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Measured Commercial Load Shapes and Energy-Use Intensities and Validation of the LBL End-Use Disaggregation Algorithm

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FINAL REPORT
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A report prepared for the
Southern California Edison Company (SCE)
and
California Institute for Energy Efficiency (CIEE)

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Abstract

The Southern California Edison Company (SCE) has conducted an extensive metering project in which electricity end use in 53 commercial buildings in Southern California has been measured. The building types monitored include offices, retail stores, groceries, restaurants, and warehouses. One year (June 1989 through May 1990) of the SCE measured hourly end-use data are reviewed in this report. Annual whole-building and end-use energy use intensities (EUIs) and monthly load shapes (LSs) have been calculated for the different building types based on the monitored data. This report compares the monitored buildings' EUIs and LSs to EUIs and LSs determined using whole-building load data and the End-Use Disaggregation Algorithm (EDA). Two sets of EDA determined EUIs and LSs are compared to the monitored data values. The data sets represent: 1) average buildings in the SCE service territory and 2) specific buildings that were monitored.

The EDA model was developed at Lawrence Berkeley Laboratory (LBL). It uses characteristics of the whole-building electric load and disaggregates it into major end-use components. The EDA based EUI and LS values presented in this study for average buildings have been determined in a previous study conducted by LBL and jointly sponsored by the California Energy Commission (CEC) and Southern California Edison. The average building types are the same as the monitored building types. The average buildings are based on the average characteristics of buildings found in SCE's service area. The data indicate that the EDA estimates and the measured average end use EUIs and LSs for all the building types reviewed, except the grocery, statistically compare well. The LBL LSs developed for non-standard days (weekends and holidays) show some questionable characteristics. These LSs were found to differ from those in the limited sample of end-use metered buildings.

The measured data from two of the end-use metered buildings (an office and a retail store) have been used to validate the LBL EDA model. The characteristics of the buildings and their measured whole-building loads were used with EDA to estimate their end use loads. In the retail store analysis, the EDA estimates of hourly end-use compare remarkably well with the monitored end-use data (average error of less than 5% during daytime operation). For the office building, the model gives a consistent bias of about 30% in over estimating the HVAC electric load at the expense of under estimating the miscellaneous load. This can be attributed to the presence of inconsistencies between the office audit information and its measured end-use data. A three-fold difference between the auditor's estimate for miscellaneous energy use (EDA input) and the metered amount has been found. The validation, however, indicates great promise for the application of EDA to whole-building load data for obtaining reliable end-use data.

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Chapter I: Introduction and Purpose

Reliable end-use electric load shape data are essential for accurate load forecasting. Metering projects to obtain the needed data are very expensive and, consequently, difficult to justify. Analytical techniques to obtain these data are promising alternatives to metering because they are far less costly. Nevertheless, validation of these techniques must rely ultimately on end-use metered data.

In 1988, the Southern California Edison Company (SCE) and the California Energy Commission (CEC) jointly sponsored a unique project at the Lawrence Berkeley Laboratory (LBL). The project was to develop an analytical technique to estimate typical commercial sector load shapes (LSs) and end-use energy use intensities (EUIs) using whole-building load research data, individual building audit data, and mail survey data from many buildings (Akbari *et al.* 1989). The building types and end uses addressed in the SCE/CEC project are summarized in **Table I.1.** These categories are the same as those used in SCE's energy forecasting model. For the project, LBL developed a disaggregation method and determined EUIs and LSs for each building type in three SCE climate zones. The climate zones are represented by Los Angeles, Burbank, and Norton Air Force Base weather.

The development of a disaggregation method is significant because such an analytical technique promises to be far less expensive than end-use metering for obtaining end-use LSs and EUIs. The LBL project was unique because it produced a new method for performing this type of analysis. The method is based on a combination of engineering analysis, building performance computer simulations and reconciliation with measured whole-building electric load data (Akbari *et al.* 1988). The project was also unique because it represented a convergence of SCE and CEC energy demand forecasting research efforts with the end result of a common set of data for use in future forecasts.

An important missing piece of the project was the absence of high quality end-use metered data to validate the technique. Although validation was envisioned in the scope of the initial effort, the needed data were not yet available. Now that the SCE metering projects are mature, we can use existing data to refine and validate the LSs and EUIs developed by LBL.

Table I.1 Building types and end uses addressed in the previous SCE/CEC study.

	Building type / End use	Space heating	Space cooling	Ventilation	Lighting Indoor	Lighting Outdoor	Water heating	Refrigeration	Cooking	Office Equipment	Misc.
*	Office	X	X	X	X	X	X			X	X
1	Small office	X	X	X	X	X	X			X	X
2	Large office	X	X	X	X	X	X			X	X
*	Retail store	X	X	X	X	X					X
3	Large retail store	X	X	X	X	X					X
4	Small retail store	X	X	X	X	X					X
5	Grocery store	X	X	X	X	X	X	X			
*	Restaurant	X	X	X	X	X	X	X	X		X
7	Sit-down restaurant	X	X	X	X	X	X	X	X		X
8	Fast food restaurant	X	X	X	X	X	X	X	X		X
*	Warehouse	X	X	X	X	X		X			X
9	Refrig. warehouse	X	X	X	X	X		X			X
10	Non-refrig. warehouse	X	X	X	X	X					X

A comparison of data collected in the SCE end-use metering project (**Table I.2**) and end-use data required for the forecasting model (Table I.1) indicates that some further disaggregation of the monitored data is required to make them useful for the model. For instance, the metered end-use data for HVAC should be further disaggregated to Heating, Ventilation, and Air-Conditioning loads. One of the purposes of this project is to compare the metered end-use data with our previous estimates of EUIs and LSs resulting from the SCE/CEC-sponsored project and, accordingly, refine the EUIs and LSs.

In the first part of this report, we compare the EUIs and LS for the 53 SCE buildings to EUIs and LS predicted by the disaggregation algorithm for the average building population. The average EUIs and LS were developed in the 1989 LBL study. We discuss the metered end-use data obtained from SCE and review them for completeness. We briefly review the characteristics of the buildings that have been submetered and compare their characteristics to those which represent the population of commercial buildings in the SCE service territory. The objective of this comparison is to assess the feasibility for making generalized findings from the limited SCE submetered building sample and relating these findings to the building population. We discuss using the end-use metered data to assess the estimates of EUIs and LSs resulting from the previous LBL project. The assessment was initially planned to be carried out for the building categories of office, retail, and grocery. But in addition, we have been able to analyze data for restaurant and warehouse buildings.

In the second part of this report, we apply the EDA to two individual buildings in the SCE metering sample , an office building and a retail building. We compare the measured EUIs and LS and the EDA-developed EUIs and LS for each building. The comparison allows for the refinement and validation of the EDA methodology.

The report concludes with a summary of the project's major findings. The possible uses for the end-use data in further validation and refinement of EDA are discussed.

Table I.2 Summary of SCE's metered end-use data

Building Type	# of Buildings	# of Channels	Measurements							
			Total	Lighting	HVAC	Refrig.	Plug	Cooking	Exhaust	Out Temp.
Office	12	8	X	X	X		X			X
Retail	10	4	X	X	X					X
Grocery	16	8	X	X	X	X				X
Restaurant	12	8	X	X	X	X		X	X	X
Full Service										
Fast Food										
Warehouse	3	4	X	X						

Chapter II: Analysis of Measured End-Use Data

Input Data

The SCE end-use monitoring project has collected short-interval (15-minutes to hourly) data for up to six end uses for five building types in 53 buildings. The building types monitored include offices, retail stores, grocery stores, restaurants, and warehouses. Only electricity consumption data are collected. The end uses monitored include total building electricity use, HVAC, lighting, refrigeration, cooking, plug load, and exhaust fan. In addition to electricity use data, outdoor temperature was also collected for some buildings. Table I.2 provides a summary of monitored building types, number of buildings, end uses, and the number of monitored channels per building. A detailed review of these data is reported in SCE (1989 and 1990).

To limit metering costs, the SCE project has been selective in monitoring end uses. A minimum of two end uses, total building and lighting energy use, has been collected for all building types. Total HVAC energy have been collected for all building types but the warehouses. Plug load and refrigeration load have been collected for offices and groceries, respectively. For restaurants, refrigeration, cooking, and exhaust fan end uses have also been monitored.

The buildings selected for the SCE end-use metering projects were a subset of the 375 buildings that had detailed on-site survey data collected for them during 1985-1986 (CEC 1986). The data were used in the 1989 LBL project for defining average building characteristics in the SCE service territory. We received the on-site survey data for the building set in electronic form, the files were formatted for use with Statistical Analysis Software (SAS). In the electronic data set, information regarding the building identification (i.e. address) was removed before the data were transferred to LBL. As part of the end-use metering project, SCE collected updated building and system information for the 53 buildings. Hard copies of the updated data along with the hourly end-use data were provided to LBL for use in this study.

We received one year of metered data (June 1, 1989 through May 31, 1990) for most of the building types. In addition to the monitored end-use data, we received a year of outside dry bulb temperature data, revised and updated information on the conditioned and unconditioned floor areas for each building, and the suggested floor area weighting factors. The weighing factors are used for estimating the population EUIs and LSs from the sample buildings' EUIs and LSs. The SCE weighting factors are derived from the fraction of floor area, by building type, that are represented by the monitored buildings in each of the SCE's four planning regions.

Since our analysis required data starting on January 1, we wrapped the metered values and created one complete calendar year of data such that January 1 to May 31 of 1990 appears at the beginning of the data stream, followed by June 1 to December 31 of 1989. For buildings in which monitoring started later than June 1, 1989, the wrapping of data caused discontinuities to appear in the plots. However, it did not affect our analysis.

For quick visual check of the data, we have generated three dimensional plots of the hourly data. A sample of these 3-D plots for an office building (Office # 5) with HVAC, lighting, receptacles, and total building metered electricity use is shown in **Figure II.1**. Similar plots have been generated for each of the metered buildings and are presented in Appendix A.

Note that the HVAC electricity use for Office #5 is primarily driven by schedules. Besides daily operational schedules of the HVAC system, two levels of HVAC use corresponding to June through November 1989 and December 1989 to May 1990 periods are observed. In fact, the observed HVAC energy use, during January and February 1990, seems to be different from the other two periods. The same variation is also observed in the plug energy use, with apparently a few weeks of significant variations from 'normal' schedules during the months of March and April 1990. The lighting energy use apparently follows a uniform daily schedule during the year.

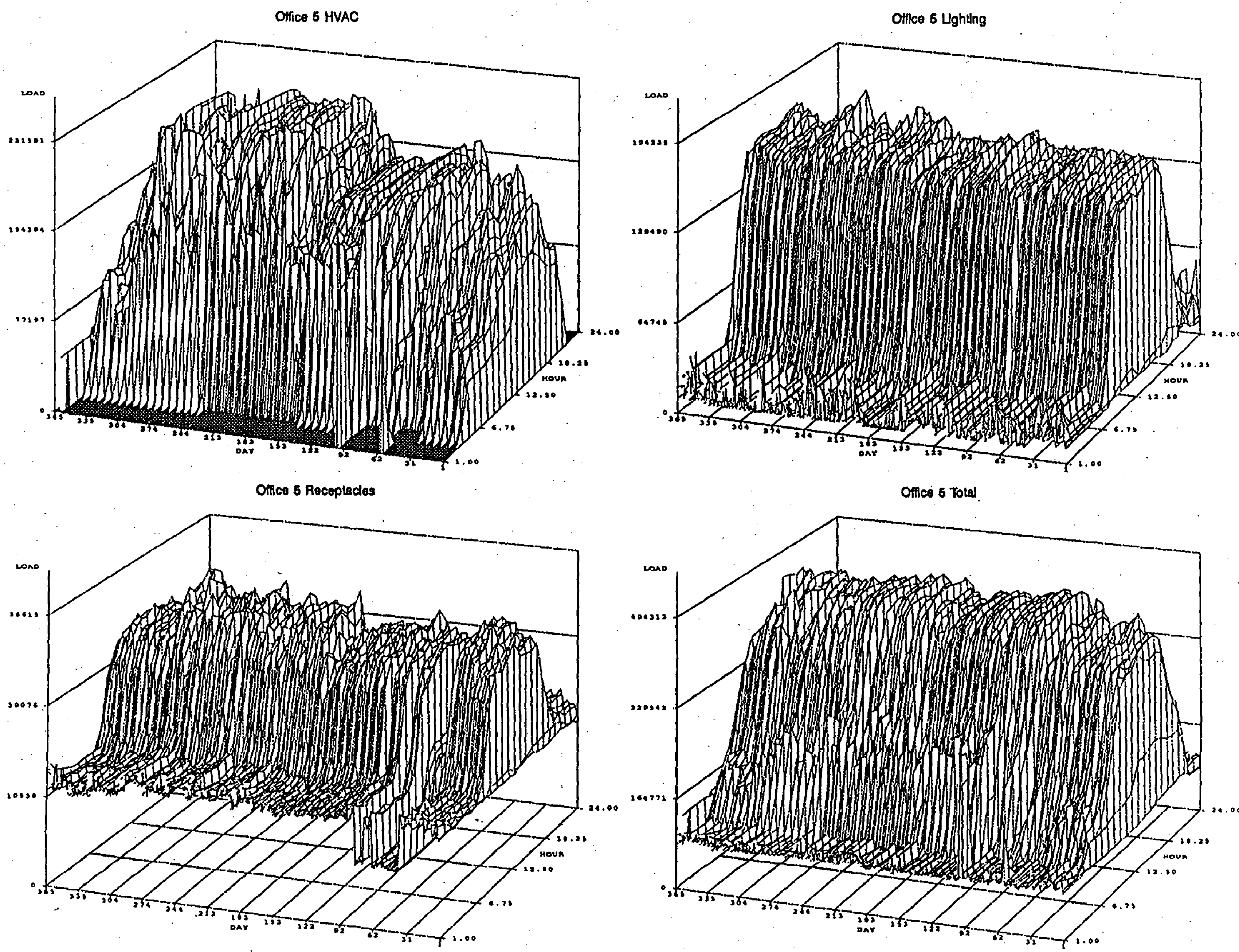
As we will discuss in the following sections, the total building electricity use is key input data to the EDA algorithm. The disaggregation of total electricity use data into end-use consumption is based on the two principle hypotheses of EDA, namely:

1. the total building electric load carries the true signature of all the major building end uses and
2. the temperature dependence of the total building electricity use is caused solely by HVAC energy use.

Metered end-use data provide a means for validating these hypotheses. Using the SCE sub-metered data however, resulted in two immediate problems. First, not all building end uses are monitored; the total building electricity use is usually larger than the summation of all the end uses.[1] Second, the definition of the metered end uses are not consistent. For instance, the plug

[1] As discussed in the appendix, two buildings have total building energy use less than the summation of all the monitored end uses.

Figure II.1
Hourly Monitored Data For Office No. 5



energy use may include task lighting or weather dependent end uses such as electric space heaters or fans.

Despite the above-mentioned problems, it is still possible to observe the characteristics of the HVAC load in the whole-building hourly electricity use. HVAC electric loads are characterized by operating schedules and climate conditions. For the two buildings examined, the periods of daily schedule changes that are observed for both the whole-building and the HVAC electricity use are; June through November 1989, December 1989 through February 1990, and March through May 1990. We will discuss and present the temperature dependency of the HVAC and whole-building load in a subsequent section.

EUI Analysis and Comparison with Forecasting Models

EUIs were developed for all monitored end uses using total building load data from the sample of monitored buildings. In determining the annual EUIs, we summed the energy use for all the hours that were monitored. In those cases where a year of data was not available, the estimated EUIs were prorated based on the ratio of 8760 to the hours of available data. For example, the sum of the energy use for all valid, metered hours of Office #6 (this building has 8,575 hours of valid data) is multiplied by the ratio of 8,760 over 8,575 in order to estimate the building's EUIs. Such a simple proration, in general, will yield an acceptable amount of accuracy for EUIs, provided that the number of hours of missing data is only a small fraction (less than 25%) of all the data. The prorated EUIs are then used to develop weighted and unweighted average EUIs for each building type.

Hourly data are not valid and not included in the analysis if

- the data are labeled missing (indicated by '.' in the SAS file),
- the data are labeled questionably (indicated by negative numbers in the SAS file),
- or the data collection for a building started later than June 1, 1989 (shown as missing data).

In the following sections, we present a summary table of EUIs including the estimated average EUIs for each building type. We compare the end use intensity values with each other and with the EUIs estimated in the 1989 LBL study.

Office buildings

There are 12 office buildings in the data sample with total floor areas ranging from 2,400 to 160,000 ft^2 and total electric EUIs ranging from 3.4 to 59 kWh/ft^2 year. We partitioned the offices into two categories; small and large. SCE has also partioned their commercial customers into small and large building categories. We used the same criteria as SCE for partitioning. The size partitions are based on 15 minute-interval whole-building Load Research Data (LRD) collected by SCE; all those offices with annual electricity use of over 400,000 kWh/year are considered large and those with annual electricity use less than 400,000 kWh/year are considered small. With this partitioning criteria, offices 1, 4, 5, and 12 are in the large office group and offices 3 and 6 through 10 are in the small office group.

Upon examination of the electricity use data, we found that office #2 is actually a warehouse (EUI=3.4 kWh / ft^2 year) and office #11 has an activity which uses a large of amount energy (EUI=59 kWh/ ft^2, such as a printing shop) that should be dealt with separately. For these reasons, in calculating the average EUIs, we did not use data from these two buildings. Note that the total building EUI, excluding office #2 and #11, ranges from 7.7 to 26.8 W/ft^2 year. **Table II.1** presents the summary data for all offices. The metered data summary includes the hours of valid and bad data, the estimated EUIs based on the conditioned and total building floor area, and the weighted and unweighted EUIs.

Figure II.2 compares the total electricity use for the twelve offices with the office total energy use developed using EDA by LBL in the 1989 study. The comparison is favorable for small office buildings but for large office buildings the LBL data is about 20% larger than the average of the monitored large offices. Knowing that the LBL values have been developed from SCE's building-class billing data and 1985 on-site building survey data, the difference between the average EUIs can probably be attributed to the small sample size of the monitored offices.

Figure II.3 compares the measured HVAC EUIs for large and small offices with the LBL EUI values. The LBL study provides data for three climate regions. However, the limited sample size of the monitored building does not allow a comparison at a regional climate zone level. Hence, we took the EUIs developed for the Burbank climate zone from the LBL study as an average of the entire SCE service area for all of our comparisons of HVAC EUIs.

Table II.1
End Use Intensities for Office Buildings

Bldg Type	Bldg Num	End Use	Observations Valid	Observations Bad	Total Floor Area	Conditioned Floor Area	End Use Intensities ($kWh/ft^2 \cdot yr$) per tot flr area	End Use Intensities ($kWh/ft^2 \cdot yr$) per cond. flr area
OFF LGE	1	HVAC	8760	0	19800	19800	9.130	9.130
OFF LGE	1	Lighting	8760	0	19800	19800	12.064	12.064
OFF LGE	1	Receptacle	8760	0	19800	19800	0.549	0.549
OFF LGE	1	Total	8760	0	19800	19800	26.798	26.798
OFF *	2	HVAC	8760	0	58632	9462	0.392	2.433
OFF *	2	Lighting	8760	0	58632	9462	2.299	14.248
OFF *	2	Receptacle	8760	0	58632	9462	0.378	2.344
OFF *	2	Total	8760	0	58632	9462	3.395	21.040
OFF SML	3	HVAC	8759	1	28880	28880	3.243	3.243
OFF SML	3	Lighting	8760	0	28880	28880	2.338	2.338
OFF SML	3	Receptacle	8760	0	28880	28880	3.919	3.919
OFF SML	3	Total	8759	1	28880	28880	11.338	11.338
OFF LGE	4	HVAC	7738	1022	51500	51500	2.513	2.513
OFF LGE	4	Lighting	8549	211	51500	51500	3.430	3.430
OFF LGE	4	Receptacle	8549	211	51500	51500	2.405	2.405
OFF LGE	4	Total	8548	212	51500	51500	17.274	17.274
OFF LGE	5	HVAC	8757	3	117600	101136	5.961	6.932
OFF LGE	5	Lighting	8757	3	117600	101136	4.419	5.139
OFF LGE	5	Receptacle	8757	3	117600	101136	2.149	2.499
OFF LGE	5	Total	8757	3	117600	101136	17.127	19.916
OFF SML	6	HVAC	8575	185	46125	37420	4.007	4.939
OFF SML	6	Lighting	8575	185	46125	37420	2.964	3.654
OFF SML	6	Receptacle	8575	185	46125	37420	1.219	1.503
OFF SML	6	Total	8575	185	46125	37420	7.714	9.509
OFF SML	7	HVAC	7751	1009	21300	21300	8.646	8.646
OFF SML	7	Lighting	7751	1009	21300	21300	8.968	8.968
OFF SML	7	Receptacle	7751	1009	21300	21300	3.202	3.202
OFF SML	7	Total	7751	1009	21300	21300	21.846	21.846
OFF SML	8	HVAC	6694	1442	32800	32800	2.079	2.079
OFF SML	8	Lighting	7617	543	32800	32800	5.260	5.260
OFF SML	8	Receptacle	7617	519	32800	32800	2.907	2.907
OFF SML	8	Total	7617	519	32800	32800	14.185	14.185
OFF SML	9	HVAC	7920	216	19150	16852	5.259	5.976
OFF SML	9	Lighting	7920	240	19150	16852	6.145	6.983
OFF SML	9	Receptacle	7920	216	19150	16852	0.540	0.614
OFF SML	9	Total	7920	216	19150	16852	21.673	24.629
OFF SML	10	HVAC	7536	264	2396	2396	4.466	4.466
OFF SML	10	Lighting	7536	264	2396	2396	7.900	7.900
OFF SML	10	Total	7535	265	2396	2396	15.073	15.073

Table II. 1 (continued)
End Use Intensities for Office Buildings

Bldg Type	Bldg Num	End Use	Observations Valid	Observations Bad	Total Floor Area	Conditioned Floor Area	End Use Intensities ($kWh/ft^2 \cdot yr$) per tot flr area	per cond. flr area
OFF *	11	HVAC	6781	1019	15900	15900	18.903	18.903
OFF *	11	Lighting	6740	1060	15900	15900	10.743	10.743
OFF *	11	Receptacle	7560	240	15900	15900	3.116	3.116
OFF *	11	Total	7560	240	15900	15900	59.462	59.462
OFF LGE	12	HVAC	5784	0	81914	50787	5.316	8.573
OFF LGE	12	Lighting	5784	0	81914	50787	2.922	4.712
OFF LGE	12	Receptacle	5544	264	81914	50787	0.971	1.566
OFF LGE	12	Total	5543	241	81914	50787	11.332	18.277
Weighted Averages :								
OFF SML		HVAC					6.002	7.554
OFF SML		Lighting					5.515	6.408
OFF SML		Receptacle					1.310	1.630
OFF SML		Total					17.085	20.549
OFF LGE		HVAC					5.818	6.186
OFF LGE		Lighting					5.924	6.220
OFF LGE		Receptacle					2.280	2.382
OFF LGE		Total					15.518	16.346
UnWeighted Averages :								
OFF SML		HVAC					5.730	6.787
OFF SML		Lighting					5.709	6.336
OFF SML		Receptacle					1.518	1.755
OFF SML		Total					18.133	20.566
OFF LGE		HVAC					4.617	4.892
OFF LGE		Lighting					5.596	5.851
OFF LGE		Receptacle					1.964	2.024
OFF LGE		Total					15.305	16.097

* Buildings 2 and 11 were anomalous and not used in calculating average EUI's.

Figure II.2

Office Total Energy Use Intensity (kWh/ft^2-year)

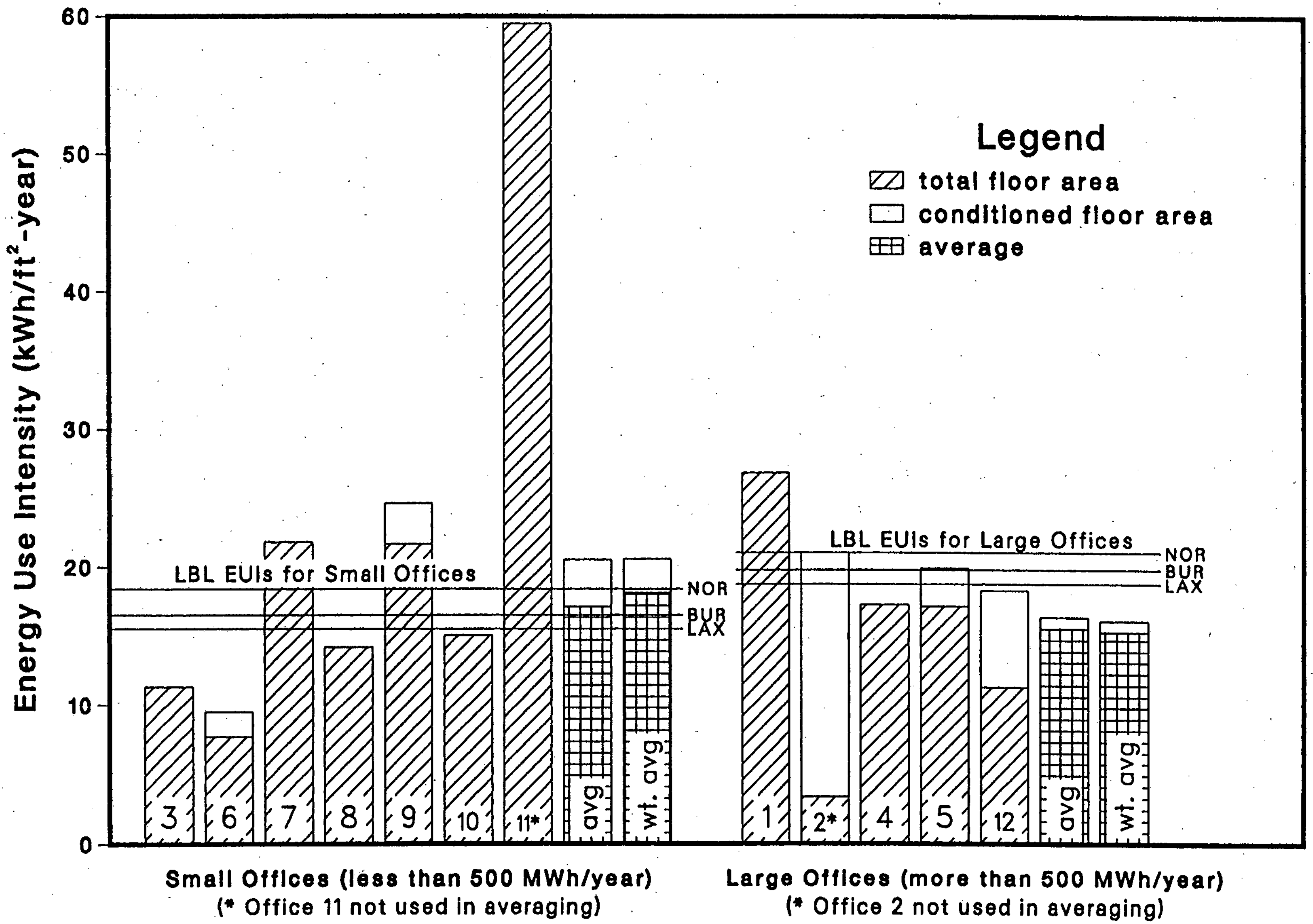
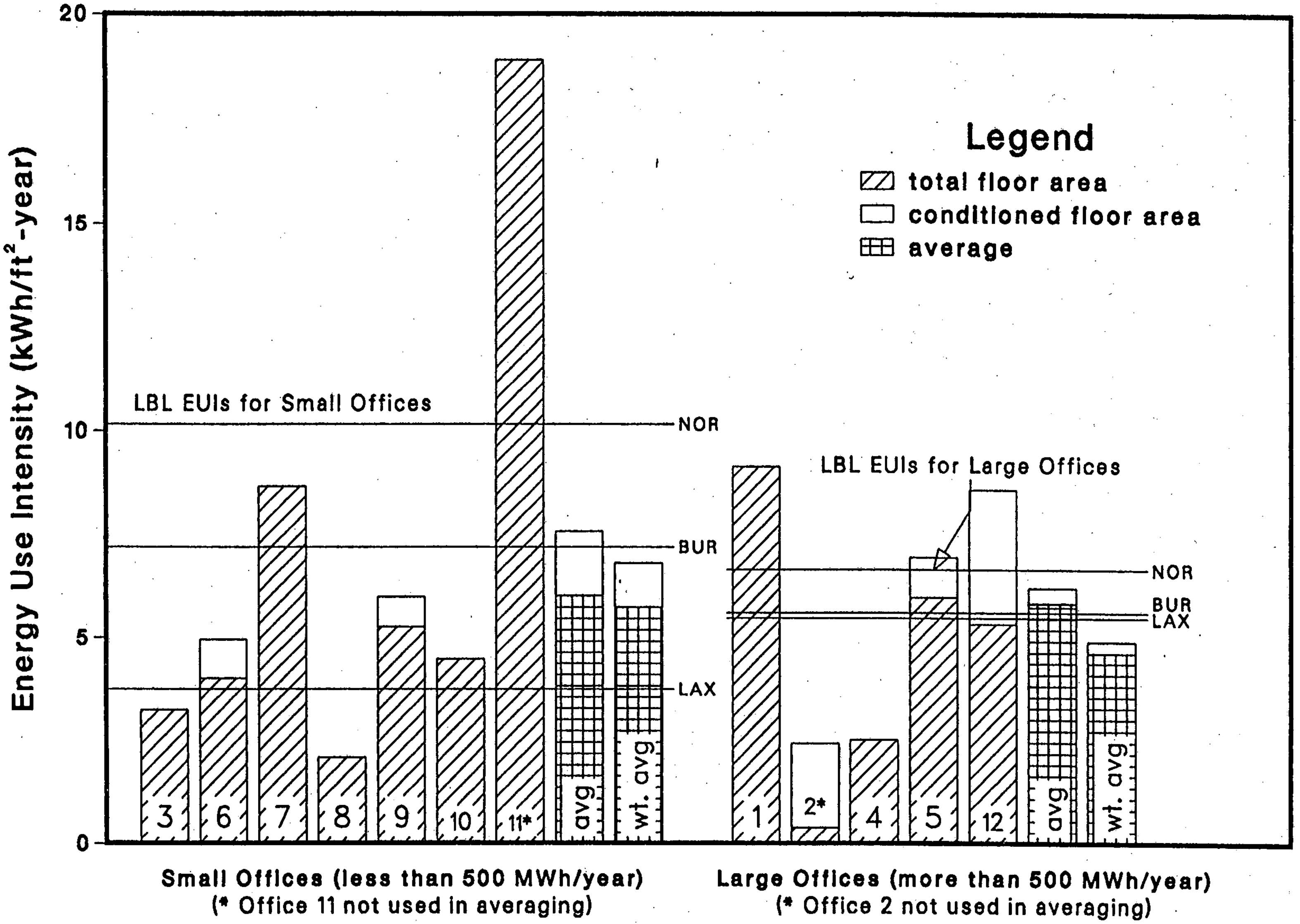


Figure II.3

Office HVAC Energy Use Intensity (kWh/ft^2-year)



The HVAC EUIs developed for the small office building compare well with the monitored data. The comparison for the large office buildings is not as close, yet still acceptable.

Figure II.4 shows the lighting EUIs for both small and large office buildings. The agreement between the measured and the LBL values for small offices is good, but the EUIs for large offices are significantly different. Further analysis of the data showed that while the characteristic office building in the LBL study has significant nighttime lighting, the nighttime lighting is very small for the monitored buildings. Also, the LBL data include the nighttime outdoor lighting in the lighting end-use value. We cannot tell whether the monitored buildings included outdoor lighting in the lighting channel.

Figure II.5 compares the 'plug' end-use data of the monitored buildings with the 'miscellaneous' end-use data estimated in the LBL study. The differences between these data are due to the different definition of these end uses. Note that the LBL EUIs for miscellaneous end uses do not include lighting, HVAC, refrigeration, cooking and water heating loads; but for the monitored buildings, the plug loads may include these end uses.

Figure II.4

Office Lighting Energy Use Intensity (kWh/ft²-year)

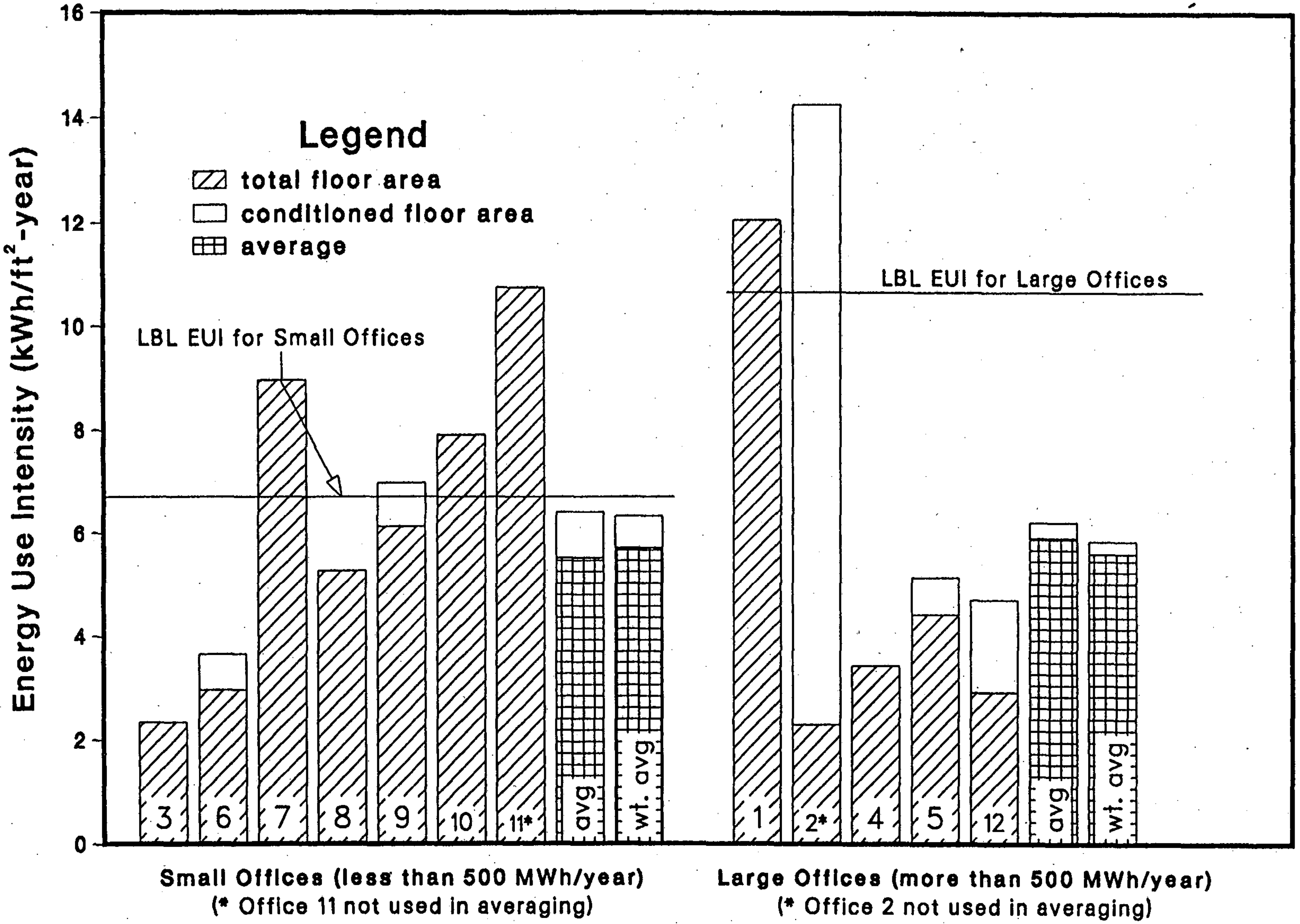
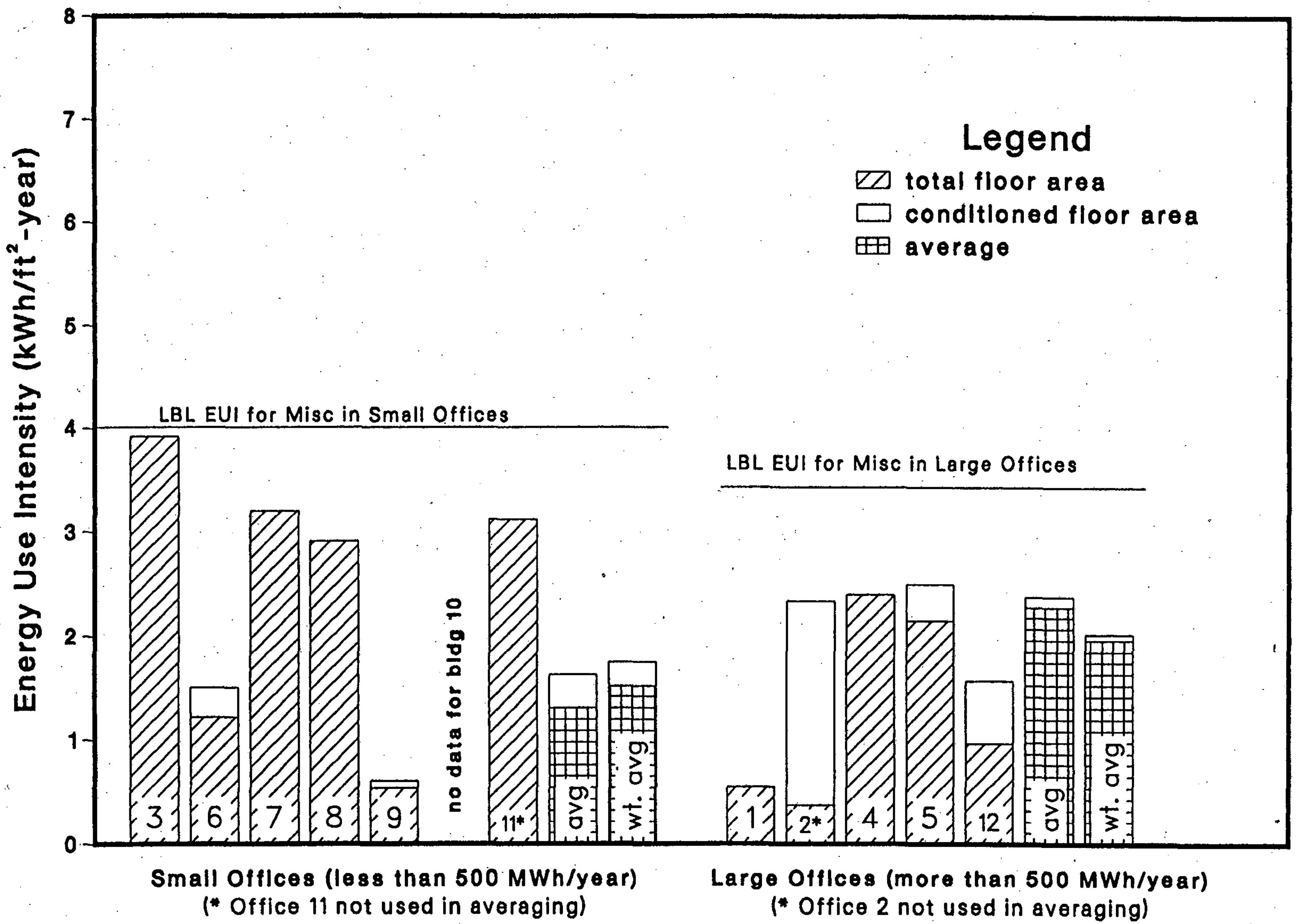


Figure II.5

Office Receptacle Energy Use Intensity (kWh/ft^2-year)



Retail buildings

There are 10 retail buildings in the submetered building sample with total floor areas ranging from 14,500 to 66,800 ft^2 and with total electric EUIs ranging from 10.4 to 34.2 $kWh/ft^2 year$. As in the office category, we partitioned the buildings in two categories of small and large retails, using the same criteria that SCE uses in their partioning. All the retail buildings with annual electricity use of over 400,000 kWh/year are considered large and those with annual electricity use less than 400,000 kWh/year are considered small. With this partitioning criteria, buildings 1, 3, 4, and 9 are in the small retail group and buildings 2, 5 through 8, and 10 are in the large retail group.

Table II.2 presents the summary data for all retail buildings including the number of missing or 'bad' data, estimated EUIs based on the conditioned and total building floor area, and weighted and unweighted end-use EUIs.

Figure II.6 compares the total building EUIs for large and small retail buildings with the LBL estimates for retail buildings. For both sizes of retail buildings, the LBL whole-building EUI is about 15 to 20 percent lower than the monitored buildings. Knowing that the LBL values are based on SCE's building-class sales data and 1985 on-site building survey data, the difference between the average total building EUIs can be probably traced to the small sample size of the monitored retail buildings.

Figure II.7 compares the HVAC EUIs for large and small retail. The LBL study predicted EUIs for three climate regions. However, the limited sample size of the monitored building does not allow a comparison at a regional climate zone level. Hence, we took LBL values developed for the Burbank climate region as an average of the entire SCE service area for all of our comparisons of HVAC EUIs.

The LBL estimate for HVAC EUI for small retail buildings is about 20% lower than average value of the the monitored data. The comparison of the large retail building HVAC EUIs is very close.

Figure II.8 shows the lighting EUIs for both small and large retail buildings. The agreement for small retail is good, but the LBL EUIs for large retail are about 20% lower than the monitored data.

Table II.2
End Use Intensities for Retail Buildings

Bldg Type	Bldg Num	End Use	Observations Valid	Observations Bad	Total Floor Area	Conditioned Floor Area	End Use Intensities (kWh/ft^2-yr) per tot flr area	per cond. flr area
RTL SML	1	HVAC	8608	152	23396	23396	4.415	4.415
RTL SML	1	Lighting	8608	152	23396	23396	8.319	8.319
RTL SML	1	Total	8608	152	23396	23396	13.049	13.049
RTL LGE	2	HVAC	8760	0	25500	25500	8.188	8.188
RTL LGE	2	Lighting	8760	0	25500	25500	24.208	24.208
RTL LGE	2	Total	8760	0	25500	25500	34.262	34.262
RTL SML	3	HVAC	6683	1837	26900	26900	3.801	3.801
RTL SML	3	Lighting	8377	143	26900	26900	4.596	4.596
RTL SML	3	Total	8382	138	26900	26900	10.405	10.405
RTL SML	4	HVAC	8625	135	19162	19162	7.536	7.536
RTL SML	4	Lighting	8625	135	19162	19162	8.235	8.235
RTL SML	4	Total	8625	135	19162	19162	16.285	16.285
RTL LGE	5	HVAC	8709	51	20640	19402	9.704	10.324
RTL LGE	5	Lighting	7128	1632	20640	19402	14.493	15.417
RTL LGE	5	Total	8709	51	20640	19402	24.888	26.476
RTL LGE	6	HVAC	8760	0	66800	66800	5.664	5.664
RTL LGE	6	Lighting	8760	0	66800	66800	8.594	8.594
RTL LGE	6	Total	8760	0	66800	66800	20.989	20.989
RTL LGE	7	HVAC	8759	1	37500	37500	2.841	2.841
RTL LGE	7	Lighting	8759	1	37500	37500	4.455	4.455
RTL LGE	7	Total	8759	1	37500	37500	10.694	10.694
RTL LGE	8	HVAC	8537	223	29350	29350	7.010	7.010
RTL LGE	8	Lighting	8760	0	29350	29350	13.851	13.851
RTL LGE	8	Total	8760	0	29350	29350	22.632	22.632
RTL SML	9	HVAC	8757	3	14500	14500	11.305	11.305
RTL SML	9	Lighting	8757	3	14500	14500	5.565	5.565
RTL SML	9	Total	8757	3	14500	14500	17.197	17.197
RTL LGE	10	HVAC	7536	600	30000	30000	6.970	6.970
RTL LGE	10	Lighting	7536	600	30000	30000	11.086	11.086
RTL LGE	10	Total	7536	600	30000	30000	20.432	20.432
Weighted Averages :								
RTL SML		HVAC					6.871	6.871
RTL SML		Lighting					6.688	6.688
RTL SML		Total					14.334	14.334
RTL LGE		HVAC					6.489	6.629
RTL LGE		Lighting					12.571	12.780
RTL LGE		Total					22.288	22.647
UnWeighted Averages :								
RTL SML		HVAC					6.764	6.764
RTL SML		Lighting					6.679	6.679
RTL SML		Total					14.234	14.234
RTL LGE		HVAC					6.730	6.833
RTL LGE		Lighting					12.781	12.935
RTL LGE		Total					22.316	22.581

Figure II.6

Retail Total Energy Use Intensity (kWh/ft^2-year)

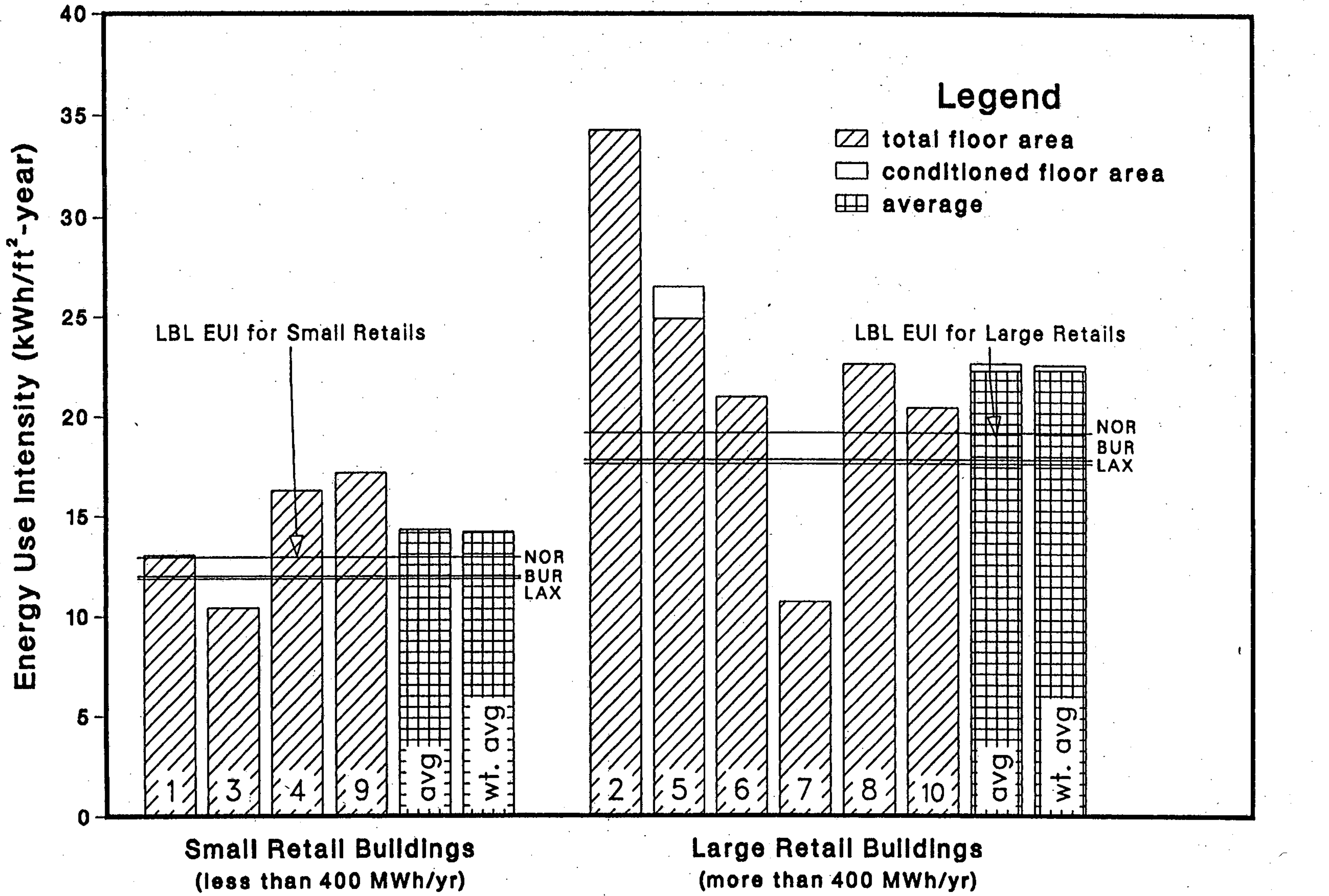


Figure II.7

Retail HVAC Energy Use Intensity (kWh/ft^2-year)

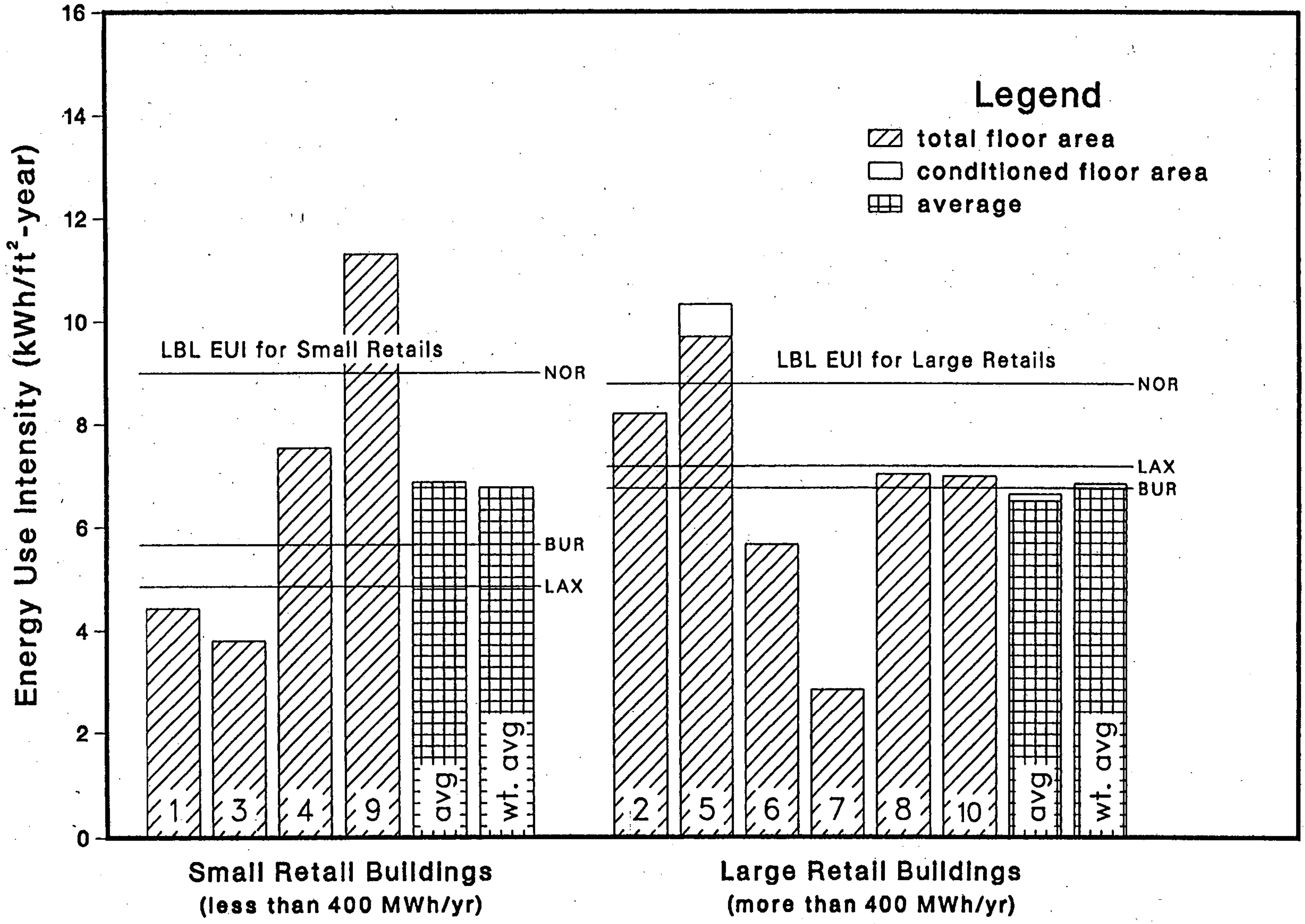
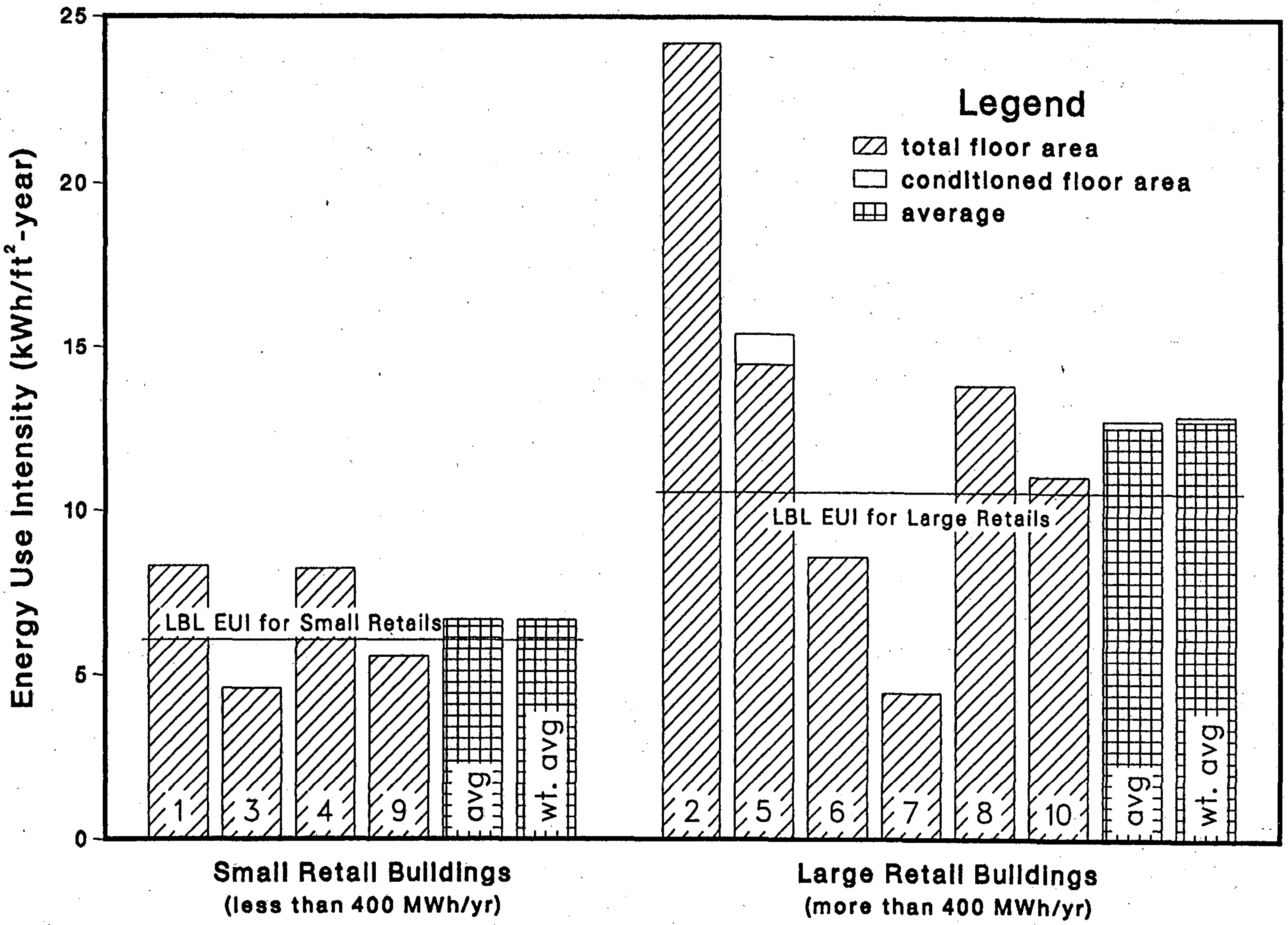


Figure II.8

Retail Lighting Energy Use Intensity (kWh/ft^2-year)



Grocery buildings

There are 14 grocery buildings in our sample with floor areas ranging from 12,000 to over 61,000 ft^2 and with total electric EUIs ranging from 36 to 89 kWh/ft^2year. Although SCE does not partition groceries by energy use, these groceries are large, having supermarket characteristics. **Table II.3** presents the summary data for the groceries. The summary includes the amount of valid and invalid hourly data, the EUIs based on the conditioned and total building floor area, and the weighted and unweighted end-use EUIs.

