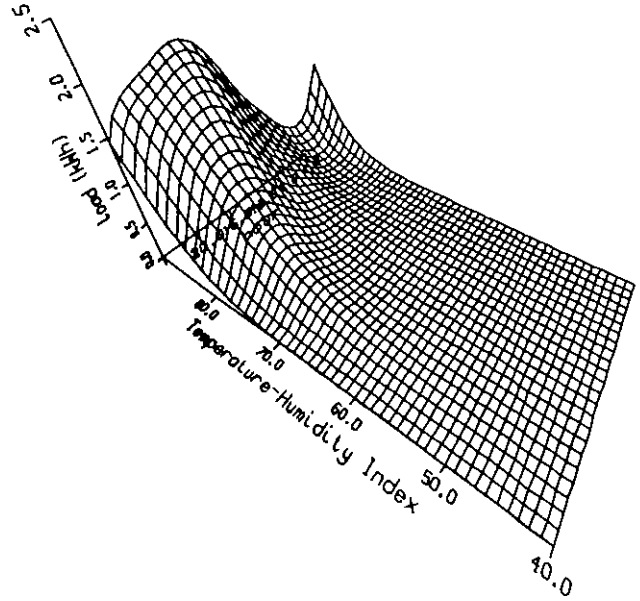

Figure 15. Smoothed Time-Temperature Matrix - Heating
source: LBL-PG&E

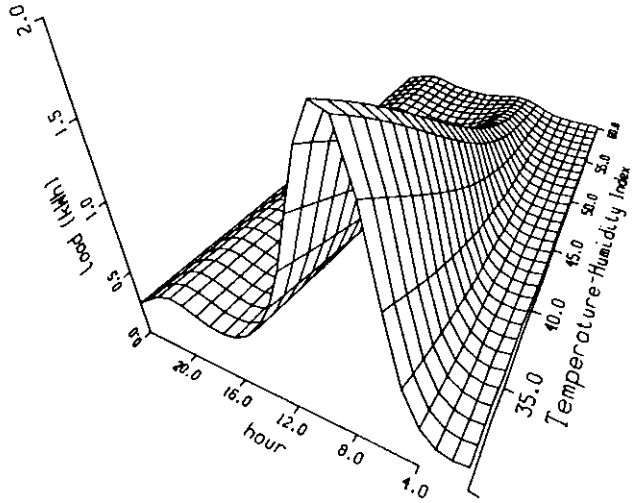

Figure 16. Smoothed Time-Temperature Matrix - Central A/C source: LBL-SCE

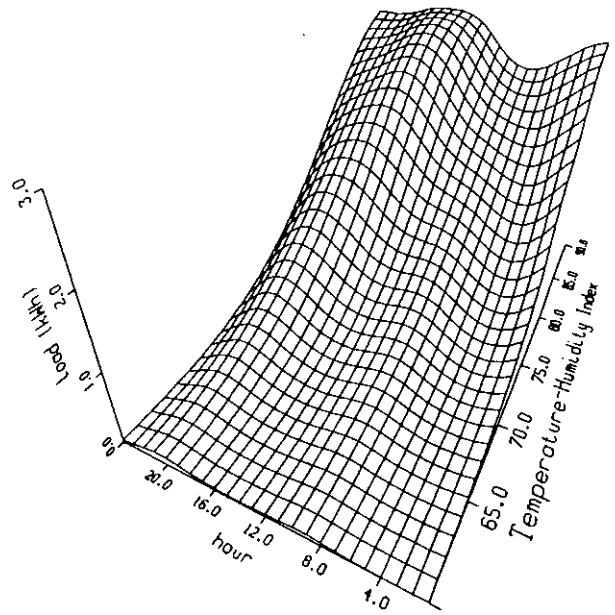
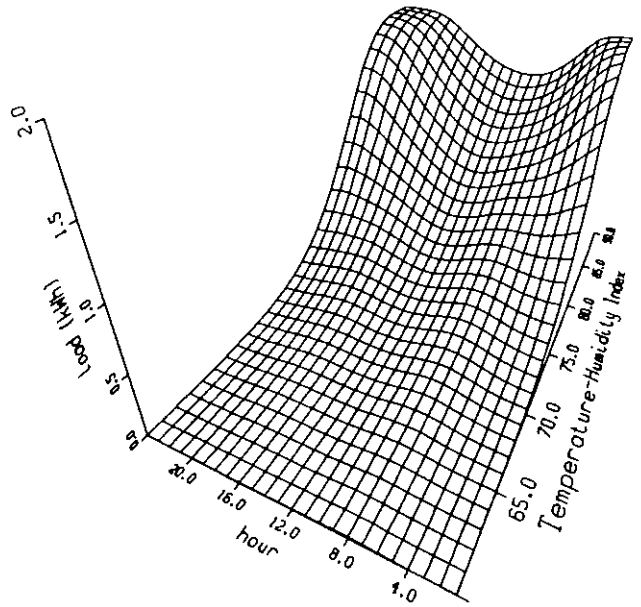
Figure 17. Smoothed Time-Temperature Matrix - Room A/C source: LBL-SCE