Figure II.9 compares the total building EUIs for grocery buildings with the LBL estimates. The SCE monitored groceries are supermarkets, whereas those used in the previous LBL study are mostly smaller "mom and pop" neighborhood grocery stores that differ significantly in both operation and equipment. Since most large supermarkets are open 24-hours a day, it is expected that the LBL estimates, based on 16 to 18 hours of operation, be on the average about 30% lower than the monitored buildings. Figure II.9, indeed, agrees with this hypothesis.

Figure II.10 compares the HVAC EUIs for grocery buildings. Although the LBL study provided data for three climate regions, we use the Burbank data as an average value representing the entire SCE service area for this comparison. The LBL HVAC EUIs for grocery buildings is about 20 to 30% lower than the EUIs based on the monitored HVAC data and the total building floor area and the conditioned floor area. However, if adjustments are made for the different hours of operation between the on-site survey sample (data used by LBL) and that of the monitored buildings, this difference will be reduced significantly.

Figure II.11 compares the lighting EUIs for grocery buildings. The LBL lighting EUIs for grocery buildings is about 10 to 20% lower than the monitored data. The difference can be traced to the different hours of operation and the different lighting systems in large and small groceries.

Figure II.12 shows the refrigeration EUIs for grocery buildings. The agreement between the LBL study and the monitored data is fairly good. This is consistent with our other findings since the refrigeration EUIs of groceries are insensitive to operating hours.

Table II.3
End Use Intensities for Grocery Buildings

Bldg Type	Bldg Num	End Use	Observations Valid	Observations Bad	Total Floor Area	Conditioned Floor Area	End Use Intensities ($kWh/ft^2 \cdot yr$) per tot flr area	End Use Intensities ($kWh/ft^2 \cdot yr$) per cond. flr area
GRY	1	HVAC	7342	1418	26440	22738	2.920	3.394
GRY	1	Lighting	7342	1418	26440	22738	19.553	22.737
GRY	1	Refrig	7342	1418	26440	22738	26.312	30.595
GRY	1	Total	7342	1418	26440	22738	57.611	66.991
GRY	2	HVAC	8450	310	23200	20416	1.773	2.015
GRY	2	Lighting	8104	656	23200	20416	20.912	23.763
GRY	2	Refrig	8489	271	23200	20416	23.814	27.061
GRY	2	Total	6559	2201	23200	20416	74.043	84.139
GRY	3	HVAC	8473	287	15923	12420	1.313	1.683
GRY	3	Lighting	8474	286	15923	12420	15.705	20.135
GRY	3	Refrig	8493	267	15923	12420	32.651	41.860
GRY	3	Total	8134	626	15923	12420	81.050	103.910
GRY	4	HVAC	8760	0	30427	24950	3.477	4.240
GRY	4	Lighting	8760	0	30427	24950	12.825	15.640
GRY	4	Refrig	8760	0	30427	24950	26.210	31.963
GRY	4	Total	8760	0	30427	24950	52.080	63.513
GRY	5	HVAC	8744	16	25565	19429	2.628	3.458
GRY	5	Lighting	8744	16	25565	19429	12.476	16.417
GRY	5	Refrig	8635	125	25565	19429	18.240	24.000
GRY	5	Total	8635	125	25565	19429	40.329	53.066
GRY	6	HVAC	8189	571	55000	53350	2.021	2.083
GRY	6	Lighting	8743	17	55000	53350	7.116	7.336
GRY	6	Refrig	8743	17	55000	53350	10.171	10.486
GRY	6	Total	8742	18	55000	53350	27.856	28.717
GRY	7	HVAC	8742	18	22632	19916	5.572	6.332
GRY	7	Lighting	8742	18	22632	19916	20.912	23.763
GRY	7	Refrig	8742	18	22632	19916	31.934	36.289
GRY	7	Total	8741	19	22632	19916	89.160	101.319
GRY	8	HVAC	8759	1	23400	18486	2.484	3.145
GRY	8	Lighting	8760	0	23400	18486	16.425	20.791
GRY	8	Refrig	8759	1	23400	18486	35.398	44.807
GRY	8	Total	8759	1	23400	18486	60.290	76.317
GRY	9	HVAC	8759	1	24400	20008	2.559	3.120
GRY	9	Lighting	8759	1	24400	20008	16.693	20.357
GRY	9	Refrig	8543	217	24400	20008	27.034	32.969
GRY	9	Total	8759	1	24400	20008	60.603	73.906
GRY	10	HVAC	8735	25	20720	14090	3.198	4.702
GRY	10	Lighting	8760	0	20720	14090	15.575	22.904
GRY	10	Refrig	8760	0	20720	14090	23.402	34.414
GRY	10	Total	8759	1	20720	14090	70.818	104.140
GRY	11	HVAC	7679	457	21400	16050	1.082	1.443
GRY	11	Lighting	7679	457	21400	16050	7.517	10.023
GRY	11	Refrig	7679	457	21400	16050	17.065	22.754
GRY	11	Total	7679	481	21400	16050	35.928	47.904

Table II.3 (continued)
End Use Intensities for Grocery Buildings

Bldg Type	Bldg Num	End Use	Observations Valid	Observations Bad	Total Floor Area	Conditioned Floor Area	End Use Intensities ($kWh/ft^2 \cdot yr$) per tot flr area	End Use Intensities ($kWh/ft^2 \cdot yr$) per cond. flr area
GRY	12	HVAC	7768	368	12000	9000	1.620	2.159
GRY	12	Lighting	7907	229	12000	9000	3.432	4.576
GRY	12	Refrig	7908	252	12000	9000	23.674	31.565
GRY	12	Total	7907	229	12000	9000	41.845	55.793
GRY	13	HVAC	5757	27	61616	43747	5.714	8.048
GRY	13	Lighting	5758	26	61616	43747	18.999	26.759
GRY	13	Refrig	5169	639	61616	43747	12.671	17.847
GRY	13	Total	5171	613	61616	43747	55.808	78.604
GRY	14	HVAC	5760	24	51072	51072	3.399	3.399
GRY	14	Lighting	5760	24	51072	51072	23.978	23.978
GRY	14	Refrig	5760	48	51072	51072	22.508	22.508
GRY	14	Total	5760	24	51072	51072	64.581	64.581
Weighted Averages :								
GRY		HVAC					2.936	3.586
GRY		Lighting					15.762	19.262
GRY		Refrig					25.629	31.598
GRY		Total					62.884	77.381
Unweighted Averages :								
GRY		HVAC					2.840	3.516
GRY		Lighting					15.151	18.513
GRY		Refrig					23.649	29.223
GRY		Total					58.000	71.636

Figure II.9

Grocery Total Energy Use Intensity (kWh/ft^2-year)

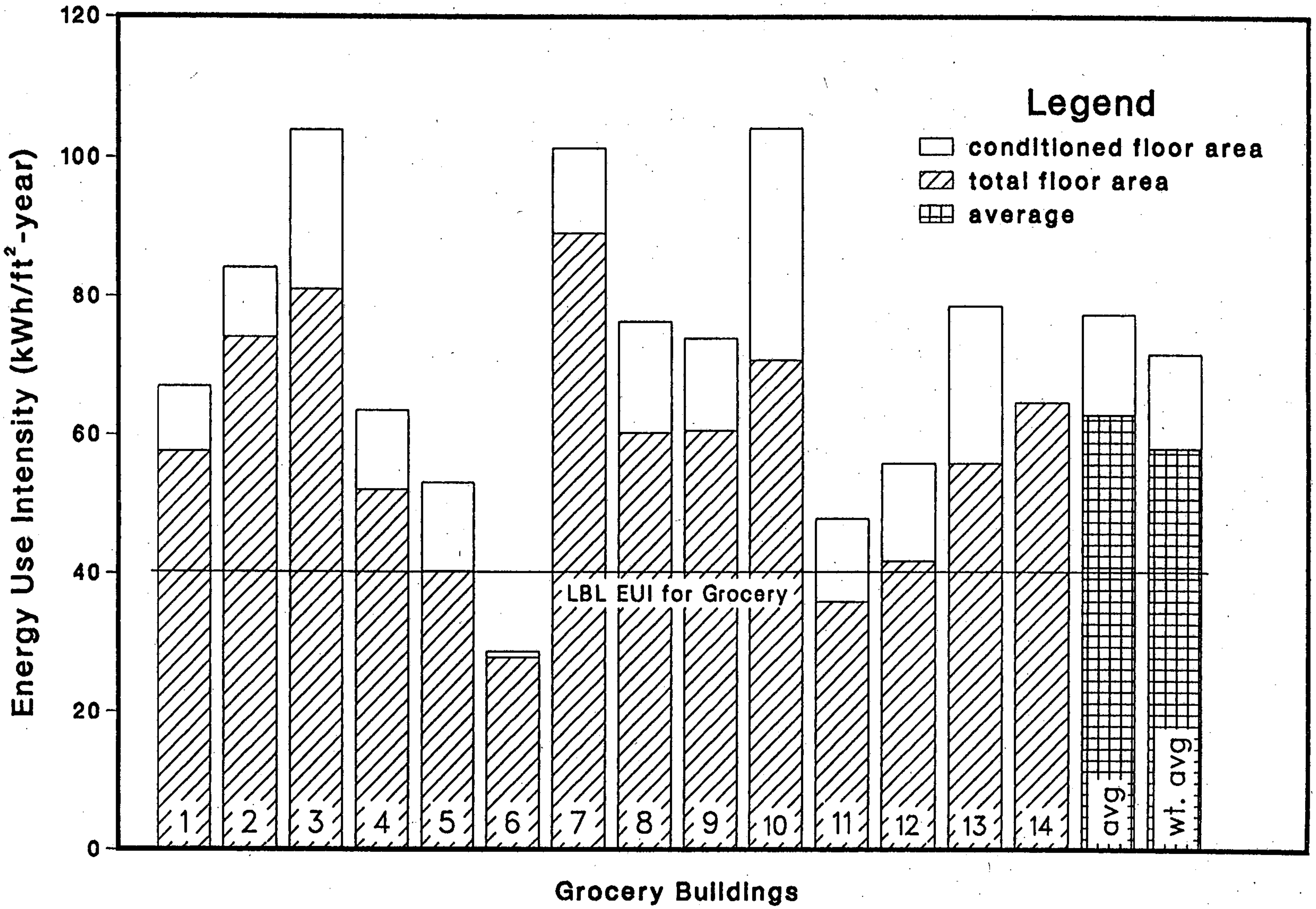


Figure II.10

Grocery HVAC Energy Use Intensity (kWh/ft^2-year)

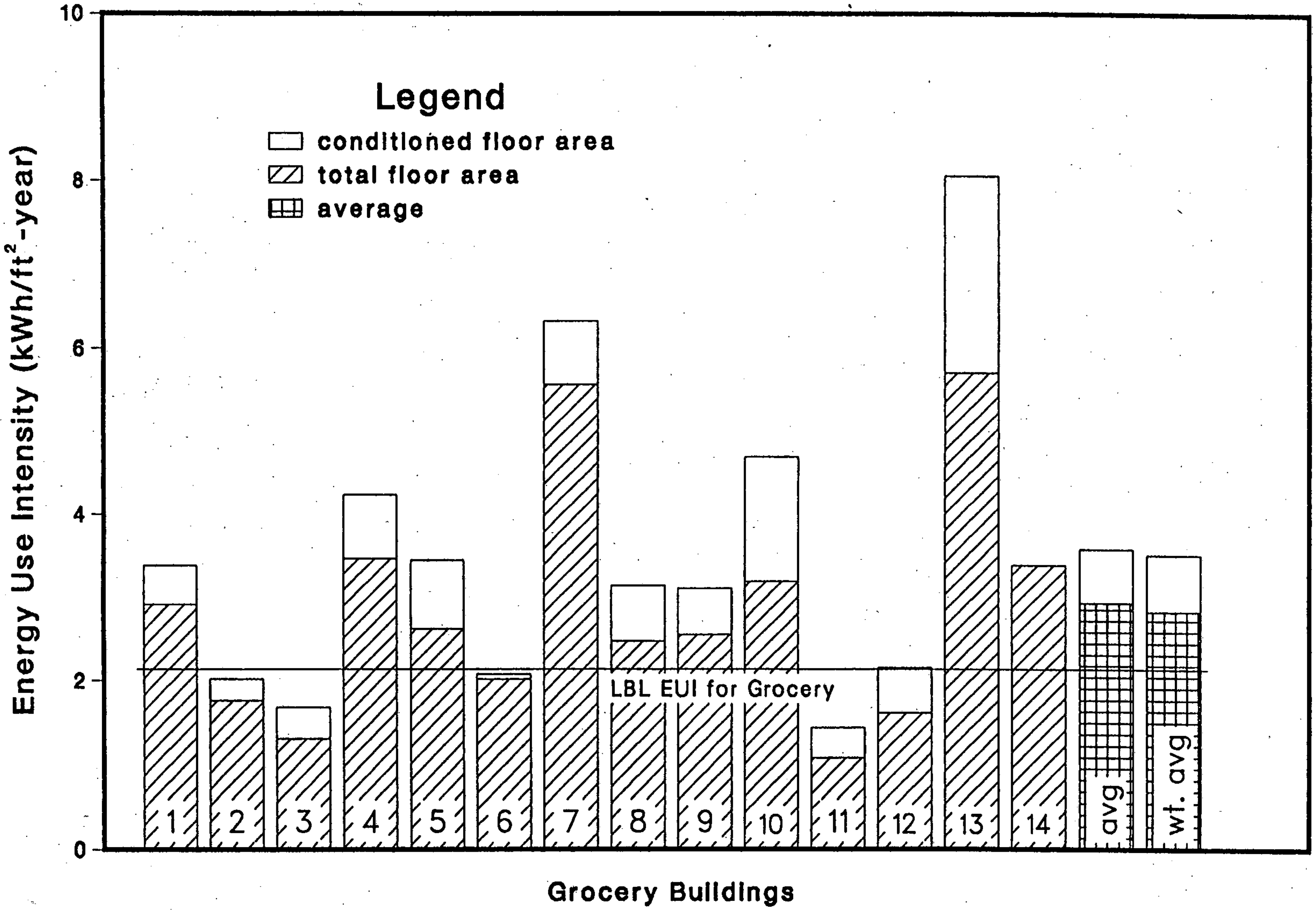


Figure II.11

Grocery Lighting Energy Use Intensity (kWh/ft²-year)

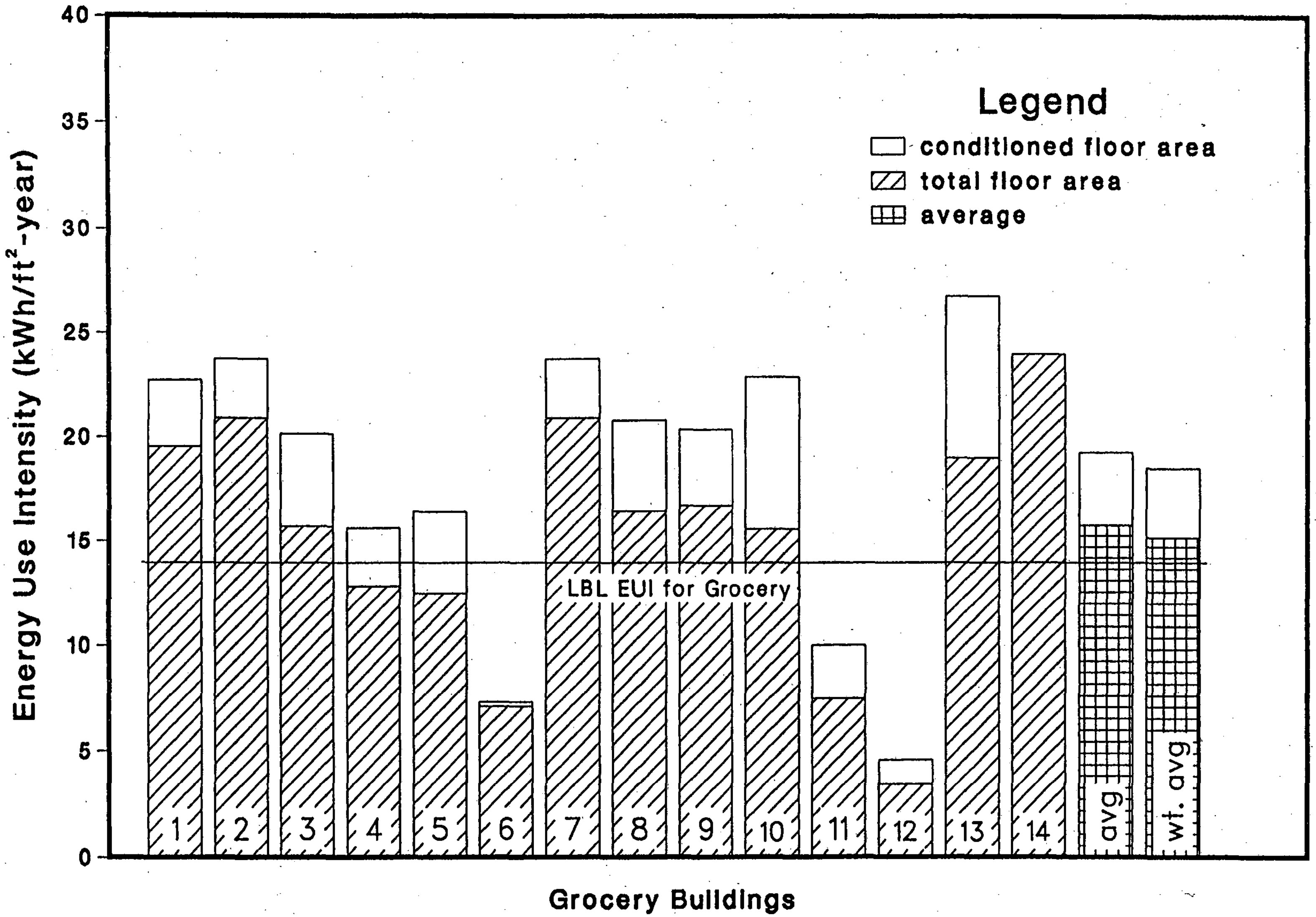
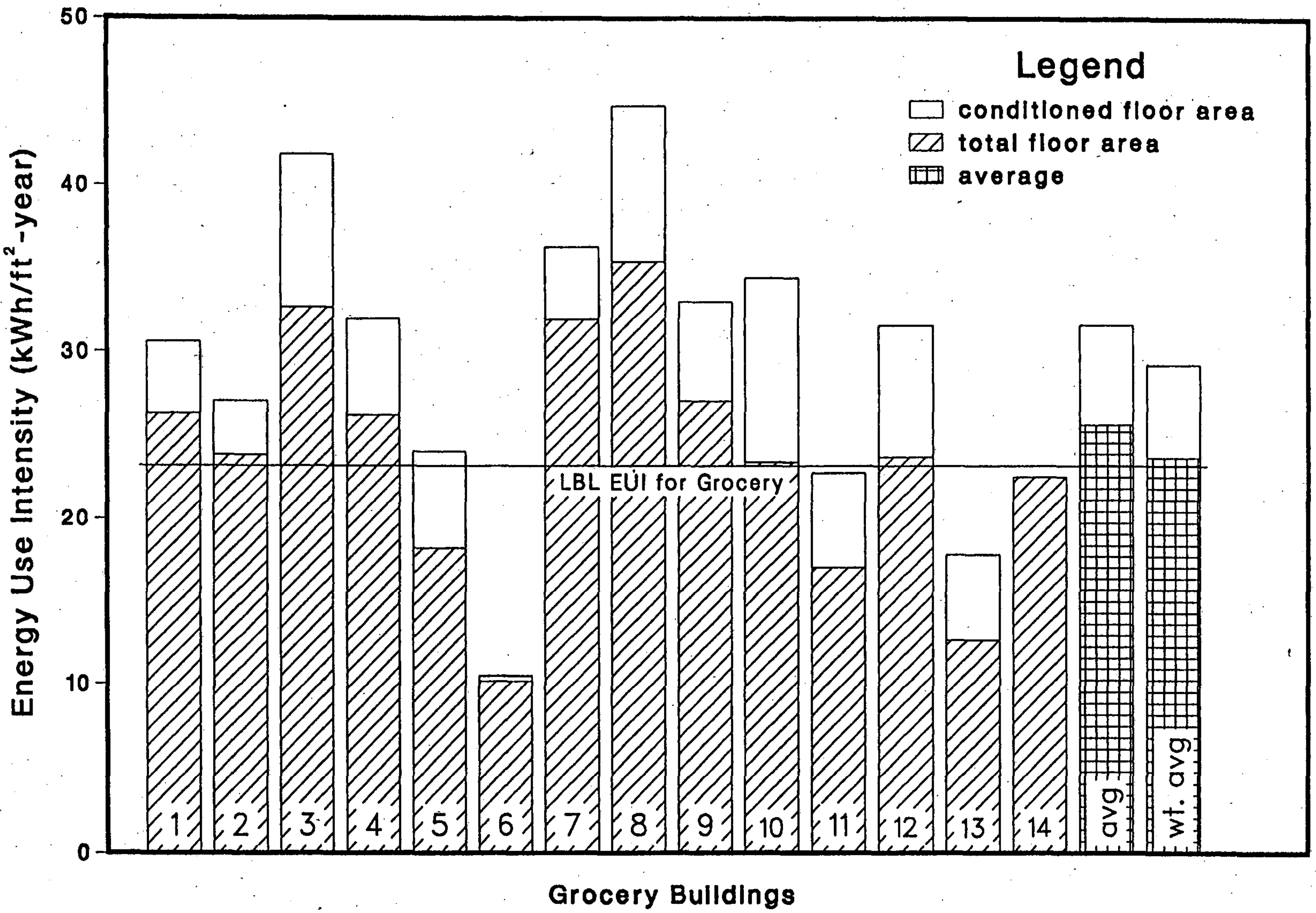


Figure II.12

Grocery Refrigeration Energy Use Intensity (kWh/ft^2-year)



Restaurant buildings

Of the 14 restaurants monitored in the SCE service area, 10 are sit-down restaurants and 4 are fast food. The fast food restaurants monitored are comparable in size and in whole-building electric EUIs. The floor areas are in a narrow range of 3,650 to 5,780 ft^2 and the total electric EUIs range from 63 to 132 kWh/ft^2year. The variation in size of the 10 sit-down restaurants is slightly larger. Their floor areas range from 7,250 to 23,5000 ft^2 and the whole-building EUIs range from 24 to 58 kWh/ft^2year.

Tables II.4 and II.5 present the summary data for the 14 sit-down and fast-food restaurants. Included in the summary are the number of hours of valid and bad data, estimated EUIs based on the conditioned and total building floor area, and weighted and unweighted end-use EUIs.

Figure II.13 compares the total building EUIs for fast food and sit-down restaurants with the LBL estimates. The LBL study predicted EUIs and LSs for the combined group of fast food and sit-down restaurants. Although, the on-site survey data distinguishes between the fast food and sit-down restaurants, the load research data combines both restaurant types together. Hence, the LBL study only provides performance data for the combined group. As is to be expected, the fast-food restaurants are more energy intensive than the sit-down restaurants. The LBL total building electric EUI estimate for the combined group is between the monitored values for the fast-food and sit-down restaurants.

Figure II.14 compares the HVAC EUIs for fast-food and sit-down restaurants in the monitored building set. The LBL average EUI for restaurants is also included. Although the LBL study developed EUIs for three climate regions, the limited sample size of the monitored restaurants does not allow a comparison at a regional climate zone level. Hence, we take Burbank data from the LBL study as an average for the restaurants in the SCE service area for all of our comparisons of HVAC EUIs. Again, the LBL HVAC EUI is between the EUIs for the fast-food and sit-down restaurants. An interesting observation from the monitored data is that the HVAC systems for the fast food restaurants are about four times as energy intensive as the sit-down restaurants.

Figure II.15 shows the lighting EUIs for both fast-food and sit-down restaurants. Again the LBL EUI is between that of the fast food and sit-down restaurants and the lighting EUI for the fast food restaurants, on the average, is about twice that of the sit-down restaurants.

Table II.4
End Use Intensities for Sit-down Restaurant Buildings

Bldg Type	Bldg Num	End Use	Observations Valid	Bad	Total Floor Area	Conditioned Floor Area	End Use Intensities ($kWh/ft^2 \cdot yr$) per tot flr area	per cond. flr area
RST SD	1	HVAC	8136	624	7550	7324	15.862	16.351
RST SD	1	Lighting	8136	624	7550	7324	8.751	9.021
RST SD	1	Cooking	7557	1203	7550	7324	0.433	0.447
RST SD	1	Exhaust-fan	8708	52	7550	7324	2.460	2.536
RST SD	1	Refrig	8700	60	7550	7324	4.396	4.531
RST SD	1	Total	8699	61	7550	7324	56.859	58.613
RST SD	2	HVAC	8760	0	11122	11122	3.368	3.368
RST SD	2	Lighting	8759	1	11122	11122	4.963	4.963
RST SD	2	Cooking	7926	834	11122	11122	4.026	4.026
RST SD	2	Exhaust-fan	8134	626	11122	11122	1.489	1.489
RST SD	2	Refrig	8134	626	11122	11122	4.411	4.411
RST SD	2	Total	8759	1	11122	11122	33.504	33.504
RST SD	3	HVAC	8708	52	11020	11020	7.731	7.731
RST SD	3	Lighting	8708	52	11020	11020	12.801	12.801
RST SD	3	Cooking	8006	754	11020	11020	7.858	7.858
RST SD	3	Exhaust-fan	7761	999	11020	11020	0.457	0.457
RST SD	3	Refrig	7797	963	11020	11020	1.471	1.471
RST SD	3	Total	8048	712	11020	11020	46.158	46.158
RST SD	4	HVAC	8690	70	15430	15430	5.332	5.332
RST SD	4	Lighting	8690	70	15430	15430	6.686	6.686
RST SD	4	Cooking	8759	1	15430	15430	2.121	2.121
RST SD	4	Exhaust-fan	8759	1	15430	15430	2.843	2.843
RST SD	4	Refrig	8759	1	15430	15430	8.365	8.365
RST SD	4	Total	8759	1	15430	15430	33.721	33.721
RST SD	5	HVAC	8756	4	8834	8569	8.536	8.280
RST SD	5	Lighting	8758	2	8834	8569	12.117	11.753
RST SD	5	Cooking	8758	2	8834	8569	16.894	16.387
RST SD	5	Exhaust-fan	8758	2	8834	8569	2.559	2.482
RST SD	5	Refrig	8758	2	8834	8569	8.624	8.365
RST SD	5	Total	8758	2	8834	8569	58.416	56.664
RST SD	8	HVAC	8654	106	8300	8051	8.811	9.084
RST SD	8	Lighting	6073	2687	8300	8051	3.328	3.431
RST SD	8	Cooking	8653	107	8300	8051	12.577	12.966
RST SD	8	Exhaust-fan	8640	120	8300	8051	0.627	0.646
RST SD	8	Refrig	8635	125	8300	8051	2.936	3.027
RST SD	8	Total	8653	107	8300	8051	41.578	42.864
RST SD	9	HVAC	6072	2688	6308	5993	10.480	11.031
RST SD	9	Lighting	6332	2428	6308	5993	8.724	9.182
RST SD	9	Cooking	6280	2480	6308	5993	10.116	10.648
RST SD	9	Exhaust-fan	6281	2167	6308	5993	1.853	1.950
RST SD	9	Refrig	6332	2428	6308	5993	5.257	5.533
RST SD	9	Total	6279	2481	6308	5993	47.936	50.456

Table II.4 (continued)
End Use Intensities for Sit-down Restaurant Buildings

Bldg Type	Bldg Num	End Use	Observations Valid	Observations Bad	Total Floor Area	Conditioned Floor Area	End Use Intensities ($kWh/ft^2\cdot yr$) per tot flr area	End Use Intensities ($kWh/ft^2\cdot yr$) per cond. flr area
RST SD	10	HVAC	6853	1907	9083	9083	9.177	9.177
RST SD	10	Lighting	6859	1901	9083	9083	9.358	9.358
RST SD	10	Cooking	7339	1421	9083	9083	5.622	5.622
RST SD	10	Exhaust-fan	7339	1421	9083	9083	1.710	1.710
RST SD	10	Refrig	7339	1421	9083	9083	6.913	6.913
RST SD	10	Total	8237	523	9083	9083	53.792	53.792
RST SD	12	HVAC	8707	53	7254	7181	6.092	6.154
RST SD	12	Lighting	8707	53	7254	7181	2.714	2.742
RST SD	12	Cooking	8577	183	7254	7181	7.477	7.553
RST SD	12	Exhaust-fan	8576	184	7254	7181	0.750	0.758
RST SD	12	Refrig	8577	183	7254	7181	7.251	7.325
RST SD	12	Total	8577	183	7254	7181	26.974	27.248
RST SD	14	HVAC	7776	312	23519	22813	5.893	6.075
RST SD	14	Lighting	7776	312	23519	22813	6.127	6.316
RST SD	14	Cooking	7734	354	23519	22813	2.315	2.385
RST SD	14	Exhaust-fan	7733	379	23519	22813	0.566	0.584
RST SD	14	Refrig	7734	354	23519	22813	2.431	2.506
RST SD	14	Total	7734	354	23519	22813	23.850	24.588
Weighted Averages :								
RST SD		HVAC					7.889	8.057
RST SD		Lighting					7.261	7.375
RST SD		Cooking					7.499	7.658
RST SD		Exhaust-fan					1.421	1.445
RST SD		Refrig					5.121	5.199
RST SD		Total					40.727	41.474
Unweighted Averages :								
RST SD		HVAC					8.128	8.284
RST SD		Lighting					7.557	7.662
RST SD		Cooking					6.944	7.052
RST SD		Exhaust-fan					1.531	1.553
RST SD		Refrig					5.205	5.271
RST SD		Total					42.279	42.936

Table II.5
End Use Intensities for Fast Food Restaurant Buildings

Bldg Type	Bldg Num	End Use	Observations Valid	Observations Bad	Total Floor Area	Conditioned Floor Area	End Use Intensities ($kWh/ft^2 \cdot yr$) per tot flr area	End Use Intensities ($kWh/ft^2 \cdot yr$) per cond. flr area
RST FF	6	HVAC	8753	7	3650	3504	34.582	36.023
RST FF	6	Lighting	8752	8	3650	3504	19.813	20.638
RST FF	6	Cooking	7103	1657	3650	3504	34.768	36.217
RST FF	6	Exhaust-fan	7103	1657	3650	3504	3.387	3.528
RST FF	6	Refrig	8755	5	3650	3504	14.404	15.004
RST FF	6	Total	7103	1657	3650	3504	131.911	137.408
RST FF	7	HVAC	8759	1	5780	3468	22.189	36.981
RST FF	7	Lighting	8758	2	5780	3468	10.499	17.499
RST FF	7	Cooking	8760	0	5780	3468	12.131	20.219
RST FF	7	Exhaust-fan	8760	0	5780	3468	2.916	4.860
RST FF	7	Refrig	8760	0	5780	3468	6.693	11.156
RST FF	7	Total	8760	0	5780	3468	63.668	106.113
RST FF	11	HVAC	8755	5	4025	3824	36.157	38.057
RST FF	11	Lighting	8755	5	4025	3824	27.120	28.545
RST FF	11	Cooking	8659	101	4025	3824	34.903	36.738
RST FF	11	Exhaust-fan	8755	5	4025	3824	4.421	4.653
RST FF	11	Refrig	8755	5	4025	3824	12.614	13.277
RST FF	11	Total	8755	5	4025	3824	115.102	121.152
RST FF	13	HVAC	7293	1131	4800	2208	36.960	80.348
RST FF	13	Lighting	7374	1050	4800	2208	19.527	42.451
RST FF	13	Cooking	6680	1744	4800	2208	21.345	46.403
RST FF	13	Exhaust-fan	7913	511	4800	2208	4.712	10.243
RST FF	13	Refrig	7817	607	4800	2208	8.413	18.289
RST FF	13	Total	7913	511	4800	2208	98.136	213.340
Weighted Averages :								
RST FF		HVAC					32.749.	51.434
RST FF		Lighting					19.232	29.020
RST FF		Cooking					24.870	35.843
RST FF		Exhaust-fan					3.962	6.348
RST FF		Refrig					10.118	14.742
RST FF		Total					100.117	151.048
Unweighted Averages :								
RST FF		HVAC					32.472	47.852
RST FF		Lighting					19.240	27.283
RST FF		Cooking					25.787	34.894
RST FF		Exhaust-fan					3.859	5.821
RST FF		Refrig					10.531	14.432
RST FF		Total					102.204	144.503

Figure II.13

Restaurant Total Energy Use Intensity (kWh/ft^2-year)

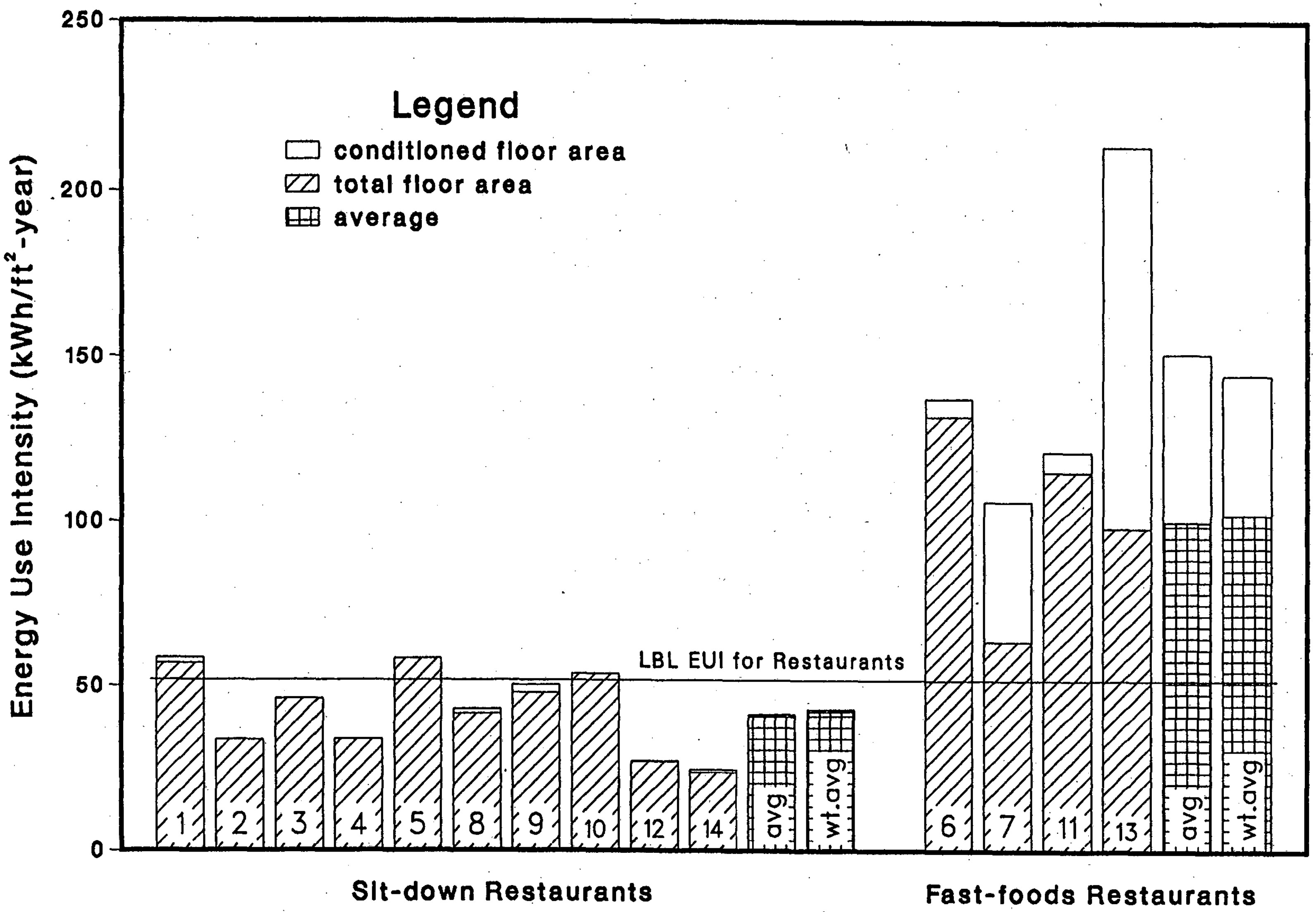


Figure II.14

Restaurant HVAC Energy Use Intensity (kWh/ft²-year)

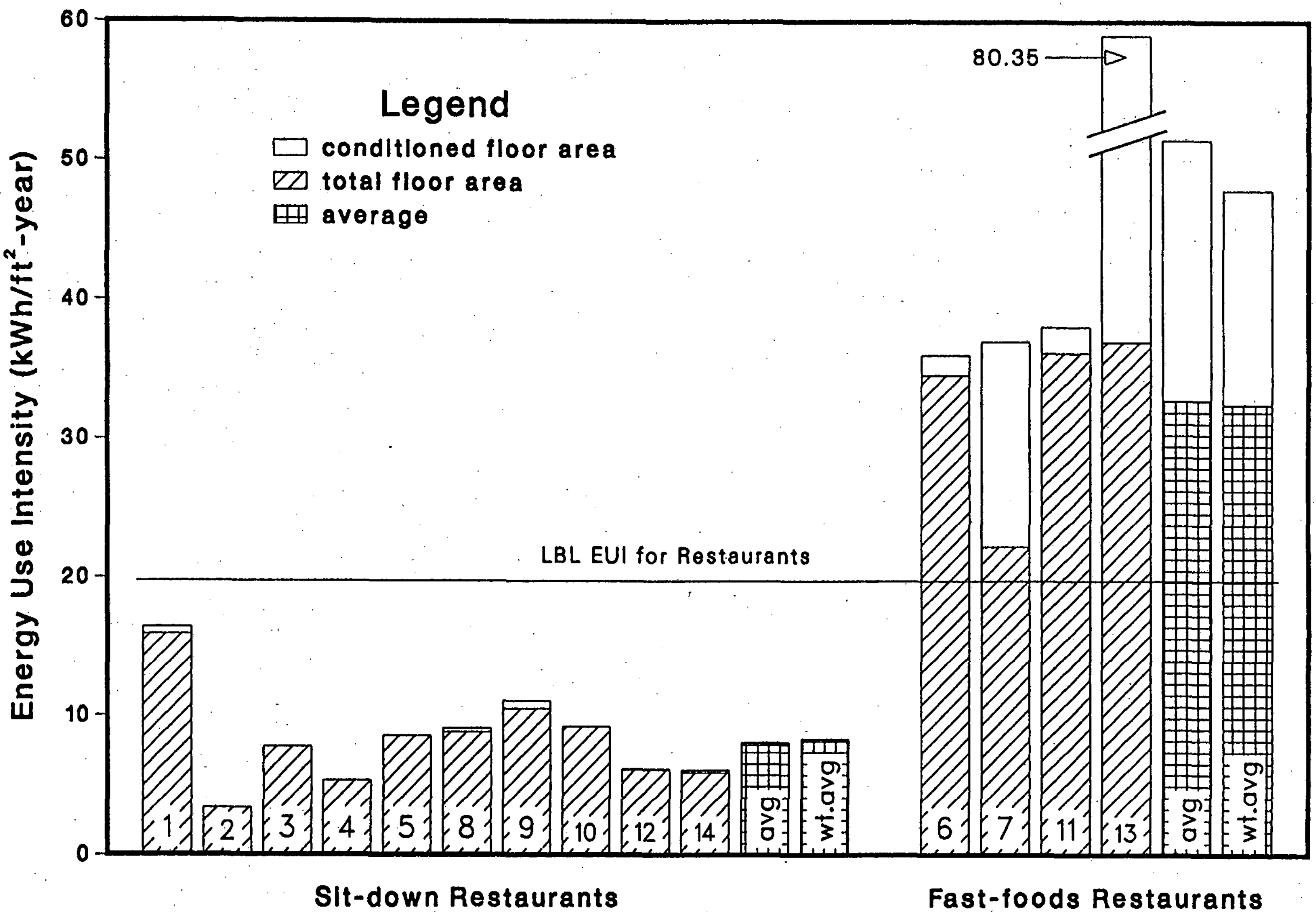


Figure II.15

Restaurant Lighting Energy Use Intensity (kWh/ft²-year)

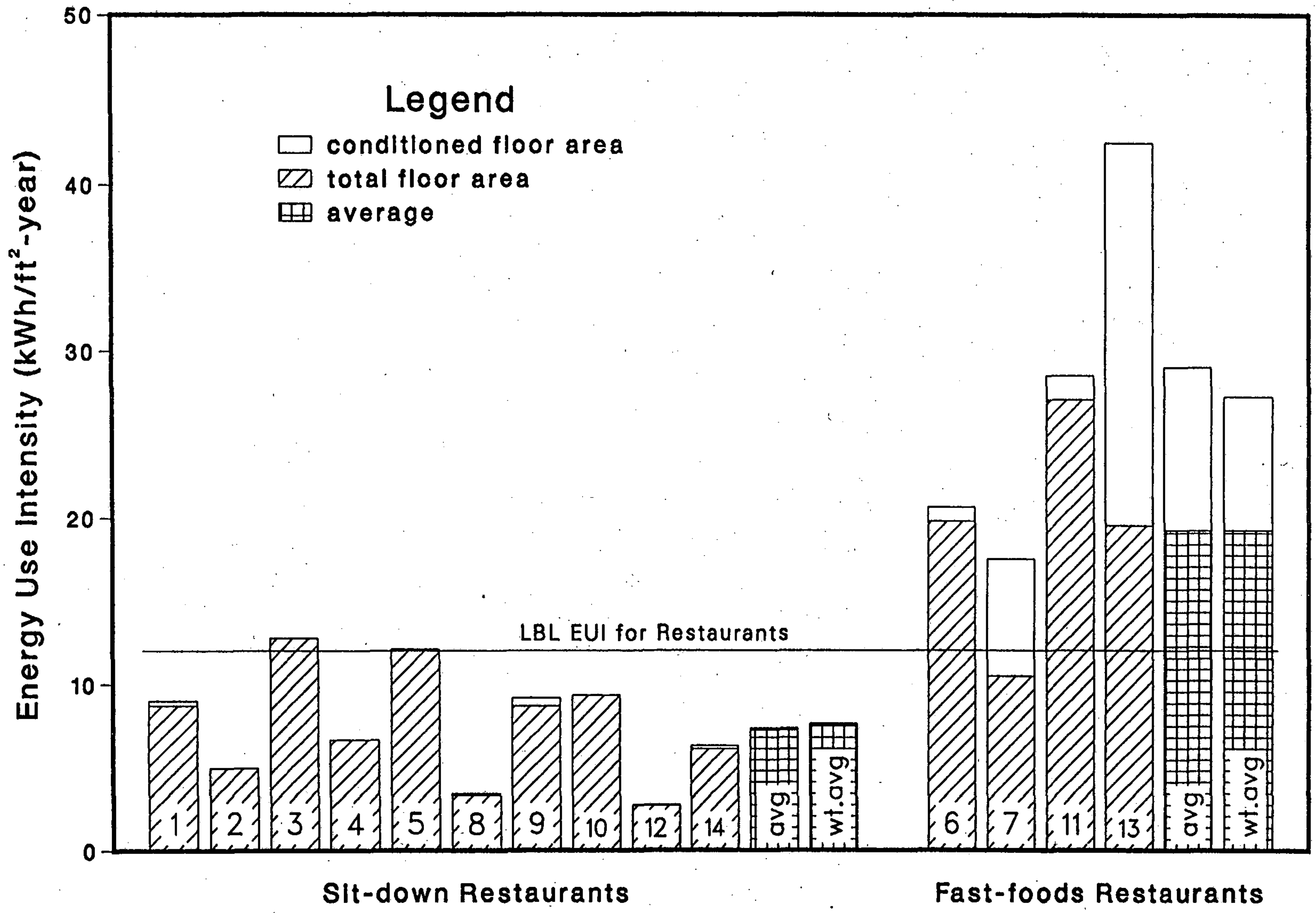


Figure II.16 compares the electric cooking EUIs of the monitored buildings with the LBL data. The LBL electric cooking EUIs are consistently smaller than monitored fast food and sit-down restaurants. The basic difference arises from the LBL study assumption of mostly gas cooking in restaurants.

Figures II.17 and II.18 show the refrigeration and exhaust fan EUIs and compare them with the LBL data. The LBL refrigeration EUI is higher than both the fast food and sit-down restaurants. LBL has used the on-site survey data to estimate the refrigeration EUI for restaurants. The LBL 'miscellaneous' EUI is comparable to the monitored restaurants' exhaust fan EUIs.

Figure II.16

Restaurant Cooking Energy Use Intensity (kWh/ft²-year)

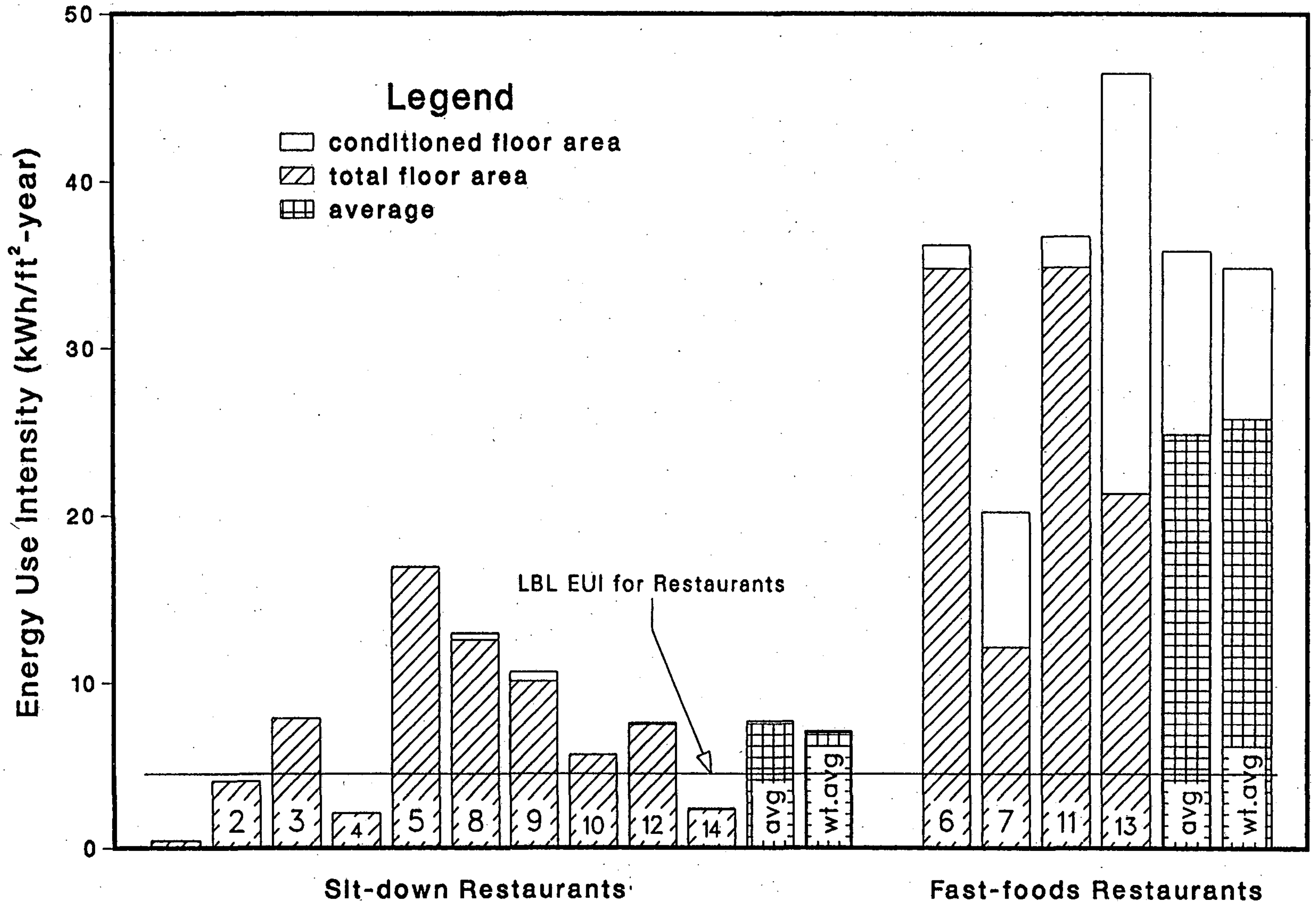


Figure II.17

Restaurant Refrigeration Energy Use Intensity (kWh/ft^2-year)

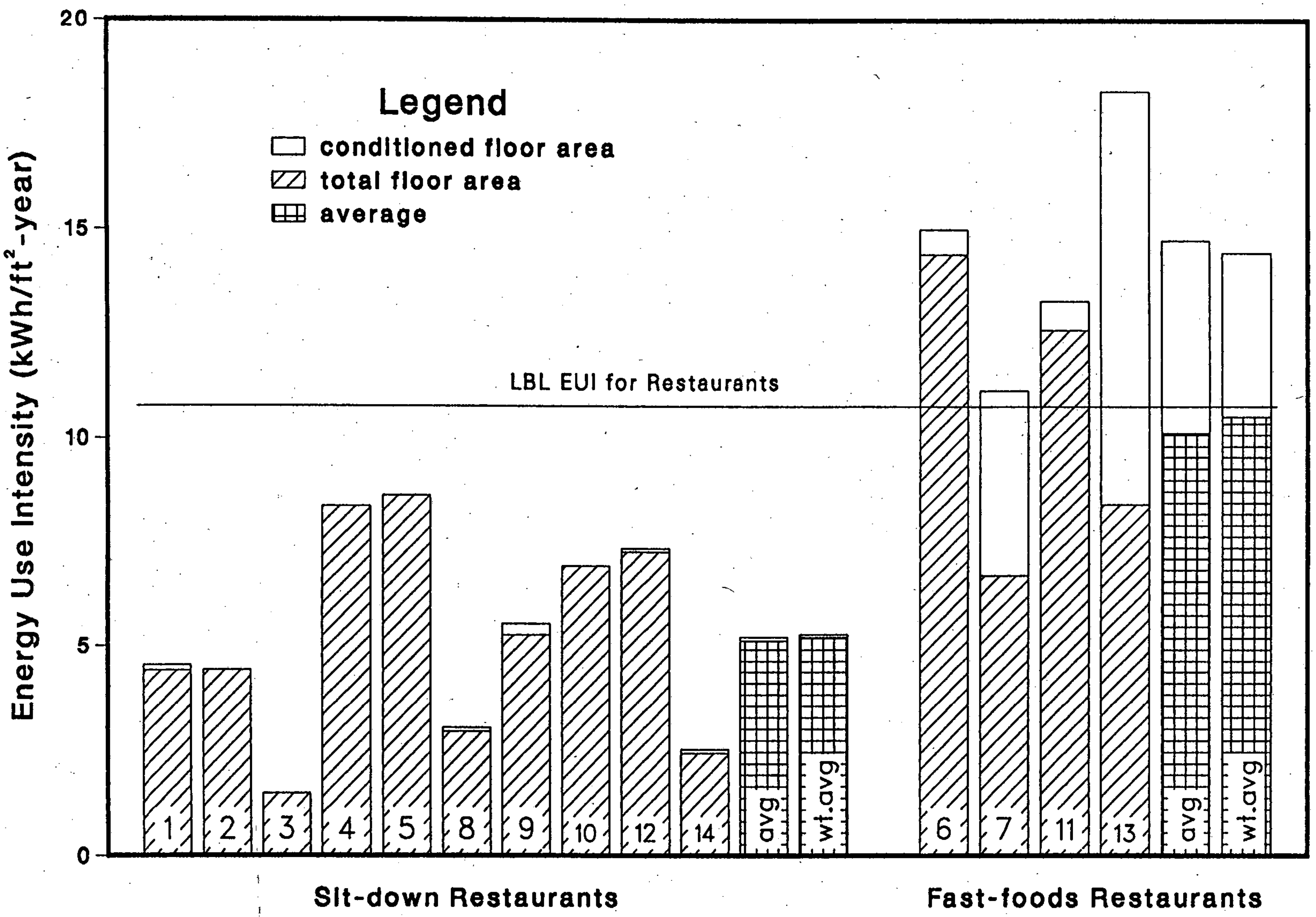
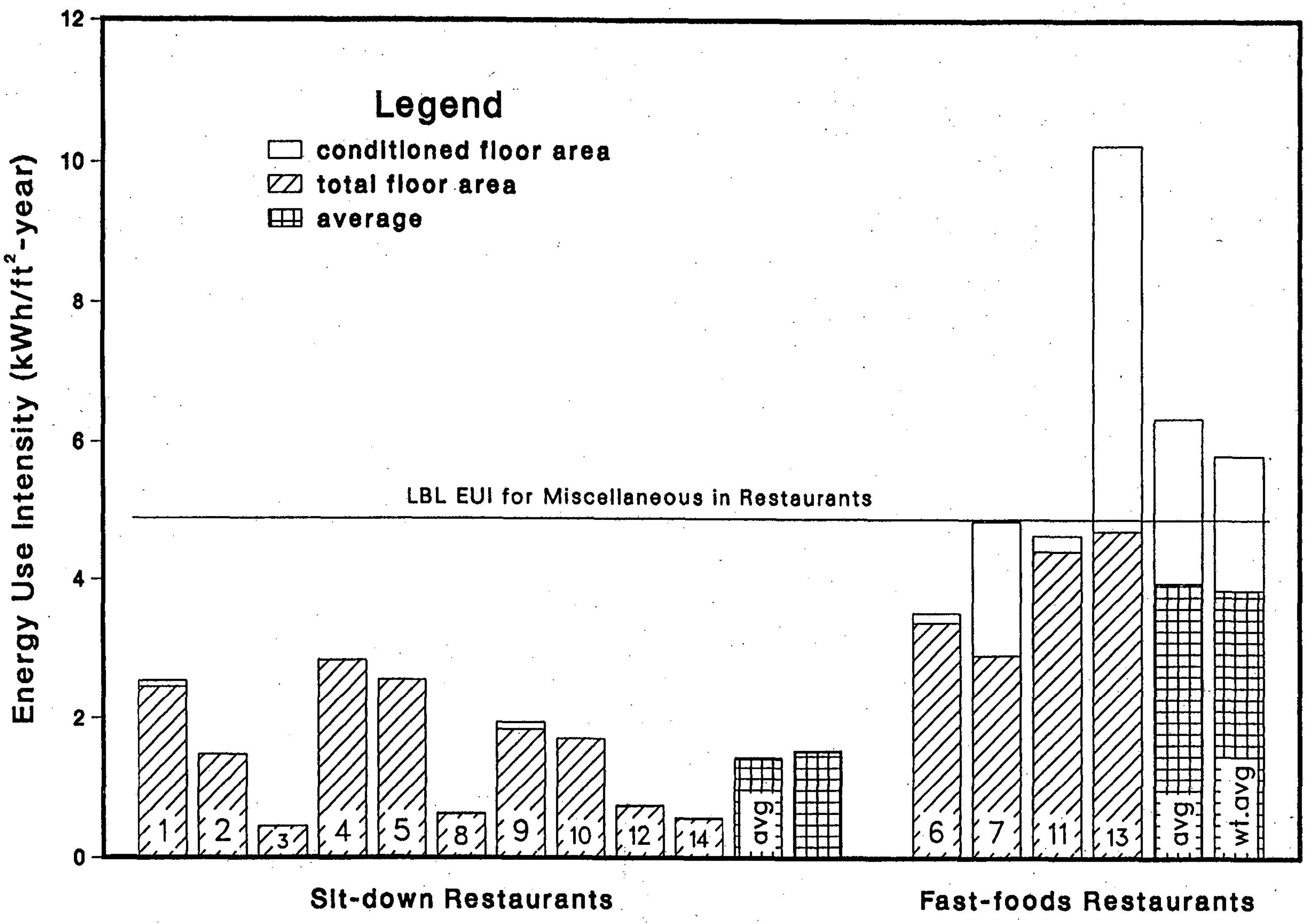


Figure II.18

Restaurant Exhaust Fan Energy Use Intensity (kWh/ft²-year)



Warehouse buildings

Only three non-refrigerated warehouses have been monitored. Their floor areas range from 41,000 to 300,000 ft^2 and their total electric EUIs range from 2.5 to 8.9 kWh/ft^2year. **Table II.6** presents the summary data for the three warehouses including the amount of valid and missing data, the estimated EUIs based on the conditioned and total building floor area, and the weighted and unweighted end-use EUIs.

Since, the sample of monitored buildings is very limited, not much can be concluded about the EUI comparison for the warehouses. **Figures II.19, II.20, and II.21** show the total building EUIs, HVAC EUIs, and lighting EUIs, respectively, for all monitored warehouses. In the figures, the values are compared with the LBL estimates. Although the sample size is very limited, there is a good comparison between the monitored and LBL whole-building electric EUIs.

Table II.6
End Use Intensities for Warehouse Buildings

Bldg Type	Bldg Num	End Use	Observations Valid	Observations Bad	Total Floor Area	Conditioned Floor Area	End Use Intensities ($kWh/ft^2 \cdot yr$) per tot flr area	End Use Intensities ($kWh/ft^2 \cdot yr$) per cond. flr area
WHS	1	Lighting	8375	385	300000	39000	2.818	21.676
WHS	1	Total	8375	385	300000	39000	5.080	39.074
WHS	2	HVAC	8759	1	41400	8280	0.696	3.481
WHS	2	Lighting	8759	1	41400	8280	0.864	4.318
WHS	2	Equipment	8758	2	41400	8280	6.766	33.829
WHS	2	Total	8709	3	41400	8280	8.950	44.748
WHS	3	Lighting	7175	1273	110000	28600	1.473	5.664
WHS	3	Total	7175	1249	110000	28600	2.537	9.758
Weighted Averages :								
WHS		HVAC					0.696	3.481
WHS		Lighting					1.718	10.553
WHS		Equipment					6.766	33.829
WHS		Total					5.522	31.193
Unweighted Averages :								
WHS		HVAC					0.696	3.481
WHS		Lighting					1.718	10.553
WHS		Equipment					6.766	33.829
WHS		Total					5.522	31.193

Figure II.19

Warehouse Total Energy Use Intensity (kWh/ft^2-year)

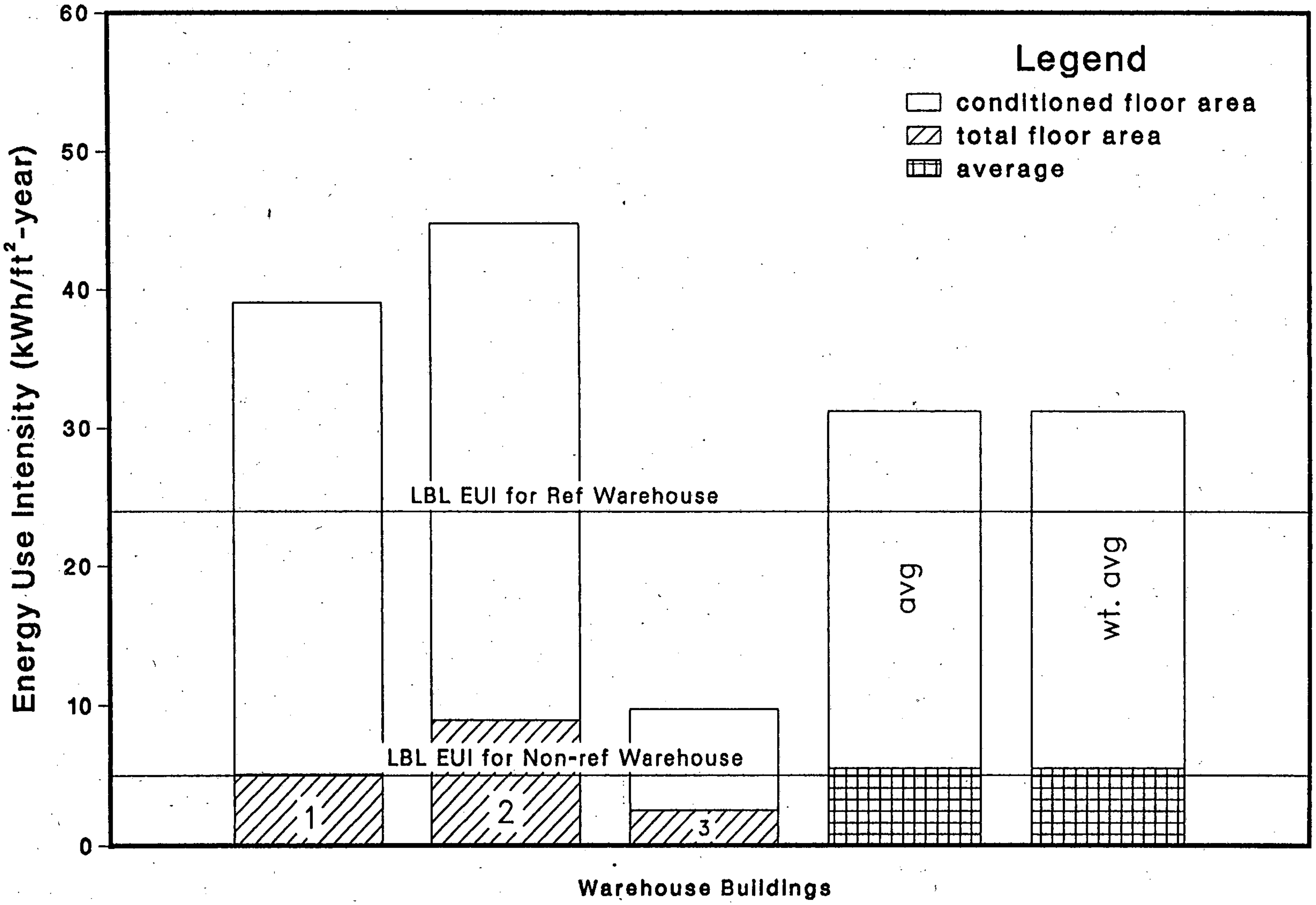


Figure II.20

Warehouse HVAC and Equipment Energy Use Intensity (kWh/ft²-year)

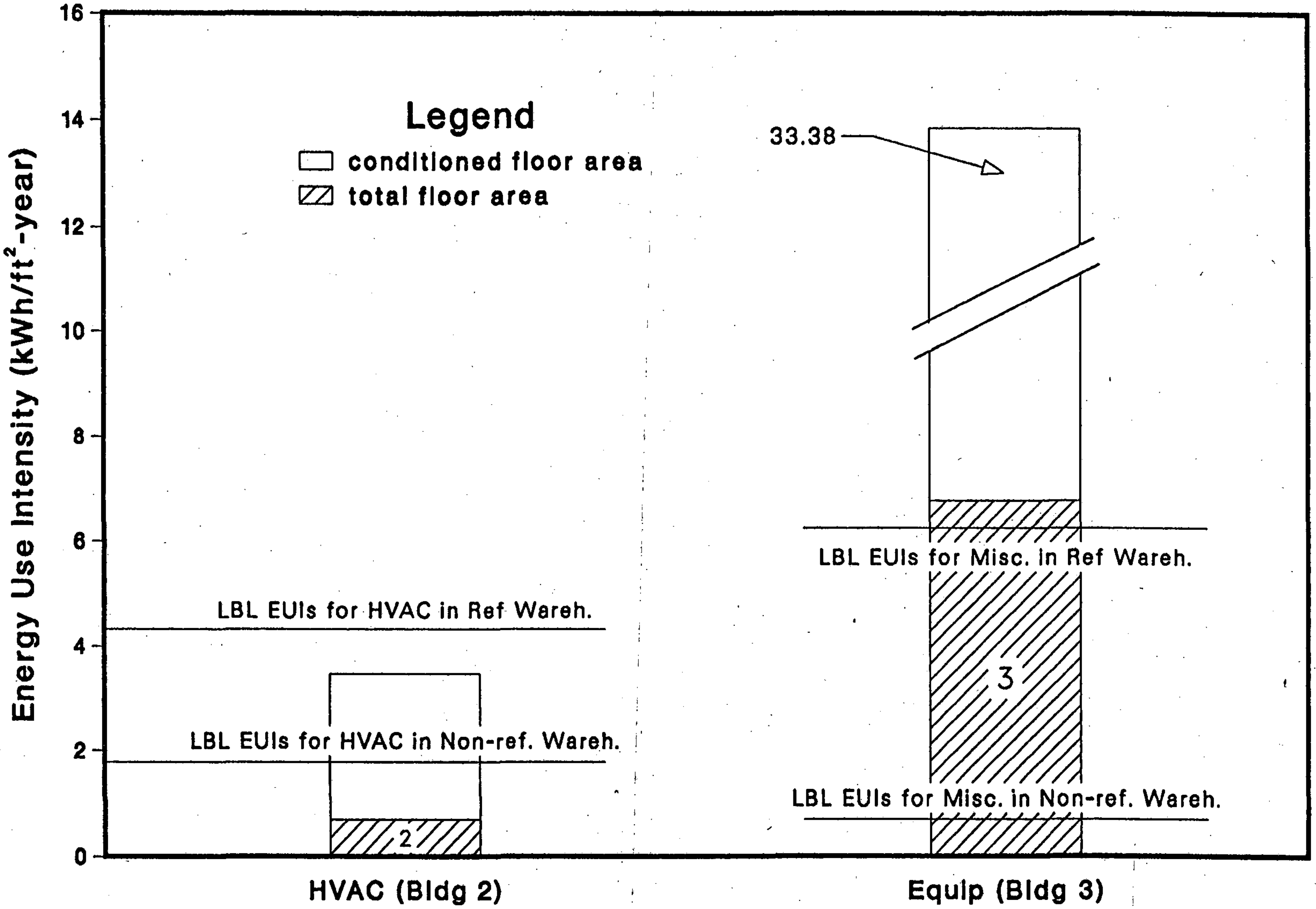
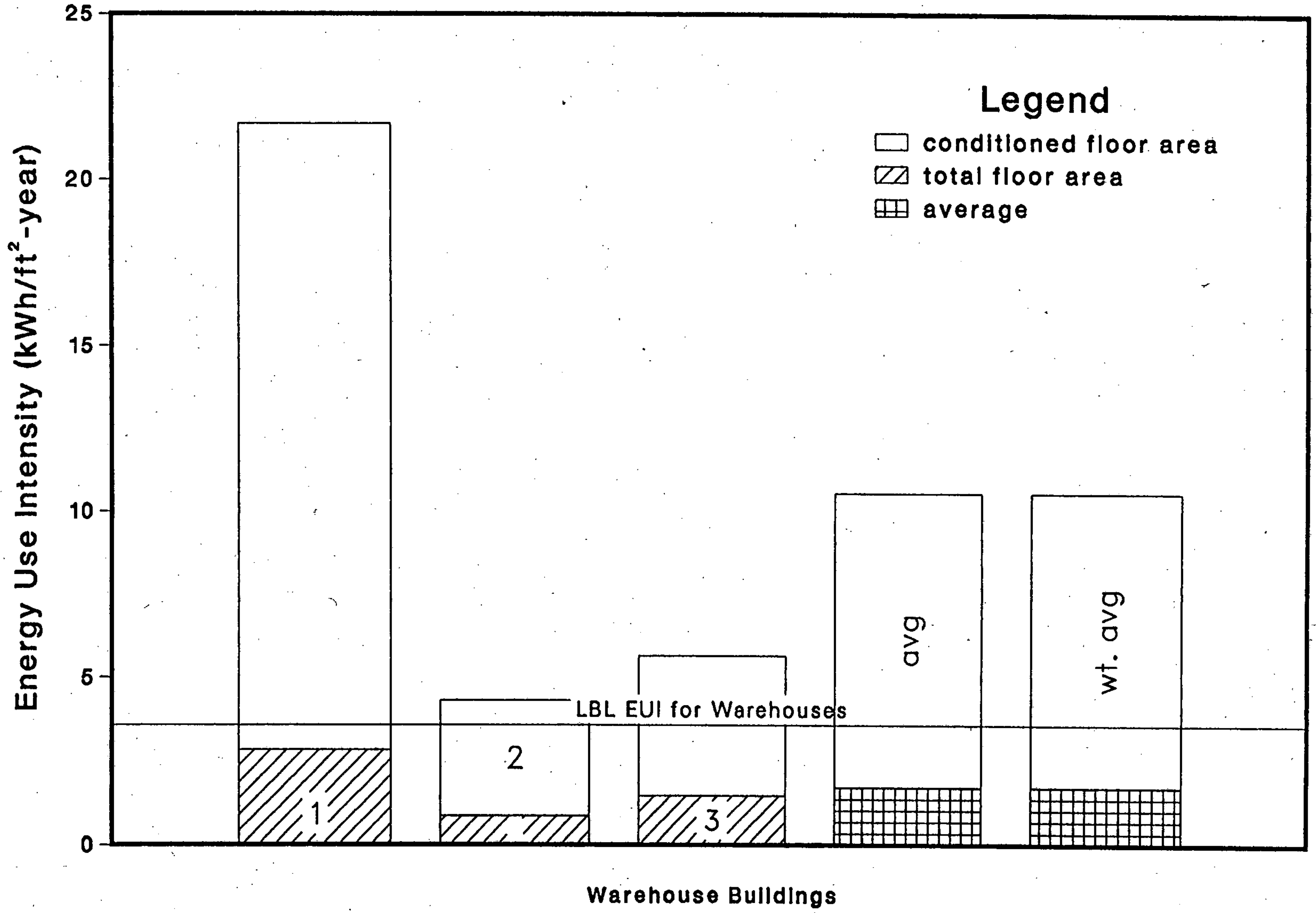


Figure II.21

Warehouse Lighting Energy Use Intensity (kWh/ft²-year)



Statistical Comparison

To further compare the EUIs from the monitored buildings to those of the LBL estimates, we performed two sets of statistical tests: the t-test (student test) and the u-test, a non-parametric test. The t-test is statistical check used when the population distribution is approximately normal but the standard deviation is unknown. A non-parametric test is used when the distribution of the population is not known.

Table II.7 shows the result of the statistical comparison for all of the buildings. The hypothesis being tested is that the monitored building's mean EUI is not significantly different, within a 95% confidence limit, from the population mean (it is assumed that the LBL data presents the population of commercial buildings in SCE service area). The first column of Table II.7 shows the range of EUIs for the monitored building sample; column 2 is the standard deviation of the sample; column 3 is the sample mean; column 4 is the population mean (LBL EUIs); column 5 is the 't'-value for normal distribution, column 7 is the 'u'-value for the non-parametric test. Columns 6 and 8 indicate the statistical significance of the sample set based on the criteria stated above using the two types of tests. The t and u values are found using the following equations:

$$t=(\text{sample mean}-\text{population mean})/(\text{sample std. dev}/\sqrt{n})$$

$$u=(\text{sample mean}-\text{population mean})/\text{sample range}$$

For a more detailed discussion of the statistical tests, refer to a standard statistics textbook, such as Lipson and Narendra (1973).

Judging from the results of the non-parametric test one can conclude that, except for groceries and restaurants, there is no significant difference between the EUIs estimated from the monitored buildings and the LBL EUIs. For groceries, the lighting and refrigeration EUIs are not statistically different. For restaurants, the HVAC, lighting, and total EUIs are also not statistically different from each other. However, the HVAC EUIs and total building EUI for the grocery buildings are significantly different. The results of the statistical comparisons using the t-test is somewhat different from the non-parametric test, as shown in Table II.7 . For those instances in which the two tests reached the same conclusion, there is a higher confidence in the conclusion. Likewise, the results can be viewed with lower confidence if both tests don't accept or reject the hypothesis.

Table II.7
Monitored Building Mean EUI Compared to Population Mean

Building Type (N) End Use	Range	Standard Deviation	Sample Mean	Poplulation Mean	t	Hypotheses Accepted	u	Hypotheses Accepted
Large Office (4)								
HVAC	6.62	1.22	7.56	5.90	2.721	yes	0.251	yes
LIGHT	9.14	2.17	5.55	10.66	-4.707	no	-0.559	yes
MISC	8.84	1.66	5.89	3.21	3.224	no	0.304	yes
TOTAL	15.47	3.50	17.14	19.88	-1.562	yes	-0.177	yes
Small Office (6)								
HVAC	6.57	1.00	6.19	7.02	-2.033	yes	-0.127	yes
LIGHT	6.63	1.26	5.92	6.71	-1.535	yes	-0.119	yes
MISC	9.53	1.22	3.78	3.59	0.373	yes	0.019	yes
TOTAL	14.14	2.88	15.52	16.82	-1.109	yes	-0.092	yes
Large Retail (6)								
HVAC	7.48	1.24	6.71	7.56	-1.668	yes	-0.113	yes
LIGHT	20.74	3.38	12.89	10.58	1.674	yes	0.111	yes
OTHER	6.24	1.04	3.30	1.67	3.862	no	0.262	yes
TOTAL	24.93	3.89	22.77	18.22	2.861	no	0.182	yes
Small Retail (4)								
HVAC	7.89	1.85	7.61	6.50	1.202	yes	0.141	yes
LIGHT	3.76	0.95	6.74	6.07	1.425	yes	0.179	yes
OTHER	1.72	0.41	0.79	1.94	-5.591	no	-0.666	yes
TOTAL	7.20	1.64	14.60	12.25	2.857	yes	0.326	yes
Grocery (14)								
HVAC	6.61	0.47	3.59	2.14	11.520	no	0.219	no
LIGHT	20.55	1.37	15.76	13.97	4.894	no	0.087	yes
REFRIG	25.23	2.12	25.63	23.17	4.328	no	0.097	yes
OTHER	25.40	2.88	18.56	2.04	21.454	no	0.650	no
TOTAL	61.30	5.21	62.88	40.27	16.229	no	0.369	no
Restaurant (14)								
HVAC	64.93	5.12	19.23	19.74	-0.375	yes	-0.008	yes
LIGHT	24.41	1.84	10.85	12.03	-2.398	no	-0.048	yes
REFRIG	12.93	0.92	6.62	10.78	-16.924	no	-0.322	no
COOKING	34.47	2.65	12.71	4.46	11.658	no	0.239	no
EXHAUST	4.25	0.38	2.18	0.00	21.513	no	0.514	no
OTHER	25.07	1.72	10.83	4.92	12.844	no	0.236	no
TOTAL	108.06	8.22	58.54	51.91	3.019	no	0.061	yes
Warehouse (4)								
HVAC	1.05	0.37	2.95	1.78	4.476	yes	1.119	yes
LIGHT	1.96	0.44	1.86	3.55	-7.764	no	-0.861	no
MISC	6.68	1.55	2.85	1.14	2.216	yes	0.257	yes
TOTAL	6.41	1.42	4.99	5.02	-0.039	yes	-0.004	yes

We also looked at the question of the statistical differences of the end-use EUIs in terms of the percentage of the whole-building electric EUI. The results are shown in **Table II.8**. For the non-parametric test, the comparison is somewhat less favorable than the results of the previous comparison. The percentage of lighting EUIs for the large office and grocery, HVAC EUI for large retail, and the refrigeration EUI for the grocery are significantly different from that of the corresponding LBL percentages.

In summary, in the absence of a statistically representative data, one can conclude that the monitored data are not statistically different from a good portion of the LBL derived end-use EUIs.

Table II.8
End Use EUIs as Percentage of Whole Building Load

Building Type (N) End Use	Range	Standard Deviation	Sample Mean	Poplulation Mean	t	Hypotheses Accepted	u	Hypotheses Accepted
Large Office (4)								
HVAC	0.611	0.131	0.499	0.297	3.082	yes	0.331	yes
LIGHT	0.251	0.052	0.297	0.536	-9.259	no	-0.950	no
MISC	0.444	0.083	0.347	0.161	4.457	no	0.418	yes
Small Office (6)								
HVAC	0.494	0.071	0.440	0.417	0.785	yes	0.046	yes
LIGHT	0.318	0.028	0.377	0.399	-1.956	yes	-0.070	yes
MISC	0.412	0.066	0.227	0.213	0.487	yes	0.032	yes
Large Retail (6)								
HVAC	0.176	0.030	0.295	0.415	-9.804	no	-0.678	no
LIGHT	0.295	0.054	0.526	0.581	-2.499	yes	-0.186	yes
OTHER	0.294	0.062	0.185	0.092	3.694	no	0.316	yes
Small Retail (4)								
HVAC	0.298	0.072	0.498	0.531	-0.900	yes	-0.109	yes
LIGHT	0.317	0.066	0.471	0.496	-0.745	yes	-0.077	yes
OTHER	0.176	0.042	0.066	0.158	-4.384	no	-0.523	yes
Grocery (14)								
HVAC	0.124	0.007	0.059	0.053	3.491	no	0.050	yes
LIGHT	0.289	0.014	0.253	0.347	-24.439	no	-0.324	no
REFRIG	0.360	0.026	0.416	0.575	-23.169	no	-0.443	no
OTHER	0.305	0.028	0.282	0.051	30.413	no	0.759	no
Restaurant (14)								
HVAC	0.593	0.042	0.279	0.380	-9.087	no	-0.171	no
LIGHT	0.197	0.015	0.179	0.232	-12.881	no	-0.267	no
REFRIG	0.237	0.019	0.127	0.208	-15.422	no	-0.339	no
COOKING	0.296	0.022	0.201	0.086	19.401	no	0.391	no
EXHAUST	0.074	0.005	0.038	0.000	25.813	no	0.505	no
OTHER	0.456	0.032	0.219	0.095	14.494	no	0.272	no
Warehouse (4)								
HVAC	0.326	0.115	0.552	0.355	2.420	yes	0.605	yes
LIGHT	0.580	0.130	0.477	0.707	-3.560	no	-0.397	yes
MISC	0.617	0.128	0.474	0.227	3.847	no	0.401	yes

Load-shape Analysis and Comparison with Forecasting Models

We used the same procedure discussed in the previous sections to develop average monthly load shapes by end use for each building type and to compare them with the LBL results. The load shapes are grouped by weekdays and weekend days. The results are shown in **Figures II.22a,b through 28a,b.** All 'a' figures correspond to the SCE monitored data and 'b' figures correspond to load-shape data from the LBL study. The following is a key to the list of figures.

Figure	Code	Building Type
Fig. II.22a	OFFLG	large office measured data
Fig. II.22b	OFFLG	large office EDA results
Fig. II.23a	OFFSM	small office measured data
Fig. II.23b	OFFSM	small office EDA results
Fig. II.24a	RTLLG	large retail measured data
Fig. II.24b	RTLLG	large retail EDA results
Fig. II.25a	RTLSM	small retail measured data
Fig. II.25b	RTLSM	small retail EDA results
Fig. II.26a	GRY	grocery (or food store) measured data
Fig. II.26b	GRY	food store EDA results
Fig. II.27a.1	RSTSD	sit-down restaurant measured data
Fig. II.27a.2	RSTFF	fast-food restaurant measured data
Fig. II.27a	RST	combined restaurant (63% sit-down, 37% fast food)
Fig. II.27b	RST	restaurant EDA results
Fig. II.28a	WHS	warehouse measured data
Fig. II.28b	WHS	warehouse EDA results

Since the 1989 LBL study focused on developing load shapes for a standard weekday, we will only concentrate on the comparison of the LSs for the standard weekday.

Large Office (Figures II.22a&b)

The average monthly whole-building electric load shapes developed in the LBL study and those produced from the monitored data compare well qualitatively. Significant differences

Figure II.22a
Large Office Monitored Data
Solid lines for winter months, dashed lines for summer months

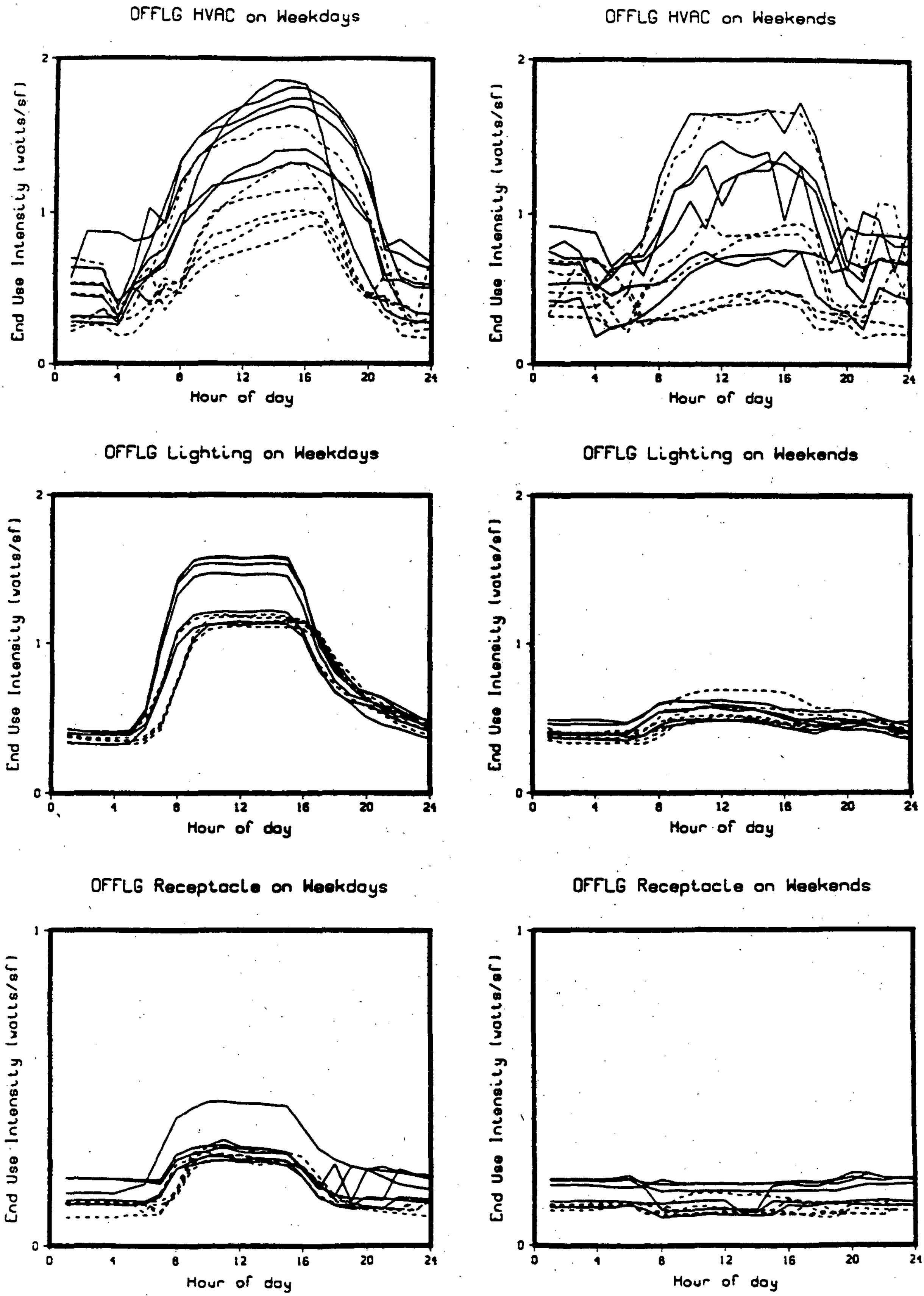


Figure II.22a (continued)
Large Office Monitored Data
Solid lines for winter months, dashed lines for summer months

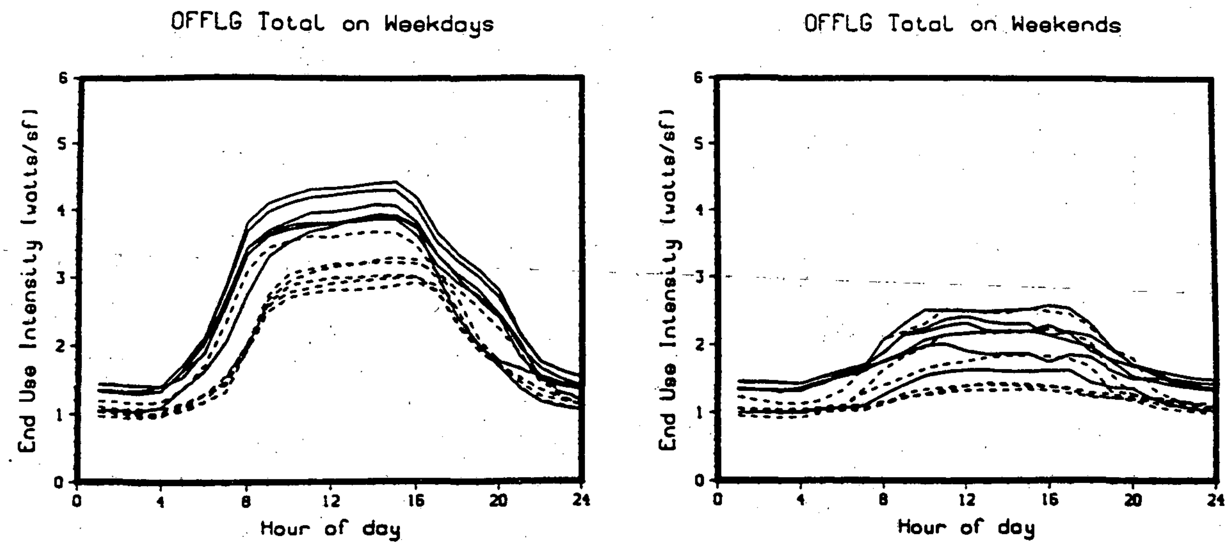


Figure II.22b
Large Office EDA Results
Solid lines for winter months, dashed lines for summer months

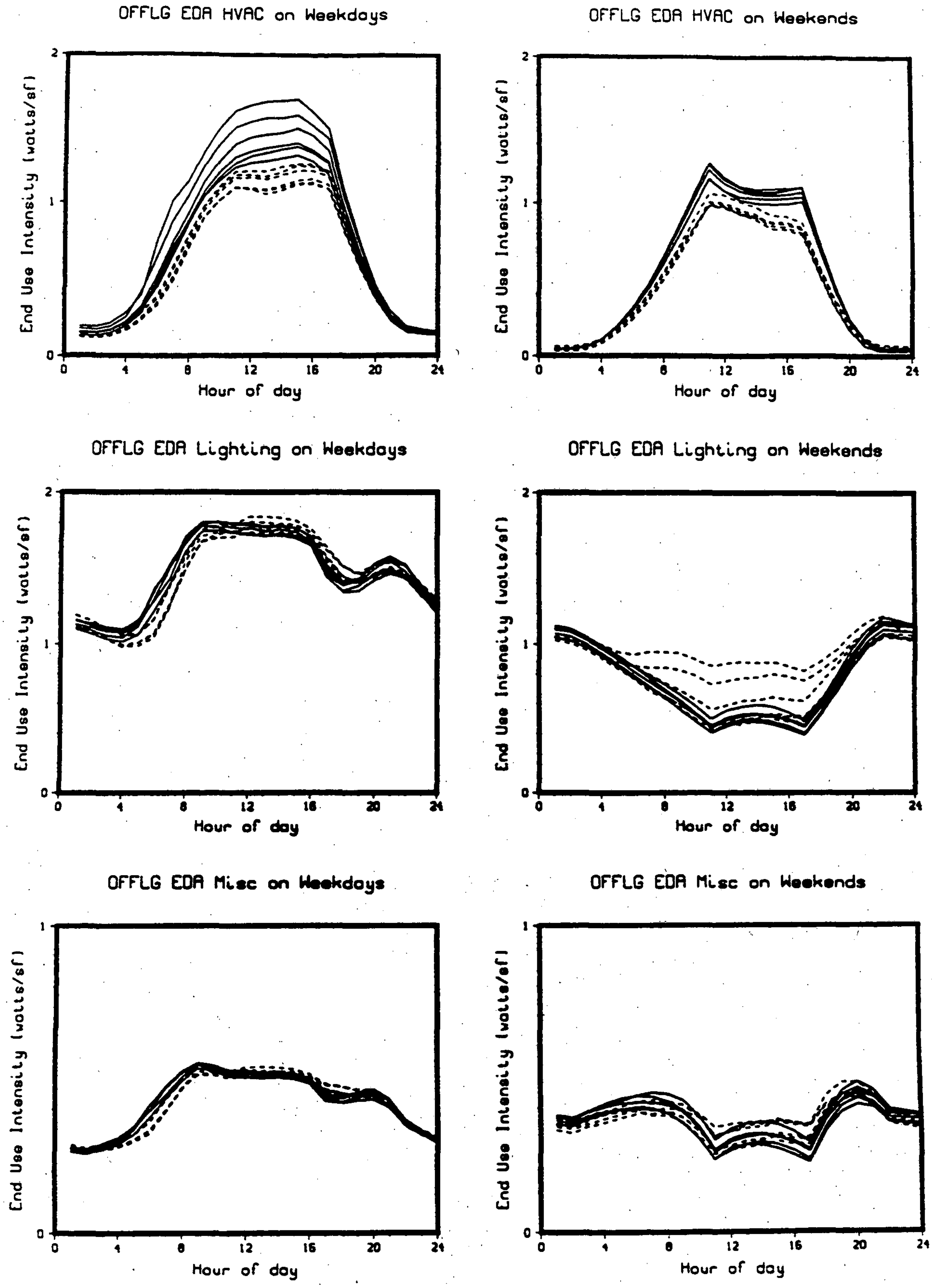


Figure II.22b (continued)
Large Office EDA Results
Solid lines for winter months, dashed lines for summer months

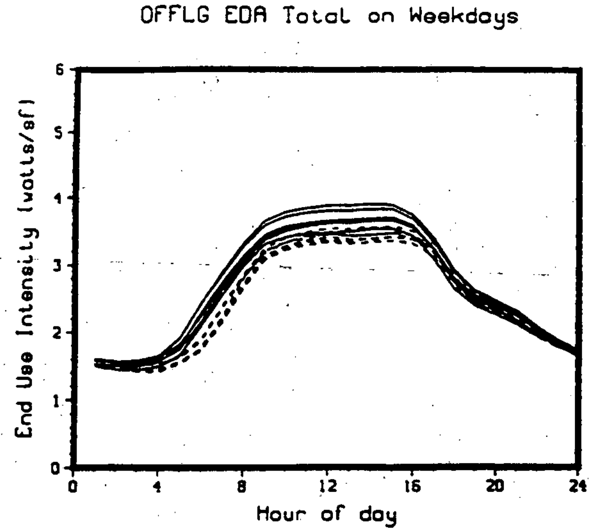


Figure II.23a
Small Office Monitored Data
Solid lines for winter months, dashed lines for summer months

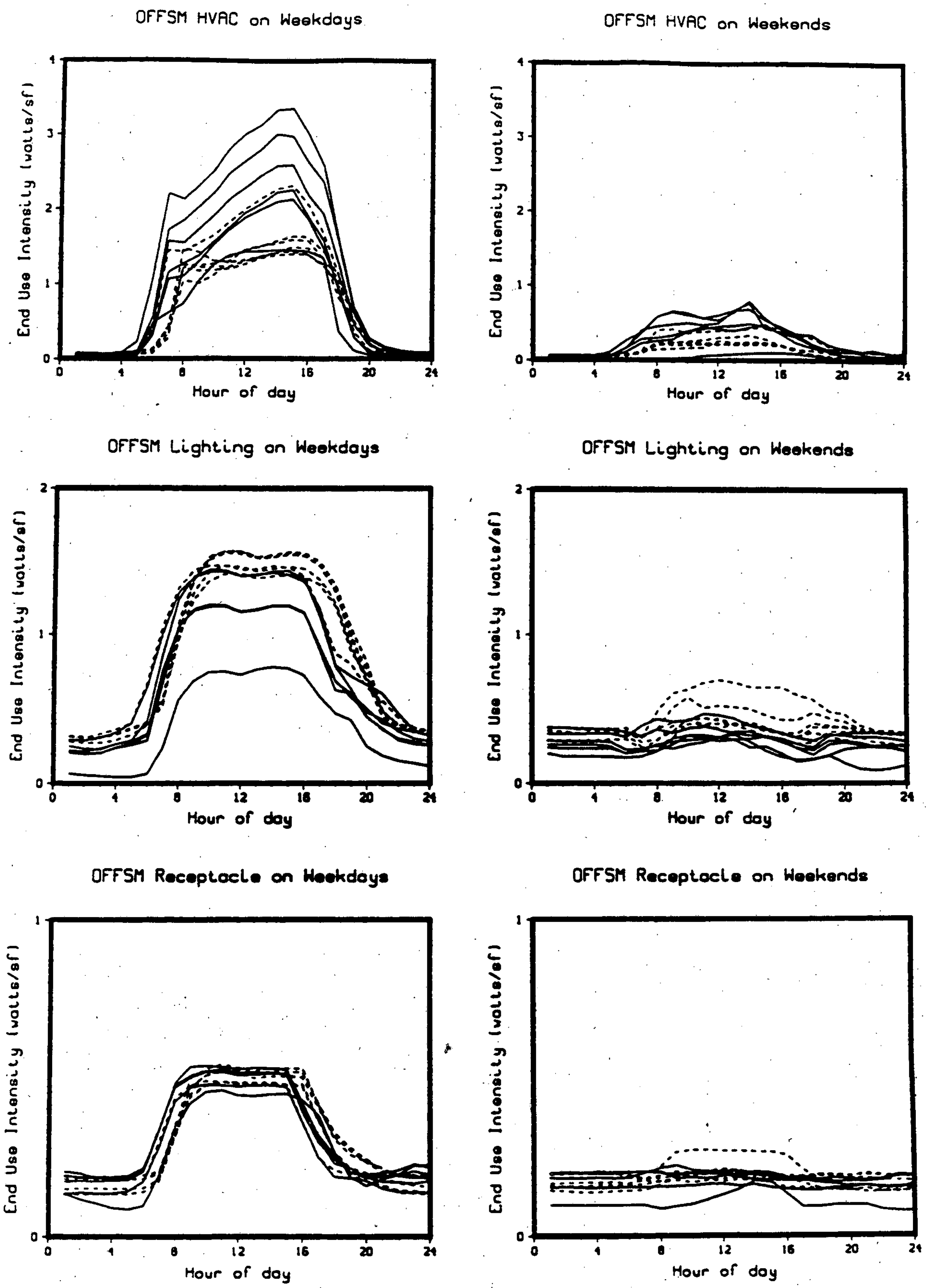


Figure II.23a (continued)
Small Office Monitored Data
Solid lines for winter months, dashed lines for summer months

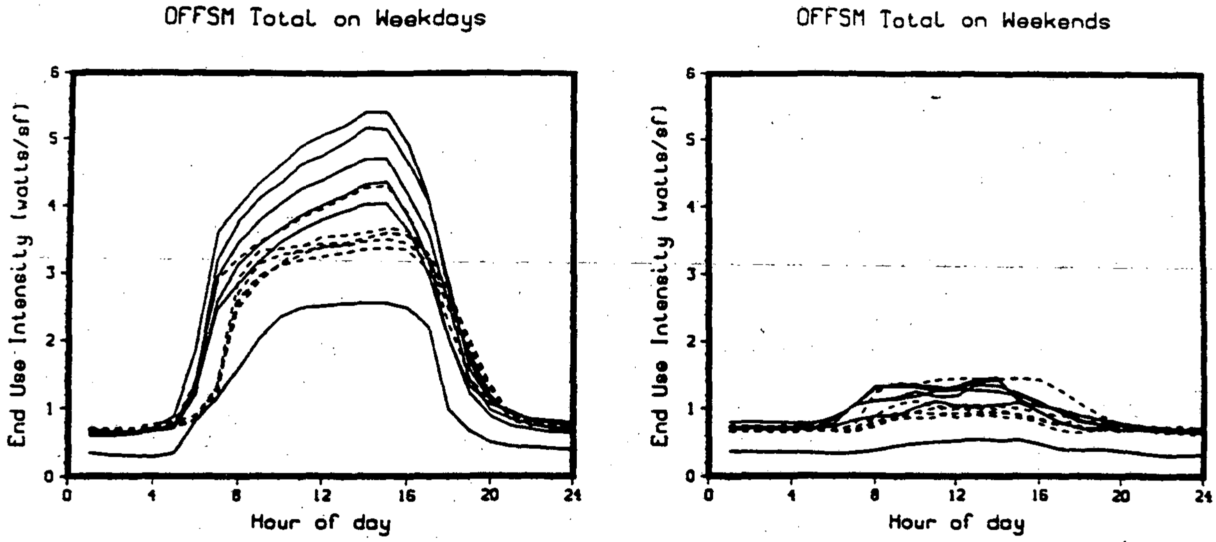


Figure II.23b
Small Office EDA Results
Solid lines for winter months, dashed lines for summer months

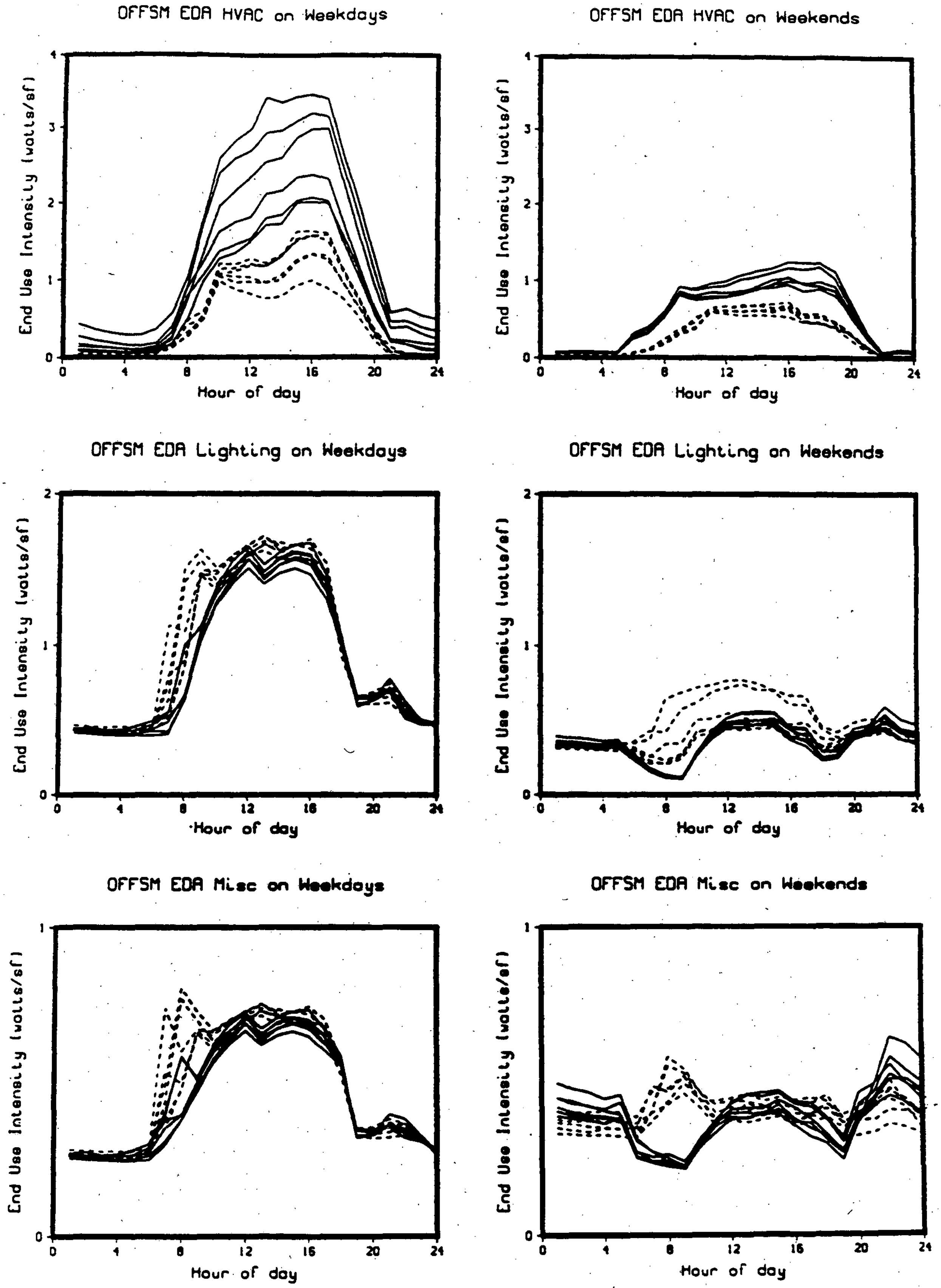
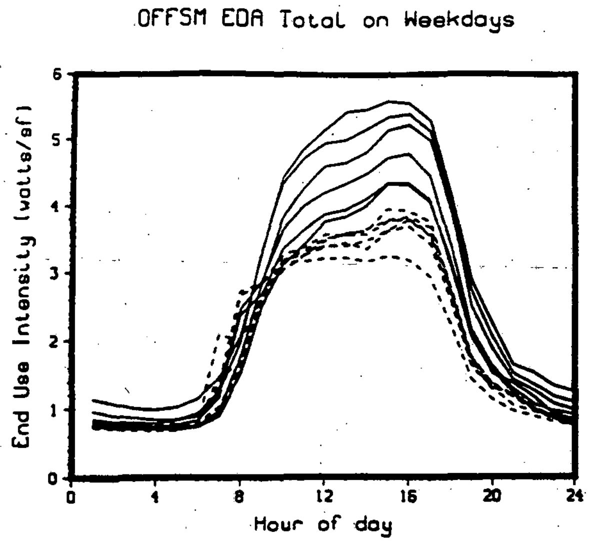


Figure II.23b (continued)
Small Office EDA Results
Solid lines for winter months, dashed lines for summer months



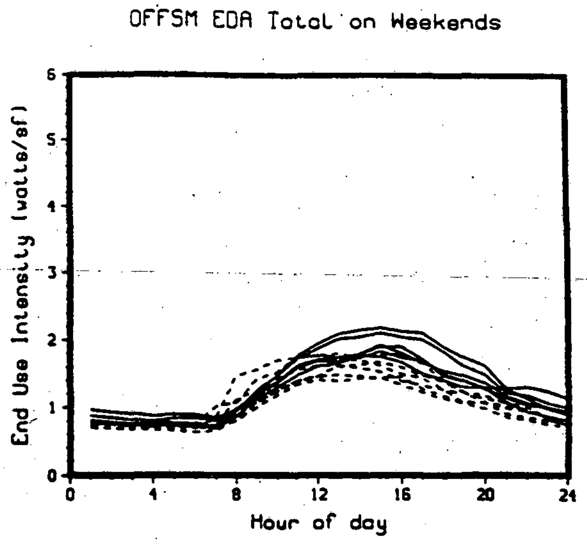


Figure II.24a
Large Retail Monitored Data
Solid lines for winter months, dashed lines for summer months

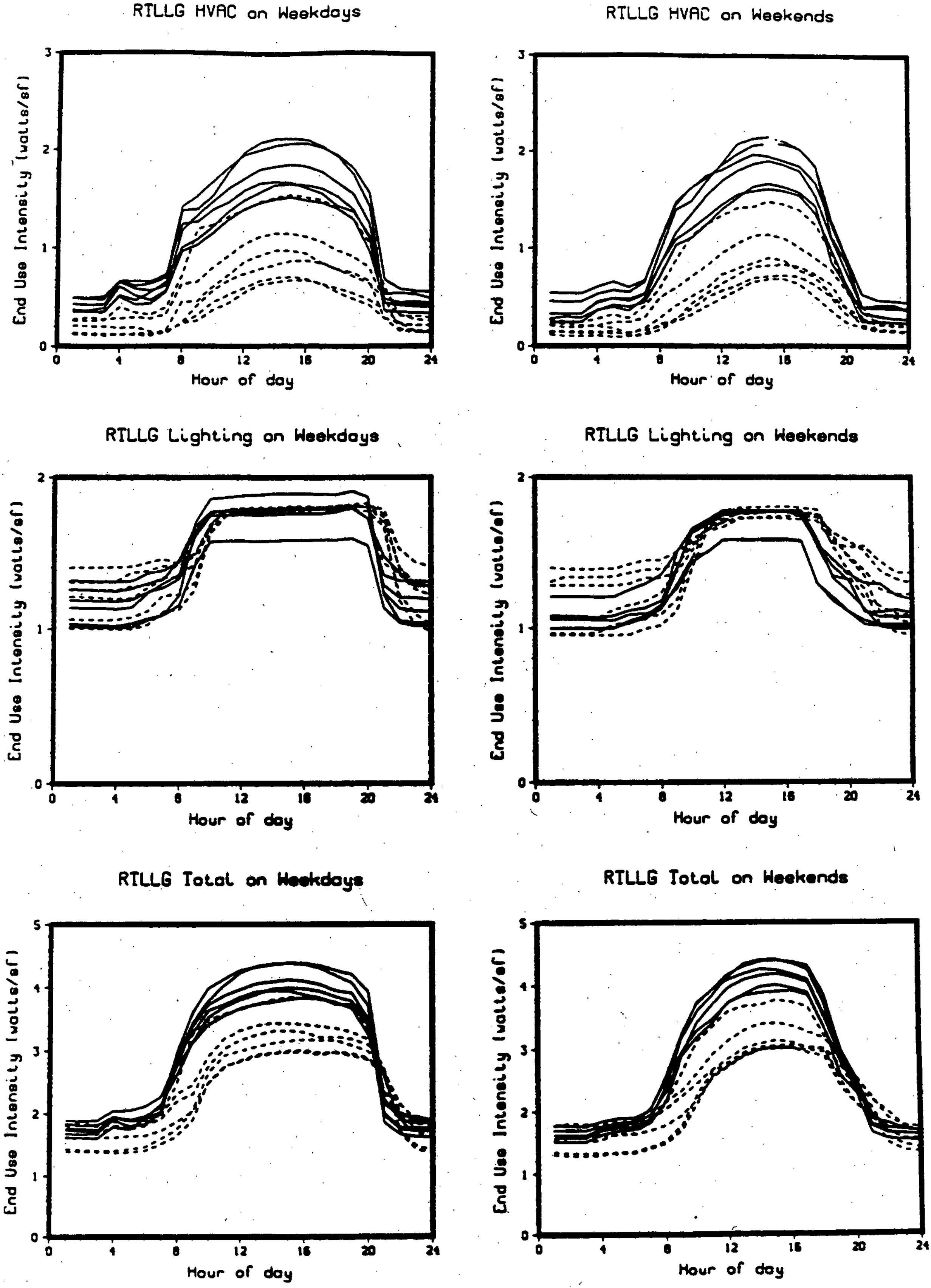


Figure II.24b
Large Retail EDA Results
Solid lines for winter months, dashed lines for summer months

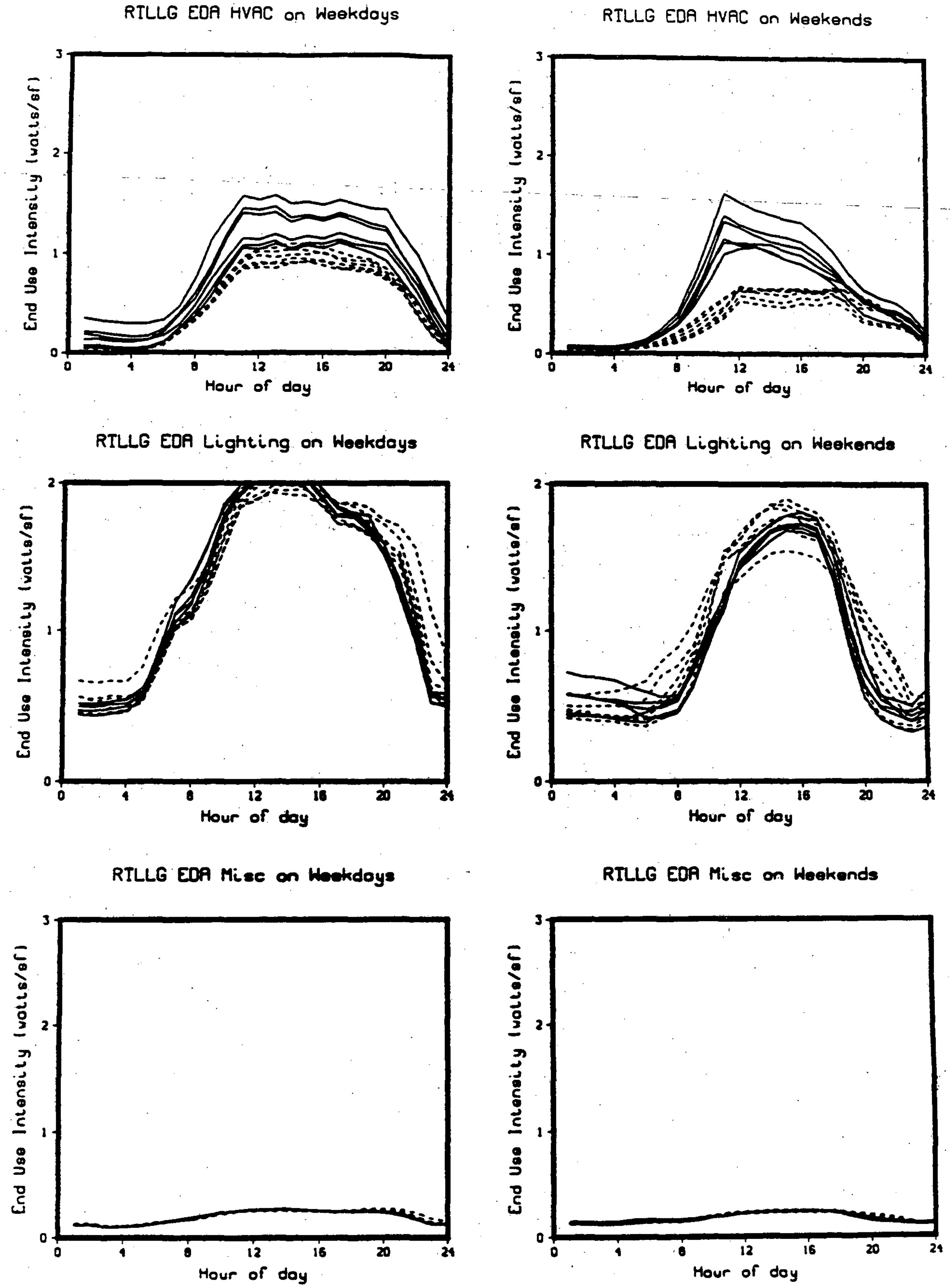
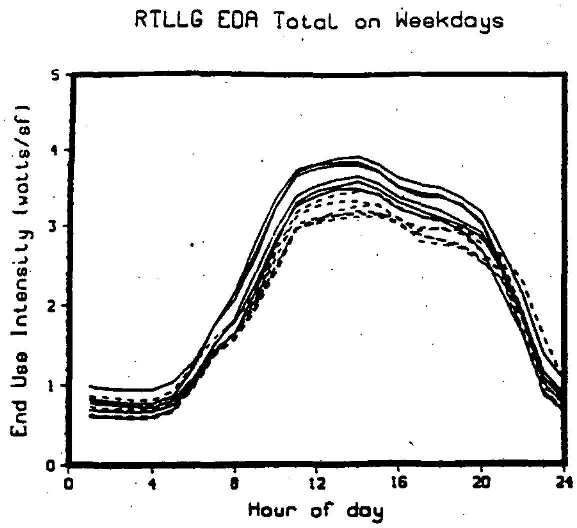


Figure II.24b (continued)
Large Retail EDA Results
Solid lines for winter months, dashed lines for summer months



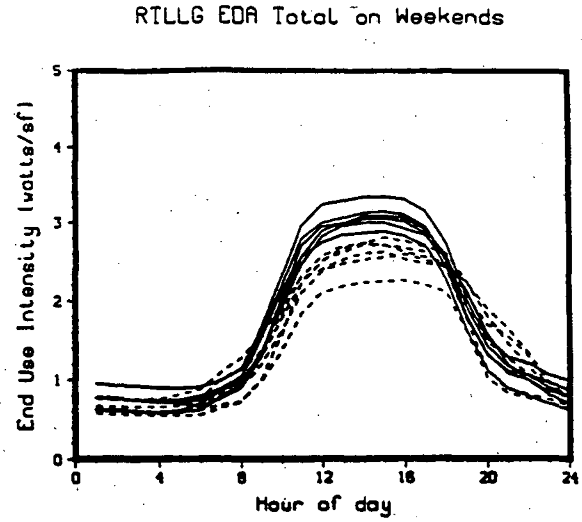


Figure II.25a
Small Retail Monitored Data
Solid lines for winter months, dashed lines for summer months

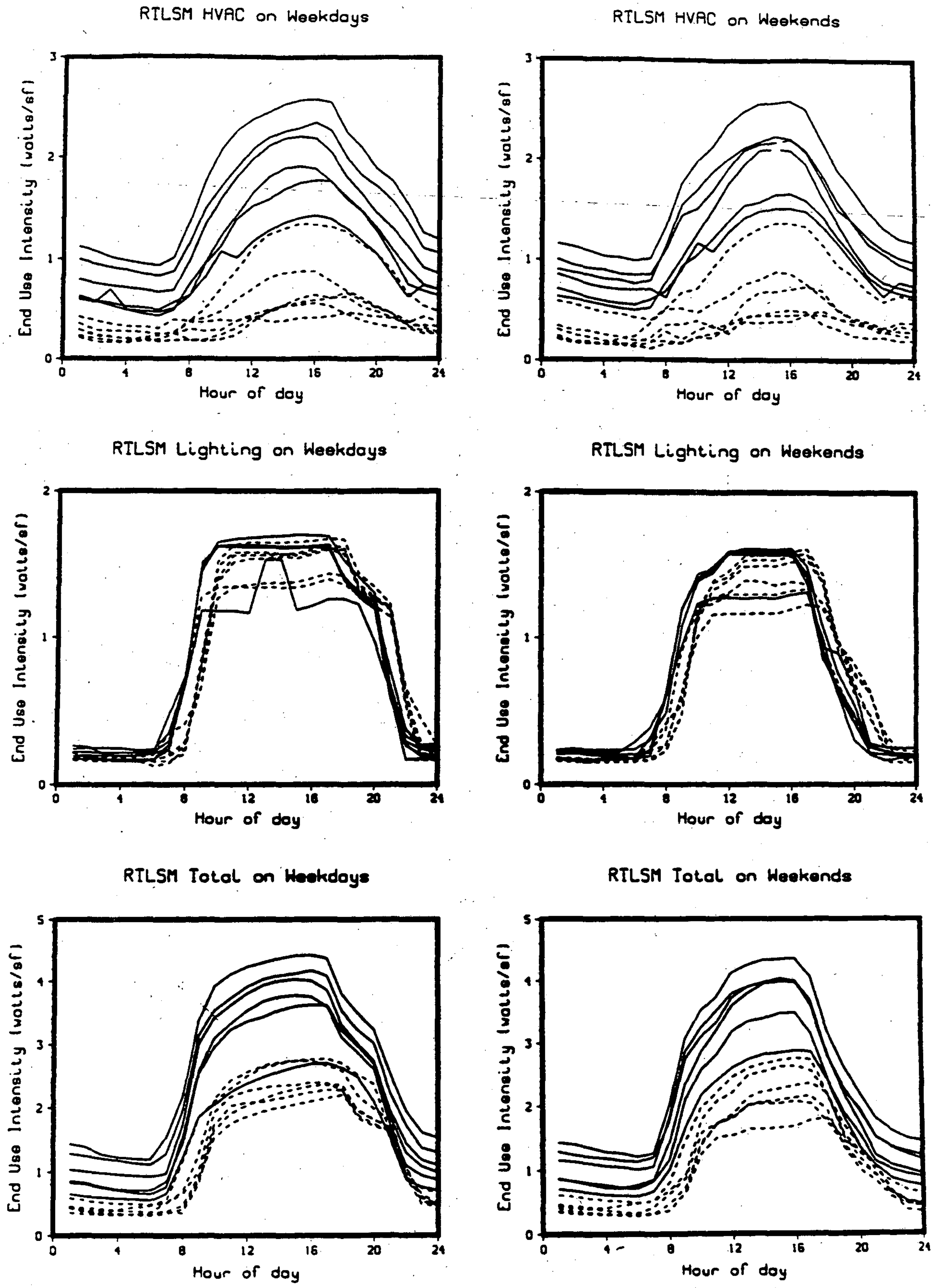


Figure II.25b
Small Retail EDA Results
Solid lines for winter months, dashed lines for summer months

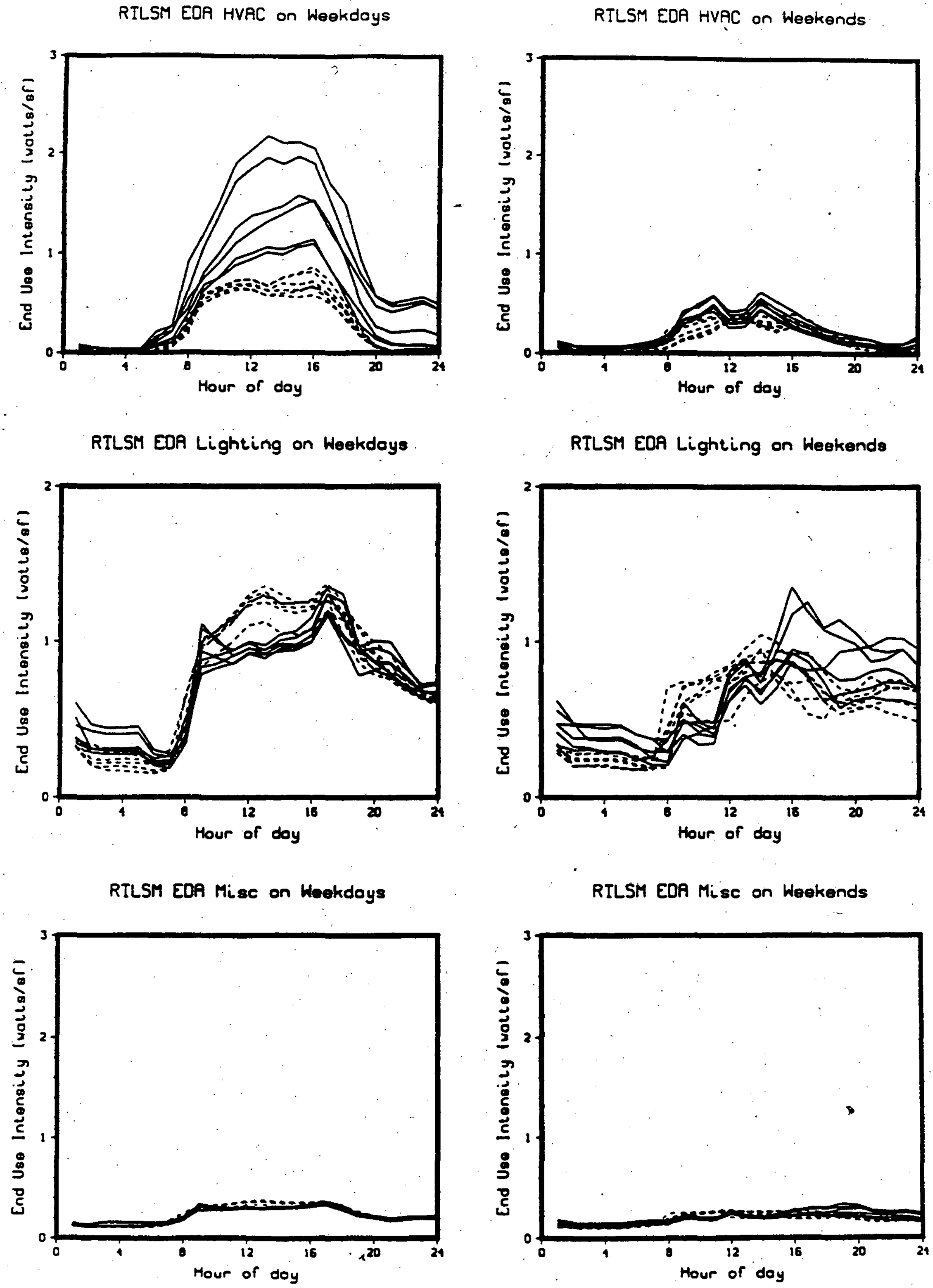


Figure II.25b (continued)
Small Retail EDA Results
Solid lines for winter months, dashed lines for summer months

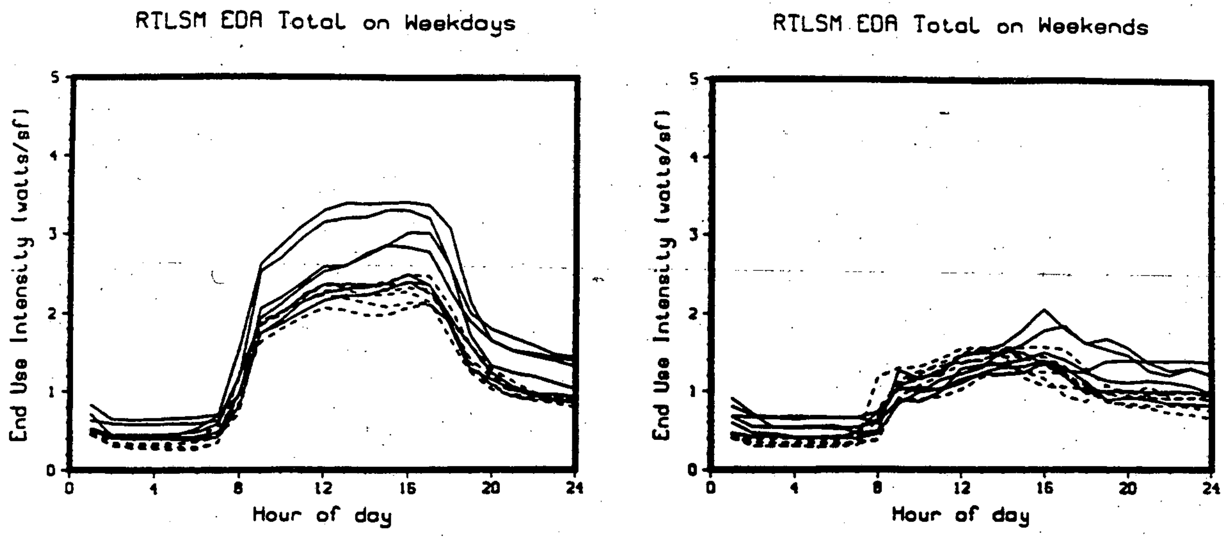


Figure II.26a
Grocery Monitored Data
Solid lines for winter months, dashed lines for summer months

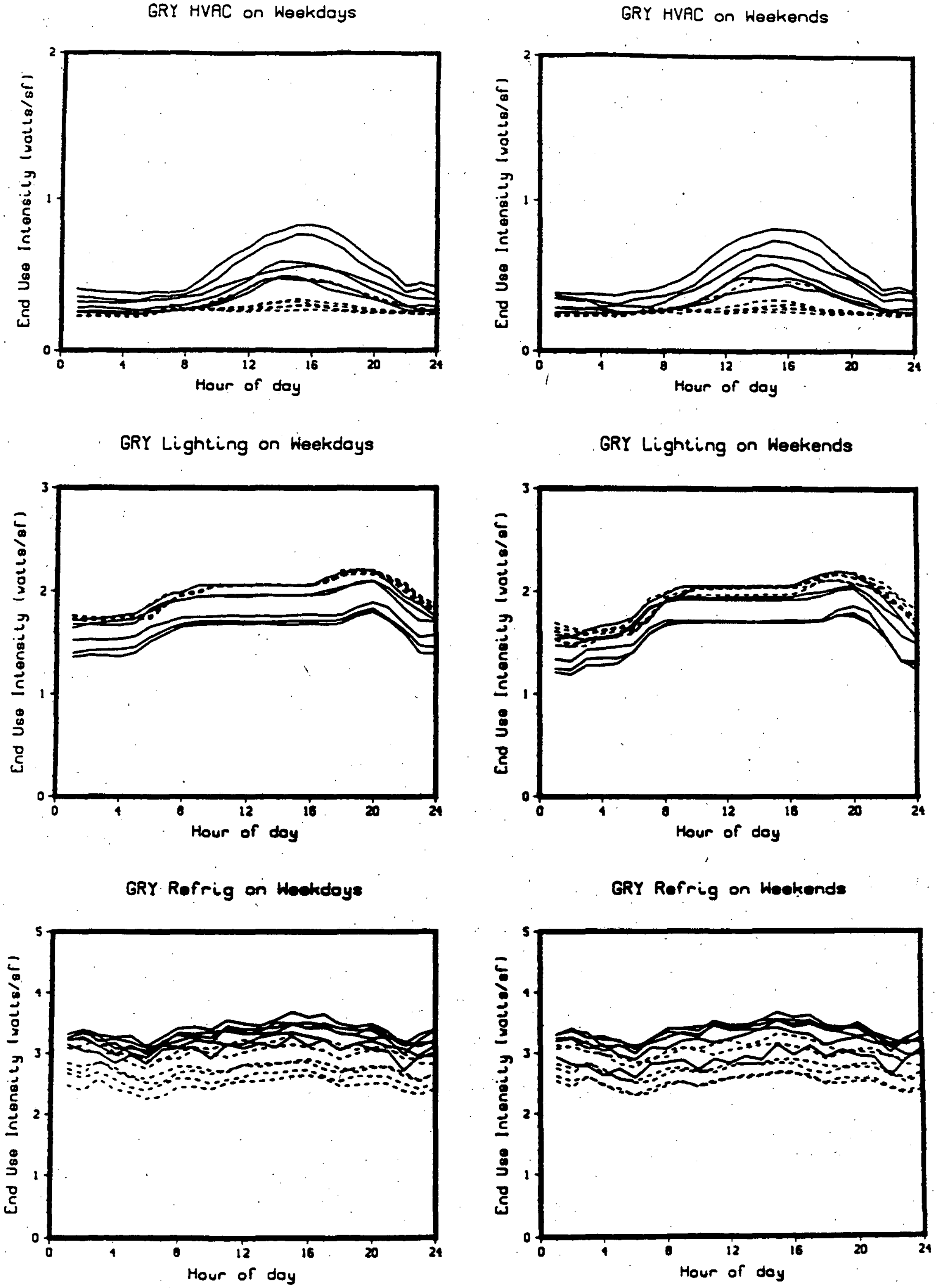
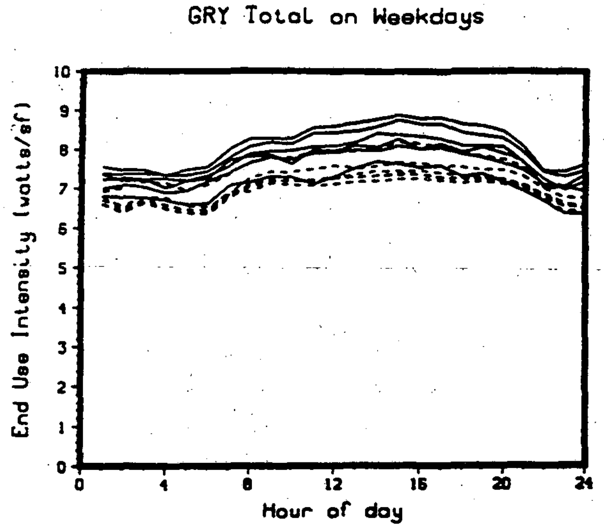


Figure II.26a (continued)
Grocery Monitored Data
Solid lines for winter months, dashed lines for summer months



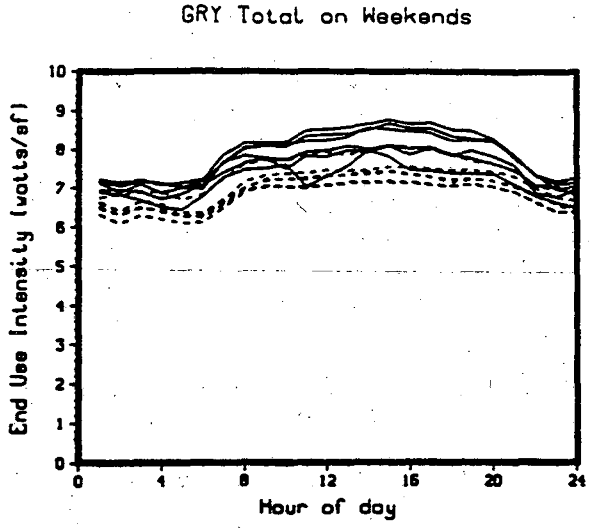


Figure II.26b
Grocery EDA Results
Solid lines for winter months, dashed lines for summer months

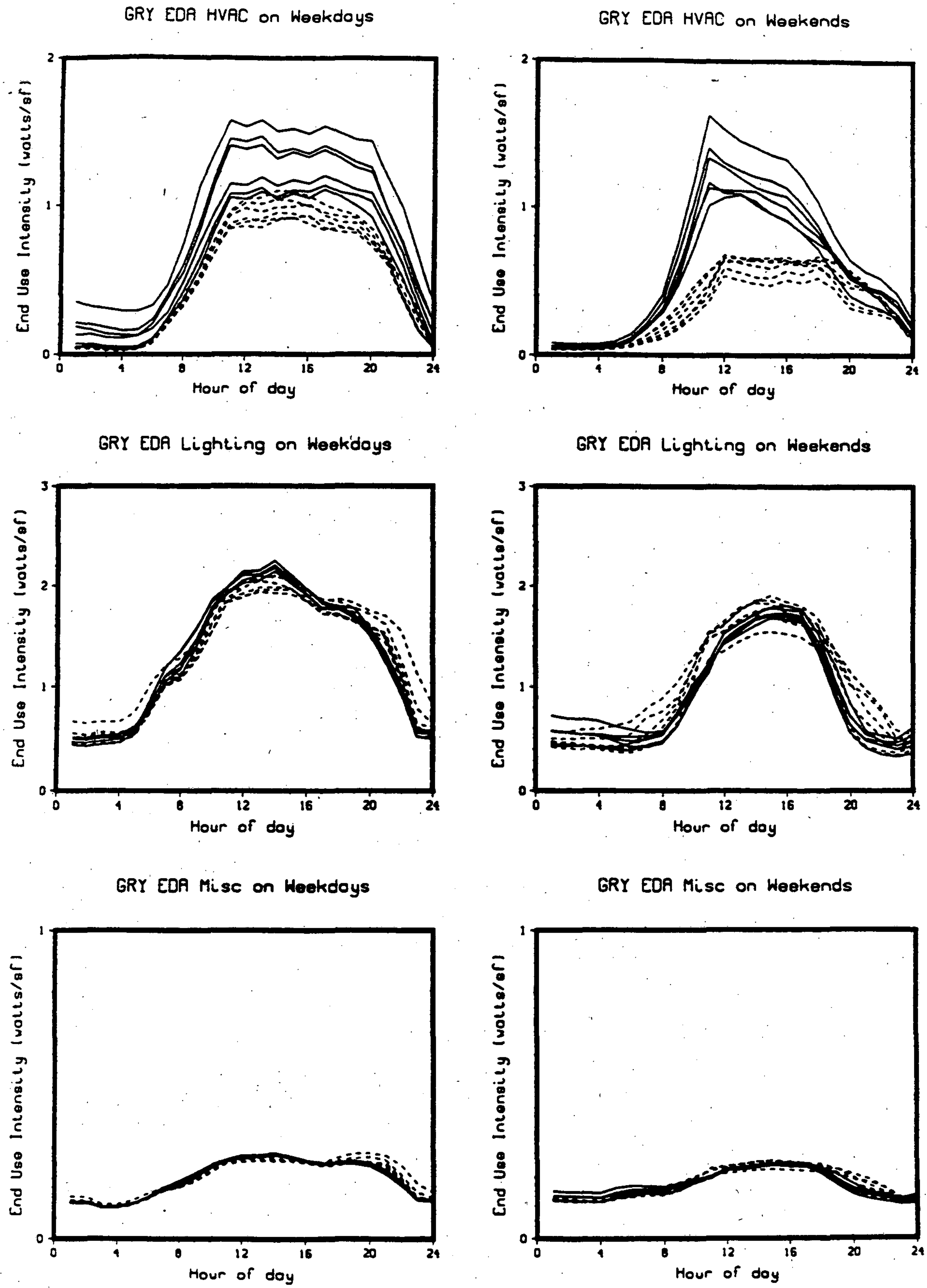


Figure II.26b (continued)
Grocery EDA Results
Solid lines for winter months, dashed lines for summer months

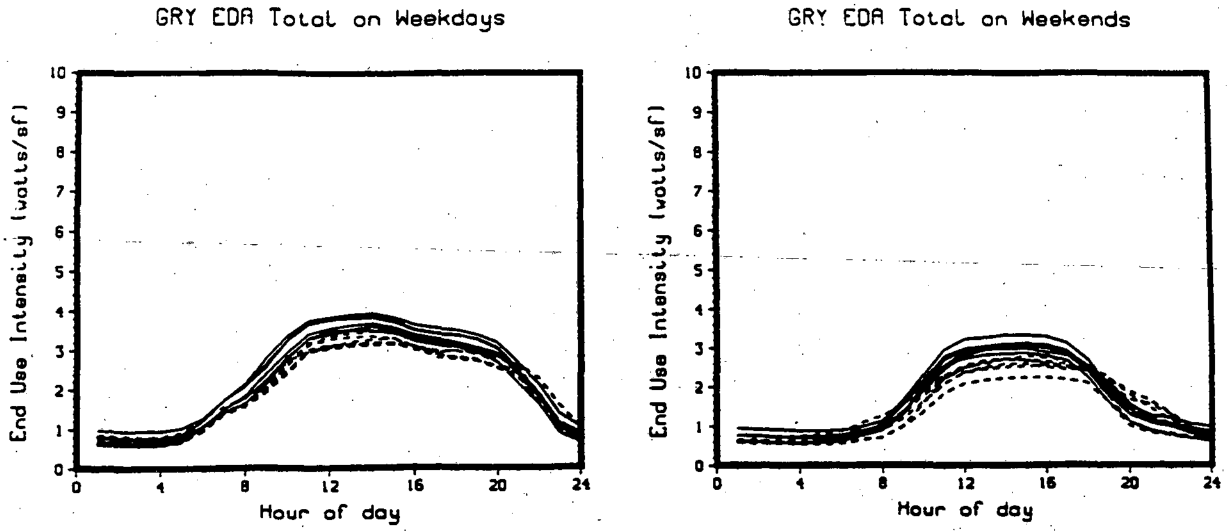


Figure II.27a.1
Sit-Down Restaurant Monitored Data
Solid lines for winter months, dashed lines for summer months

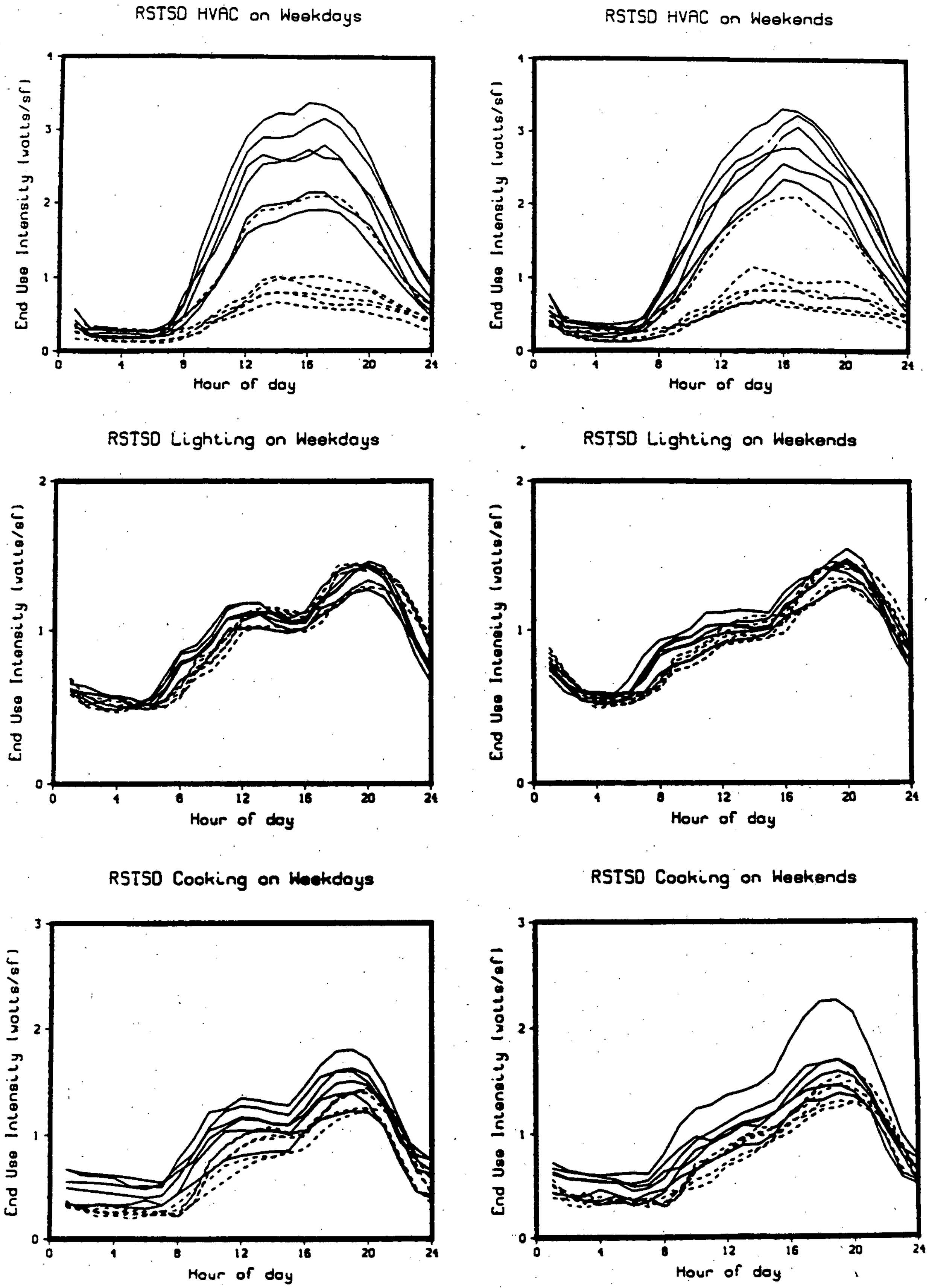


Figure II.27a.1 (continued)
Sit-Down Restaurant Monitored Data
Solid lines for winter months, dashed lines for summer months

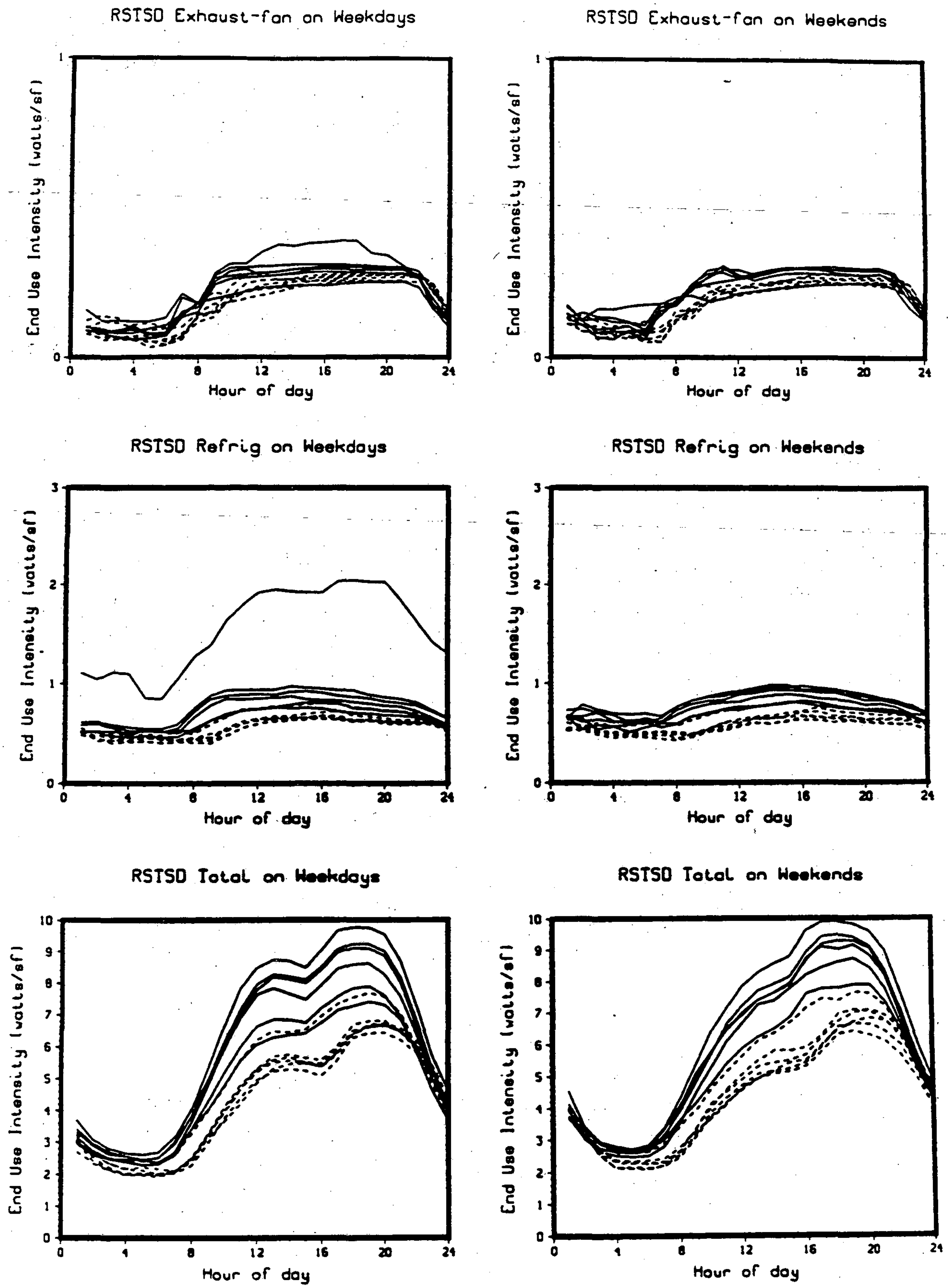


Figure II.27a.2
Fast-food Restaurant Monitored Data
Solid lines for winter months, dashed lines for summer months

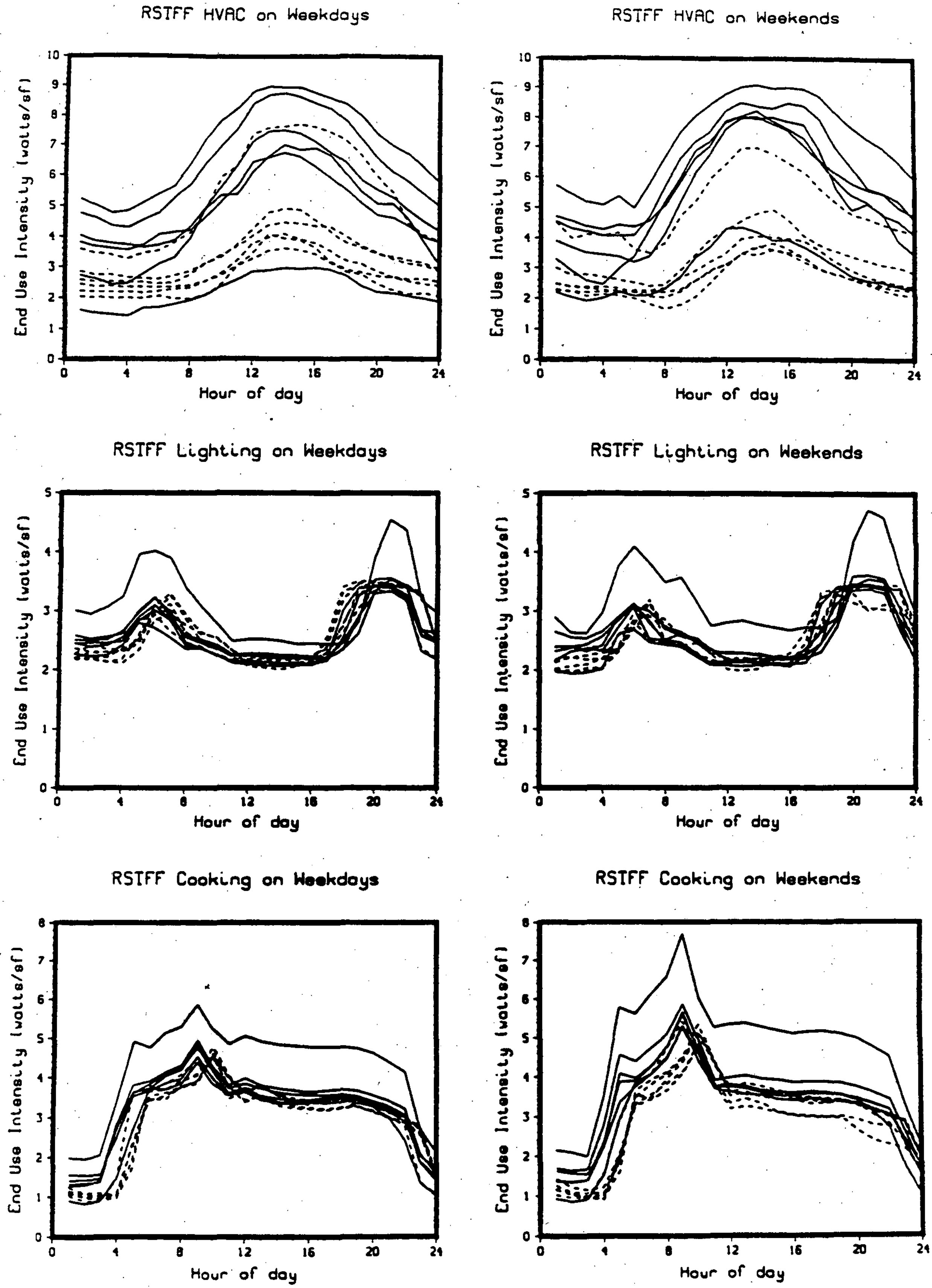


Figure II.27a.2 (continued)
Fast-food Restaurant Monitored Data
Solid lines for winter months, dashed lines for summer months

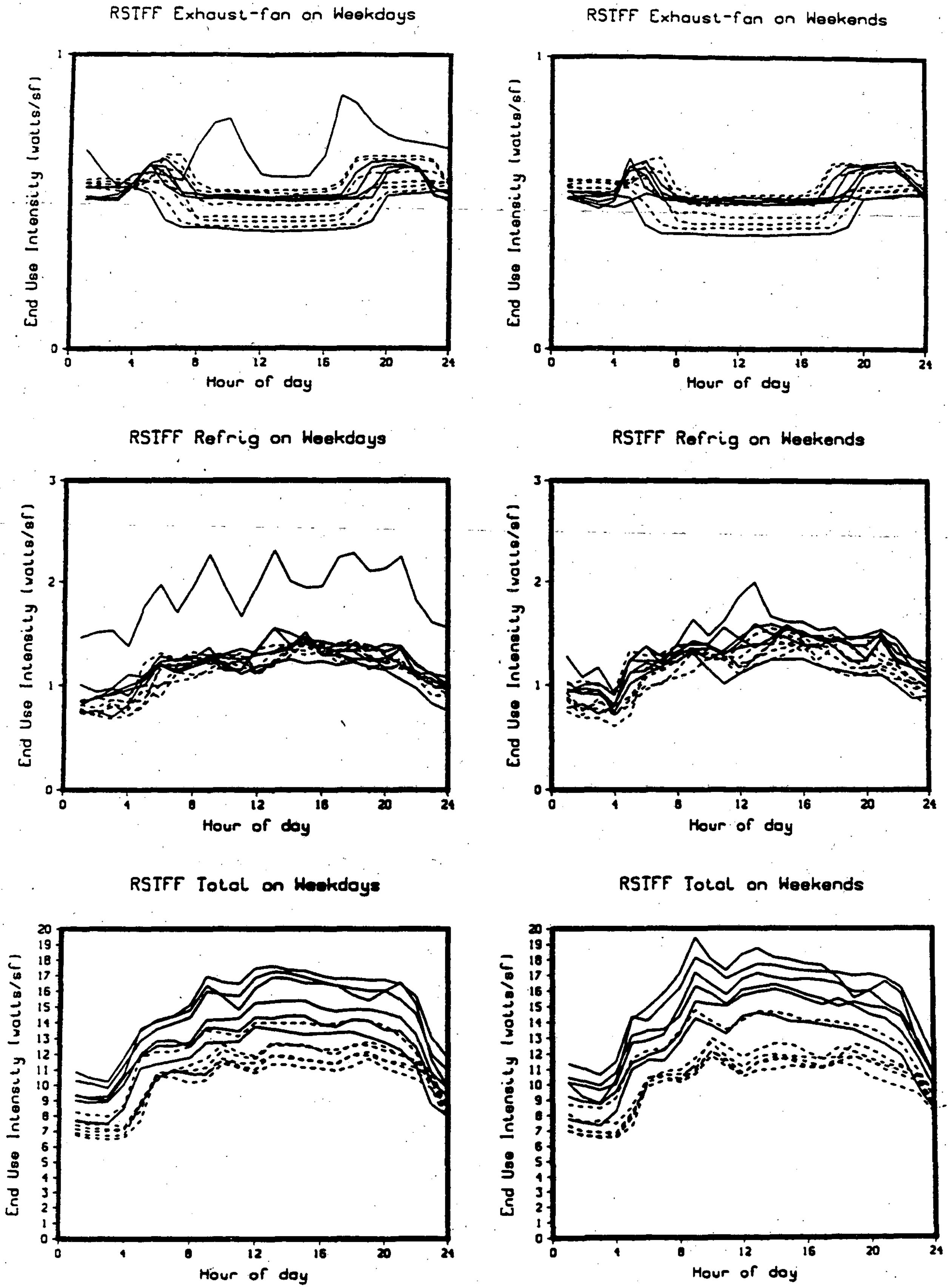


Figure II.27a
Combined Restaurant Monitored Data
Solid lines for winter months, dashed lines for summer months

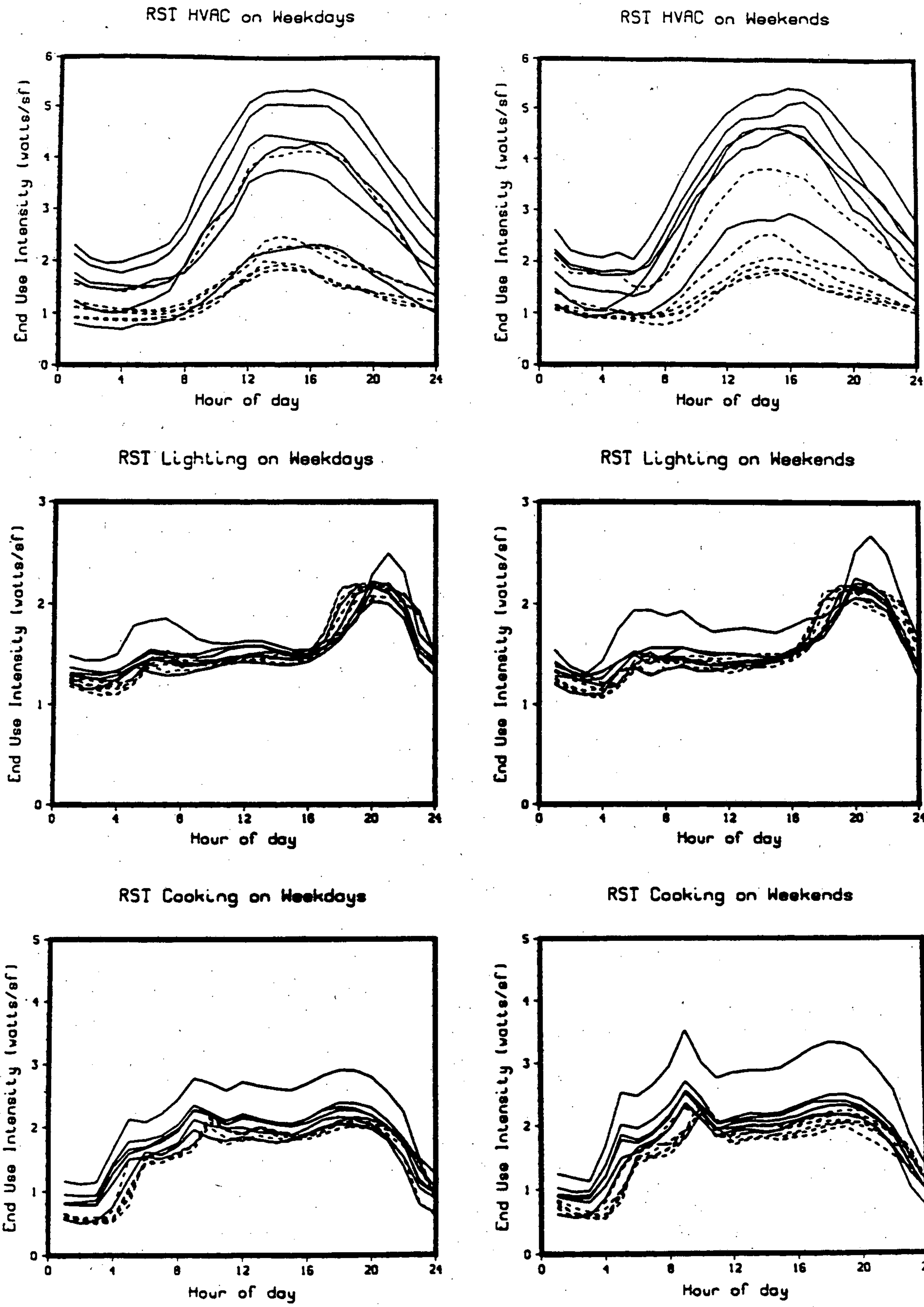


Figure II.27a (continued)
Combined Restaurant Monitored Data
Solid lines for winter months, dashed lines for summer months

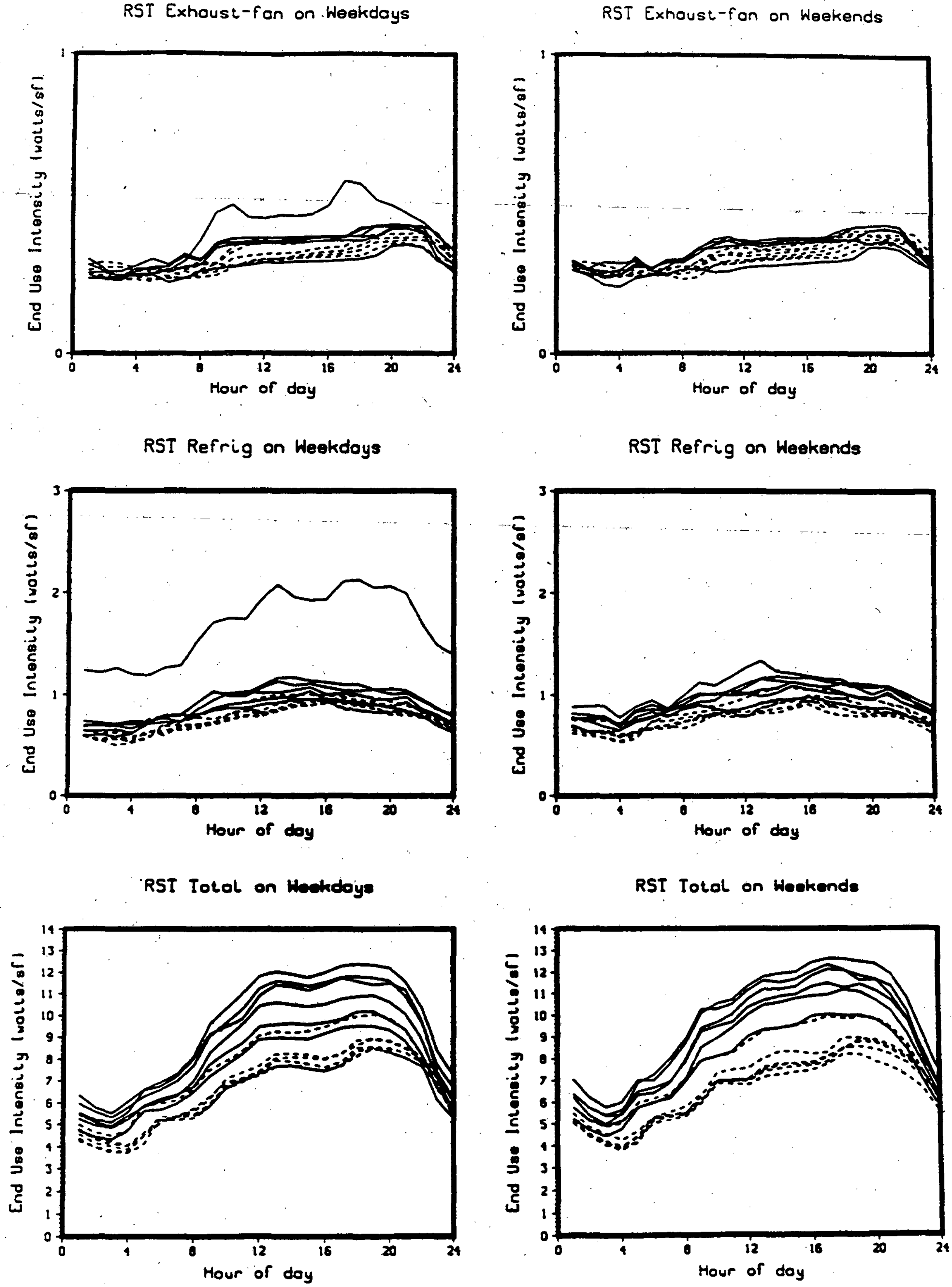


Figure II.27b
Restaurant EDA Results
Solid lines for winter months, dashed lines for summer months

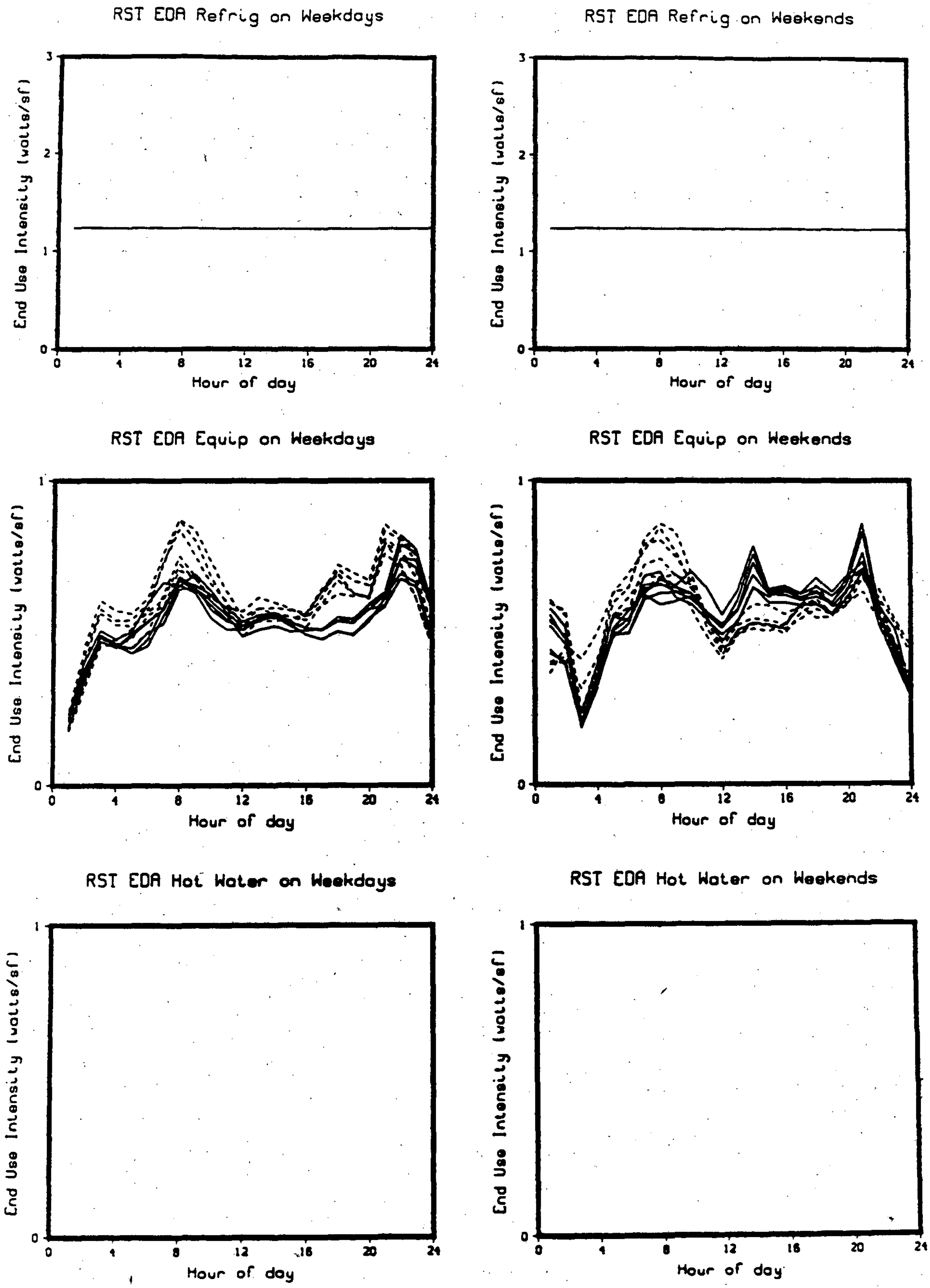


Figure II.27b (continued)
Restaurant EDA Results
Solid lines for winter months, dashed lines for summer months

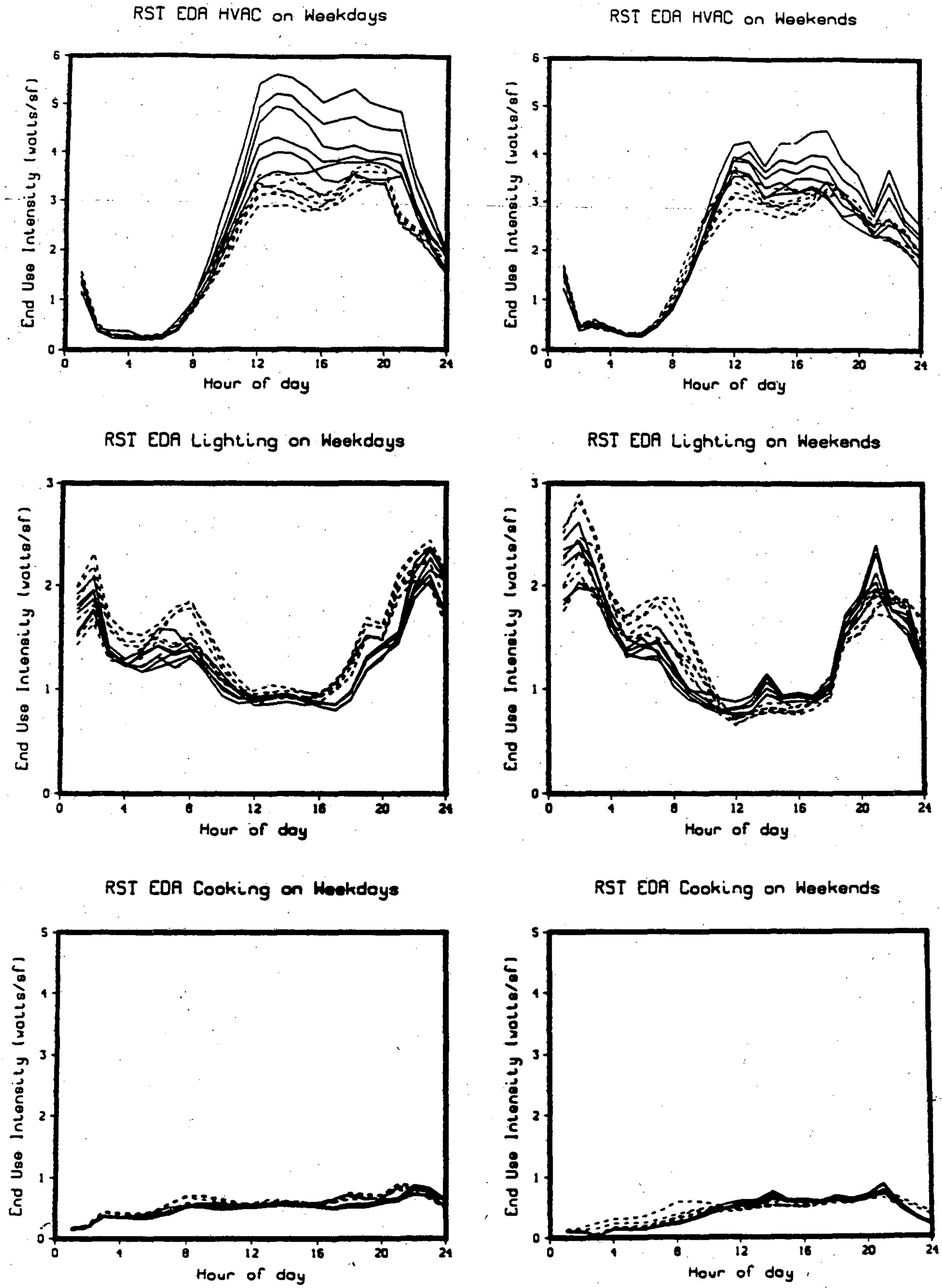
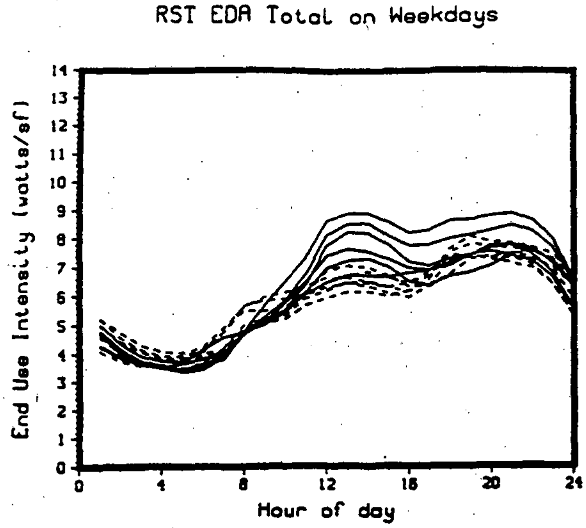


Figure II.27b (continued)
Restaurant EDA Results
Solid lines for winter months, dashed lines for summer months



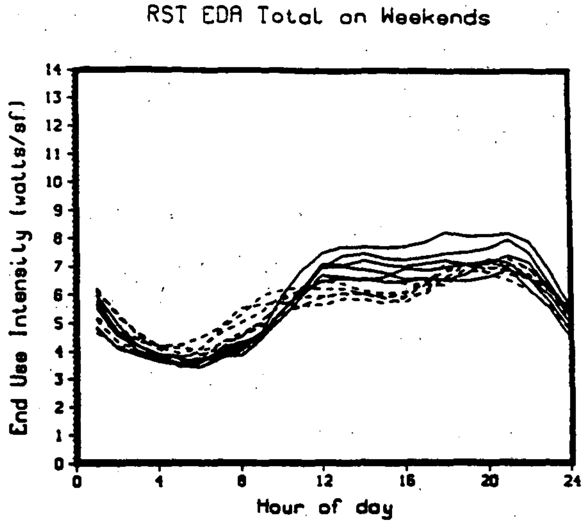


Figure II.28a
Warehouse Monitored Data
Solid lines for winter months, dashed lines for summer months

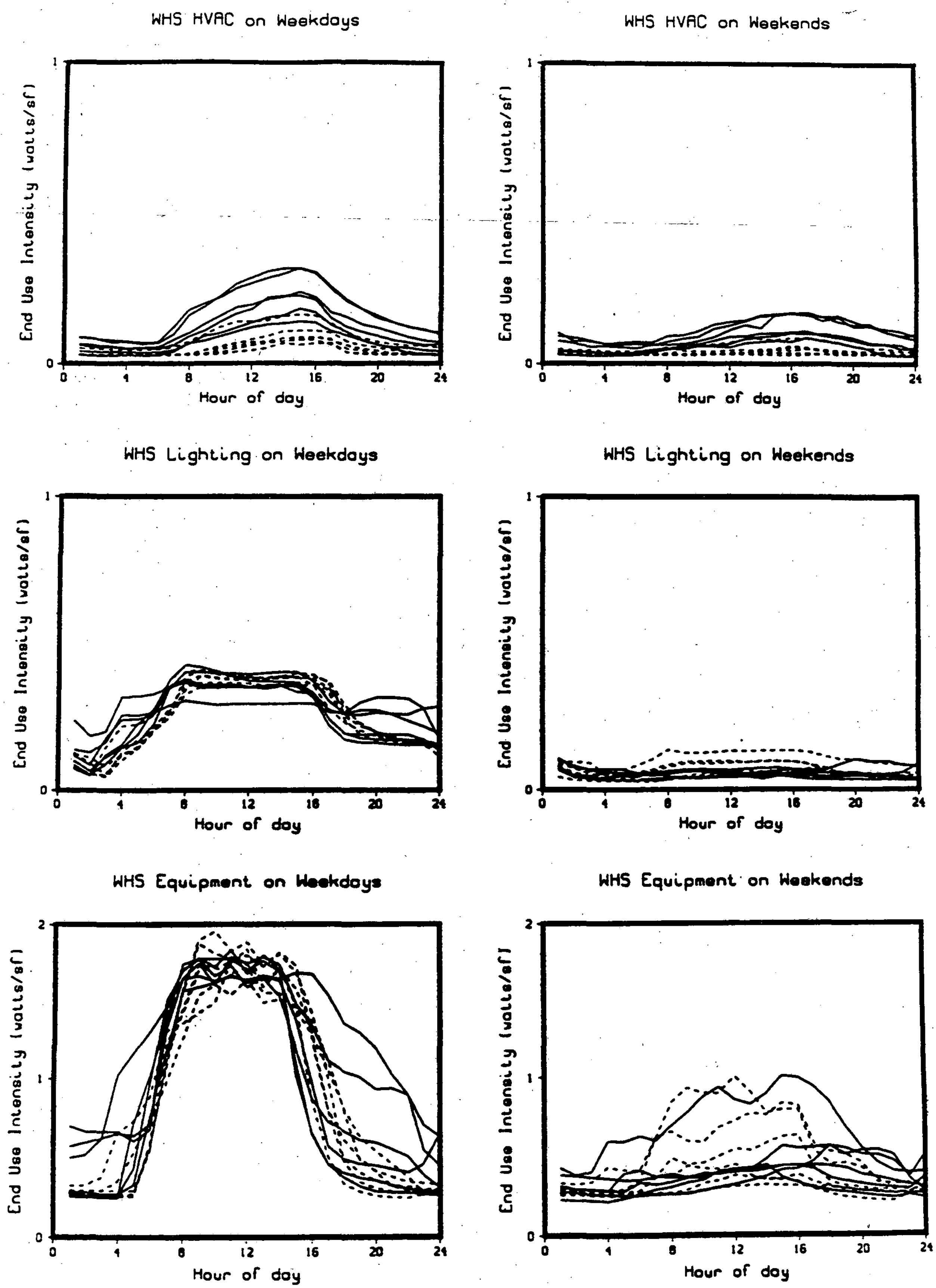


Figure II.28a (continued)
Warehouse Monitored Data
Solid lines for winter months, dashed lines for summer months

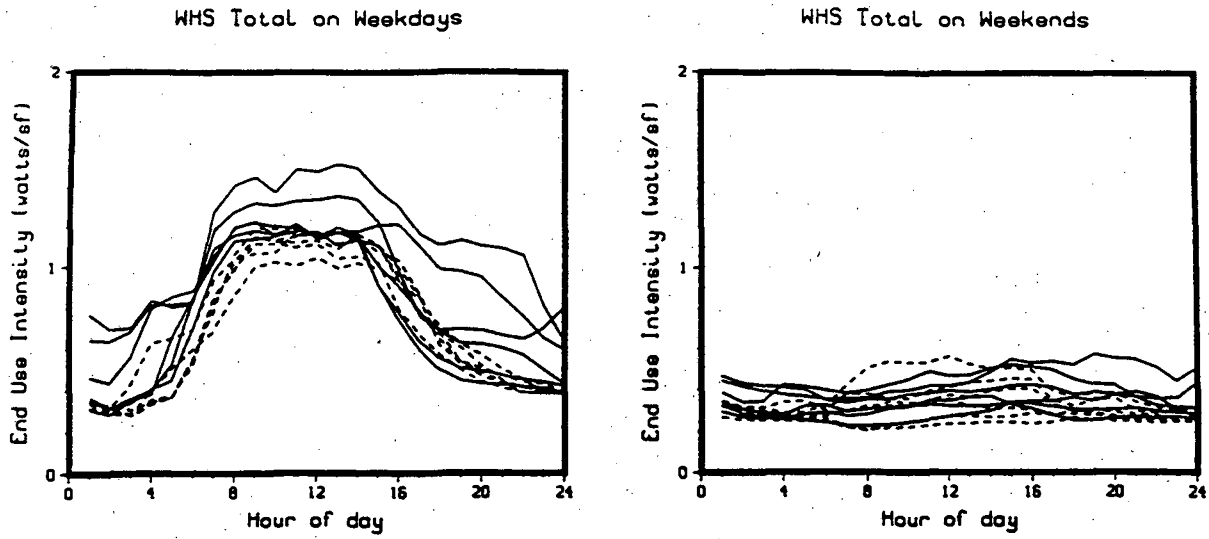


Figure II.28b
Warehouse EDA Results
Solid lines for winter months, dashed lines for summer months

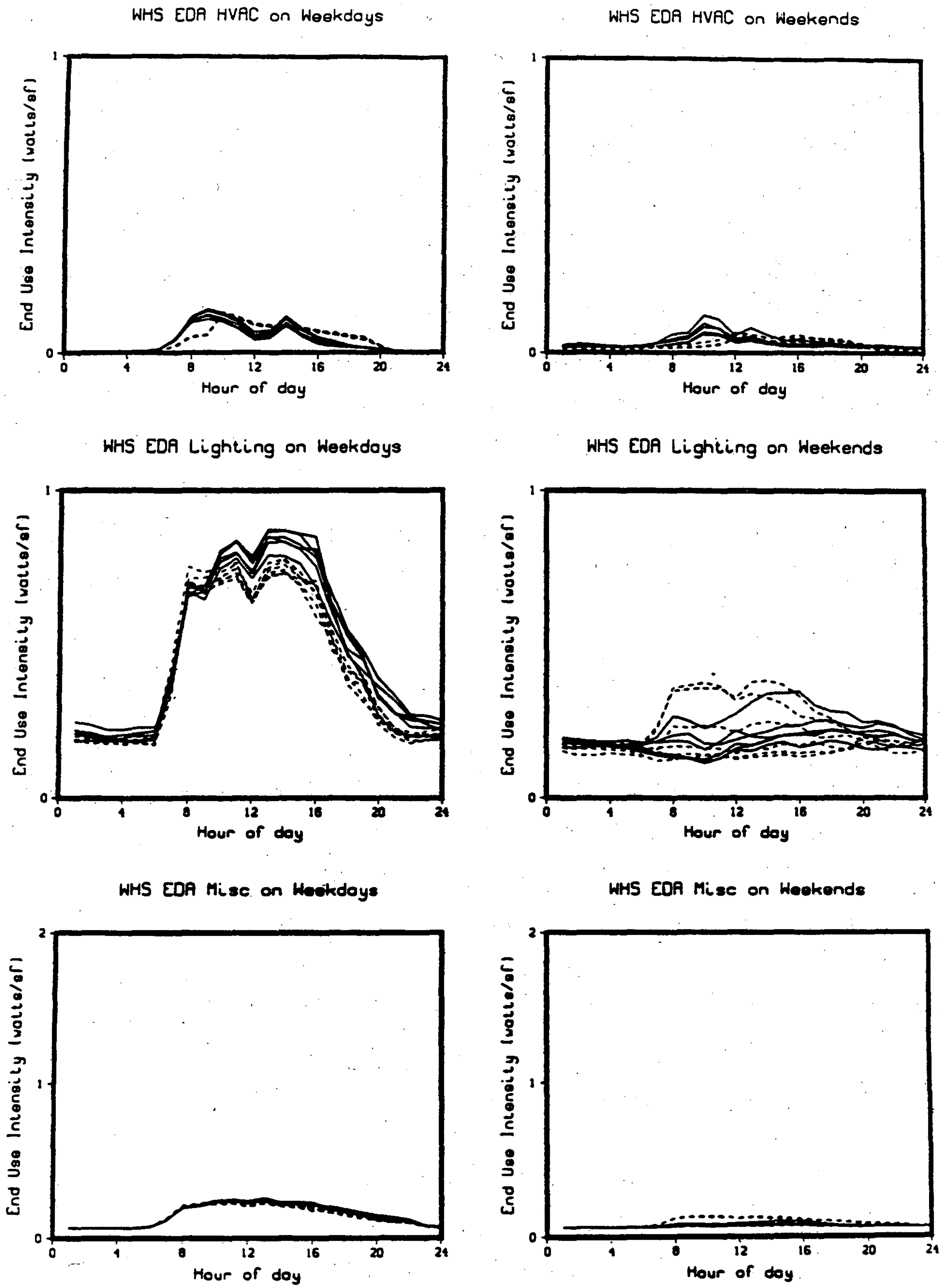
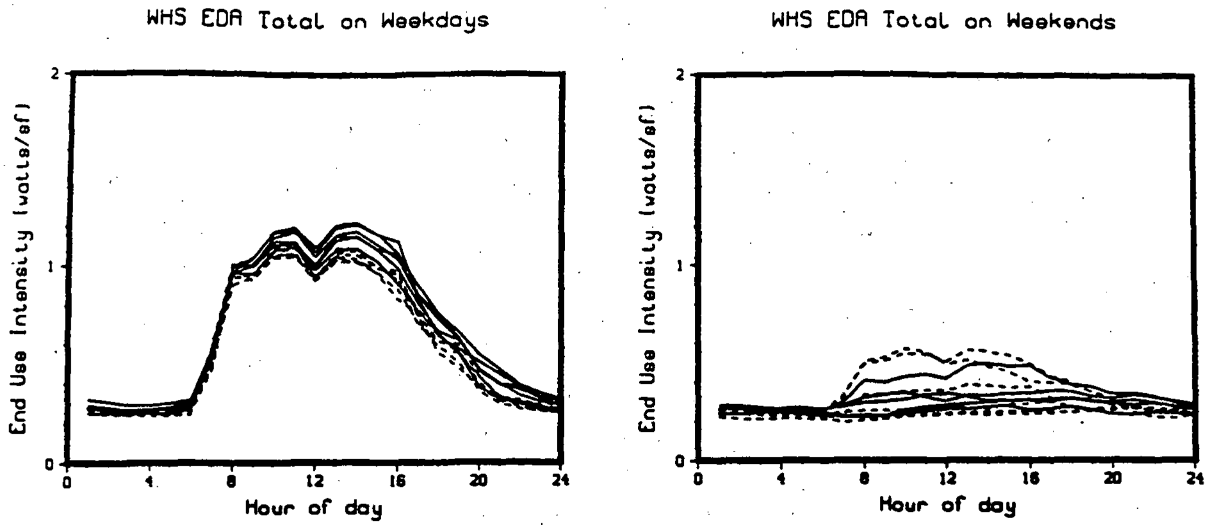


Figure II.28b (continued)
Warehouse EDA Results
Solid lines for winter months, dashed lines for summer months



between the monthly load shapes in the monitored data graphs, can be attributed to some months having different building data sets. Some months are based on data from more buildings than other months. Since the monitoring did not start for all the buildings at the same time, more data were available for the later months than the earlier ones.

The major differences between the monitored and LBL LSs are in the maximum daytime intensity (monitored: 4.2 W/ft^2, LBL: 3.7 W/ft^2) and evening shoulder hours (monitored: shorter hours of evening usage, LBL: longer hours of evening usage). It should be noted that the LBL whole-building LSs are averages based on the SCE load research data.

The HVAC and plug (miscellaneous) LSs for weekdays compare well, but the lighting LSs of the LBL study show a secondary peak during the evening hours. Thus the lighting end use accounts for the total electric load-shape differences in the evening hours that occur in the load research data and the monitored data.

Small Office (Figures II.23a&b)

The comments on large office buildings also applies to the small office load shapes.

Large Retail (Figures II.24a&b)

Average monthly whole-building electric load shapes from the LBL study and the monitored data are significantly different, particularly during the nighttime hours. This difference directly contributes to significant differences in load shapes for all end uses, especially HVAC and lighting.

Small Retail (Figures II.25a&b)

Average monthly whole-building electric load shapes from the LBL study and the monitored data are somewhat different during the nighttime hours. This difference directly contributes to significant differences in all end uses, especially HVAC and lighting LSs. The HVAC LSs for the monitored data shows a higher level of activity during the night. Also, the lighting LSs of the monitored data do not show a secondary peak during the evening shoulder hours.

Grocery (Figures II.26a&b)

Average monthly whole-building electric load shapes from the LBL study and the monitored data are significantly different particularly during the nighttime hours. The main reason for this difference is the difference between the types of buildings in the LBL study and SCE monitoring program. Recall that the grocery stores in the LBL work are fairly small, averaging about 6,000 ft^2 in floor area and operating mainly during the day, while the monitored buildings are larger and appear to operate 24-hours a day. Furthermore, the peak, whole-building electric use intensity determined in the LBL study is about 4 kWh/ft^{2}year versus 9 kWh/ft^{2}year for the monitored buildings. These differences contribute directly to the significant differences in all end uses, especially HVAC and lighting LSs.

Restaurant (Figures II.27a.1, II.27a.2, II.27a&b)

The SCE monitoring project has provided data for both sit-down and fast-food restaurants. But the LBL study, which uses SCE LRD based data, only provides LSs for the combined group of restaurants. From the monitored data, we have developed LSs for both sit-down (Figure 27a.1) and fast-food (Figure 27a.2) restaurants and combined them together (the mixture of restaurants are two-thirds sit-down and one-third fast food to be consistent with the LBL study). (Figure 27a).

A qualitative comparison between the whole-building load shapes reveals the same load shape for these two sources. But the load shapes for the end uses are, in general, different. The HVAC load shapes are different in the early morning hours and in the number of peaks which occur during the day. The lighting LSs (including outdoor lighting) of the LBL study show two peaks during morning and evening hours, but the monitored data show flat profiles during the day with sharp nighttime peaks. We are not sure whether the monitored lighting includes outdoor lighting.

The monitored data LSs shows much more electric cooking than the LBL LSs. This, however, is a saturation effect and can be dealt with by separately modeling the EUIs and LSs for restaurant electric cooking. The refrigeration LS of LBL study is flat but the monitored data show small peaks during the day.

Warehouse (Figures II.28a&b)

There are only three buildings in the sample of the monitored data. The average LSs for these buildings are plotted and compared with the EDA result. In general, the comparison between the whole-building LSs and HVAC LSs are fairly good. But the equipment and lighting LSs are significantly different in their shape and maximum intensities. For instance, the average maximum equipment intensity for the monitored buildings is about 1.7W/ft^2, while the corresponding figure for LBL study is only 0.3W/ft^2.

Summary

In summary, for standard weekdays and for most building types, the whole-building and HVAC load shapes developed in the LBL study and those calculated from the monitored data compare well. There are some differences in the lighting LSs that are caused mainly by the different operating schedules of the buildings in the two data sets. The weekend load shapes developed in the LBL study show some physically suspect characteristics and have not been given additional consideration at this time. The budget limitations of this study did not permit their reexamination. Since weekend load shapes are of secondary importance for forecasting models, we have concentrated on the development of the weekday loads.

Chapter III: EDA Validation

EDA Methodology

The End-Use Disaggregation Algorithm (EDA) developed at LBL is an integrated method for the estimation of EUIs and LSs, which relies explicitly on measured whole-building hourly load to reconcile preliminary engineering estimates. The end-use disaggregation is a two step process. First, we develop preliminary end-use EUIs and LSs for the building of interest using the integrated on-site survey data, the non-HVAC EUI/LS and DOE-2 Input Generator (NELDIG), and the DOE-2 building energy analysis program. NELDIG performs two functions: 1) it estimates preliminary LSs and annual EUIs for non-HVAC end uses and 2) it prepares building input data for simulations. For a group of buildings, NELDIG prepares prototypical building characteristics by averaging building characteristics of sample buildings. The building is then simulated, using DOE-2, to obtain preliminary EUIs and LSs for the HVAC end uses.

Second, using the initial building loads by end use from the first step and the measured whole-building hourly loads, we apply the End-use Disaggregation Algorithm (EDA) to obtain adjusted, reconciled end-use load profiles for the building. The corresponding EUIs are simply the integration of the hourly profiles for the entire year.

EDA is a deterministic model that primarily utilizes the statistical characteristics of the measured, hourly, whole-building load and its inferred dependence on temperature. Simulation is only used to supply information that is not evident from the load/temperature relationship. In the EDA, the sum of the end uses is constrained, at hourly intervals, to be equal to the measured whole-building load. This constraint provides a reality check that is not always possible with pure simulation. In addition, the load/temperature relationship helps to characterize the HVAC end use, providing an additional constraint on the remaining end uses and preventing some of the errors possible with simple proration. Finally, EDA also attempts to deal with the fluctuations of hourly loads by incorporating observed statistical variation.

The primary component of the EDA is regression of hourly loads with climatic variables. If the weather dependency of the building load changes with season, we use two season-specific (summer and winter) sets of weather regression coefficients. The weather regression equations are used to separate the load predicted by the regression into a temperature-dependent part and a temperature-independent part. We assume the temperature-dependent load is attributable to HVAC equipment. The temperature-independent load is the sum of loads such as lighting, ventilation, and miscellaneous equipment, as well as temperature-independent cooling at base weather conditions. Because the regression will provide no information about how to break down the temperature-independent load, we simply prorate it according to the loads predicted by simulation. The actual load at a particular hour on a particular day will probably not lie on the best-fit regression line, so the difference between the actual load and the regressed load is split between the two parts of the load.

A flow chart of the EDA and its data requirements are shown schematically in **Figure III.1.** For each building, the inputs to the EDA are:

- the actual hourly whole-building load during a given period of time;
- the actual measured outside weather conditions during this same period of time;
- statistics from the regression of load with the selected weather variables, calculated separately for summer and winter and
- the results of simulating the building at the base weather condition.

Using these data, EDA disaggregates the whole-building hourly load into end uses. The output of the EDA is hourly load profile estimated for all end uses described in the initial conditions. The hourly end-use load profiles can be used to develop end-use load shapes by type of day, month, season, or for the entire year. A detailed description of the EDA and a comparison of its performance versus pure simulation is reported in Akbari *et al.* (1988).

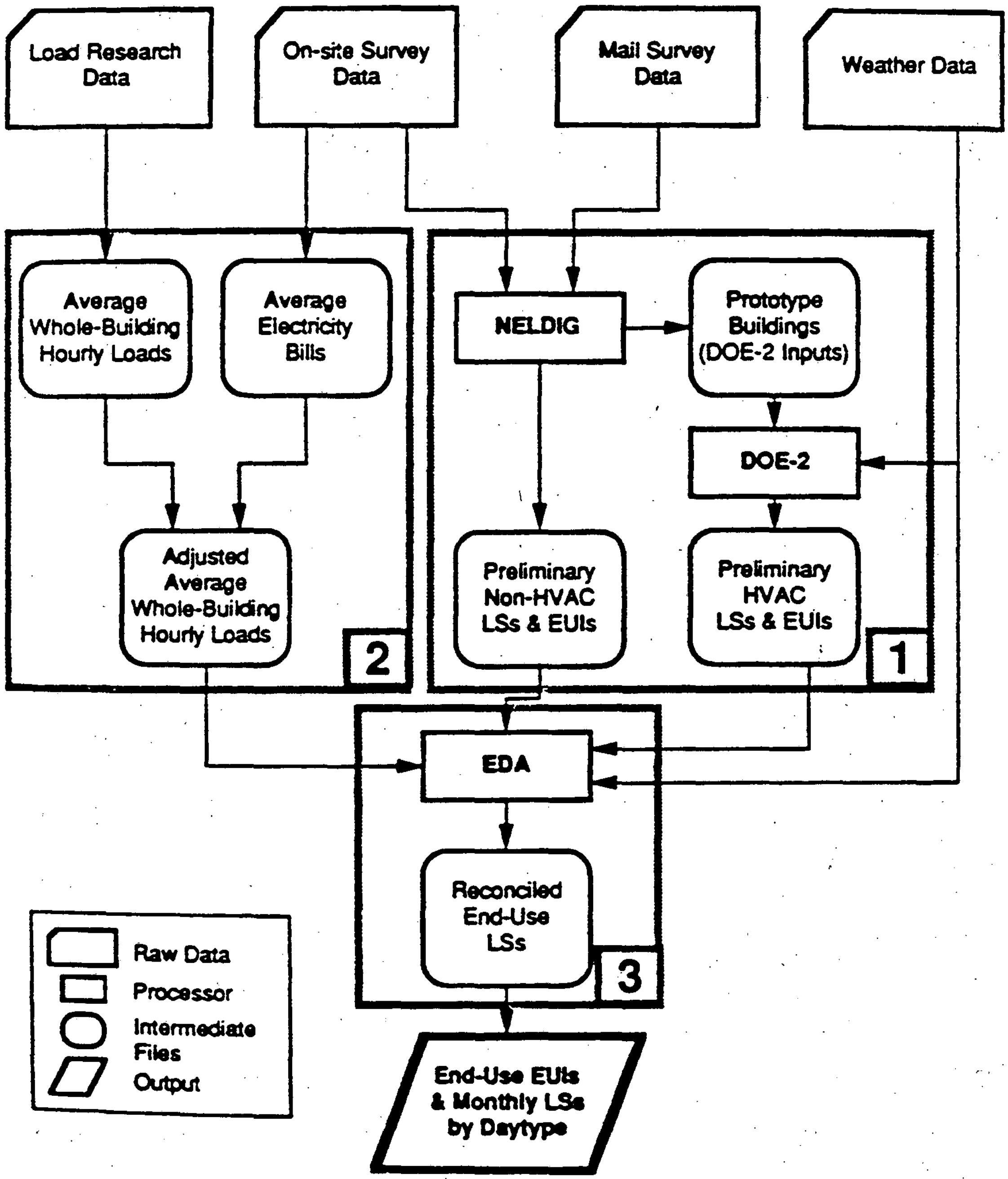
EDA can be used for analysis of measured hourly data for both prototypical and individual buildings. EDA has been applied to SCE data and average end-use data have been calculated for each of the SCE planning regions (Akbari et al 1989,1990). For the validation purposes in this analysis, we apply the EDA to two buildings from SCE's end-use metering project. We develop hourly end-use load profiles for each of the selected buildings and compare the results with the metered end-use data.

Validation

The buildings we have selected for the validation are an office and a retail store. These buildings were selected because of their continuous data sets (little or no missing data), complete on-site surveys, and reasonable load shapes (no apparent changes in occupancy or operation).

In the remainder of this chapter, we discuss the process of validation for the two selected buildings. For each building, we first present a brief description of the building followed by a

Figure III.1
Integrated Commercial LS and EUI Estimation Methodology



discussion of the DOE-2 simulation input and results. Then, we discuss the hourly correlations of the whole-building load with respect to weather parameters, particularly drybulb temperature and relative humidity. The audit information, DOE-2 results, and the temperature correlations are used in the EDA to develop end-use load profiles. Finally, the EDA output is compared with the monitored data with particular emphasis on the strengths and weaknesses of the model.

Office building # 5

Building Description

This 117,600 ft^2 building is a six story multi-tenant office built in 1971 in the coastal region of SCE's service area (SCE 1990, 1989). About 86% of the building floor area is conditioned office space and 14% basement parking. Natural gas is used for heating and hot water. All other systems are electric.

The building is occupied by 435 people and operated Monday through Friday from 7 a.m. to 6 p.m. All the interior lights are fluorescent with installed intensity of 1.9 W/ft^2 (based on conditioned floor area, 1.6 W/ft^2 based on gross floor area). The lights are controlled by local switches and have typical operating hours of 7 a.m. to 6 p.m. The outdoor lighting is fluorescent and has an installed intensity of about 0.04 W/ft^2 (based on the gross total building floor area), operated from 6 p.m. to 6 a.m., Monday through Friday, and controlled by the energy management system. The installed intensity of other building loads (personal computers, typewriters, copiers, water coolers, air compressor, elevators, and water pumps), as estimated by the auditor, is about 0.65 W/ft^2 (based on the total building floor area).

The building has three multi-zone HVAC systems. Heating is provided by forced air furnaces with total capacity of 1.6 MBtu/h and cooling by two hermetic reciprocating compressors with total capacity of 190 tons. Total electricity load for HVAC systems is 250 kW. The heating and cooling set point is 74°F from 7 a.m. to 6 p.m., Monday through Friday, operated and controlled manually.

DOE-2 Simulation

We used information provided to us by the hardcopy of the 1989 audit and the 1985 on-site survey data to simulate the energy use of the building with DOE-2. The audit data provide information on the operation, schedules, equipment type, and equipment energy use for the building. The audit does not provide information on the architectural and construction characteristics of the building.

We simulated the building, using a square floor plan in 6 stories with a total conditioned floor area of 101,000 ft^2 and total gross floor area of 117,000 ft^2. The building was simulated with a forced air gas furnace, two central reciprocating chillers with cooling towers, and three multizone air handling units. The total heating capacity was 1.6 MBtu/h and the total cooling capacity was 190 tons. Each air handling unit (AHU) served two floors of the building; each floor was simulated with two zones: a perimeter and a core zone. The internal load of the building was calculated using the methodology discussed in Akbari et al. (1989). The HVAC schedule of the building was modified, using the characteristics of the whole-building load.

We did not have the complete actual weather data to simulate HVAC energy use for 1989-1990. Instead, we used the following alternative. The building was simulated using the Los Angeles WYEC (Weather Year for Energy Calculations) weather tape and the resulting hourly HVAC energy use was regressed against the WYEC drybulb temperature. The resulting correlations were then used in conjunction with actual 1989-1990 hourly drybulb temperatures to estimate the hourly cooling energy use for the period of June 1, 1989 to May 31, 1990.

The simulated annual HVAC, indoor lighting, and plug loads are 8.36, 4.62, and 0.99 kWh/ft^2, respectively. The simulated whole-building energy use only accounts for 14.0 kWh/ft^2 compared to 17.1 kWh/ft^2 as measured for this office building. Also, the shape of the simulated whole-building load is significantly different from that of the measured load, both during the peak day and during an average day. Simulation indicated that, in contrast to measured data, building electricity use peaks during the early morning hours, mainly due to the high start up cooling demands. EDA will adopt the characteristics of the measured whole-building load in the reconciliation process (shown in **Figure III.2**).

It is also interesting to note that the hourly plot of the simulated HVAC electricity use versus drybulb temperature does not indicate a base temperature (i.e. a temperature below which there is no temperature dependency) (See **Figure III.3**). This is consistent with the observed characteristics of the measured data which are discussed in the next section. The regression results of the simulated hourly HVAC load against the WYEC drybulb temperatures are presented in **Table III.1**. Using these correlations and the measured drybulb temperatures, we calculated the new estimate of the simulated HVAC electricity use for the actual year of 1989-1990. For a typical summer day, **Figure III.4** compares the new estimate of simulated HVAC electricity use for the 1989-1990 temperature data with the original DOE-2 results based on simulations with WYEC weather data. This process reduced the simulated annual HVAC

Table III.1

Regression results of the simulated weekday hourly HVAC load against dry-bulb temperature for Office #5

Hour	Coefficients		Statistics		
	60° Base (W/ft^2)	Dry Bulb Temp ($W/ft^2/°F$)	R^2	Sig. of F-Stat.	N
1	0.000	0.000	0.00	0.000	96
2	0.000	0.000	0.00	0.000	94
3	0.000	0.000	0.00	0.000	90
4	0.000	0.000	0.00	0.000	85
5	1.334	0.028	0.43	0.000	84
6	1.225	0.017	0.53	0.000	90
7	1.219	0.012	0.51	0.000	102
8	1.295	0.011	0.51	0.000	123
9	1.287	0.012	0.58	0.000	156
10	1.285	0.012	0.64	0.000	189
11	1.292	0.013	0.61	0.000	210
12	1.306	0.012	0.59	0.000	218
13	1.321	0.012	0.65	0.000	224
14	1.342	0.013	0.71	0.000	224
15	1.363	0.013	0.73	0.000	223
16	1.382	0.014	0.73	0.000	205
17	1.391	0.015	0.69	0.000	172
18	1.398	0.015	0.59	0.000	150
19	1.333	0.015	0.58	0.000	139
20	1.296	0.012	0.54	0.000	131
21	0.000	0.000	0.00	0.000	123
22	0.000	0.000	0.00	0.000	112
23	0.000	0.000	0.00	0.000	110
24	0.000	0.000	0.00	0.000	105

O.F.1

Figure III.2
Measured whole-building average load for Office #5 by day of week

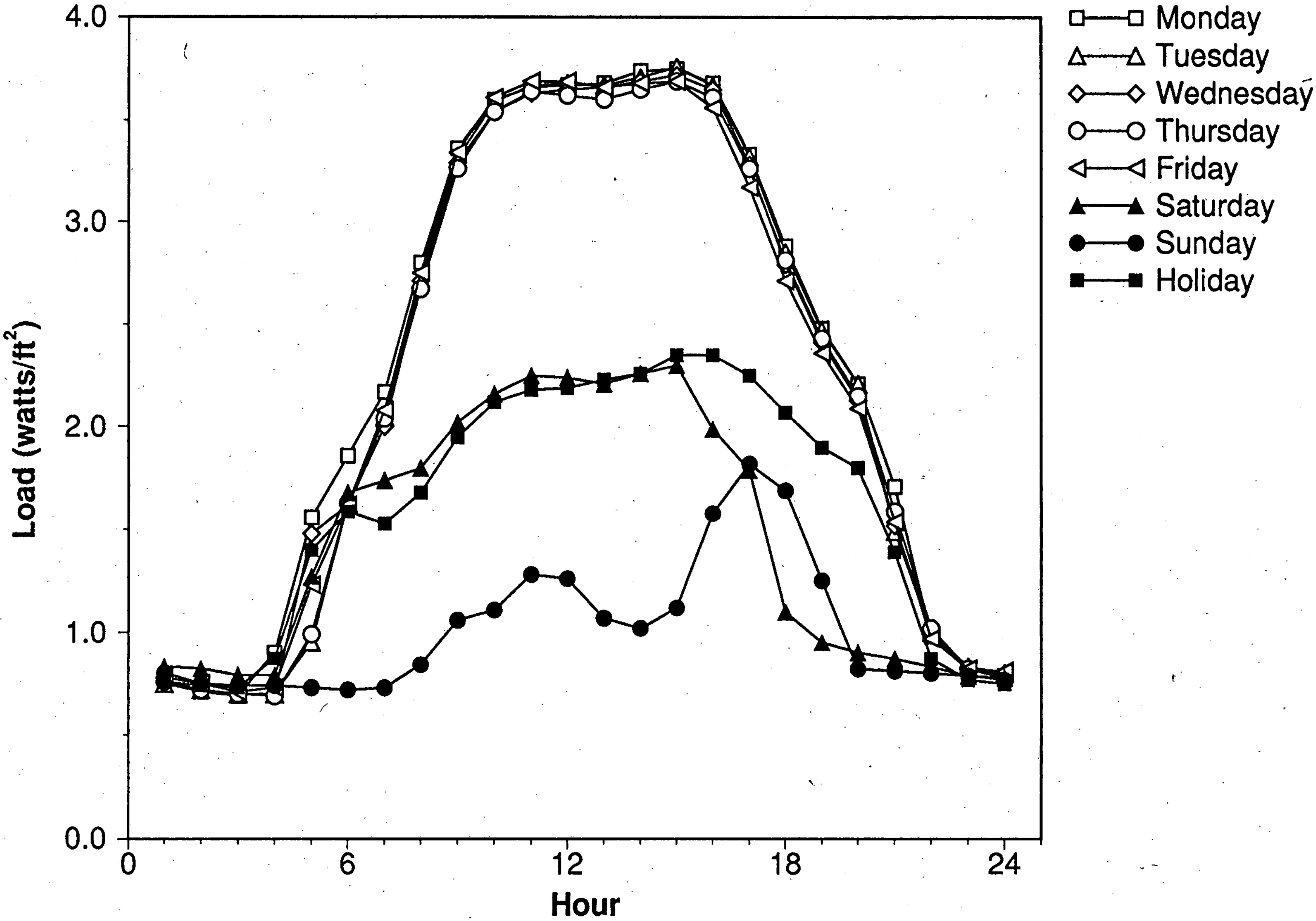


Figure III.3
Hourly plots of simulated weekday HVAC electricity use versus outside temperature for Office #5

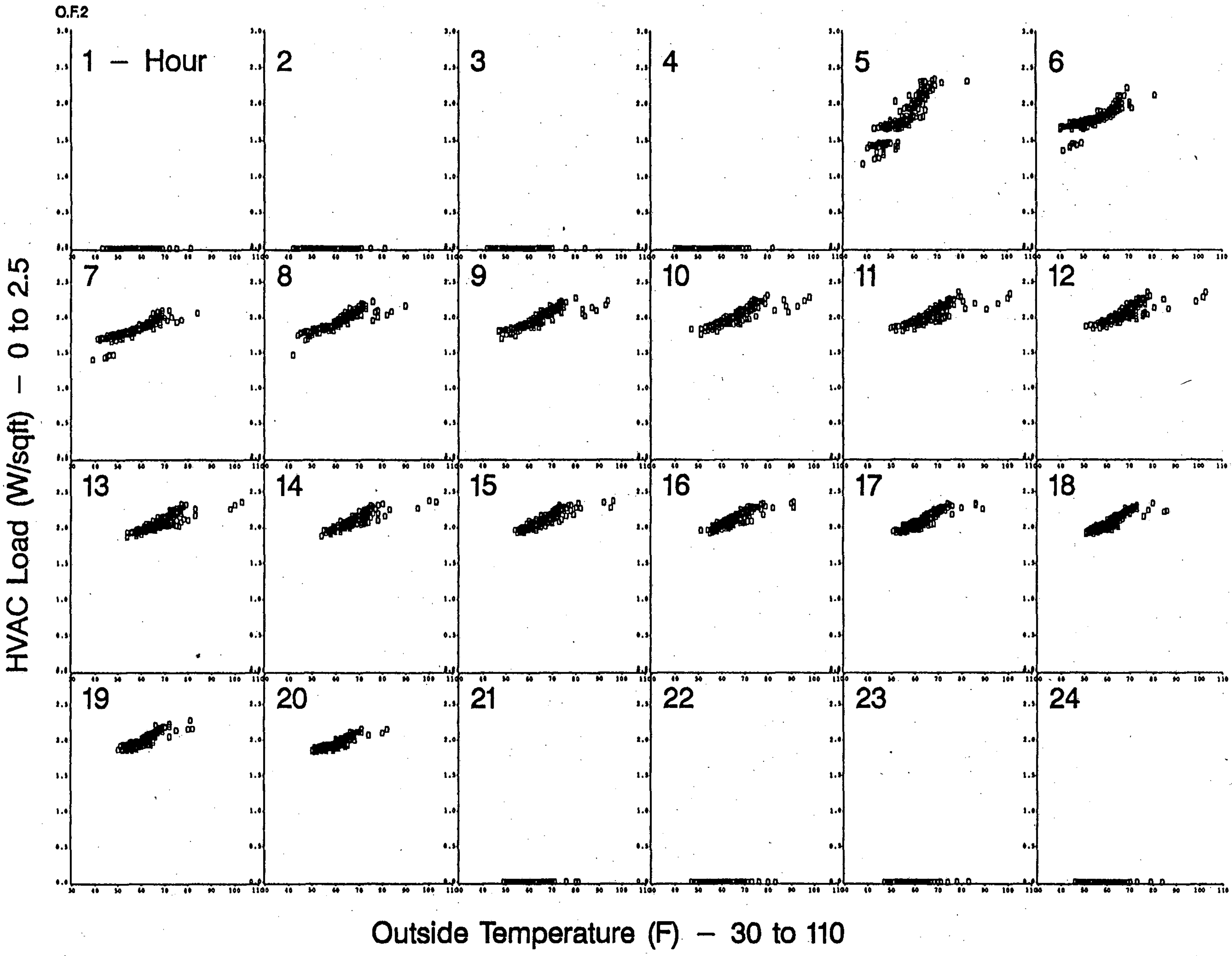
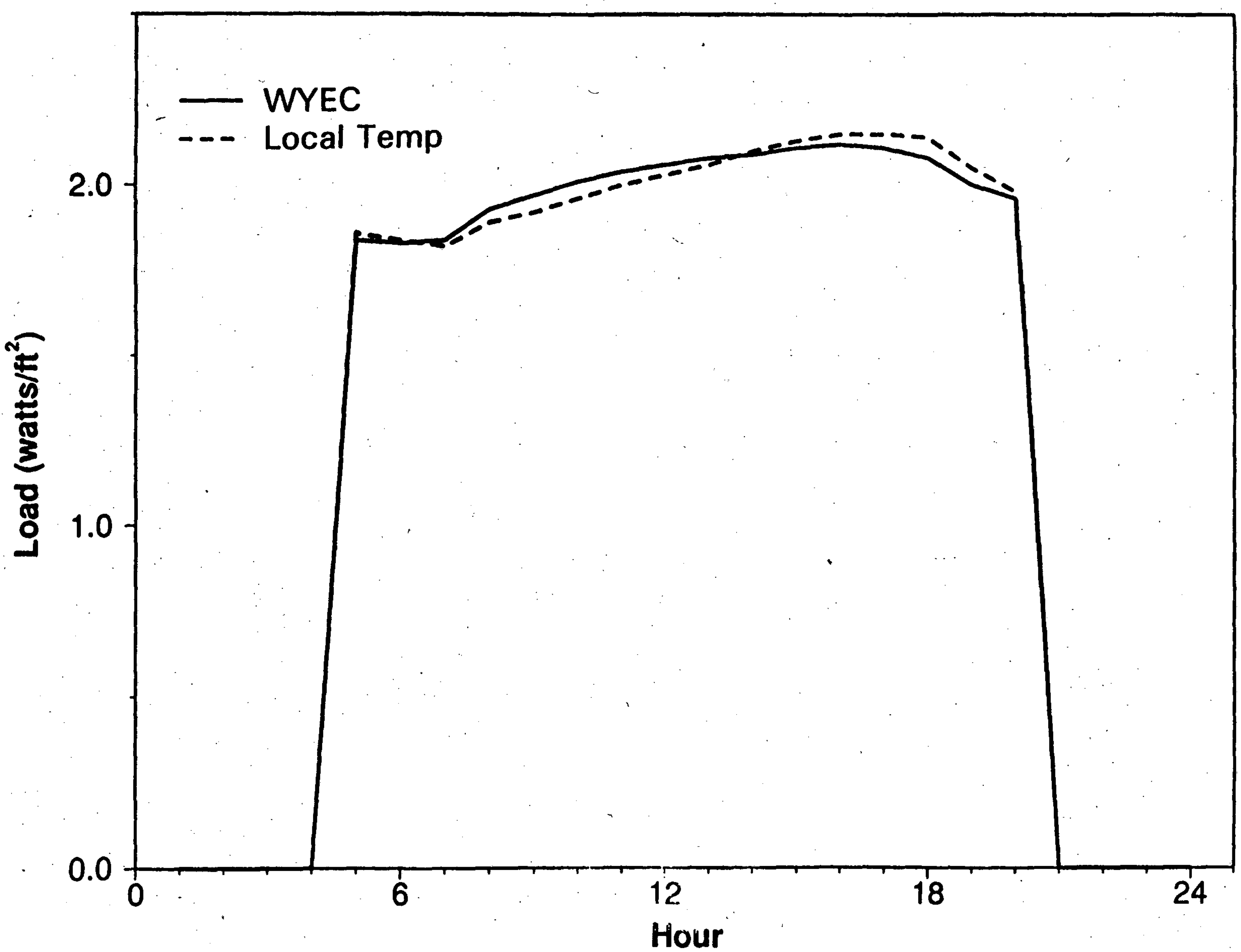


Figure III.4
Simulated HVAC load using WYEC and local temperature data for a typical summer day for Office #5



energy use from 8.36 to 7.99 kWh/ft^2.

Load/Temperature Regressions

Figures III.5-III.7 show the yearly, summer, and winter plots of hourly whole-building load against the ambient drybulb temperatures. The summer and winter period are defined as May 1 to October 31 and November 1 to April 30, respectively. These figures indicate a few interesting points that warrant further discussion. The hours that the building is shut down, judged by the lowest level of energy use of 0.7 W/ft^2, are between 11 p.m. to 3 a.m. This indirectly contradicts the building audit which indicate the hours of operation are from 7 a.m. to 6 p.m. In fact, judging from the whole-building hourly load, the normal hours of operation of the building are between 9 a.m. and 5 p.m. Hours 4 a.m. to 8 a.m. and 6 p.m. to 10 p.m. are morning and evening shoulder hours, respectively.

It is also interesting to note that neither of the plots indicate a definite and identifiable base temperature for any hours of the day, except the period between 11 p.m. to 3 a.m. As we will discuss later, this has introduced some difficulties in identifying a clear base cooling load for the building. Of the 0.7 W/ft^2 nighttime load, only about 0.04W/ft^2 is for outdoor lighting (based on on-site survey data). The rest is for nighttime indoor lighting (including emergency lighting) and other miscellaneous equipment (identified or not identified in the audit).

We regressed the whole-building hourly load in summer and winter against drybulb temperature. **Table III.2** shows the summary of regression statistics. The table indicates that for both summer and winter significant correlations for most hours of the day exist. Significant correlations exist for summer from 10 a.m. to 7 p.m. and 10 p.m. to 3 a.m., however a closer review of the table indicates that the nighttime correlations are statistical artifacts and indeed the correlation coefficients are fairly weak during the nighttime hours. In the winter, significant correlations exist from 5 a.m. to 9 p.m.

The R^2 values for both the summer and winter regressions are generally poor, in the range of 0.14 to 0.23 for the summer and 0.13 to 0.41 for winter. One reason that the winter time R^2 are better than the summer time R^2 is the wider range of temperature variation during the winter. Other probable reasons are further discussed in Chapter IV in the review of the characteristics of the measured end-use data. The poor statistics of the whole-building load indicate that temperature variations can only describe a small portion of the variation in the whole-building load. These poor statistics may be the result of the manual operation of the HVAC system, indicating a poor temperature control of the HVAC system.

Figure III.5
Hourly plots of measured weekday whole-building load versus outdoor temperature for the entire year for Office #5

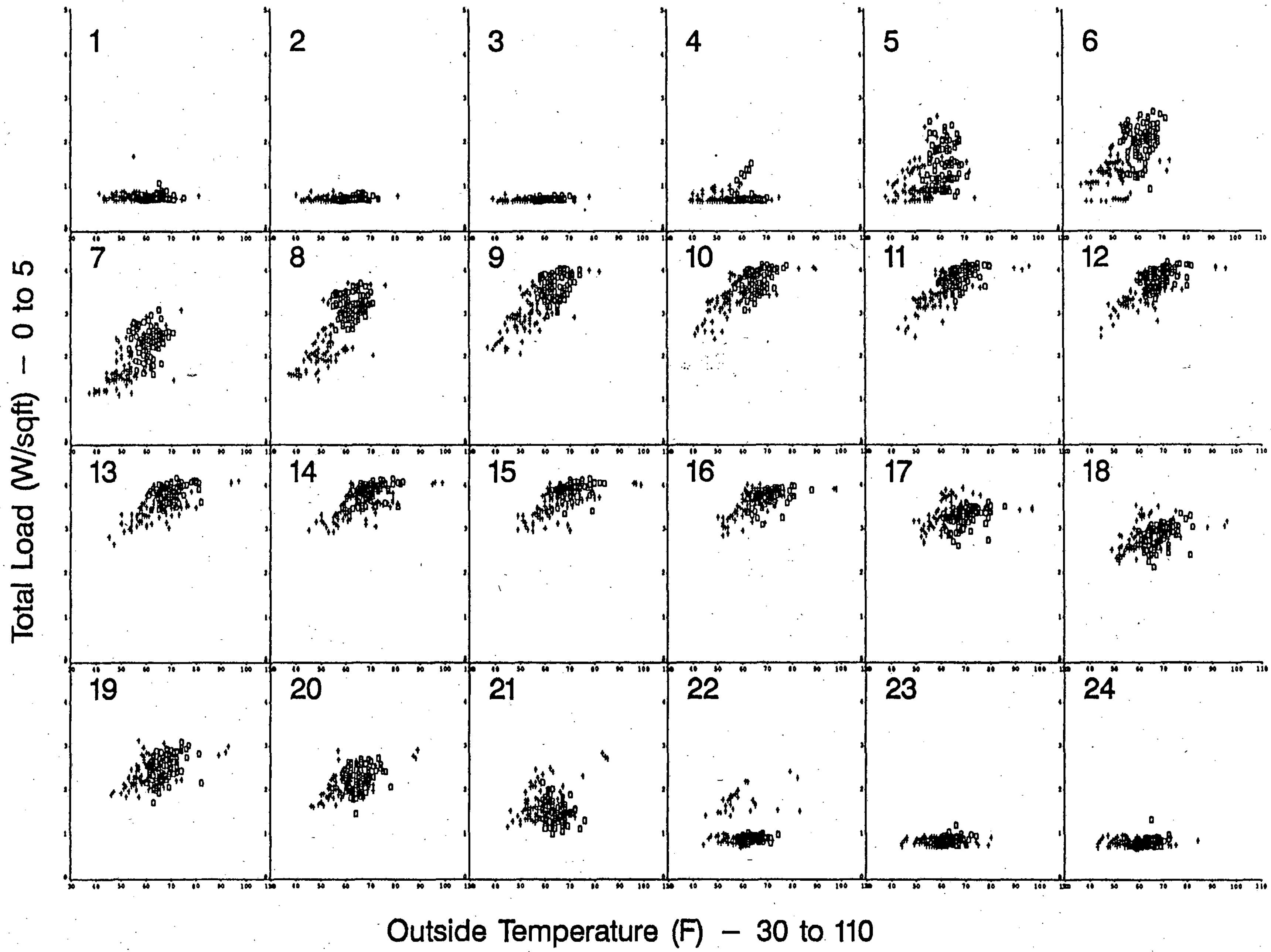


Figure III.6
Hourly plots of measured weekday whole-building load versus outdoor temperature for the summer for Office #5

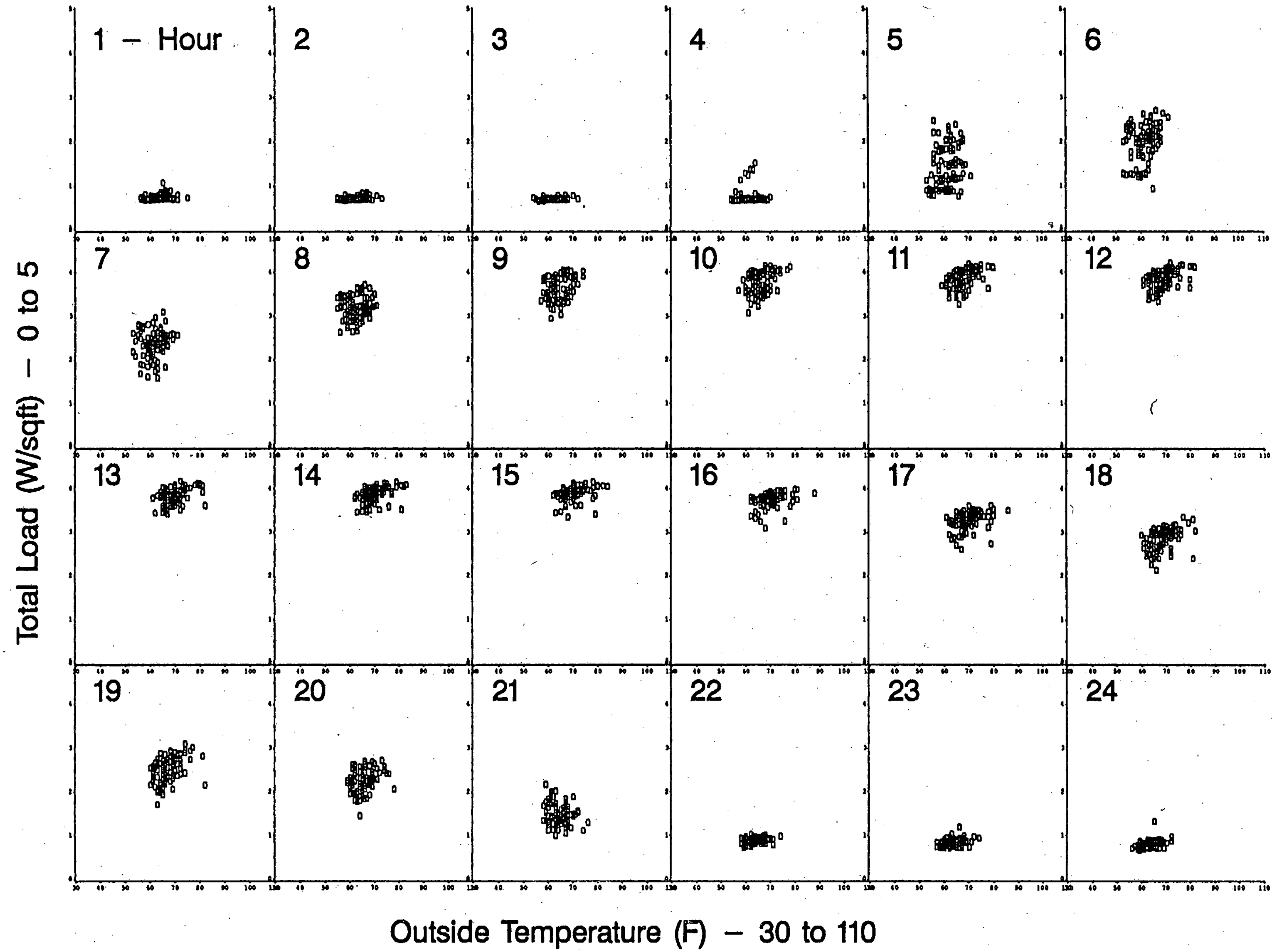


Figure III.7
Hourly plots of measured weekday whole-building load versus outdoor temperature for winter for Office #5

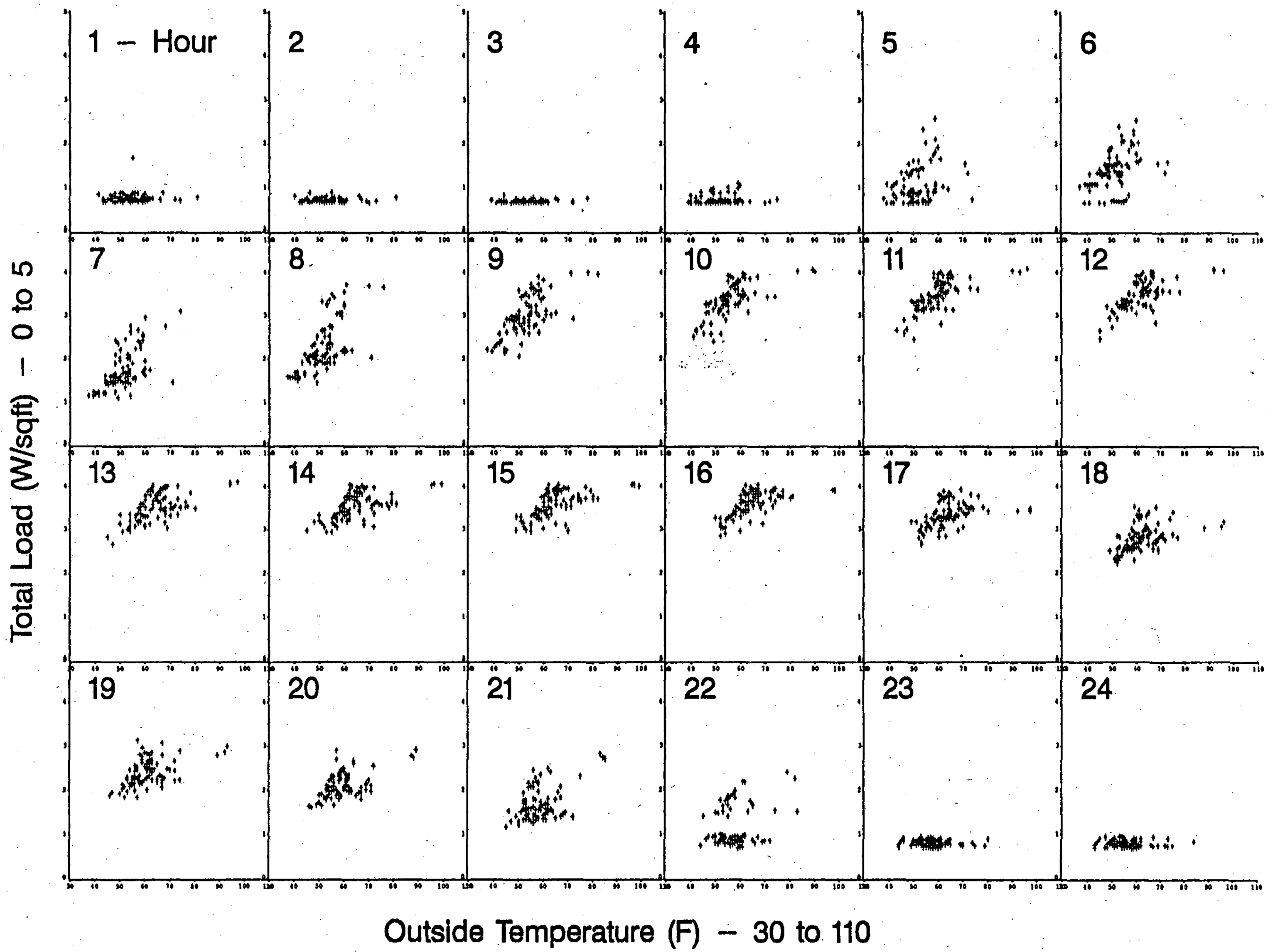


Table III.2

Regression results of the measured weekday hourly whole-building load against dry-bulb temperature for Summer and Winter for Office #5

Hour	Summer: Coefficients: 60° Base (W/ft^2)	Summer: Coefficients: Dry Bulb Temp ($W/ft^2/°F$)	Summer: Statistics: R^2	Summer: Statistics: Sig. of F-Stat.	Summer: Statistics: N	Winter: Coefficients: 60° Base (W/ft^2)	Winter: Coefficients: Dry Bulb Temp ($W/ft^2/°F$)	Winter: Statistics: R^2	Winter: Statistics: Sig. of F-Stat.	Winter: Statistics: N
1	0.722	0.007	0.19	0.000	124	0.790	0.004	0.02	0.098	121
2	0.706	0.004	0.15	0.000	122	0.756	0.004	0.04	0.029	121
3	0.699	0.002	0.12	0.000	121	0.701	0.000	0.00	0.989	121
4	0.748	-0.000	0.00	0.912	119	0.766	0.004	0.03	0.047	121
5	1.382	0.014	0.02	0.136	118	1.199	0.020	0.12	0.000	121
6	1.921	0.024	0.07	0.004	116	1.616	0.029	0.19	0.000	120
7	2.383	0.004	0.00	0.542	116	2.112	0.043	0.39	0.000	121
8	3.168	0.005	0.01	0.351	120	2.706	0.054	0.42	0.000	121
9	3.547	0.016	0.06	0.005	126	3.277	0.042	0.37	0.000	121
10	3.635	0.023	0.17	0.000	126	3.472	0.031	0.29	0.000	121
11	3.670	0.023	0.23	0.000	128	3.467	0.029	0.27	0.000	121
12	3.673	0.019	0.19	0.000	128	3.412	0.027	0.26	0.000	121
13	3.671	0.016	0.15	0.000	128	3.385	0.024	0.24	0.000	121
14	3.718	0.013	0.14	0.000	128	3.425	0.021	0.21	0.000	121
15	3.750	0.012	0.14	0.000	128	3.452	0.021	0.21	0.000	121
16	3.591	0.013	0.13	0.000	128	3.442	0.021	0.21	0.000	121
17	3.102	0.016	0.13	0.000	128	3.221	0.017	0.13	0.000	121
18	2.629	0.024	0.20	0.000	128	2.719	0.019	0.15	0.000	121
19	2.319	0.025	0.15	0.000	128	2.335	0.022	0.24	0.000	121
20	2.134	0.017	0.07	0.002	128	2.095	0.024	0.30	0.000	121
21	1.548	-0.015	0.05	0.009	128	1.690	0.023	0.20	0.000	121
22	0.851	0.006	0.10	0.000	127	1.162	0.014	0.05	0.016	121
23	0.806	0.007	0.10	0.000	128	0.804	-0.001	0.01	0.304	121
24	0.759	0.010	0.17	0.000	127	0.787	-0.001	0.00	0.561	121

In order to improve the statistics, we regressed the whole-building load against both drybulb temperature and relative humidity. The addition of relative humidity to the summer and winter regressions did not significantly improve the R^2 **(Table III.3)**. Regressions of the load against relative humidity alone indicated no correlation between these variables **(Table III.4)**. Hence, for the remainder of this analysis, we only considered the variation of the whole-building load against the drybulb temperature (Table III.2).

To further investigate methods of improving the statistics of the load temperature correlations, we regressed the load against drybulb temperature using data for the entire year; see **Table III.5**. The R^2 of the regressions improved significantly, particularly during the morning hours. Of special attention is the robustness of the base load at 60°F which for most part of the normal hours of the day is about 3.5 W/ft^2 (10 a.m. to 4 p.m.). We also regressed the total daily electricity use against the average daily drybulb and relative humidity. The results indicated that daily whole-building load is sensitive to drybulb temperature and not sensitive to relative humidity **(Table III.6)**. The statistics for the daily correlations are much better than the hourly ones. The average daily electricity use at 60°F ambient temperature is about 54 Wh/ft^2 and the daily electricity use increases by about 0.55 Wh/ft^2 per degree F. We will discuss the daily regressions in further detail in Chapter IV.

EDA Output and Comparison with Monitored End Uses

We performed a series of successive EDA runs to estimate the EUIs and LSs for the office building. The results of the runs as well as the summary of the monitored data and the DOE-2 simulations are summarized in **Table III.7**.

For comparing the EDA run results with measured data, we used the same end-use categories that are represented in the submetered data. The monitored data include channels for the HVAC end uses, indoor lighting, plug loads, and whole-building electricity use. Note that of the total 17.12 kWh/ft^2 annual electricity use, the end-use monitored data account for 13.50 kWh/ft^2, leaving some 3.62 kWh/ft^2 unaccounted for. For this reason, we combined the plug load and unaccounted for loads into the single class of miscellaneous load and used the miscellaneous load in the comparison. The first row of data in Table III.7 summarizes the measured end-use EUIs.

The second row of data indicates the annual electricity use of interior lighting and miscellaneous end uses as obtained from analysis of on-site survey information, and HVAC electricity use (using WYEC weather tapes) simulated using DOE-2. Although, at this stage we have not

Table III.3

Regression results of the measured weekday hourly whole-building load against dry-bulb temperature and relative humidity for Summer and Winter for Office #5

	Summer						Winter					
	Coefficients			Statistics			Coefficients			Statistics		
Hour	60° Base (W/ft^2)	Relative Humidity ($W/ft^2/°F$)	Dry Bulb Temp ($W/ft^2/°F$)	R^2	Sig. of F-Stat.	N	60° Base (W/ft^2)	Relative Humidity ($W/ft^2/°F$)	Dry Bulb Temp ($W/ft^2/°F$)	R^2	Sig. of F-Stat.	N
1	0.694	0.001	0.006	0.21	0.000	124	0.790	-0.000	0.004	0.02	0.256	121
2	0.690	0.000	0.003	0.17	0.000	122	0.759	-0.001	0.004	0.05	0.061	121
3	0.686	0.000	0.002	0.15	0.000	121	0.700	0.000	0.000	0.00	0.964	121
4	0.633	0.003	-0.005	0.05	0.051	119	0.765	0.000	0.004	0.03	0.134	121
5	1.365	0.001	0.013	0.02	0.327	118	1.137	0.006	0.023	0.22	0.000	121
6	2.327	-0.012	0.038	0.18	0.000	116	1.547	0.006	0.032	0.30	0.000	120
7	2.600	-0.007	0.011	0.07	0.012	116	2.092	0.002	0.045	0.40	0.000	121
8	3.371	-0.007	0.011	0.11	0.001	120	2.685	0.002	0.055	0.42	0.000	121
9	3.703	-0.005	0.017	0.13	0.000	126	3.260	0.003	0.044	0.39	0.000	121
10	3.745	-0.004	0.023	0.22	0.000	126	3.471	0.002	0.032	0.30	0.000	121
11	3.713	-0.002	0.022	0.24	0.000	128	3.472	0.003	0.032	0.29	0.000	121
12	3.701	-0.001	0.019	0.20	0.000	128	3.420	0.004	0.030	0.28	0.000	121
13	3.684	-0.001	0.016	0.15	0.000	128	3.395	0.004	0.028	0.28	0.000	121
14	3.714	0.000	0.013	0.14	0.000	128	3.430	0.003	0.024	0.23	0.000	121
15	3.737	0.001	0.012	0.14	0.000	128	3.457	0.004	0.026	0.24	0.000	121
16	3.609	-0.001	0.013	0.13	0.000	128	3.441	0.003	0.024	0.22	0.000	121
17	3.144	-0.002	0.016	0.15	0.000	128	3.222	-0.000	0.016	0.13	0.000	121
18	2.774	-0.006	0.022	0.29	0.000	128	2.715	0.002	0.021	0.16	0.000	121
19	2.562	-0.009	0.021	0.30	0.000	128	2.324	0.003	0.026	0.28	0.000	121
20	2.312	-0.007	0.018	0.18	0.000	128	2.082	0.003	0.028	0.36	0.000	121
21	1.691	-0.005	-0.010	0.13	0.000	128	1.689	0.000	0.024	0.20	0.000	121
22	0.840	0.000	0.006	0.10	0.001	127	1.172	-0.002	0.011	0.06	0.021	121
23	0.779	0.001	0.006	0.12	0.000	128	0.803	0.000	-0.000	0.04	0.117	121
24	0.738	0.001	0.009	0.17	0.000	127	0.788	0.000	-0.000	0.00	0.812	121

Table III.4

Regression results of the measured weekday hourly whole-building load against relative humidity for Summer and Winter for Office #5

Hour	Summer					Winter				
	Coefficients		Statistics			Coefficients		Statistics		
	60° Base (W/ft²)	Relative Humidity (W/ft²/°F)	R^2	Sig. of F-Stat.	N	60° Base (W/ft²)	Relative Humidity (W/ft²/°F)	R^2	Sig. of F-Stat.	N
1	0.686	0.002	0.10	0.000	124	0.774	-0.000	0.00	0.636	121
2	0.684	0.001	0.08	0.002	122	0.740	-0.001	0.02	0.176	121
3	0.682	0.001	0.09	0.001	121	0.700	0.000	0.00	0.796	121
4	0.648	0.003	0.04	0.030	119	0.735	-0.000	0.00	0.894	121
5	1.320	0.002	0.00	0.470	118	0.967	0.005	0.07	0.003	121
6	2.175	-0.006	0.03	0.048	116	1.294	0.005	0.06	0.007	120
7	2.569	-0.005	0.05	0.014	116	1.728	-0.000	0.00	0.837	121
8	3.369	-0.006	0.08	0.002	120	2.256	-0.001	0.00	0.626	121
9	3.767	-0.005	0.06	0.005	126	2.993	-0.001	0.00	0.748	121
10	3.900	-0.005	0.06	0.004	126	3.359	-0.001	0.00	0.548	121
11	3.908	-0.003	0.03	0.070	128	3.456	-0.001	0.00	0.757	121
12	3.879	-0.002	0.01	0.227	128	3.464	-0.001	0.00	0.707	121
13	3.835	-0.001	0.00	0.671	128	3.469	-0.001	0.00	0.636	121
14	3.852	0.000	0.00	0.772	128	3.508	-0.002	0.01	0.340	121
15	3.868	0.001	0.00	0.550	128	3.546	-0.001	0.00	0.517	121
16	3.748	-0.001	0.01	0.276	128	3.524	-0.002	0.01	0.252	121
17	3.310	-0.003	0.02	0.095	128	3.272	-0.004	0.04	0.037	121
18	2.995	-0.007	0.13	0.000	128	2.760	-0.002	0.01	0.259	121
19	2.744	-0.010	0.20	0.000	128	2.348	-0.000	0.00	0.805	121
20	2.408	-0.006	0.10	0.000	128	2.077	-0.000	0.00	0.927	121
21	1.671	-0.006	0.10	0.000	128	1.668	-0.003	0.03	0.054	121
22	0.842	0.001	0.04	0.033	127	1.154	-0.004	0.04	0.028	121
23	0.777	0.002	0.07	0.002	128	0.803	0.001	0.03	0.040	121
24	0.725	0.002	0.08	0.002	127	0.789	0.000	0.00	0.632	121

Table III.5

Regression results of the measured weekday hourly whole-building load against dry-bulb temperature for the entire year for Office #5

Hour	Coefficients		Statistics		
	60° Base (W/ft^2)	Dry Bulb Temp ($W/ft^2/°F$)	R^2	Sig. of F-Stat.	N
1	0.758	0.002	0.01	0.163	246
2	0.726	0.002	0.01	0.064	244
3	0.703	0.000	0.01	0.098	243
4	0.747	0.002	0.01	0.105	241
5	1.306	0.026	0.20	0.000	240
6	1.805	0.041	0.38	0.000	237
7	2.225	0.047	0.51	0.000	238
8	2.898	0.062	0.60	0.000	242
9	3.362	0.046	0.53	0.000	248
10	3.527	0.034	0.43	0.000	248
11	3.529	0.033	0.41	0.000	250
12	3.483	0.031	0.37	0.000	250
13	3.462	0.028	0.33	0.000	250
14	3.503	0.025	0.30	0.000	250
15	3.529	0.025	0.29	0.000	250
16	3.473	0.021	0.25	0.000	250
17	3.183	0.013	0.10	0.000	250
18	2.700	0.019	0.18	0.000	250
19	2.335	0.023	0.25	0.000	250
20	2.099	0.023	0.26	0.000	250
21	1.558	0.004	0.01	0.158	250
22	1.000	-0.001	0.00	0.666	249
23	0.820	0.002	0.02	0.018	250
24	0.791	0.001	0.01	0.108	249

Table III.6

Regression results of the measured weekday daily whole-building load against dry-bulb temperture for Office #5

Season	Coefficients: 60° Base (W/ft²)	Coefficients: Relative Humidity (W/ft²/°F)	Coefficients: Dry Bulb Temp (W/ft²/°F)	Statistics: R^2	Statistics: Sig. of F-Stat.	Statistics: N
Summer	55.455	-	0.320	0.16	0.000	110
Winter	53.080	-	0.557	0.38	0.000	121
Year	53.634	-	0.573	0.48	0.000	232
Year[1]	53.892	-	0.550	0.58	0.000	230
Summer	58.649	-0.062	-	0.05	0.014	110
Winter	51.565	-0.017	-	0.00	0.568	121
Summer	57.791	-0.113	0.436	0.32	0.000	110
Winter	52.941	0.054	0.606	0.40	0.000	121
Year	53.325	0.021	0.562	0.48	0.000	232
Year[1]	53.636	0.018	0.541	0.59	0.000	230

1. Excluding two outliers.

Table III.7

Comparison of the EDA estimated EUIs with measured EUIs
for Office #5

Run	EUI ($kWh/ft^2/yr$) HVAC	Indoor Lighting	Plugs	Miscellaneous (Including Plugs)	Total
Monitored	6.93	4.42	2.15	5.78	17.12
DOE-2 estimate with WYEC weather	8.36	4.62		0.99	13.97
DOE-2 with 1989 weather	7.99	4.62		0.99	13.60
EDA with cooling based on regression of total load	7.73	5.63		3.73	17.09
EDA with cooling based on DOE-2 estimates	5.69	6.87		4.38	16.94

used the monitored data in the EDA analysis, note that there is a significant difference of miscellaneous electricity use between the monitored data and on-site survey information. In the third row of the table we have estimated the 1989 HVAC electricity use from the DOE-2 simulation results of the second row. The hourly information on the third row is used as the initial condition for EDA. **Figure III.8** shows the simulated DOE-2 end-use load shape for the building peak day. In these simulations, based on the analysis of the measured whole-building load, we have extended the hours of operation of HVAC systems from 7 a.m. to 6 p.m. to 5 a.m. to 8 p.m. Note that the simulated peak cooling load occur at 5 a.m. to cool down the building from the last night accumulated heat.

The results of applying EDA to the DOE-2 simulated initial conditions are summarized in rows 4 and 5. In the EDA process we have used the annual regressions of whole-building hourly loads. Row 4 provides end-use EUIs with all end uses at all hours having equal weight. Comparing the results with the monitored data indicate that the lighting and HVAC EUIs are overestimated by about 27% and 12%, respectively. The miscellaneous EUI is underestimated by 5%. The majority of the discrepancy for the lighting and miscellaneous EUIs initiate from a ill-defined, initial condition miscellaneous end use. Recall that EDA relies entirely on the initial condition information in apportioning loads between non-HVAC (i.e., lighting and miscellaneous) end uses. In an attempt to improve the EUIs for lighting and miscellaneous, we repeated the EDA calculation using varying weight for different end uses (row 5). We used higher weights for lighting based on the assumption that the on-site survey information are probably more accurate for the interior lighting than miscellaneous end uses. The weighting only slightly modified the resulting EUIs and LSs. We also performed another EDA run, using the DOE-2 simulation results as HVAC initial conditions (row 5). The result was an underestimation of HVAC and miscellaneous EUIs by 18% and 24% respectfully. The lighting EUI was over estimated by 55%.

In order to gain insight into the differences between the EDA results and the monitored data, in **Figures III.9** and **III.10**, we compare the average hourly energy use load shapes of the monitored data with those estimated by EDA. Figure III.9 corresponds to EDA simulations with cooling based on regression of total load and Figure III.10 is for EDA simulations with cooling based on DOE-2 estimates. The differences between the EDA estimates and measured data are plotted in **Figures III.11 and III.12**.

Figure III.8
Simulated peak day load for Office #5

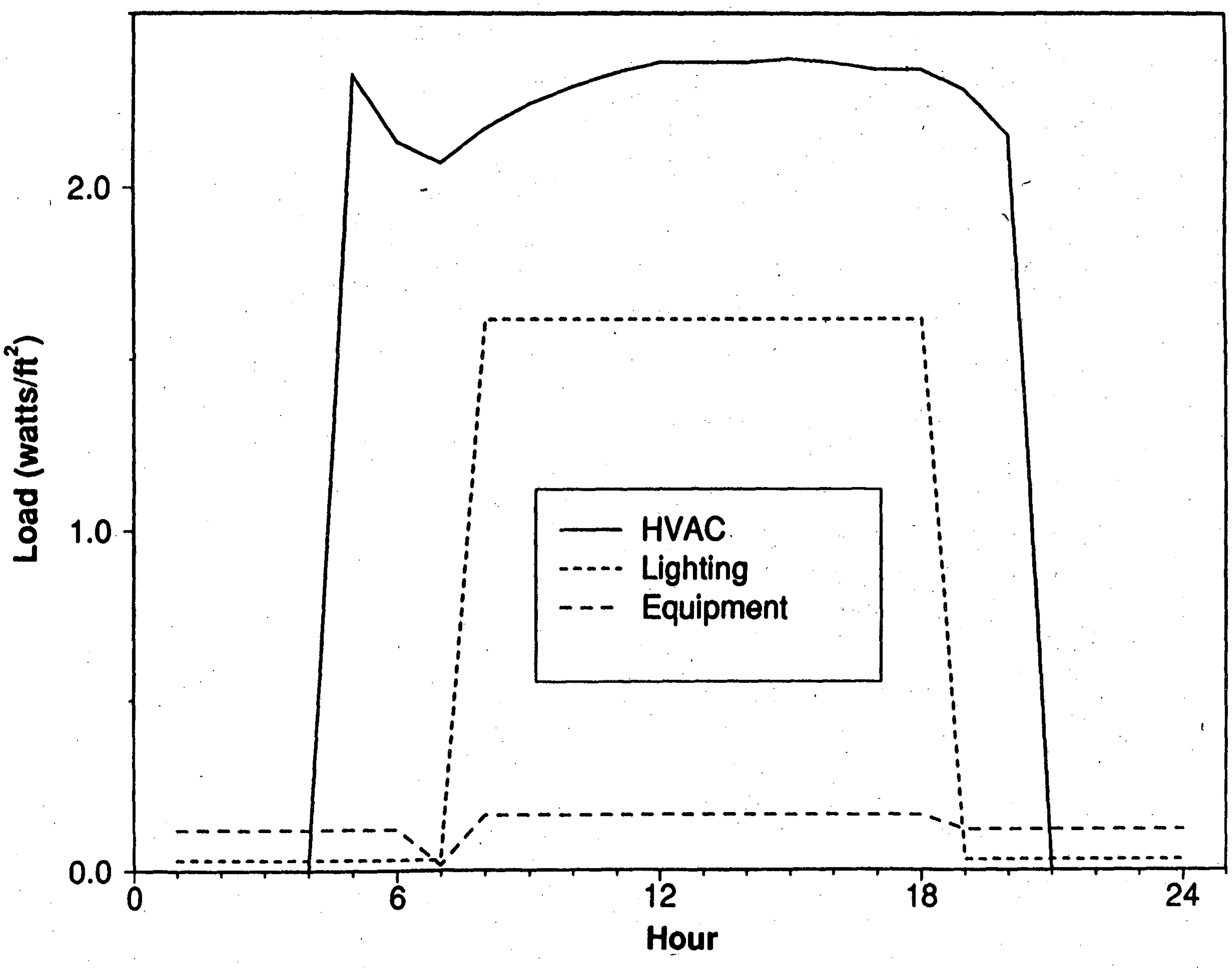


Figure III.9
Measured and EDA load shapes for Office #5
Initial EDA HVAC estimates are based on regression of measured whole-building load

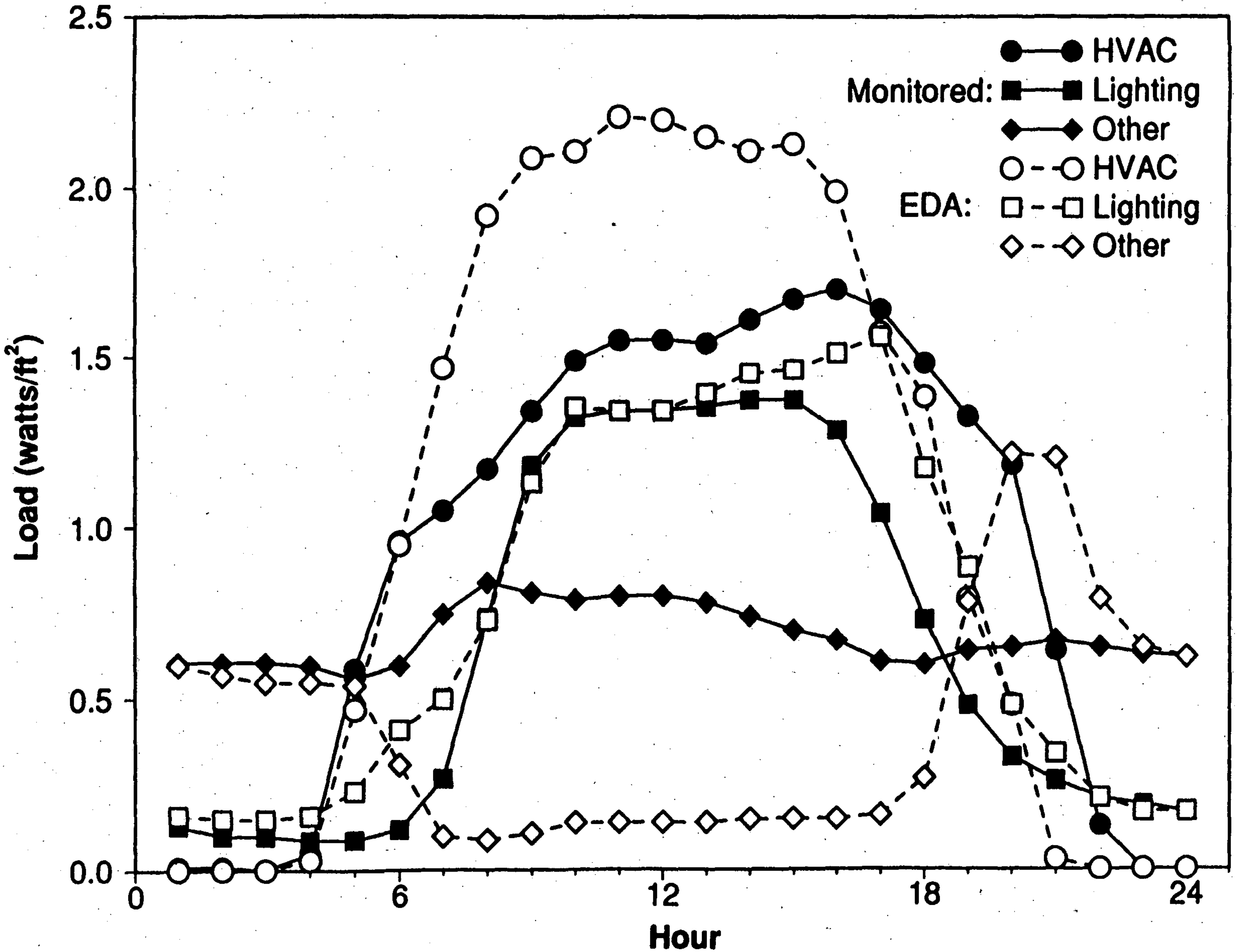


Figure III.10
Measured and EDA load shapes for Office #5
Initial EDA HVAC estimates are based on DOE-2 simulation

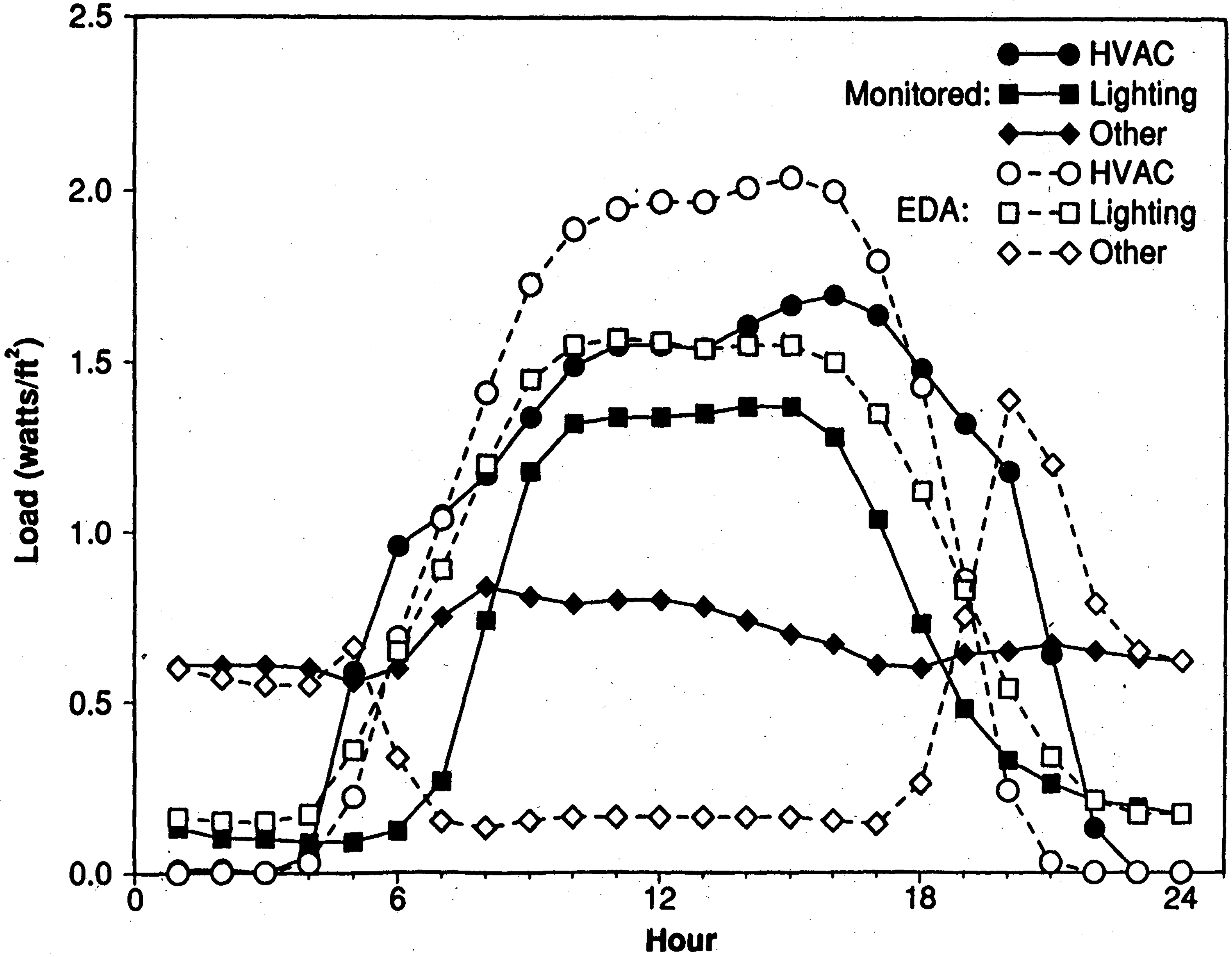


Figure III.11
Differences between EDA estimated and measured loads for Office #5
Initial EDA HVAC estimates are based on regression of measured whole-building load
Dashed line shows min/max range; bold line extends from 25% to 75% quartile; mean values connected

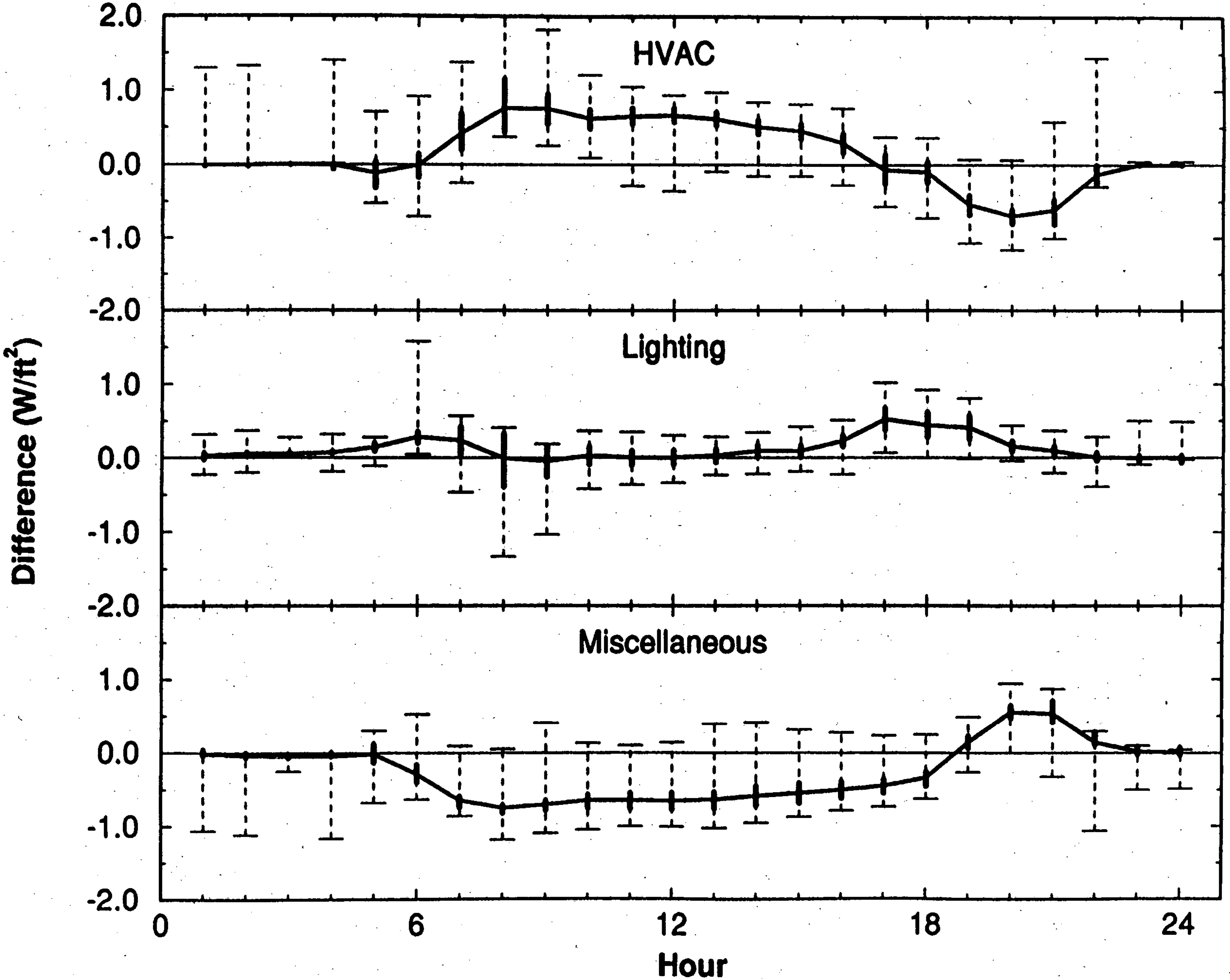
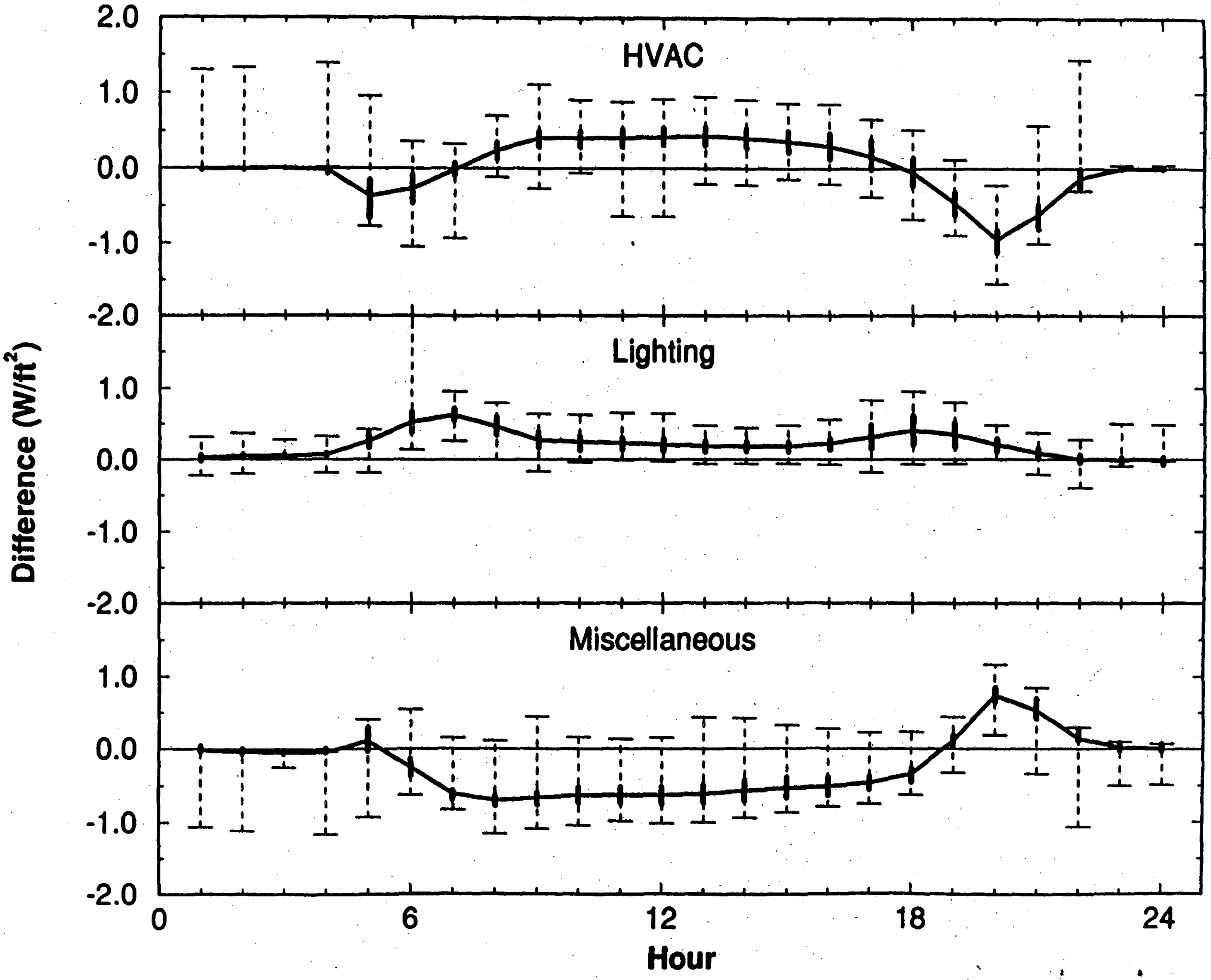


Figure III.12
Differences between EDA estimated and measured loads for Office #5
Initial EDA HVAC estimates are based on simulation estimates
Dashed line shows min/max range; bold line extends from 25% to 75% quartile; mean values connected



In inspecting these figures, two points become evident. First, during the night, estimates of electricity use by EDA for all end uses agree very well with those of the measured data. This is no surprise, since the initial conditions for air-conditioning electricity use during the night is zero. When the HVAC energy equals zero, EDA allocates the difference between the measured and estimated whole-building load to the end uses, namely miscellaneous and indoor lighting. During the day, when the air conditioning is an end use, most of the differences between the measured whole-building load and the simulated initial conditions is allocated to the lighting and air conditioning. In fact, there is a consistent positive bias in EDA's estimates of air conditioning at the expense of miscellaneous end use. The EDA-estimated miscellaneous end-use intensity drops from the nighttime levels of approximately 0.6 W/ft^2 to daytime levels of approximately 0.1 W/ft^2.

Clearly, the EDA-estimated end-use load shape for the miscellaneous end use is in contradiction with the audit information (see Figure III.8). The audit estimates for the miscellaneous end use electricity consumption is about 0.2 W/ft^2, during the day, and 0.15 W/ft^2 during the night. There are two ways to adjust this inconsistency in miscellaneous load shape: either by reducing the nighttime level miscellaneous load (resulting in an increase in nighttime lighting and HVAC usage) or by increasing the daytime level (resulting in a decrease in daytime lighting and HVAC usage). Without comparison with the measured data, it is hard to decide what to do. The measured data however indicate that the nighttime miscellaneous electricity use is probably correct and the daytime use should be increased. If we assume that the nighttime miscellaneous electricity use is indeed a lower estimate of the hourly electricity use for this end use, we can develop a new set of initial conditions for EDA simulations and repeat the calculation.

Retail building # 1

Building Description

This 23,396 ft^2 building is a one story one-tenant retail store built in 1960 and located in Tustin (inland valley south of Los Angeles) (SCE 1990,1989). The entire store is conditioned (both heated and cooled); about 89% of the building is used for retail space and 11% as conditioned storage area. All building systems are electric.

The maximum occupancy of the building is 6 staff and 10 customers. The store is operated Monday through Saturday from 9:00 a.m. to 9:30 p.m. and Sunday from 10:00 a.m. to 7:00 p.m. Most interior lights (94% by installed capacity) are fluorescent but there are some incandescent lights as well (6%). The total installed lighting intensity is 2.09 W/ft^2, operated by central switches with the same hours of operation as the store. The outdoor lighting is fluorescent and mercury vapor with an intensity of about 0.14 W/ft^2 operated from 6 p.m. to 6 a.m., every day. The audit of the building also indicates that the outdoor lighting is controlled by photocells. For our simulations, we rely on the fixed hours of outdoor lighting operation. The installed intensity of other building loads (refrigerator, drinking fountain, instantaneous domestic hot water heaters, cash register, microwave oven, coffee pot, etc.) is estimated at 0.37 W/ft^2.

The building has six single-zone heat-pump units. The total heating and cooling capacities are 816 kBtu/h and 65 tons, respectively. The total electricity load for all HVAC equipment is about 122 kW. All heat-pump units have economizers. The heating and cooling set point is 66°F and 72°F, respectively. The systems are operated during business hours and controlled by time clocks.

DOE-2 Simulation

We used information provided to us by the hardcopy of the audit (SCE 1989) and the 1985 on-site survey data to simulate the energy use of the building with DOE-2. Like the office building, the audit data provided information on the operation, schedule, equipment type, and equipment energy use for the building. The audit did not provide information on the architectural and construction characteristics of the building.

We simulated the building, with a square floor plan and a total conditioned floor area of 23,396 ft^2. The building was simulated with six single-zone heat-pump units. The internal load of the building was calculated using the methodology discussed in Akbari et al. (1989).

The DOE-2 simulations were performed using the Los Angeles WYEC weather tape and the resulting hourly HVAC energy use was regressed against the WYEC drybulb temperature. The resulting correlations were then used in conjunction with actual 1989-1990 hourly drybulb temperatures to estimate the hourly cooling energy use for the period of June 1, 1989 to May 31, 1990.

The simulated annual HVAC, lighting, and other miscellaneous loads are 2.76, 6.91, and 0.28 kWh/ft^2, respectively. Note that the simulated whole-building energy use of 9.95 kWh/ft^2 is within 10% of the 9.06 kWh/ft^2 measured energy use for this office building. EDA will adopt the characteristics of the measured whole-building load in the reconciliation process (See **Figure III.13**).

Contrary to the office building, the hourly plot of the simulated HVAC electricity use does indicate a base load (See **Figure III.14**). This is consistent with the observed characteristics of

Figure III.13
Measured whole-building average load for Retail #1 by day of week

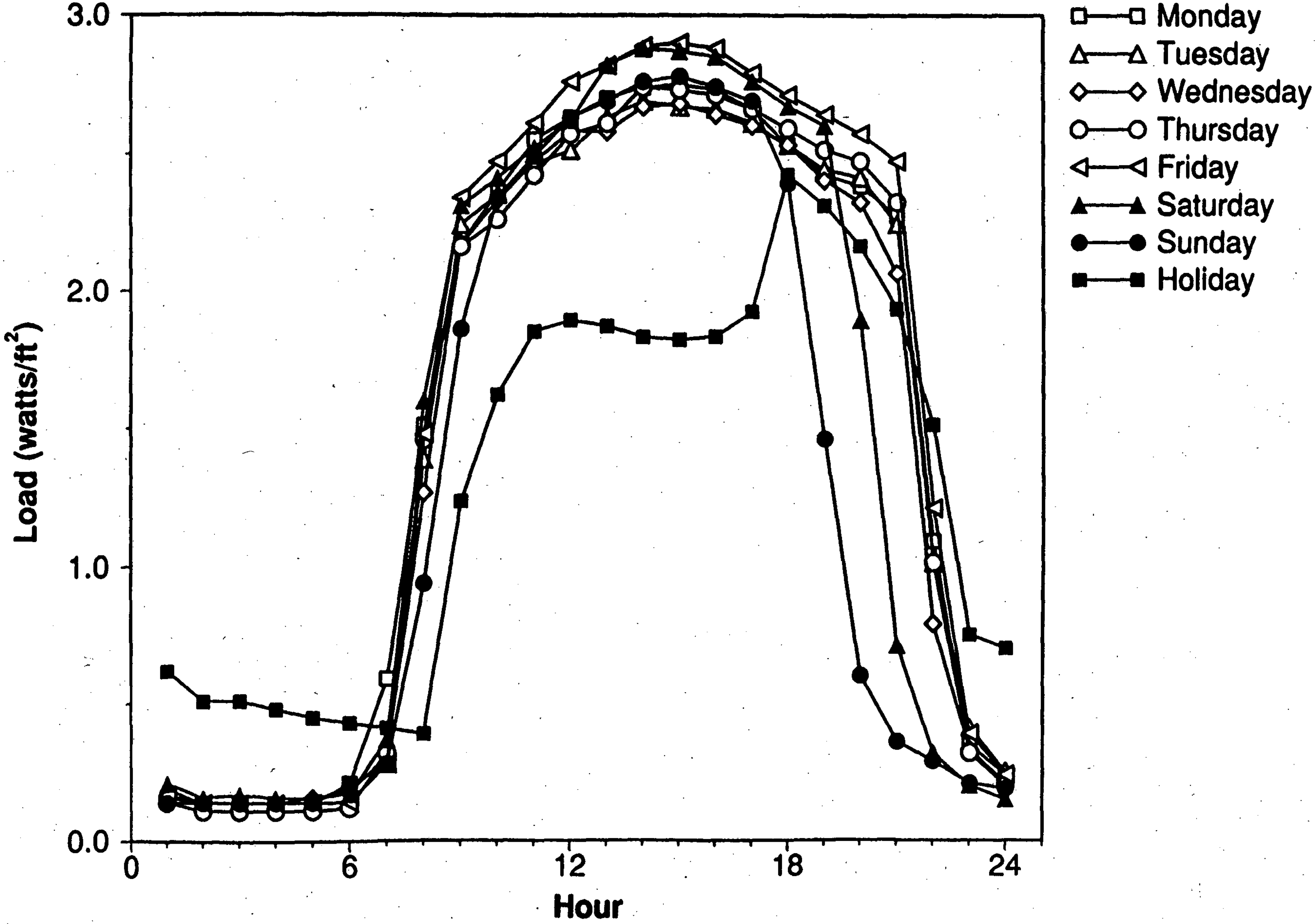
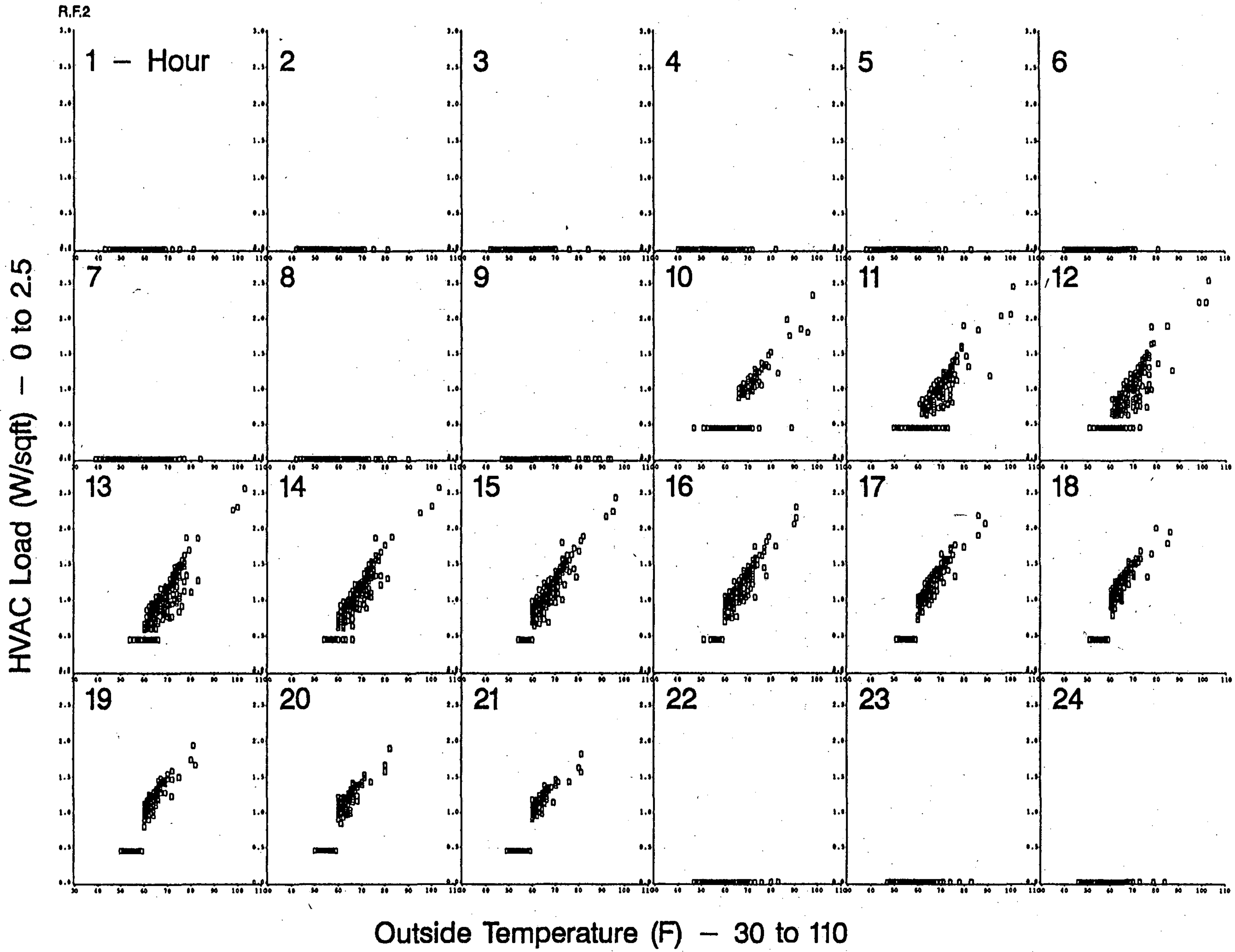


Figure III.14
Hourly plots of simulated weekday HVAC electricity use versus outside temperature for Retail #1



the measured data as are discussed in the next section. The regression results of the simulated hourly HVAC load against the WYEC drybulb temperatures are presented in **Table III.8**. Using these correlations and the measured drybulb temperatures, we calculated new estimates of the HVAC electricity end use. For a typical summer day, **Figure III.15** compares the new estimate of simulated HVAC electricity use for the 1989-1990 temperature data with the original DOE-2 results, using WYEC weather data. This process modified the simulated annual HVAC energy use from 2.76 to 3.67 kWh/ft^2.

Load/Temperature Regressions

Figures III.16-III.18 show the yearly, summer, and winter plots of hourly whole-building load against the ambient drybulb temperatures. The summer and winter period are defined as May 1 to October 31 and November 1 to April 30, respectively. These figures indicate a few interesting points that warrant further discussions. Judging from the observed load data, the normal hours of operation are 9 a.m. to 9 p.m. (consistent with the audit information). There are some occasional activities during the early morning hours of 7 and 8 a.m. and late evening hours of 10 and 11 p.m. The building load during the nighttime hours (12 p.m. to 6 a.m.) is almost flat at 0.2 W/ft^2.

The summer data does not show a clear base load, but both the winter data and the annual data indicate a flat base load for temperature conditions approximately below 65°F. The base load varies by hour of day; for normal operating conditions it is between 2.0 to 2.2 W/ft^2. The audit of the building does not indicate any electricity use during the night. But the measured data indicate electricity use of about 0.2 W/ft^2 which is probably for the nighttime emergency indoor lighting and other miscellaneous equipment (identified or not identified in the audit).

We regressed the whole-building hourly load against drybulb temperature. **Table III.9** shows the summary of regression statistics of the whole-building load versus drybulb temperature, for the entire year (summer and winter included). The table indicates that significant correlations for most hours of the day (8 a.m. to 10 p.m.) exist. The base load electricity use at 60°F varies between 1.9 to 2.2 W/ft^2, and the regression coefficients for drybulb temperature mostly are between 0.04 to 0.05 W/ft^2/F. During hour 9 a.m., the drybulb temperature sensitivity of the hourly load is higher by 30%; this may be only a statistical fluke.

The regression R^2 values for all hours are in general better than those for the office building and are in the range of 0.3 to 0.7. To try to improve the statistics, we regressed the whole-

Table III.8

Regression results of the simulated weekday hourly HVAC load against dry-bulb temperature for Retail #1

Hour	Coefficients: 60° Base (W/ft^2)	Coefficients: Dry Bulb Temp ($W/ft^2/°F$)	Statistics: R^2	Statistics: Sig. of F-Stat.	Statistics: N
1	0.000	0.000	0.00	0.000	96
2	0.000	0.000	0.00	0.000	94
3	0.000	0.000	0.00	0.000	90
4	0.000	0.000	0.00	0.000	85
5	0.000	0.000	0.00	0.000	84
6	0.000	0.000	0.00	0.000	90
7	0.000	0.000	0.00	0.000	102
8	0.000	0.000	0.00	0.000	123
9	0.000	0.000	0.00	0.000	156
10	-0.107	0.049	0.68	0.000	189
11	-0.008	0.048	0.71	0.000	210
12	0.067	0.047	0.72	0.000	218
13	0.150	0.046	0.77	0.000	224
14	0.246	0.046	0.82	0.000	224
15	0.341	0.045	0.84	0.000	223
16	0.430	0.044	0.84	0.000	205
17	0.487	0.045	0.85	0.000	172
18	0.557	0.042	0.78	0.000	150
19	0.581	0.040	0.75	0.000	139
20	0.591	0.036	0.72	0.000	131
21	0.596	0.033	0.76	0.000	123
22	0.000	0.000	0.00	0.000	112
23	0.000	0.000	0.00	0.000	110
24	0.000	0.000	0.00	0.000	105

Table III.9

Regression results of the measured weekday hourly whole-building load against dry-bulb temperature for the entire year for Retail #1

Hour	Coefficients		Statistics		
	60° Base (W/ft^2)	Dry Bulb Temp ($W/ft^2/°F$)	R^2	Sig. of F-Stat.	N
1	0.193	0.003	0.01	0.315	109
2	0.169	0.004	0.03	0.104	99
3	0.182	0.001	0.00	0.727	90
4	0.161	0.004	0.03	0.107	80
5	0.184	0.001	0.00	0.723	78
6	0.243	-0.007	0.01	0.319	75
7	0.492	-0.003	0.00	0.851	75
8	1.590	0.054	0.19	0.000	86
9	2.180	0.069	0.40	0.000	121
10	2.147	0.046	0.31	0.000	149
11	2.185	0.039	0.33	0.000	190
12	2.126	0.042	0.37	0.000	201
13	2.018	0.045	0.44	0.000	211
14	1.974	0.046	0.48	0.000	221
15	1.922	0.046	0.46	0.000	223
16	1.908	0.047	0.47	0.000	224
17	1.936	0.046	0.49	0.000	223
18	2.006	0.051	0.76	0.000	214
19	2.043	0.050	0.63	0.000	201
20	2.114	0.050	0.58	0.000	186
21	1.983	0.062	0.53	0.000	170
22	0.803	0.036	0.08	0.000	157
23	0.279	0.004	0.01	0.314	142
24	0.224	0.002	0.00	0.551	123

Figure III.15
Simulated HVAC load using WYEC and local temperature data for a typical summer day for Retail #1

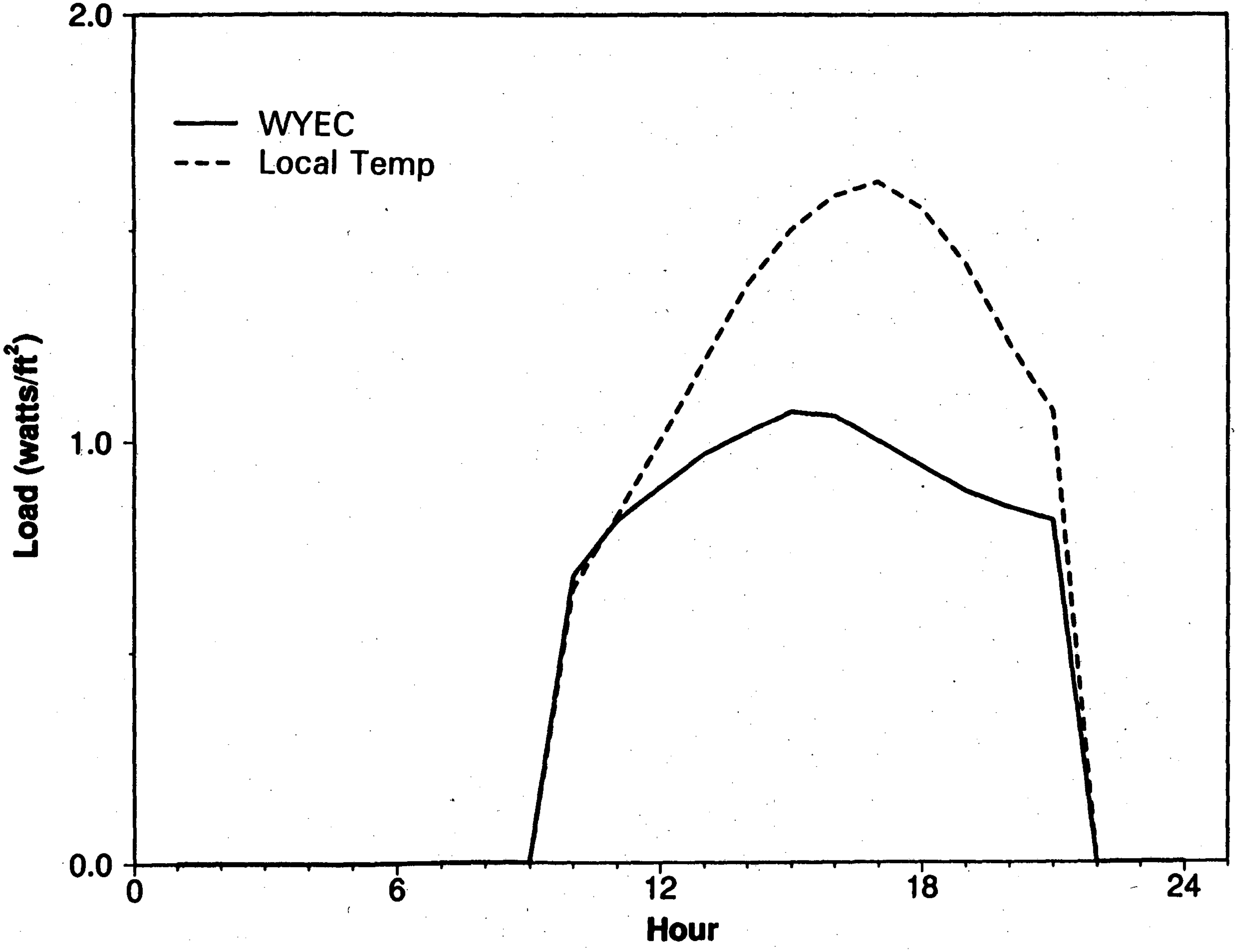


Figure III.16
Hourly plots of measured weekday whole-building load versus outdoor temperature for the entire year for Retail #1

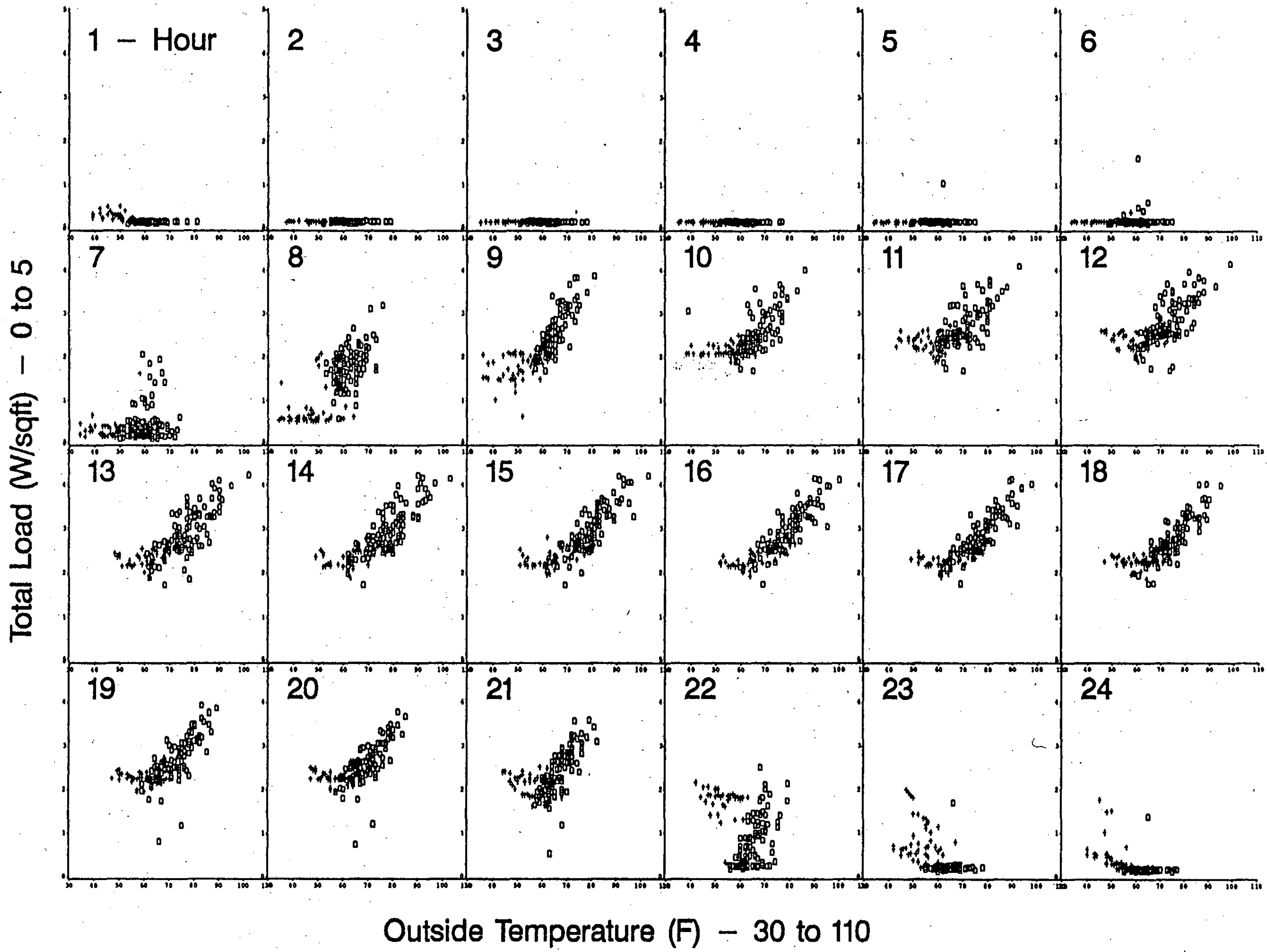


Figure III.17
Hourly plots of measured weekday whole-building load versus outdoor temperature for summer for Retail #1

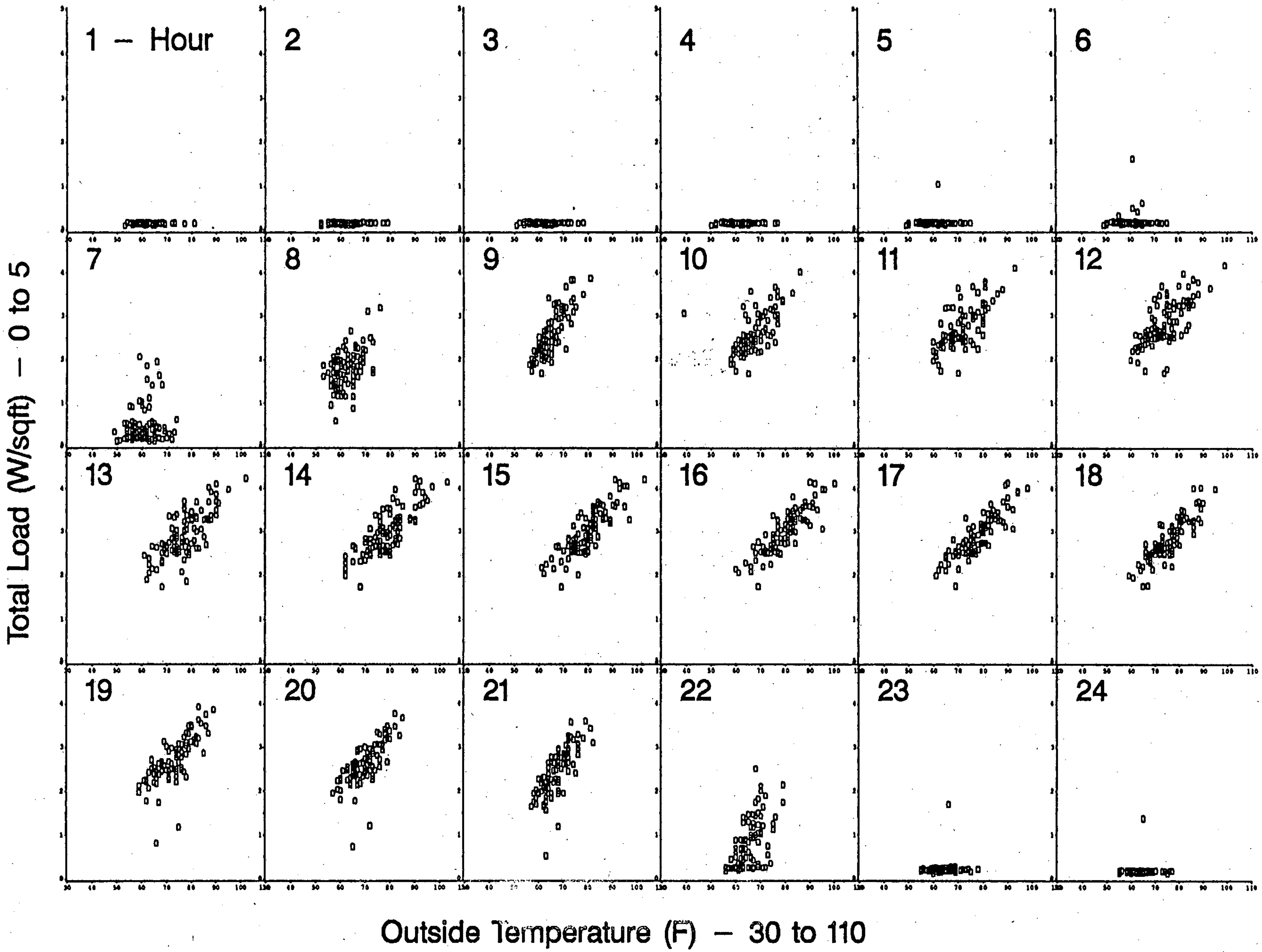
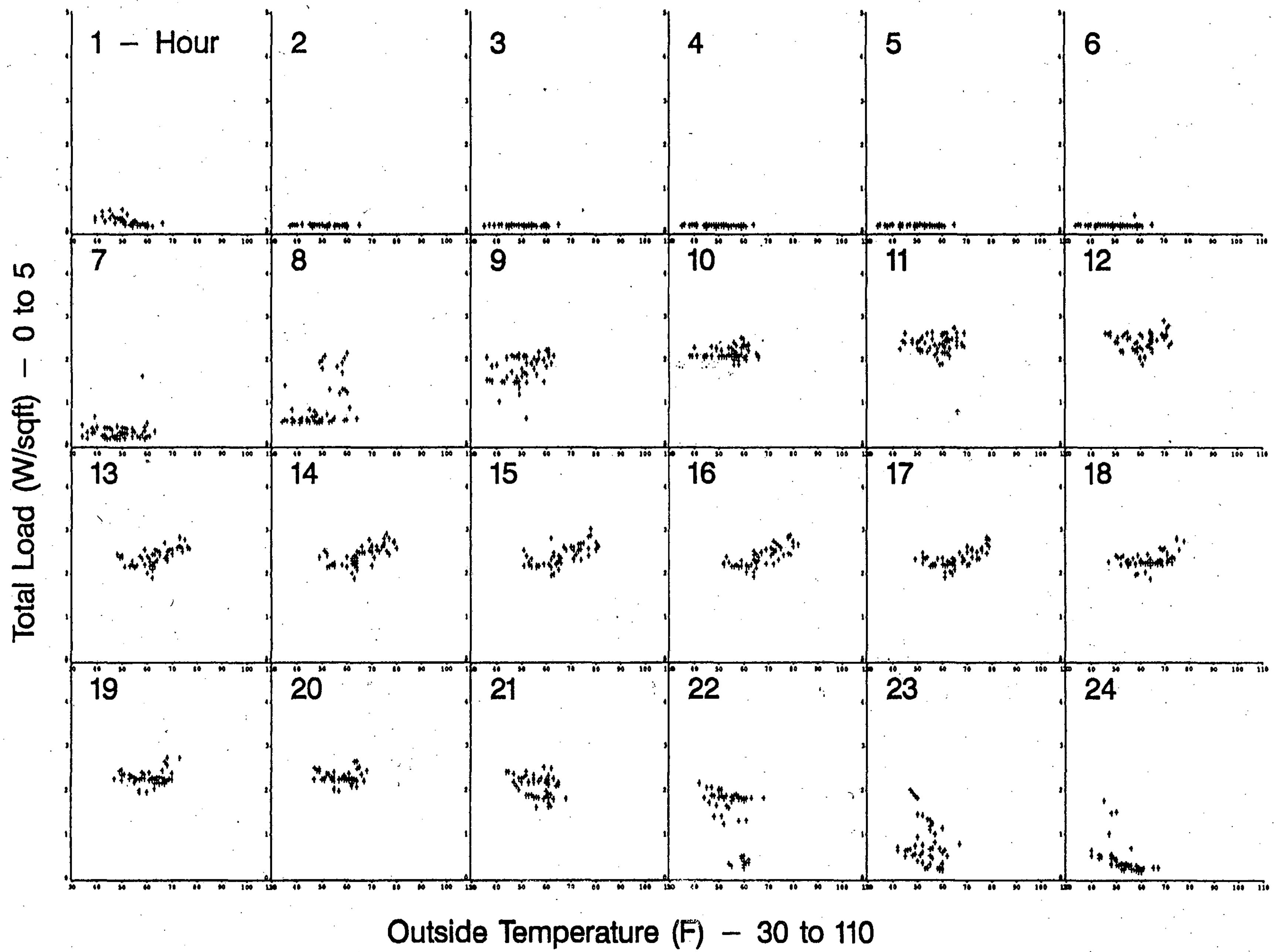


Figure III.18
Hourly plots of measured weekday whole-building load versus outdoor temperature for winter for Retail #1



building load simultaneously against both drybulb temperature and relative humidity. The addition of the relative humidity did not significantly improve the R^2 (see **Table III.10**). Regressions of the load against relative humidity alone indicated no correlation between these variables either (**Table III.11**). Hence, for the remainder of this analysis, we only considered the variation of the whole-building load against the drybulb temperature.

A closer inspection of the hourly data indicated that the operation of the building between days 19 to 96 (January 19 to April 7) is significantly different from the rest of the year. For this period, the whole-building hourly load is fairly constant and does not vary with outside temperature, even on hot days. Clearly, on these days the HVAC systems had not operated. Once, these data were filtered out of the regressions, the R^2 significantly improved (see **Table III.12a**). Regression of the hourly loads for the days 19 to 96, except for a few hours in the evening (6 p.m. to 9 p.m.), indeed showed no correlation to the drybulb temperature (see **Table III.12b**). For the EDA analysis, we used regression results from Table III.12a.

We also regressed the total daily electricity use against the average daily drybulb and relative humidity. The results indicated that daily whole-building load is sensitive to drybulb temperature and not sensitive to relative humidity (**Table III.13**). The statistics for Day 19 through 96 are excluded from the data set. The daily correlations are much better than the hourly ones. The average daily electricity use at 60°F ambient temperature is about 33 W/ft^2 and the daily electricity use increases by about 1 W/ft^2 F. We will discuss the daily regressions in further detail in Chapter IV.

EDA Output and Comparison with Monitored End Uses

We performed a series of successive EDA simulations to estimate the energy use intensities and LSs for this retail store. The results of the EDA runs as well as the summary of the monitored data and the DOE-2 simulations are summarized in **Table III.14**.

To establish a common reference for comparing these data we rely on the level of end-use disaggregation provided by the monitored data (row 1). The monitored data include channels for the HVAC and indoor lighting end uses and whole-building electricity use. Note that of the total 9.06 kWh/ft^2 annual electricity use, the monitored end uses account for 8.85 kWh/ft^2 leaving 0.21 kWh/ft^2 unaccounted for. We assumed the unaccounted for load may be classified as miscellaneous load.

The second row of data indicates the annual electricity use for the interior lighting and the miscellaneous end uses as obtained from the analysis of on-site survey information and HVAC

Table III.10

Regression results of the measured weekday hourly whole-building load against dry-bulb temperature and relative humidity for the entire year for Retail #1

Hour	Coefficients 60° Base (W/ft^2)	Relative Humidity ($W/ft^2/°F$)	Dry Bulb Temp ($W/ft^2/°F$)	Statistics R^2	Sig. of F-Stat.	N
1	0.302	-0.004	-0.003	0.20	0.000	109
2	0.231	-0.002	0.000	0.13	0.002	99
3	0.252	-0.003	-0.002	0.21	0.000	90
4	0.224	-0.002	0.001	0.19	0.000	80
5	0.270	-0.003	-0.002	0.13	0.005	78
6	0.375	-0.005	-0.011	0.14	0.004	75
7	0.587	-0.004	-0.005	0.01	0.616	75
8	1.451	0.007	0.057	0.23	0.000	86
9	1.809	0.017	0.089	0.58	0.000	121
10	1.846	0.015	0.065	0.51	0.000	149
11	2.068	0.010	0.048	0.43	0.000	190
12	2.028	0.013	0.051	0.49	0.000	201
13	1.975	0.014	0.055	0.56	0.000	211
14	1.987	0.015	0.054	0.59	0.000	221
15	1.952	0.014	0.053	0.56	0.000	223
16	1.922	0.014	0.054	0.56	0.000	224
17	1.927	0.012	0.053	0.59	0.000	223
18	1.975	0.006	0.056	0.79	0.000	214
19	1.972	0.007	0.058	0.68	0.000	201
20	1.997	0.009	0.060	0.66	0.000	186
21	1.836	0.009	0.073	0.59	0.000	170
22	0.943	-0.007	0.027	0.10	0.000	157
23	0.430	-0.008	-0.004	0.23	0.000	142
24	0.358	-0.006	-0.005	0.20	0.000	123

Table III.11
Regression results of the measured weekday hourly whole-building load against relative humidity for the entire year for Retail #1

Hour	Coefficients		Statistics		
	60° Base (W/ft^2)	Relative Humidity ($W/ft^2/°F$)	R^2	Sig. of F-Stat.	N
1	0.284	-0.004	0.20	0.000	109
2	0.234	-0.002	0.13	0.000	99
3	0.239	-0.003	0.20	0.000	90
4	0.228	-0.002	0.19	0.000	80
5	0.258	-0.003	0.13	0.001	78
6	0.312	-0.004	0.10	0.005	75
7	0.561	-0.004	0.01	0.351	75
8	1.774	0.004	0.01	0.271	86
9	2.485	0.006	0.03	0.075	121
10	2.438	0.005	0.02	0.071	149
11	2.533	0.002	0.01	0.251	190
12	2.634	0.003	0.01	0.223	201
13	2.687	0.003	0.01	0.301	211
14	2.726	0.003	0.01	0.222	221
15	2.728	0.004	0.01	0.178	223
16	2.691	0.003	0.00	0.342	224
17	2.633	0.002	0.00	0.418	223
18	2.658	-0.006	0.04	0.005	214
19	2.598	-0.004	0.02	0.047	201
20	2.558	-0.002	0.01	0.243	186
21	2.430	-0.002	0.01	0.284	170
22	1.139	-0.011	0.07	0.001	157
23	0.405	-0.007	0.22	0.000	142
24	0.325	-0.005	0.19	0.000	123

Table III.12a

Regression results of the measured weekday hourly whole-building load against dry-bulb temperature excluding days 19-96 for Retail #1

Hour	Coefficients: 60° Base (W/ft^2)	Coefficients: Dry Bulb Temp (W/ft^2/°F)	Statistics: R^2	Statistics: Sig. of F-Stat.	Statistics: N
1	0.166	0.000	0.00	0.797	99
2	0.166	0.000	0.00	0.775	94
3	0.167	0.000	0.00	0.935	85
4	0.166	-0.000	0.00	0.946	78
5	0.186	-0.002	0.00	0.584	76
6	0.232	-0.007	0.02	0.286	73
7	0.473	-0.003	0.00	0.848	73
8	1.594	0.056	0.22	0.000	83
9	2.160	0.083	0.62	0.000	115
10	2.180	0.054	0.52	0.000	134
11	2.208	0.047	0.55	0.000	162
12	2.167	0.047	0.59	0.000	170
13	2.130	0.047	0.65	0.000	175
14	2.096	0.047	0.71	0.000	180
15	2.024	0.049	0.73	0.000	180
16	1.990	0.051	0.76	0.000	180
17	1.974	0.052	0.77	0.000	179
18	1.983	0.053	0.73	0.000	173
19	2.033	0.053	0.59	0.000	165
20	2.123	0.052	0.55	0.000	157
21	1.954	0.070	0.55	0.000	147
22	0.628	0.051	0.16	0.000	138
23	0.261	-0.002	0.00	0.571	127
24	0.186	0.000	0.00	0.965	109

Table III.12b

Regression results of the measured weekday hourly whole-building load against dry-bulb temperature for days 19-96 for Retail #1

Hour	Coefficients		Statistics		
	60° Base (W/ft^2)	Dry Bulb Temp ($W/ft^2/°F$)	R^2	Sig. of F-Stat.	N
1	0.448	0.046	0.77	0.002	8
2	0.342	0.046	0.62	0.212	3
3	0.370	0.045	0.44	0.337	3
4	0.000	0.000	0.00	0.000	0
5	0.000	0.000	0.00	0.000	0
6	0.000	0.000	0.00	0.000	0
7	0.000	0.000	0.00	0.000	0
8	1.891	-0.124	1.00	0.000	1
9	1.667	-0.007	0.47	0.201	4
10	1.673	-0.000	0.00	0.997	13
11	2.045	-0.017	0.19	0.025	25
12	2.054	-0.012	0.08	0.135	28
13	1.890	-0.003	0.01	0.561	33
14	1.846	0.000	0.00	0.963	38
15	1.849	0.001	0.00	0.866	40
16	1.840	0.001	0.00	0.817	41
17	1.857	0.006	0.05	0.149	41
18	2.049	0.047	0.85	0.000	38
19	2.047	0.043	0.83	0.000	33
20	2.027	0.043	0.78	0.000	26
21	1.969	0.045	0.65	0.000	20
22	1.930	-0.021	0.09	0.245	16
23	0.488	0.049	0.80	0.000	13
24	0.517	0.036	0.79	0.000	12

Table III.13

Regression results of the measured weekday daily whole-building load against dry-bulb temperature and relative humidity for Retail #1

Season	Coefficients: 60° Base (W/ft²)	Coefficients: Relative Humidity (W/ft²/°F)	Coefficients: Dry Bulb Temp (W/ft²/°F)	Statistics: R^2	Statistics: Sig. of F-Stat.	Statistics: N
Summer	31.773	-	1.110	0.77	0.000	115
Winter	33.355	-	0.441	0.43	0.000	47
Winter[1]	34.544	-	0.518	0.44	0.000	28
Year	32.491	-	0.956	0.69	0.000	162
Year[1]	32.708	-	1.014	0.75	0.000	143
Summer	42.652	-0.144	-	0.06	0.010	115
Winter	35.248	-0.075	-	0.14	0.010	47
Winter[1]	36.280	-0.079	-	0.27	0.004	28
Year	39.573	-0.027	-	0.00	0.449	162
Year[1]	40.846	-0.082	-	0.03	0.040	143
Summer	29.594	0.115	1.217	0.80	0.000	115
Winter	33.463	-0.017	0.414	0.43	0.000	47
Winter[1]	35.021	-0.053	0.434	0.55	0.000	28
Year	31.465	0.079	1.012	0.72	0.000	162
Year[1]	32.298	0.028	1.032	0.76	0.000	143

1. Day 19 through 96 are excluded from the data set.

Table III.14
Comparison of the EDA estimated EUIs with measured EUIs for Retail #1

Run	EUI ($kWh/ft^2/yr$) HVAC	Lighting	Miscellaneous	Total
Monitored	3.20	5.65	0.21	9.06
Doe-2 estimate	2.76	6.91	0.28	9.95
Doe-2 with 1989 weather	3.67	6.91	0.28	10.86
EDA with cooling based on regression of total load	2.94	5.87	0.25	9.06
EDA with cooling based on Doe-2 estimates	2.93	5.90	0.22	9.05

electricity use simulated using DOE-2 (using WYEC weather tapes). Although at this stage we have not used the monitored data for further EDA analysis, note that the audit overestimates the lighting EUI by 22% and underestimates the HVAC EUI by 14%. Once the HVAC EUI are calculated for the actual 1989 weather, the simulation overestimates the HVAC EUI by 15% (see row 3 of Table III.14). The hourly information on the third row is used as the initial condition for EDA. **Figure III.19** shows the simulated DOE-2 end-use load shape for the building peak day. In these simulations, based on the analysis of the measured whole-building load, we adjusted the hours of operation of the HVAC system.

The results of the EDA application, using the DOE-2 simulated initial conditions, are summarized in rows 4 and 5. In the EDA process we used the annual regressions of whole-building hourly loads. Row 4 provides end-use EUIs with all end uses at all hours having an equal weight. Comparing the results with the monitored data indicate that the lighting EUI is overestimated only by 4% and the HVAC EUI is underestimated by 8%. In an attempt to improve the EUIs even further, we repeated the EDA calculation using varying weight for different end uses (row 5). We used higher weights for lighting based on the assumption that the on-site survey information are probably more accurate for the interior lighting than miscellaneous end uses. The weighting only slightly modified the resulting EUIs and LSs.

In order to gain insight into the differences between the EDA results and the monitored data, **Figure III.20** compares the average daily energy use load shapes of the monitored data with those estimated by EDA. This figure corresponds to EDA simulations with cooling based on regression of total load, Row 4 of Table III.14. The differences between the EDA estimates and measured data are plotted in **Figure III.21**.

The results are very promising. In inspecting these figures it is clear that during both nighttime and daytime hours, EDA's estimates of electricity use for all end uses agree very well with those of the measured data. This is no surprise, since our initial conditions for all end uses were within 20% of measured data. The maximum average differences between the hourly measured load and EDA estimates are 0.2, 0.15, 0.02 W/ft^2, for HVAC, lighting and miscellaneous end uses, respectively. Maximum differences between the measured end-use data and the EDA estimates occur when there is a mismatch between the actual and the assumed schedules.

For the retail store, the EDA estimates of hourly end-use data compare remarkably well with those of the monitored data. This indicates great promise for applying the EDA analysis to whole-building load for obtaining reliable end-use data.

Figure III.19
Simulated peak day load for Retail #1

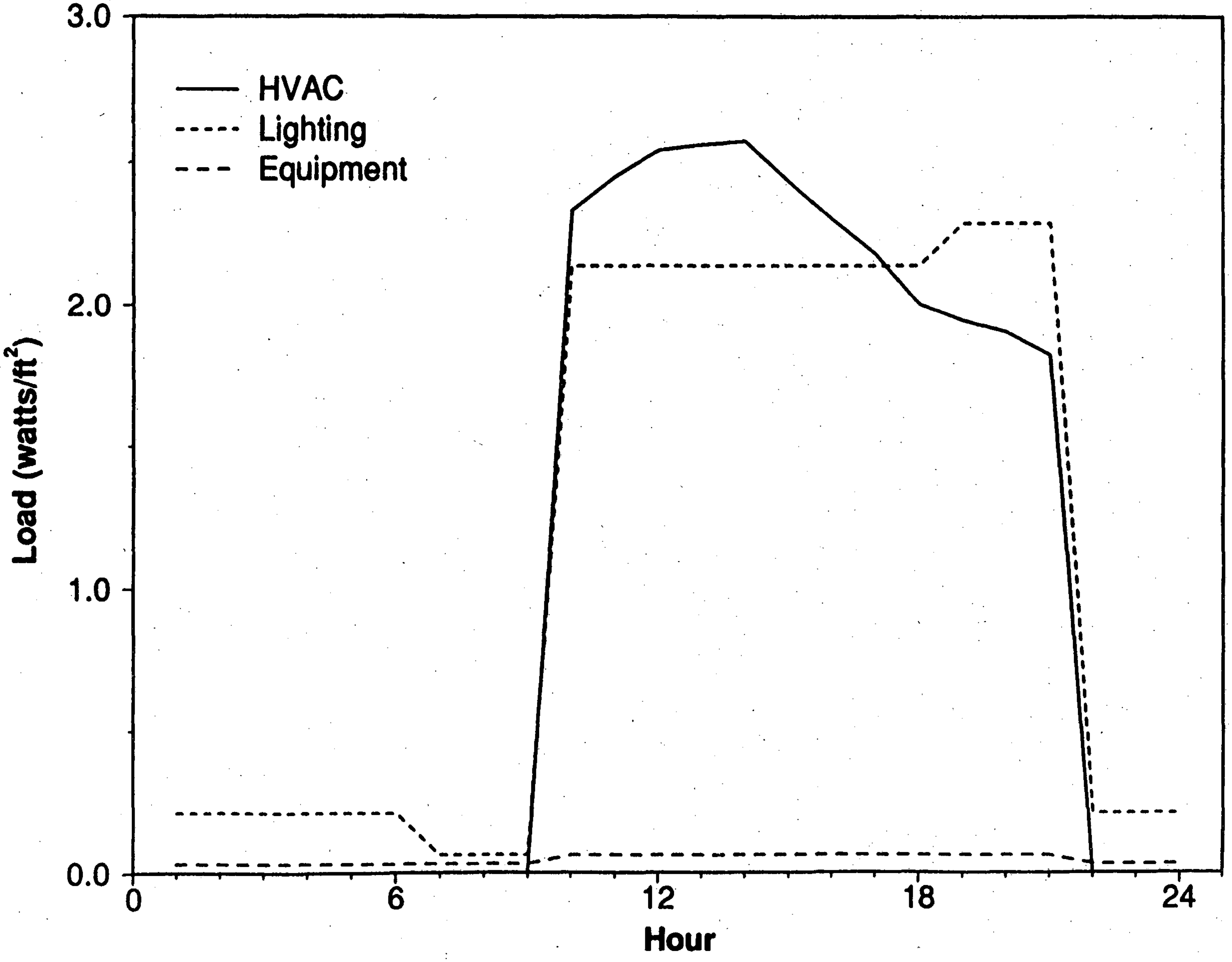


Figure III.20
Measured and EDA load shapes for Retail #1
Initial EDA HVAC estimates are based on regression of measured whole-building load

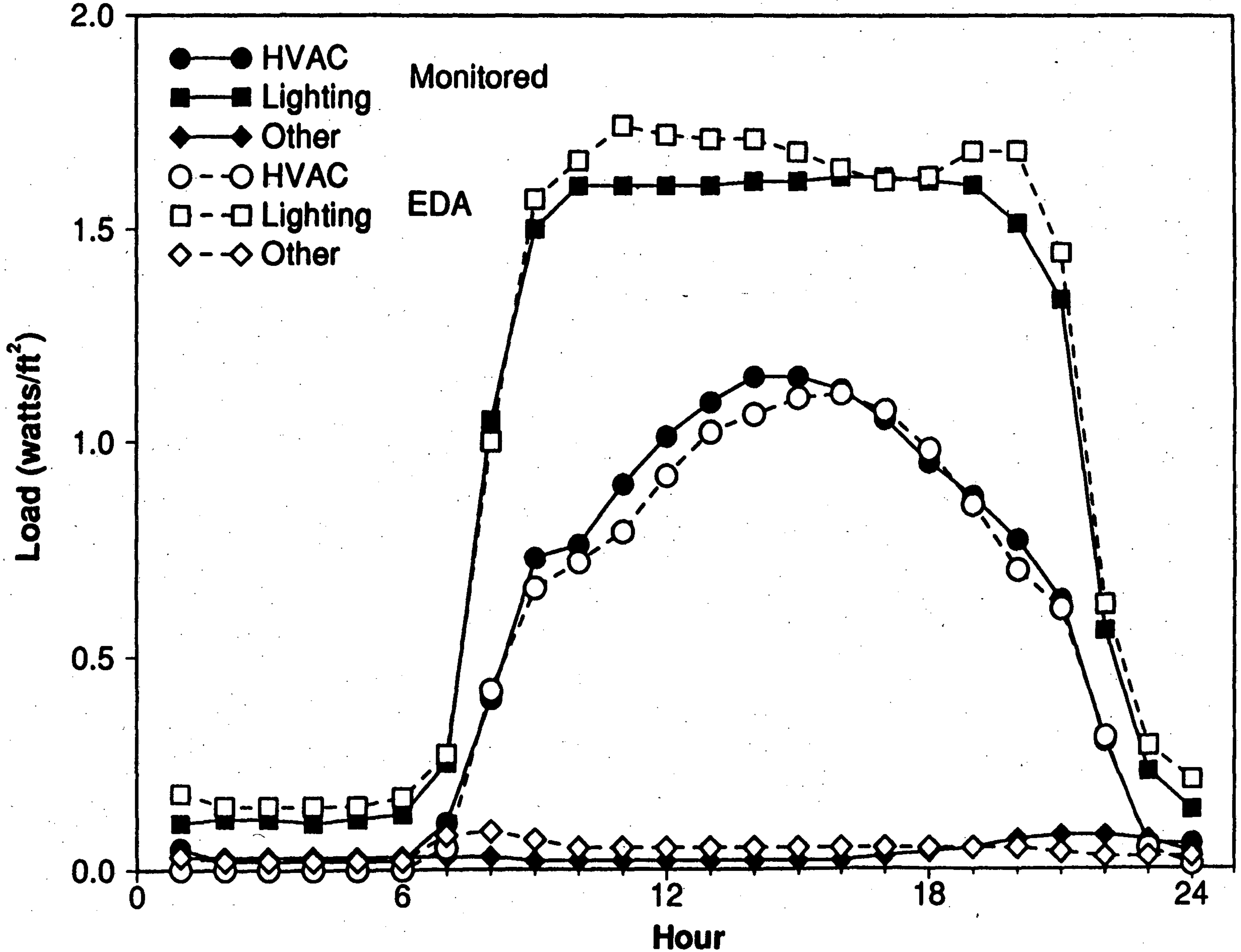
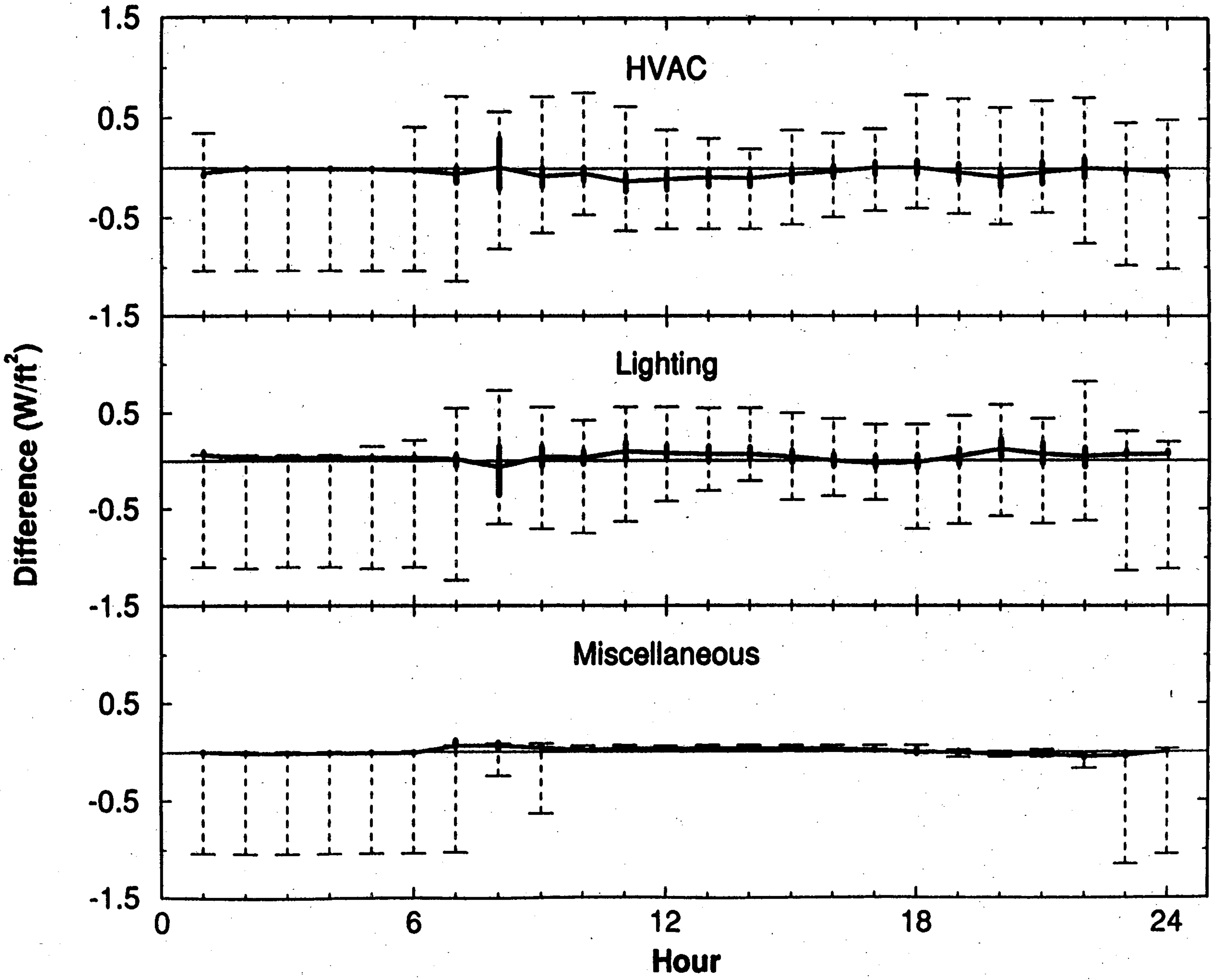


Figure III.21
Differences between EDA estimated and measured loads for Retail #1
Initial EDA HVAC estimates are based on regression of measured whole-building load
Dashed line shows min/max range; bold line extends from 25% to 75% quartile; mean values connected



Chapter IV: Conclusion and Recommendation

In Chapter III, we compared the hourly end-use loads estimated by LBL/EDA model with the corresponding measured data. Before we make an attempt to recommend methods for improving the performance of the EDA, we will first review its strengths and weaknesses. Recall that EDA has three major components; analysis of hourly load-temperature regressions, estimation of the components of the non-temperature dependent load, and the review of the hourly end-use loads for "permissible" hourly end-use load variation. In this chapter, we will discuss the EDA assumptions for each of these components and verify them using measured data. We conclude the chapter with recommendations for improving EDA.

Load-Temperature Regressions

The principle EDA assumption is that all of the weather (in this report temperature) dependency of the whole-building load is due to the HVAC system. In other words, among all the end uses in a commercial building, only the HVAC load is sensitive to the outdoor temperature. Although, this assumption seems plausible in a large number of commercial buildings, particularly in offices, retail stores, schools, and colleges, there are other building types characterized by non-HVAC end uses such as refrigeration whose loads are also weather dependent. Restaurants, supermarkets, and refrigerated warehouses are examples of commercial buildings where HVAC is not the only weather-dependent load.

For the buildings we have studied in this report, the HVAC, lighting, and plug loads constitute the majority of the whole-building load and the contribution of the refrigeration load (which may be limited to a few residential refrigerators in each building) is fairly minimal. So for those cases where no significant refrigeration occurs, we can check our first hypothesis with the available end-use data.

Recall that the regressions of the hourly whole-building load against the outdoor temperature provide two pieces of information; the weather-dependency of the hourly load (estimated by the regression coefficients) and the significance of the estimated correlations. The weather-dependency of the hourly whole-building load provides an estimate of the weather-dependency of the HVAC loads. The significance of the correlations identifies the operating schedules of the HVAC systems: if there is no significant correlation, the HVAC system is assumed to be off.

Is the temperature dependency of the whole-building load the same as that of the HVAC load?

Tables IV.1a, IV.1b, and IV.2 summarize the hourly statistics of the drybulb temperature regression for the office and retail store. The summary statistics for the office building are presented separately for summer and winter periods, which have been defined by the HVAC seasonality. Table IV.1a shows low R^2 values and thus fairly weak temperature correlation for the whole-building load when compared to the values for the HVAC load. This indicates that there is less scatter in the HVAC regression than in the whole-building regression. Also, the drybulb temperature regression coefficients for the whole-building load are significantly smaller than those for the HVAC load, indicating that the HVAC load is more temperature dependent.

For the office in the winter and for the retail store, the R^2 values and the drybulb temperature regression coefficients for the whole-building load compare very well with those for the HVAC load (see Tables IV.1b and IV.2). For the office building in winter, the temperature regression coefficients for the loads compare well, but the whole-building load correlations are weaker than those for the HVAC load. As shown for the retail store in Table IV.2, the R^2 and regression coefficients for hours with significant correlations are very close, generally within a few percentage points of each other. Also, it is reassuring to note that the regressions do no indicate any temperature-dependency for the lighting and plug loads.

A closer look at the measured end-use data for the office building indicates that about 10% of the daytime whole-building load has not been sub-metered. This load is indicated by the "Other" category in Tables IV.1a and IV.1b. The Other load is calculated from the whole-building load by subtracting the HVAC, Lighting, and Plug loads. For the summer period, the hourly Other load has negative regression coefficients, indicating a decrease in the Other load as drybulb temperature increases. The unmonitored Other load may be caused by the electricity used in the air distribution reheat boxes. The Other load does not show significant correlation during the winter. Once the HVAC load is adjusted by including the Other load, the hourly regression coefficients compare very well with those of the whole-building load. If the weather-dependency of the Other load is, indeed, accurate and it accounts for some unmeasured part of the HVAC load, the HVAC load should be corrected for such unmeasured load. In those cases where some part of the HVAC load is not monitored, one may argue that the weather dependency of the HVAC load determined from the regression of the whole-building load represents the true characteristics of the HVAC load.

Table IV.1a

Whole-building and end-use regression statistics for summer for Office #5

Load(W/ft^2)= a+b(T-60)

		Total				HVAC				Light				Plug			
Hour	N	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.
1	124	0.722	0.007	0.19	0.000	-0.000	0.000	0.00	0.526	0.106	0.000	0.00	0.050	0.199	0.001	0.23	0.000
2	122	0.706	0.004	0.15	0.000	0.000	-0.000	0.00	0.846	0.094	0.000	-0.00	0.000	0.199	0.001	0.21	0.000
3	121	0.699	0.002	0.12	0.000	-0.000	-0.000	0.01	0.326	0.092	0.000	-0.00	0.010	0.198	0.001	0.23	0.000
4	119	0.748	-0.000	0.00	0.912	0.058	-0.002	0.00	0.592	0.092	0.000	-0.00	0.010	0.196	0.001	0.23	0.000
5	118	1.382	0.014	0.02	0.136	0.728	0.023	0.05	0.011	0.090	0.000	-0.00	0.010	0.195	0.001	0.26	0.000
6	116	1.921	0.024	0.07	0.004	1.137	0.039	0.18	0.000	0.146	0.000	0.01	0.160	0.200	0.002	0.26	0.000
7	116	2.383	0.004	0.00	0.542	1.191	0.016	0.06	0.008	0.379	0.000	0.01	0.100	0.252	0.003	0.16	0.000
8	120	3.168	0.005	0.01	0.351	1.337	0.012	0.04	0.025	0.966	0.000	0.01	0.070	0.356	0.002	0.07	0.002
9	126	3.547	0.016	0.06	0.005	1.396	0.032	0.19	0.000	1.300	0.000	0.00	0.000	0.401	0.001	0.01	0.186
10	126	3.635	0.023	0.17	0.000	1.435	0.039	0.35	0.000	1.354	0.000	-0.00	0.000	0.410	-0.000	0.00	0.930
11	128	3.670	0.023	0.23	0.000	1.439	0.038	0.46	0.000	1.364	0.000	-0.00	0.000	0.410	0.000	0.00	0.779
12	128	3.673	0.019	0.19	0.000	1.420	0.035	0.46	0.000	1.351	0.000	0.00	0.010	0.424	-0.000	0.00	0.862
13	128	3.671	0.016	0.15	0.000	1.403	0.032	0.44	0.000	1.362	0.000	0.00	0.010	0.405	0.001	0.02	0.146
14	128	3.718	0.013	0.14	0.000	1.463	0.031	0.46	0.000	1.393	0.000	0.00	0.000	0.407	0.000	0.00	0.734
15	128	3.750	0.012	0.14	0.000	1.544	0.029	0.45	0.000	1.396	0.000	-0.00	0.000	0.402	-0.000	0.00	0.906
16	128	3.591	0.013	0.13	0.000	1.576	0.029	0.42	0.000	1.274	0.000	-0.00	0.010	0.368	-0.000	0.01	0.331
17	128	3.102	0.016	0.13	0.000	1.498	0.033	0.42	0.000	0.920	0.000	-0.00	0.020	0.293	0.000	0.00	0.735
18	128	2.629	0.024	0.20	0.000	1.329	0.039	0.38	0.000	0.563	0.000	-0.00	0.000	0.241	0.001	0.02	0.082
19	128	2.319	0.025	0.15	0.000	1.230	0.036	0.29	0.000	0.354	0.000	0.00	0.010	0.214	0.001	0.08	0.001
20	128	2.134	0.017	0.07	0.002	1.124	0.028	0.20	0.000	0.293	0.000	0.00	0.000	0.205	0.001	0.07	0.003
21	128	1.548	-0.015	0.05	0.009	0.611	-0.011	0.04	0.029	0.241	0.000	-0.00	0.000	0.202	0.001	0.09	0.000
22	127	0.851	0.006	0.10	0.000	-0.000	-0.000	0.03	0.037	0.213	0.000	0.00	0.000	0.198	0.001	0.14	0.000
23	128	0.806	0.007	0.10	0.000	0.000	0.000	0.00	0.000	0.179	0.000	0.00	0.010	0.199	0.001	0.11	0.000
24	127	0.759	0.010	0.17	0.000	0.000	-0.000	0.00	0.660	0.135	0.000	0.01	0.050	0.199	0.002	0.21	0.000

Table IV.1a (Continued)

Whole-building and end-use regression statistics for summer for Office #5

Load(W/ft^2)= a+b(T-60)

		Total - HVAC				Other			
		a	b	R^2	Sig.	a	b	R^2	Sig.
Hour	N	(W/ft^2)	(W/ft^2/°F)			(W/ft^2)	(W/ft^2/°F)		
1	124	0.722	0.007	0.19	0.000	0.416	0.002	0.02	0.156
2	122	0.706	0.004	0.15	0.000	0.412	0.002	0.07	0.003
3	121	0.698	0.002	0.12	0.000	0.409	0.002	0.04	0.025
4	119	0.689	0.002	0.08	0.001	0.401	0.002	0.03	0.051
5	118	0.654	-0.010	0.28	0.000	0.368	-0.010	0.35	0.000
6	116	0.784	-0.015	0.31	0.000	0.438	-0.021	0.44	0.000
7	116	1.192	-0.012	0.16	0.000	0.562	-0.020	0.34	0.000
8	120	1.831	-0.007	0.05	0.010	0.509	-0.016	0.28	0.000
9	126	2.150	-0.016	0.24	0.000	0.449	-0.018	0.24	0.000
10	126	2.201	-0.015	0.27	0.000	0.436	-0.015	0.18	0.000
11	128	2.230	-0.016	0.29	0.000	0.456	-0.016	0.21	0.000
12	128	2.253	-0.016	0.31	0.000	0.478	-0.017	0.24	0.000
13	128	2.268	-0.017	0.30	0.000	0.499	-0.019	0.26	0.000
14	128	2.255	-0.017	0.28	0.000	0.455	-0.018	0.22	0.000
15	128	2.206	-0.017	0.26	0.000	0.408	-0.017	0.20	0.000
16	128	2.014	-0.016	0.18	0.000	0.370	-0.012	0.13	0.000
17	128	1.604	-0.017	0.23	0.000	0.385	-0.012	0.12	0.000
18	128	1.300	-0.015	0.24	0.000	0.489	-0.014	0.22	0.000
19	128	1.089	-0.010	0.17	0.000	0.518	-0.014	0.25	0.000
20	128	1.010	-0.011	0.17	0.000	0.511	-0.012	0.19	0.000
21	128	0.937	-0.004	0.04	0.025	0.493	-0.004	0.03	0.046
22	127	0.851	0.006	0.10	0.000	0.442	0.003	0.03	0.055
23	128	0.806	0.007	0.10	0.000	0.428	0.002	0.01	0.237
24	127	0.759	0.010	0.17	0.000	0.426	0.002	0.01	0.193

Table IV.1b
Whole-building and end-use regression statistics for winter for Office #5
Load(W/ft^2)= a+b(T-60)

		Total				HVAC				Light				Plug			
Hour	N	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.
1	121	0.790	0.004	0.02	0.098	0.042	0.005	0.04	0.025	0.128	0.000	-0.00	0.040	0.184	0.000	0.00	0.443
2	121	0.756	0.004	0.04	0.029	0.038	0.004	0.05	0.010	0.111	0.000	-0.00	0.020	0.182	0.001	0.02	0.105
3	121	0.701	0.000	0.00	0.989	-0.000	0.000	0.02	0.156	0.099	0.000	-0.00	0.010	0.181	0.001	0.02	0.091
4	121	0.766	0.004	0.03	0.047	0.071	0.004	0.03	0.067	0.094	0.000	-0.00	0.000	0.181	0.001	0.03	0.071
5	121	1.199	0.020	0.12	0.000	0.514	0.018	0.10	0.001	0.094	0.000	-0.00	0.000	0.181	0.001	0.04	0.037
6	120	1.616	0.029	0.19	0.000	0.896	0.024	0.16	0.000	0.094	0.000	-0.00	0.000	0.180	0.001	0.04	0.039
7	121	2.112	0.043	0.39	0.000	1.145	0.031	0.45	0.000	0.187	0.000	0.01	0.120	0.190	0.001	0.07	0.004
8	121	2.706	0.054	0.42	0.000	1.212	0.032	0.46	0.000	0.606	0.000	0.02	0.190	0.265	0.004	0.18	0.000
9	121	3.277	0.042	0.37	0.000	1.306	0.029	0.39	0.000	1.082	0.000	0.01	0.110	0.333	0.002	0.07	0.004
10	121	3.472	0.031	0.29	0.000	1.355	0.024	0.35	0.000	1.265	0.000	0.00	0.000	0.355	0.001	0.02	0.149
11	121	3.467	0.029	0.27	0.000	1.336	0.024	0.33	0.000	1.290	0.000	0.00	0.000	0.357	0.001	0.03	0.068
12	121	3.412	0.027	0.26	0.000	1.276	0.022	0.34	0.000	1.301	0.000	0.00	0.000	0.360	0.001	0.03	0.048
13	121	3.385	0.024	0.24	0.000	1.256	0.021	0.39	0.000	1.298	0.000	0.00	0.010	0.363	0.001	0.02	0.089
14	121	3.425	0.021	0.21	0.000	1.315	0.018	0.33	0.000	1.313	0.000	0.00	0.010	0.354	0.001	0.02	0.108
15	121	3.452	0.021	0.21	0.000	1.379	0.018	0.31	0.000	1.322	0.000	0.00	0.000	0.354	0.001	0.02	0.109
16	121	3.442	0.021	0.21	0.000	1.416	0.019	0.31	0.000	1.303	0.000	0.00	0.000	0.352	0.001	0.02	0.105
17	121	3.221	0.017	0.13	0.000	1.366	0.018	0.26	0.000	1.201	0.000	-0.00	0.020	0.328	0.000	0.00	0.701
18	121	2.719	0.019	0.15	0.000	1.207	0.019	0.26	0.000	0.907	0.000	-0.00	0.040	0.263	0.000	0.00	0.565
19	121	2.335	0.022	0.24	0.000	1.110	0.020	0.29	0.000	0.594	0.000	-0.00	0.020	0.217	0.001	0.01	0.250
20	121	2.095	0.024	0.30	0.000	1.078	0.020	0.31	0.000	0.367	0.000	0.00	0.000	0.195	0.001	0.02	0.099
21	121	1.690	0.023	0.20	0.000	0.754	0.020	0.18	0.000	0.276	0.000	-0.00	0.000	0.189	0.001	0.02	0.135
22	121	1.162	0.014	0.05	0.016	0.307	0.014	0.04	0.025	0.207	0.000	-0.00	0.010	0.184	0.001	0.01	0.234
23	121	0.804	-0.001	0.01	0.304	0.001	0.000	0.00	0.570	0.183	0.000	-0.00	0.000	0.184	0.001	0.01	0.216
24	121	0.787	-0.001	0.00	0.561	0.001	0.000	0.03	0.066	0.185	0.000	0.00	0.000	0.185	0.001	0.02	0.145

Table IV.1b (Continued)
Whole-building and end-use regression statistics for winter for Office #5
Load(W/ft^2)= a+b(T-60)

		Total - HVAC				Other			
		a	b	R^2	Sig.	a	b	R^2	Sig.
Hour	N	(W/ft^2)	(W/ft^2/°F)			(W/ft^2)	(W/ft^2/°F)		
1	121	0.748	-0.001	0.01	0.314	0.436	0.001	0.01	0.263
2	121	0.718	-0.000	0.00	0.893	0.425	0.000	0.00	0.636
3	121	0.700	0.000	0.00	0.997	0.420	-0.000	0.00	0.802
4	121	0.695	0.001	0.01	0.248	0.420	0.000	0.00	0.923
5	121	0.685	0.002	0.05	0.011	0.410	0.002	0.03	0.070
6	120	0.720	0.005	0.08	0.002	0.445	0.004	0.06	0.008
7	121	0.968	0.012	0.15	0.000	0.590	0.006	0.07	0.002
8	121	1.494	0.021	0.23	0.000	0.623	0.001	0.00	0.534
9	121	1.971	0.013	0.14	0.000	0.558	0.003	0.02	0.092
10	121	2.117	0.007	0.06	0.006	0.499	0.004	0.05	0.010
11	121	2.131	0.005	0.03	0.048	0.486	0.003	0.02	0.115
12	121	2.136	0.005	0.03	0.068	0.475	0.002	0.01	0.263
13	121	2.128	0.003	0.01	0.226	0.468	0.000	0.00	0.926
14	121	2.109	0.003	0.01	0.256	0.444	0.000	0.00	0.845
15	121	2.073	0.003	0.01	0.191	0.398	0.001	0.00	0.557
16	121	2.026	0.002	0.01	0.330	0.373	0.001	0.00	0.614
17	121	1.855	-0.001	0.00	0.672	0.325	0.002	0.01	0.342
18	121	1.512	-0.000	0.00	0.915	0.342	0.004	0.03	0.054
19	121	1.225	0.002	0.01	0.243	0.414	0.004	0.05	0.018
20	121	1.018	0.004	0.04	0.024	0.456	0.002	0.02	0.177
21	121	0.936	0.003	0.03	0.056	0.471	0.003	0.02	0.097
22	121	0.855	0.001	0.00	0.546	0.464	0.001	0.01	0.424
23	121	0.804	-0.001	0.01	0.284	0.435	-0.001	0.01	0.226
24	121	0.787	-0.001	0.00	0.497	0.415	-0.002	0.01	0.184

Table IV.2

Whole-building and end-use regression statistics for the year excluding days 19-96 for Retail #1

Load(W/ft^2)=a+b(T-60)

		Total				HVAC				Light				Total - HVAC - Light			
Hour	N	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.	a (W/ft^2)	b (W/ft^2/°F)	R^2	Sig.
1	99	0.166	0.000	0.00	0.797	0.021	-0.001	0.04	0.041	0.112	0.001	0.04	0.058	0.033	-0.00030	0.07	0.008
2	94	0.166	0.000	0.00	0.775	0.018	-0.003	0.26	0.000	0.115	0.001	0.02	0.149	0.034	-0.00035	0.13	0.000
3	85	0.167	0.000	0.00	0.935	0.018	-0.000	0.26	0.000	0.117	0.001	0.02	0.237	0.033	-0.00034	0.13	0.001
4	78	0.166	-0.000	0.00	0.946	0.017	-0.000	0.19	0.000	0.117	0.000	0.01	0.430	0.033	-0.00028	0.08	0.011
5	76	0.186	-0.002	0.00	0.584	0.017	-0.000	0.18	0.000	0.137	-0.001	0.00	0.701	0.033	-0.00030	0.10	0.006
6	73	0.232	-0.007	0.02	0.286	0.022	0.000	0.00	0.960	0.175	-0.006	0.02	0.297	0.035	-0.00052	0.13	0.002
7	73	0.473	-0.003	0.00	0.848	0.154	-0.006	0.01	0.304	0.290	0.003	0.00	0.789	0.030	-0.00010	0.00	0.632
8	83	1.594	0.056	0.22	0.000	0.363	0.033	0.16	0.000	1.199	0.023	0.06	0.020	0.031	-0.00028	0.03	0.099
9	115	2.160	0.083	0.62	0.000	0.505	0.083	0.63	0.000	1.629	0.001	0.01	0.339	0.026	-0.00053	0.39	0.000
10	134	2.180	0.054	0.52	0.000	0.519	0.054	0.54	0.000	1.635	0.000	0.00	0.930	0.026	-0.00028	0.22	0.000
11	162	2.208	0.047	0.55	0.000	0.544	0.047	0.57	0.000	1.638	-0.000	0.00	0.782	0.025	-0.00026	0.22	0.000
12	170	2.167	0.047	0.59	0.000	0.501	0.048	0.60	0.000	1.641	-0.000	0.00	0.531	0.026	-0.00026	0.23	0.000
13	175	2.130	0.047	0.65	0.000	0.458	0.047	0.65	0.000	1.646	-0.000	0.01	0.122	0.025	-0.00025	0.27	0.000
14	180	2.096	0.047	0.71	0.000	0.421	0.048	0.72	0.000	1.649	-0.001	0.02	0.045	0.026	-0.00030	0.45	0.000
15	180	2.024	0.049	0.73	0.000	0.345	0.050	0.73	0.000	1.653	-0.001	0.03	0.030	0.027	-0.00030	0.40	0.000
16	180	1.990	0.051	0.76	0.000	0.310	0.052	0.76	0.000	1.653	-0.001	0.02	0.049	0.027	-0.00030	0.45	0.000
17	179	1.974	0.052	0.77	0.000	0.288	0.053	0.78	0.000	1.653	-0.001	0.02	0.052	0.033	-0.00049	0.31	0.000
18	173	1.983	0.053	0.73	0.000	0.268	0.055	0.75	0.000	1.651	-0.001	0.00	0.448	0.064	-0.00175	0.30	0.000
19	165	2.033	0.053	0.59	0.000	0.321	0.055	0.71	0.000	1.637	-0.000	0.00	0.810	0.074	-0.00219	0.40	0.000
20	157	2.123	0.052	0.55	0.000	0.411	0.053	0.68	0.000	1.631	-0.001	0.00	0.814	0.080	-0.00045	0.41	0.000
21	147	1.954	0.070	0.55	0.000	0.374	0.064	0.63	0.000	1.500	0.006	0.03	0.055	0.079	-0.00032	0.17	0.000
22	138	0.628	0.051	0.16	0.000	0.146	0.051	0.32	0.000	0.402	0.001	0.00	0.942	0.080	-0.00070	0.15	0.000
23	127	0.261	-0.002	0.00	0.571	0.028	-0.001	0.01	0.238	0.166	-0.002	0.00	0.464	0.067	0.00101	0.06	0.004
24	109	0.186	0.000	0.00	0.965	0.022	-0.001	0.02	0.133	0.126	0.001	0.00	0.770	0.038	-0.00015	0.01	0.426

We do not understand why there is not any apparent weather dependency for the Other end use during the winter. Also, it is not clear why the Other end use is showing higher nighttime intensities during the winter. We are not yet aware of end uses, other than HVAC, with a strong temperature correlation. Future studies determining the weather dependency of all end uses, using measured and synthetic data, must be conducted to better answer these questions and validate these assumptions.

Assuming that the Other load is an unmeasured HVAC load, our hypothesis has not been contradicted. Thus, given the uncertainties in the measured data, the analysis of the measured end-use data for these two buildings generally indicate that the temperature-dependency of the whole-building load is the same as that of the HVAC load.

Is the significance of the whole-building-load temperature correlation a valid indicator for the operating schedules of the HVAC systems?

The regression of the hourly whole-building load against the dry-bulb temperature, in addition to the regression coefficients, provides information about the significance of the correlation. The significance of a correlation is given as the probability that the obtained correlation is the result of statistical errors. A significance of 0.0001 indicates that a probability of 99.99% exists that the correlation is valid.

One of the uncertainties in the analysis of building energy use is usually the schedules of operation of the building and its systems. Scheduling information is usually obtained from the on-site survey of the building. Yet the analysis of the measured building data usually indicates a significant difference between actual and surveyed schedules.

For example, the whole-building load and the HVAC load for the office building show significant correlations with outdoor temperature during the hours 9 to 20 (the hours where correlation coefficients are clearly non-zero). The HVAC loads during the shoulder hours of 6, 7, 8, and 21 do not show significant temperature correlations for either load. All other end uses do not show any significant temperature dependency except the Other end use. It shows significant correlations between the hours of 5 to 20.

For the office during the winter, the hours of the significant temperature correlations for whole-building load and HVAC load are the same. The retail store data also show that the hours of significant correlations for the whole-building load and the HVAC load are the same.

The regression of the hourly whole-building load against outdoor temperature provides a fairly accurate tool to estimate, on the average, the temperature-dependency of the HVAC load.

It also provides an indicator for modifying the audit estimates for the operating hours of the HVAC systems. During the shoulder hours, outdoor temperature alone will not provide an accurate estimate of the hours of HVAC operation. For these shoulder hours, other indicators should be developed.

Can we improve the load-temperature regressions statistics?

Although the regressions of the hourly whole-building load provide strong statistical correlations, the R^2 values are in general low. For the office building the R^2s vary from 0.12 to 0.42; the lower R^2s usually correspond to shoulder hours. There are in general two ways to improve the load-temperature statistics; by performing regression analyses on a selected period of the year (winter vs summer vs yearly regressions) and by performing regression analyses on data for larger time intervals (using daily or weekly data).

In general, the R^2 values for the entire year are better than those for summer and for winter. Two factors explain the better yearly regression statistics; more data points and a larger, seasonal temperature range. In some cases, however, the changes in the seasonal operations of a building may result in different correlations between HVAC energy use and outdoor temperature. In such cases, one needs to review both seasonal and annual statistics of the data before deciding on the type of correlations to be used for EDA simulations.

Integrating hourly data into daily data will substantially improve the regression statistics. Table III.6 and III.13 (of Chapter III) show the statistics of the daily, whole-building load for standard day operations regressed against average daily drybulb and wetbulb temperature. As expected, the annual R^2 improved significantly. The R^2 for the office building during the summer did not improve as much as the others. This is mainly due to the smaller range of average daily temperature which occur during the summer and the fact that the air conditioner operation exhibited little temperature dependence since it was operating near full capacity during the summer.

Hence, one way to improve the EDA prediction may be to estimate the weather dependency of the whole-building load at the daily level. With the daily load defined, an algorithm can be developed, based on hourly temperatures and the operating schedules of the HVAC system, to distribute the daily load into hourly loads. The details of such an algorithm have yet to be designed.

Components of the Non-Temperature-Dependent Load

Once the temperature-dependent part of the load is separated from the whole-building load, the remaining components include non-temperature-dependent HVAC, lighting, equipment, miscellaneous, refrigeration, and possibly other loads. We rely on three sources of data to disaggregate the non-temperature-dependent base load into its components:

1. audit estimates of the building and equipment energy intensity, characteristics, and operation;
2. DOE-2 simulation of the building; and
3. simplified engineering analysis.

In the following section, we discuss the various methods for base-load disaggregation in further detail.

How can we estimate the air-conditioning load at a base temperature from the analysis of the whole-building load?

We cannot accurately estimate the baseload, air-conditioning electricity use from the analysis of the whole-building load alone. In order to analyze the base load, we need to understand the contribution of each HVAC system component to the HVAC electricity use. During cooling, the two major components contributing to the HVAC energy use are the compressor and the ventilation fan. Assuming that we have separated the weather-dependent part of the whole-building load, we need to find correlations between the base-temperature HVAC load and the other loads in the building.

DOE-2 simulations of the building and its systems provide an estimate of the HVAC electricity use at a base temperature. Simulations require extensive information on the building and its HVAC system. Instead of DOE-2 simulations, one may also rely on simplified default values for the air-conditioning and ventilation electricity use. The fraction of the energy used by the HVAC system is primarily a function of HVAC type and its operation schedules. In order to develop default tables for estimating the HVAC contribution at the base temperature, one would need to review and analyze significant quantities of measured end-use data and condense the results of the analysis into simplified default values. The same rules also apply to estimating the electricity use for other end uses such as lighting and equipment. Currently, this information is supplied by the audit.

Tables IV.3a, IV.3b, and IV.4 show the hourly electricity use by end use at the base 60°F temperature as a fraction of whole-building electricity use for the office and the retail building. For the office building during the hours 9 to 16, the HVAC electricity use is 38% to 44% of the whole-building electricity use at the base temperature 60°F. In the retail store, the HVAC contribution to the whole-building electricity use at base temperature is 20% to 25% (hours 9 to 14). These tables indicate that the whole-building-load temperature regressions alone cannot provide a good estimate of the air-conditioning load at the base temperature. One must rely on other sources (DOE-2 simulations or hourly rules-of-thumbs) for estimating the air-conditioning electricity use at the base temperature.

Can we estimate the non-HVAC end uses from the analysis of whole-building data?

In a majority of building types, chillers and air-handling systems are usually operated together during cooling. Hence, their presence can be identified from the regressions of the whole-building load. If the whole-building energy use data showed some hours with no significant correlation to temperature (usually nighttime hours), it can be assumed that the energy use for those hours are for non-HVAC end uses.

"Permissible" Hourly End-use Load Variations

One key factor in estimating end-use load shapes is the hour to hour variation of the end use load during normal operation of the building and systems. Even though abrupt hourly variations of the end-use loads are possible during the normal operation of the building, we expect these variations to be fairly smooth and , hence constraint our estimates to be smooth. In order to test this hypothesis, we performed statistical analyses for the normalized whole-building load and normalized end-use loads. The hourly loads for each day were normalized by dividing them by the maximum hourly value for that day. The variation of the mean hourly end-use values over the day were compared as well as the standard deviation of the values for a particular hour of day over the analysis period. The results are presented in **Tables IV.5 and IV.6.**

For the retail store, the mean lighting electricity use between the hours 9 to 20 varies from 0.98 to 0.99 of the maximum daily use . This corresponds to about 1% variation in the hourly lighting load. The standard deviation of the normalized hourly load for hours 9 to 18 is about 4%; for hours 19 and 20, it is 10%. The mean HVAC electricity use varies between 0.64 to 0.93 during hours 9 to 20. The maximum hourly variation of the load is about 15% (changes between hours 10 to 11 and 19 to 20). The standard deviations for HVAC energy use are much larger

Table IV.3a
Summary statisitics by end use for summer (May 1 to October 31) for Office #5
Total(W/ft^2)=a+b(T-60); End-use(W/ft^2)=a(a')+b(T-60)

		Total		HVAC		Light		Plug	
Hour	N	a (W/ft^2)	b ($W/ft^2/°F$)	a'	b ($W/ft^2/°F$)	a'	b ($W/ft^2/°F$)	a'	b ($W/ft^2/°F$)
1	124	0.722	0.007	-0.000	0.000	0.147	0.000	0.276	0.001
2	122	0.706	0.004	0.000	-0.000	0.133	0.000	0.282	0.001
3	121	0.699	0.002	-0.000	-0.000	0.132	0.000	0.283	0.001
4	119	0.748	-0.000	0.078	-0.002	0.123	0.000	0.262	0.001
5	118	1.382	0.014	0.527	0.023	0.065	0.000	0.141	0.001
6	116	1.921	0.024	0.592	0.039	0.076	0.000	0.104	0.002
7	116	2.383	0.004	0.500	0.016	0.159	0.000	0.106	0.003
8	120	3.168	0.005	0.422	0.012	0.305	0.000	0.112	0.002
9	126	3.547	0.016	0.394	0.032	0.367	0.000	0.113	0.001
10	126	3.635	0.023	0.395	0.039	0.372	0.000	0.113	-0.000
11	128	3.670	0.023	0.392	0.038	0.372	0.000	0.112	0.000
12	128	3.673	0.019	0.387	0.035	0.368	0.000	0.115	-0.000
13	128	3.671	0.016	0.382	0.032	0.371	0.000	0.110	0.001
14	128	3.718	0.013	0.393	0.031	0.375	0.000	0.109	0.000
15	128	3.750	0.012	0.412	0.029	0.372	0.000	0.107	-0.000
16	128	3.591	0.013	0.439	0.029	0.355	0.000	0.102	-0.000
17	128	3.102	0.016	0.483	0.033	0.297	0.000	0.094	0.000
18	128	2.629	0.024	0.506	0.039	0.214	0.000	0.092	0.001
19	128	2.319	0.025	0.530	0.036	0.153	0.000	0.092	0.001
20	128	2.134	0.017	0.527	0.028	0.137	0.000	0.096	0.001
21	128	1.548	-0.015	0.395	-0.011	0.156	0.000	0.130	0.001
22	127	0.851	0.006	-0.000	-0.000	0.250	0.000	0.233	0.001
23	128	0.806	0.007	0.000	0.000	0.222	0.000	0.247	0.001
24	127	0.759	0.010	0.000	-0.000	0.178	0.000	0.262	0.002

Table IV.3b

Summary statisitics by end use for winter (Nov 1 to April 30) for Office #5

Total(W/ft^2)=a+b(T-60); End-use(W/ft^2)=a(a')+b(T-60)

		Total		HVAC		Light		Plug	
		a	b	a'	b	a'	b	a'	b
Hour	N	(W/ft^2)	(W/ft^2/°F)		(W/ft^2/°F)		(W/ft^2/°F)		(W/ft^2/°F)
1	121	0.790	0.004	0.053	0.005	0.162	0.000	0.233	0.000
2	121	0.756	0.004	0.050	0.004	0.147	0.000	0.241	0.001
3	121	0.701	0.000	-0.000	0.000	0.141	0.000	0.258	0.001
4	121	0.766	0.004	0.093	0.004	0.123	0.000	0.236	0.001
5	121	1.199	0.020	0.429	0.018	0.078	0.000	0.151	0.001
6	120	1.616	0.029	0.554	0.024	0.058	0.000	0.111	0.001
7	121	2.112	0.043	0.542	0.031	0.089	0.000	0.090	0.001
8	121	2.706	0.054	0.448	0.032	0.224	0.000	0.098	0.004
9	121	3.277	0.042	0.399	0.029	0.330	0.000	0.102	0.002
10	121	3.472	0.031	0.390	0.024	0.364	0.000	0.102	0.001
11	121	3.467	0.029	0.385	0.024	0.372	0.000	0.103	0.001
12	121	3.412	0.027	0.374	0.022	0.381	0.000	0.106	0.001
13	121	3.385	0.024	0.371	0.021	0.383	0.000	0.107	0.001
14	121	3.425	0.021	0.384	0.018	0.383	0.000	0.103	0.001
15	121	3.452	0.021	0.399	0.018	0.383	0.000	0.103	0.001
16	121	3.442	0.021	0.411	0.019	0.379	0.000	0.102	0.001
17	121	3.221	0.017	0.424	0.018	0.373	0.000	0.102	0.000
18	121	2.719	0.019	0.444	0.019	0.334	0.000	0.097	0.000
19	121	2.335	0.022	0.475	0.020	0.254	0.000	0.093	0.001
20	121	2.095	0.024	0.515	0.020	0.175	0.000	0.093	0.001
21	121	1.690	0.023	0.446	0.020	0.163	0.000	0.112	0.001
22	121	1.162	0.014	0.264	0.014	0.178	0.000	0.158	0.001
23	121	0.804	-0.001	0.001	0.000	0.228	0.000	0.229	0.001
24	121	0.787	-0.001	0.001	0.000	0.235	0.000	0.235	0.001

Table IV.4

Yearly summary statistics by end use excluding days 19-96 for Retail #1

Total(W/ft^2)=a+b*(T-60); End-use(W/ft^2)=a*a'+b*(T-60)

Hour	N	Total a (W/ft^2)	Total b (W/ft^2/°F)	HVAC a'	HVAC b (W/ft^2/°F)	Light a'	Light b (W/ft^2/°F)	Total - HVAC - Light a'	Total - HVAC - Light b (W/ft^2/°F)
1	99	0.166	0.000	0.127	-0.001	0.675	0.001	0.199	-0.000
2	94	0.166	0.000	0.108	-0.003	0.693	0.001	0.205	-0.000
3	85	0.167	0.000	0.108	-0.000	0.701	0.001	0.198	-0.000
4	78	0.166	-0.000	0.102	-0.000	0.705	0.000	0.199	-0.000
5	76	0.186	-0.002	0.091	-0.000	0.737	-0.001	0.177	-0.000
6	73	0.232	-0.007	0.095	0.000	0.754	-0.006	0.151	-0.001
7	73	0.473	-0.003	0.326	-0.006	0.613	0.003	0.063	-0.000
8	83	1.594	0.056	0.228	0.033	0.752	0.023	0.019	-0.000
9	115	2.160	0.083	0.234	0.083	0.754	0.001	0.012	-0.001
10	134	2.180	0.054	0.238	0.054	0.750	0.000	0.012	-0.000
11	162	2.208	0.047	0.246	0.047	0.742	-0.000	0.011	-0.000
12	170	2.167	0.047	0.231	0.048	0.757	-0.000	0.012	-0.000
13	175	2.130	0.047	0.215	0.047	0.773	-0.000	0.012	-0.000
14	180	2.096	0.047	0.201	0.048	0.787	-0.001	0.012	-0.000
15	180	2.024	0.049	0.170	0.050	0.817	-0.001	0.013	-0.000
16	180	1.990	0.051	0.156	0.052	0.831	-0.001	0.014	-0.000
17	179	1.974	0.052	0.146	0.053	0.837	-0.001	0.017	-0.000
18	173	1.983	0.053	0.135	0.055	0.833	-0.001	0.032	-0.002
19	165	2.033	0.053	0.158	0.055	0.805	-0.000	0.036	-0.002
20	157	2.123	0.052	0.194	0.053	0.768	-0.001	0.038	-0.000
21	147	1.954	0.070	0.191	0.064	0.768	0.006	0.040	-0.000
22	138	0.628	0.051	0.232	0.051	0.640	0.001	0.127	-0.001
23	127	0.261	-0.002	0.107	-0.001	0.636	-0.002	0.257	0.001
24	109	0.186	0.000	0.118	-0.001	0.677	0.001	0.204	-0.000

Table IV.5
Normalized, weekday, hourly end-use loads for the year for Office #5

		Total				HVAC				Light				Plug			
Hour	N	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.
1	120	0.166	0.511	0.196	0.040	0.000	0.734	0.006	0.067	0.044	0.435	0.089	0.060	0.411	0.929	0.478	0.053
2	106	0.164	0.529	0.189	0.042	0.000	0.754	0.007	0.073	0.042	0.432	0.068	0.044	0.415	0.914	0.474	0.054
3	101	0.163	0.206	0.180	0.008	0.000	0.001	0.000	0.000	0.043	0.168	0.061	0.023	0.401	0.577	0.467	0.034
4	97	0.163	0.522	0.196	0.061	0.000	0.777	0.040	0.129	0.043	0.235	0.062	0.028	0.410	0.580	0.465	0.033
5	91	0.180	0.644	0.363	0.106	0.000	0.962	0.417	0.232	0.042	0.130	0.061	0.021	0.397	0.547	0.461	0.033
6	93	0.229	0.653	0.500	0.091	0.006	0.970	0.644	0.192	0.047	0.207	0.107	0.040	0.396	0.563	0.473	0.034
7	90	0.387	0.754	0.601	0.069	0.259	0.958	0.647	0.126	0.047	0.463	0.262	0.069	0.437	0.756	0.591	0.068
8	106	0.538	0.918	0.797	0.071	0.480	0.964	0.718	0.123	0.174	0.821	0.672	0.123	0.510	0.976	0.827	0.086
9	134	0.775	0.998	0.914	0.057	0.511	0.988	0.808	0.132	0.655	0.996	0.907	0.067	0.729	1.000	0.934	0.055
10	156	0.821	1.000	0.959	0.042	0.572	1.000	0.883	0.110	0.849	1.000	0.951	0.032	0.596	1.000	0.947	0.045
11	192	0.689	1.000	0.973	0.040	0.000	1.000	0.911	0.111	0.550	1.000	0.957	0.041	0.573	1.000	0.953	0.043
12	205	0.708	1.000	0.970	0.041	0.000	1.000	0.896	0.126	0.780	1.000	0.963	0.029	0.606	1.000	0.977	0.035
13	213	0.779	1.000	0.967	0.032	0.000	1.000	0.891	0.105	0.788	1.000	0.969	0.027	0.831	1.000	0.969	0.031
14	219	0.812	1.000	0.977	0.025	0.584	1.000	0.929	0.064	0.901	1.000	0.983	0.019	0.847	1.000	0.955	0.035
15	220	0.824	1.000	0.985	0.022	0.000	1.000	0.965	0.081	0.768	1.000	0.983	0.029	0.790	1.000	0.945	0.045
16	220	0.866	1.000	0.961	0.030	0.000	1.000	0.980	0.075	0.664	1.000	0.916	0.072	0.696	1.000	0.893	0.079
17	215	0.701	0.978	0.860	0.058	0.000	1.000	0.944	0.094	0.389	1.000	0.723	0.163	0.578	0.997	0.763	0.121
18	204	0.531	1.000	0.738	0.058	0.000	0.997	0.855	0.149	0.201	1.000	0.491	0.169	0.463	1.000	0.622	0.093
19	187	0.452	0.761	0.641	0.060	0.374	0.980	0.773	0.138	0.115	0.635	0.315	0.113	0.417	0.714	0.535	0.057
20	178	0.402	0.710	0.570	0.052	0.325	0.977	0.682	0.120	0.090	0.432	0.227	0.070	0.409	0.636	0.497	0.042
21	165	0.271	0.691	0.394	0.073	0.062	0.951	0.337	0.163	0.060	0.339	0.173	0.056	0.409	0.609	0.485	0.036
22	154	0.185	0.587	0.244	0.072	0.000	0.811	0.045	0.159	0.054	0.344	0.154	0.052	0.407	0.571	0.476	0.032
23	147	0.172	0.295	0.212	0.022	0.000	0.024	0.000	0.002	0.045	0.433	0.137	0.068	0.413	0.615	0.477	0.035
24	134	0.171	0.328	0.204	0.022	0.000	0.025	0.000	0.002	0.044	0.479	0.116	0.076	0.409	0.569	0.477	0.033

Table IV.6
Weekday, normalized, hourly end-use loads for the year excluding days 19-96 for Retail #1

		Total				HVAC				Light			
Hour	N	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.
1	99	0.03	0.08	0.05	0.01	0.01	0.10	0.01	0.01	0.04	0.09	0.07	0.01
2	94	0.03	0.08	0.05	0.01	0.01	0.03	0.01	0.01	0.04	0.09	0.07	0.01
3	85	0.03	0.08	0.05	0.01	0.01	0.03	0.01	0.01	0.04	0.09	0.07	0.01
4	78	0.03	0.08	0.05	0.01	0.01	0.03	0.01	0.01	0.04	0.09	0.07	0.01
5	76	0.03	0.32	0.06	0.03	0.01	0.02	0.01	0.00	0.04	0.61	0.08	0.06
6	73	0.03	0.49	0.06	0.06	0.01	0.19	0.01	0.02	0.04	0.95	0.09	0.11
7	73	0.03	0.56	0.14	0.12	0.01	0.42	0.08	0.10	0.04	0.98	0.18	0.22
8	83	0.23	0.85	0.57	0.12	0.01	0.82	0.33	0.18	0.06	1.00	0.79	0.21
9	115	0.50	1.00	0.83	0.09	0.02	1.00	0.63	0.20	0.64	1.00	0.99	0.04
10	134	0.56	0.98	0.84	0.07	0.02	0.96	0.64	0.15	0.63	1.00	0.99	0.03
11	162	0.59	1.00	0.89	0.07	0.02	1.00	0.74	0.16	0.64	1.00	0.99	0.03
12	170	0.66	1.00	0.93	0.06	0.02	1.00	0.82	0.15	0.72	1.00	0.99	0.02
13	175	0.64	1.00	0.95	0.05	0.17	1.00	0.89	0.13	0.96	1.00	0.99	0.01
14	180	0.79	1.00	0.97	0.04	0.43	1.00	0.93	0.10	0.97	1.00	0.99	0.01
15	180	0.66	1.00	0.97	0.04	0.21	1.00	0.93	0.11	0.97	1.00	0.99	0.01
16	180	0.74	1.00	0.97	0.04	0.42	1.00	0.91	0.11	0.97	1.00	0.99	0.01
17	179	0.78	1.00	0.94	0.05	0.45	1.00	0.85	0.12	0.98	1.00	0.99	0.01
18	173	0.62	1.00	0.91	0.06	0.03	1.00	0.77	0.16	0.43	1.00	0.99	0.04
19	165	0.32	1.00	0.88	0.09	0.04	0.97	0.70	0.16	0.08	1.00	0.98	0.10
20	157	0.29	1.00	0.86	0.09	0.03	0.95	0.64	0.14	0.08	1.00	0.98	0.10
21	147	0.20	1.00	0.80	0.10	0.07	0.96	0.56	0.17	0.08	1.00	0.93	0.12
22	138	0.07	0.80	0.29	0.19	0.01	0.74	0.28	0.24	0.04	1.00	0.24	0.26
23	127	0.04	0.52	0.08	0.06	0.01	0.40	0.02	0.04	0.04	0.95	0.09	0.10
24	109	0.03	0.42	0.06	0.04	0.01	0.15	0.02	0.02	0.04	0.79	0.08	0.07

than the other end uses, typically 10 to 15% during daytime and up to 25% during the early morning and early evening hours. The mean whole-building load for hours 9 to 20 varies between 0.83 to 0.97 with typical standard deviations from 4% to 9%.

For the office building, the mean lighting load between the hours 9 to 16 varies from 0.92 to 0.98 (about an 8% variation) with standard deviations ranging from 2 to 7%. The normalized plug load for the same hours varies from 0.89 to 0.98 (about 11% variation) with slightly larger standard deviations. The mean values for the HVAC system has about the same variation as the lighting and plug loads but with standard deviations in the range of 7% to 13%. Also, the office whole-building load for the same hours, is fairly flat; varying only from 0.91 to 0.98 with fairly small standard deviations.

This analysis of the two buildings indicates that most variations in the whole-building hourly load are typically caused by HVAC systems. Furthermore, the operations of the lighting, plug, and other end uses, on the average, seem to be fairly smooth.

We use this information in EDA to smooth out any abnormal variations in the estimated hourly, non-HVAC, end-use loads. These variations mainly occur during the shoulder hours, when there is a mismatch between the auditor's estimate of the operation of the building and that indicated by the measured whole-building load.

Recommendation

With the above background information, we see three general directions for improving the performance of EDA. The first improvement concerns integrating the hourly and daily regressions. Using the daily regressions enables us to obtain more robust estimates of the temperature-dependent HVAC electricity use by the day. Then with the help of the hourly regressions, we can distribute the daily electricity use to hours of the day. We have yet to design such an algorithm.

A second area for improving the performance of EDA concerns the initial estimates of the non-temperature dependent end uses (both HVAC and non-HVAC end uses). Currently, we rely on simulations based on audit information for estimating the non-temperature dependent end uses. Our analysis has indicated that both simulations and auditor's estimates can be grossly different from what measured data suggest. Utilities have collected end-use data that can be analyzed to provide information on the contribution of non-temperature dependent end uses to the whole-building load. To improve our estimates of the non-temperature-dependent end uses, we recommend analysis of *all* available measured end-use data and condensing the results of the analysis into look-up tables that can be used as initial estimates in EDA applications.

Finally, EDA, in its present form, cannot be applied to buildings that have extensive refrigeration, load-shaping technologies (thermal energy storage system and daylighting), coincident electric cooling and heating loads, erratic load shapes, or unreliable schedules. Although extending EDA to some of these applications may be fairly straightforward, completing such a task should be considered in future EDA development.

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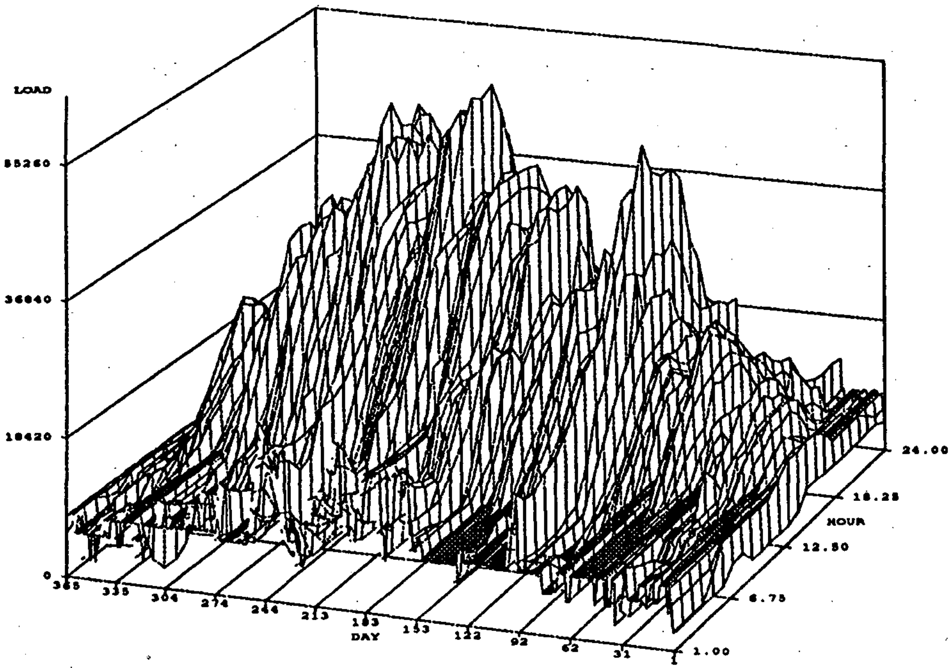
Appendix A

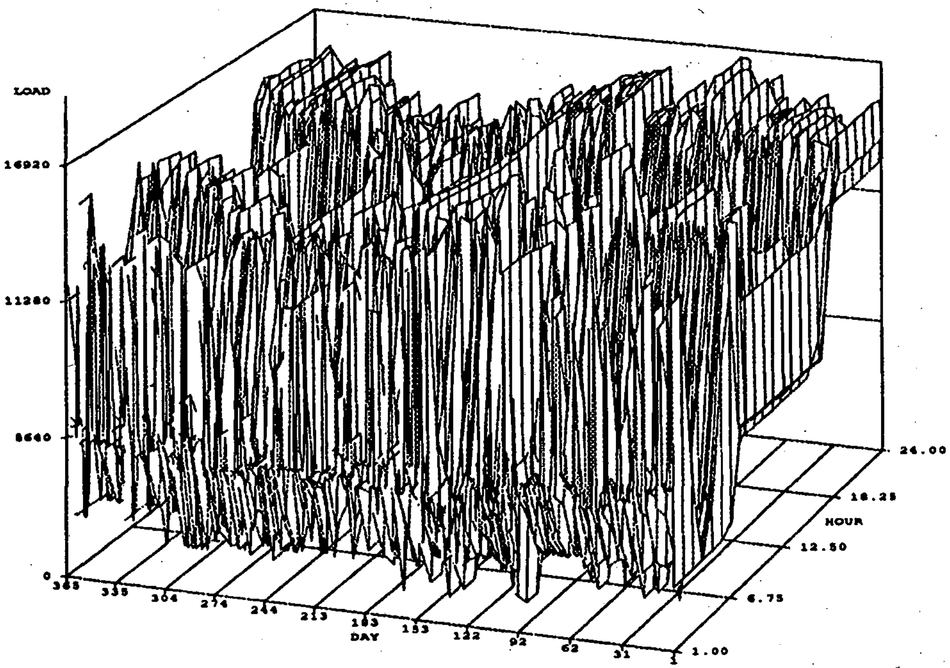
3-D Plots of Metered Data

For a quick visual check of the SCE monitored data for the 53 commercial buildings, we have generated three dimensional plots of the hourly data. The total building metered electricity and the monitored end uses are shown. Since monitoring started in June of 1989 and ended in May of 1990, there may appear to be discontinuities in the data since we have wrapped the values to create one complete calender year.

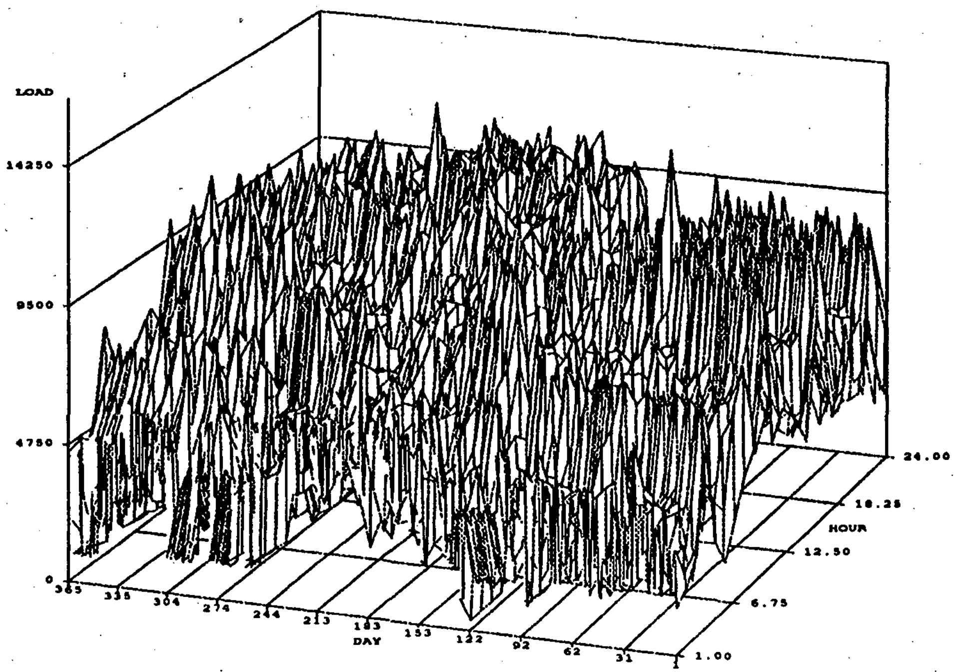
Fastfood Restaurant 6 HVAC



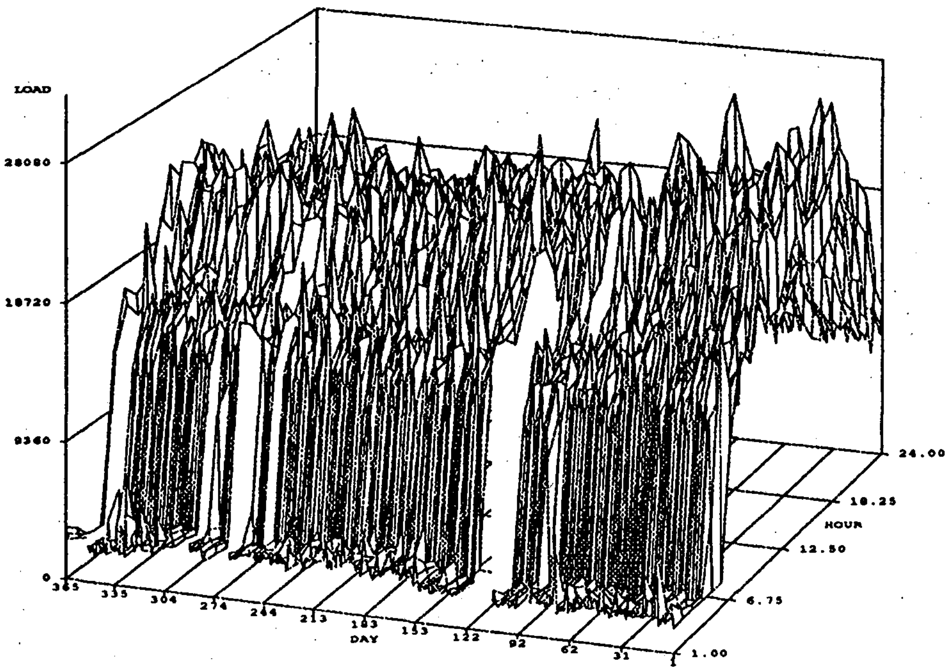
Fastfood Restaurant 6 Lighting



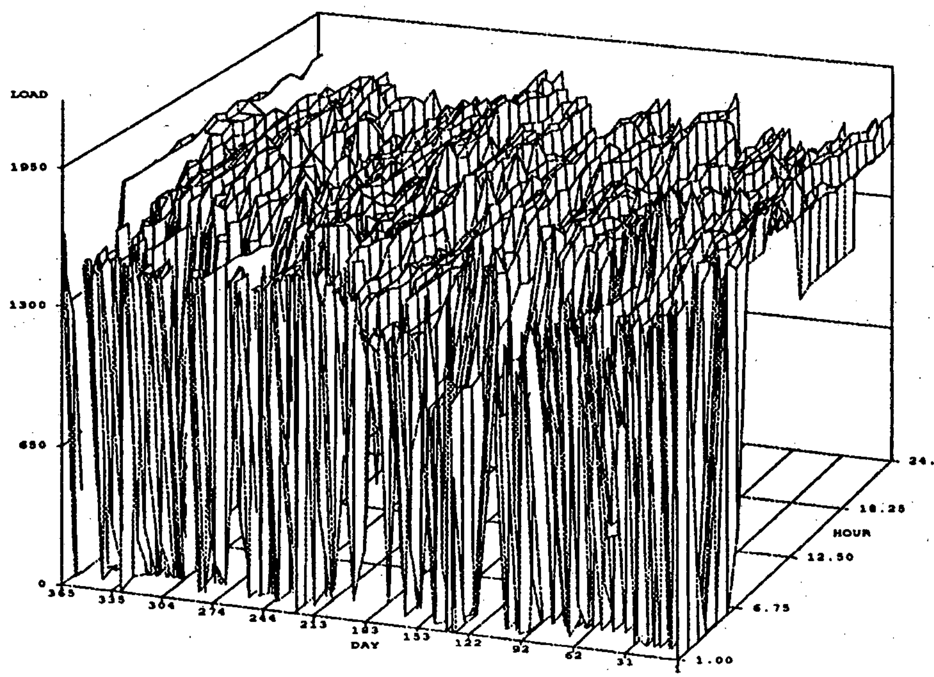
Fastfood Restaurant 6 Refrigeration



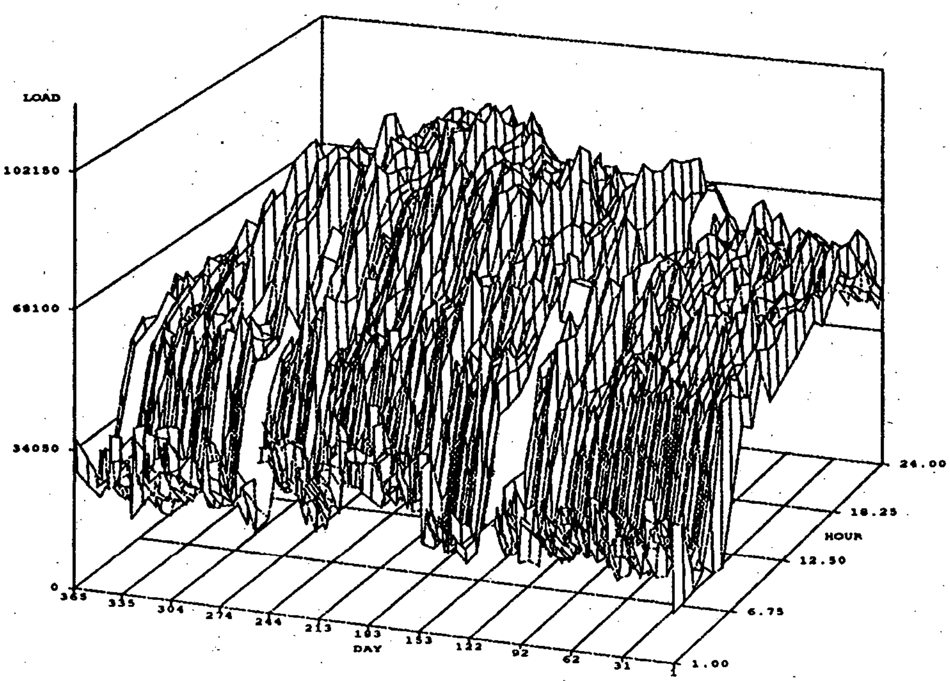
Fastfood Restaurant 6 Cooking



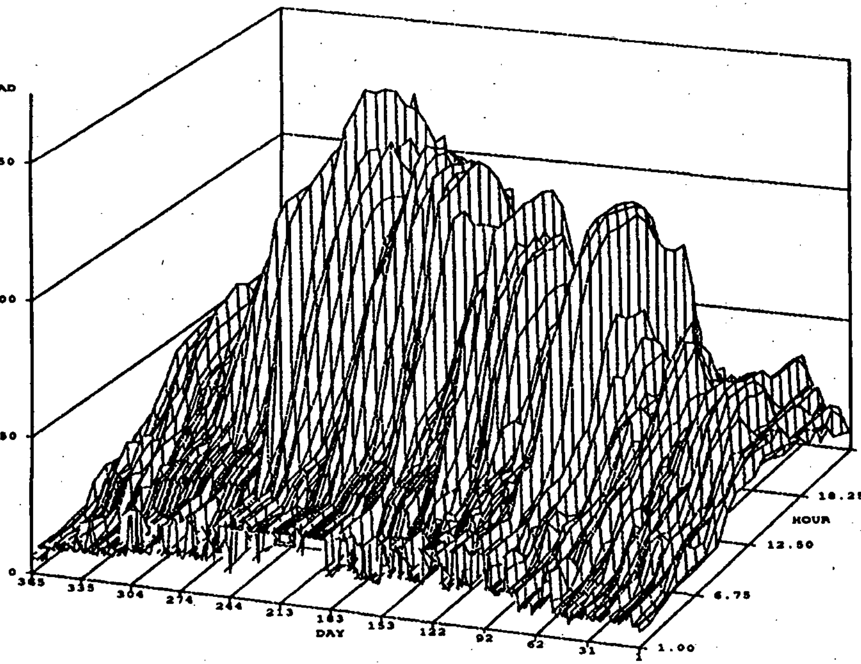
Fastfood Restaurant 6 Exhaust Fan



Fastfood Restaurant 6 Total



Fastfood Restaurant 7 HVAC



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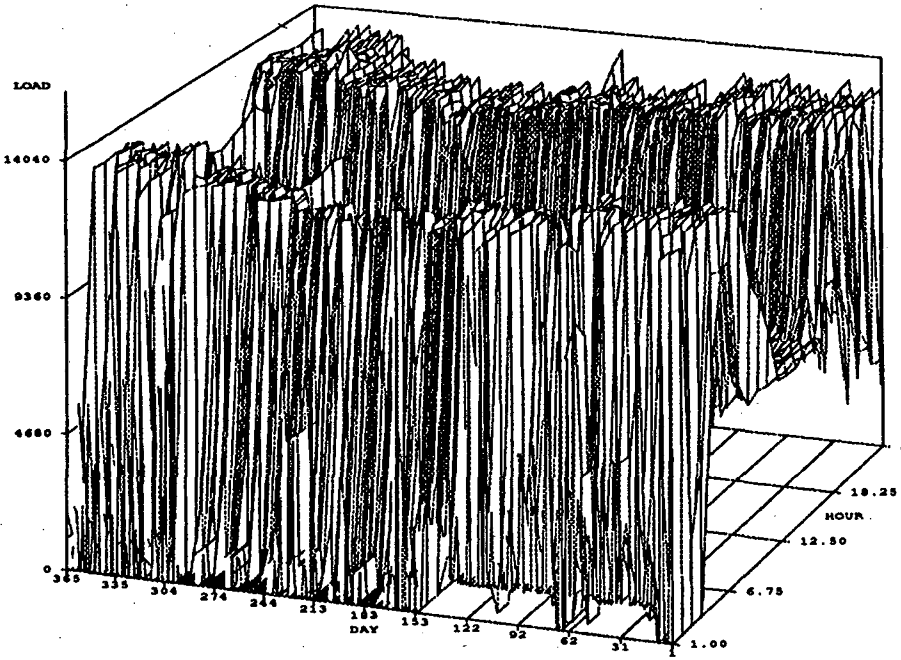

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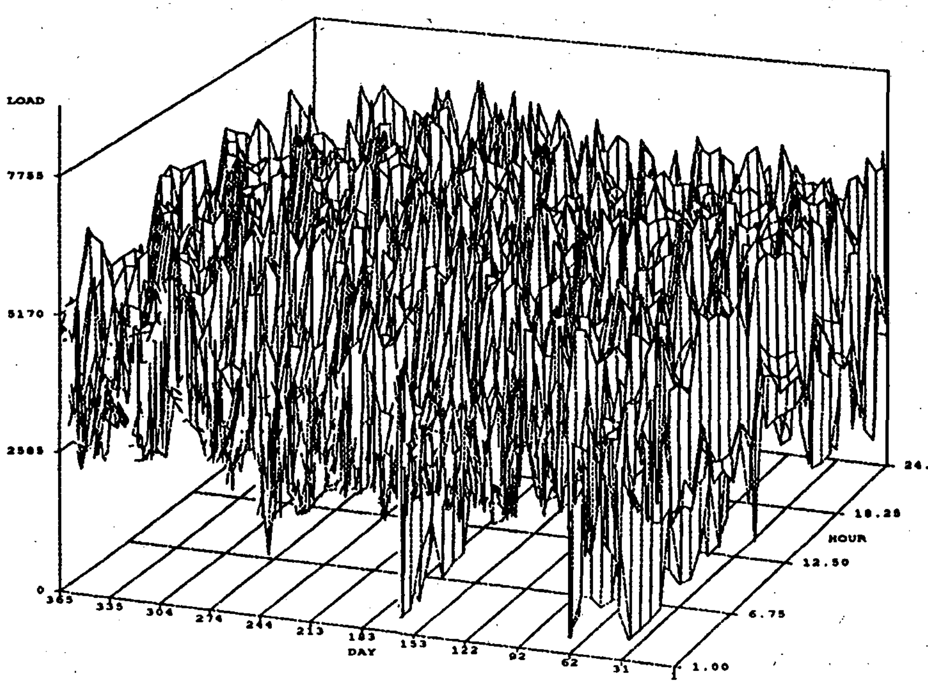

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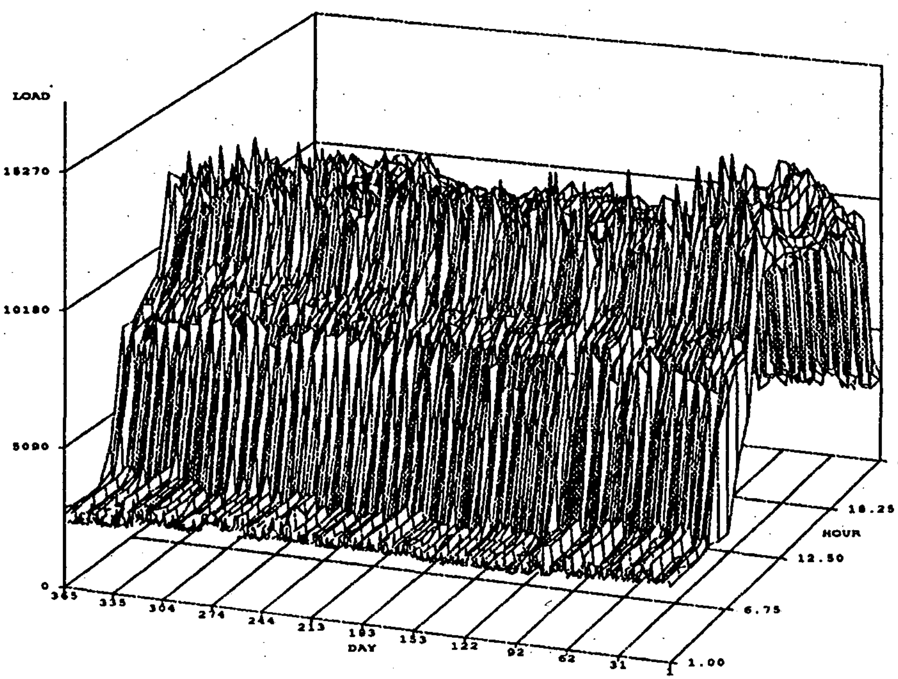
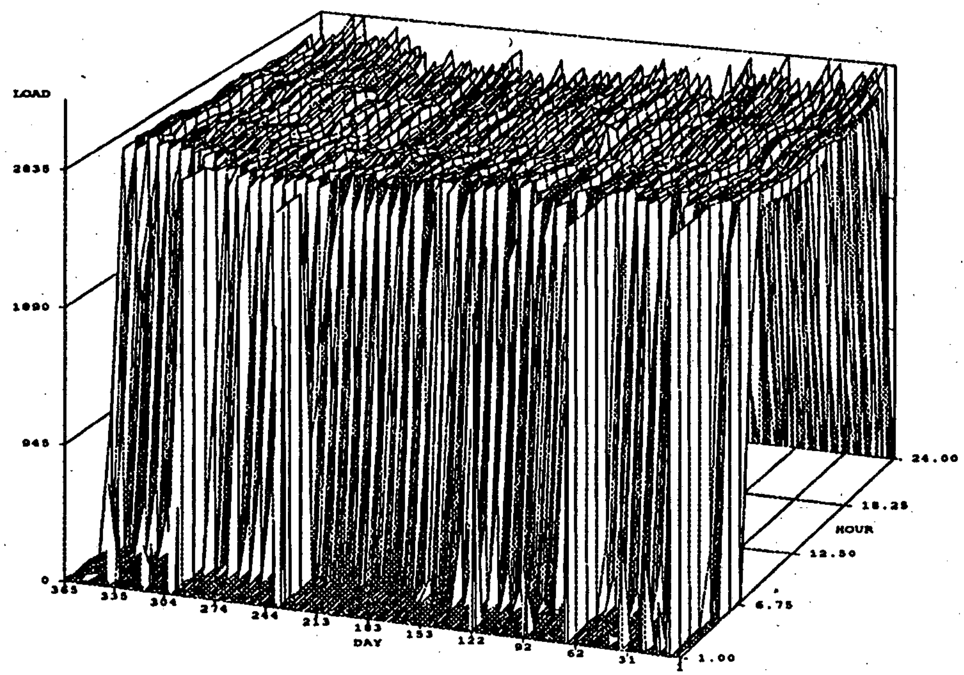
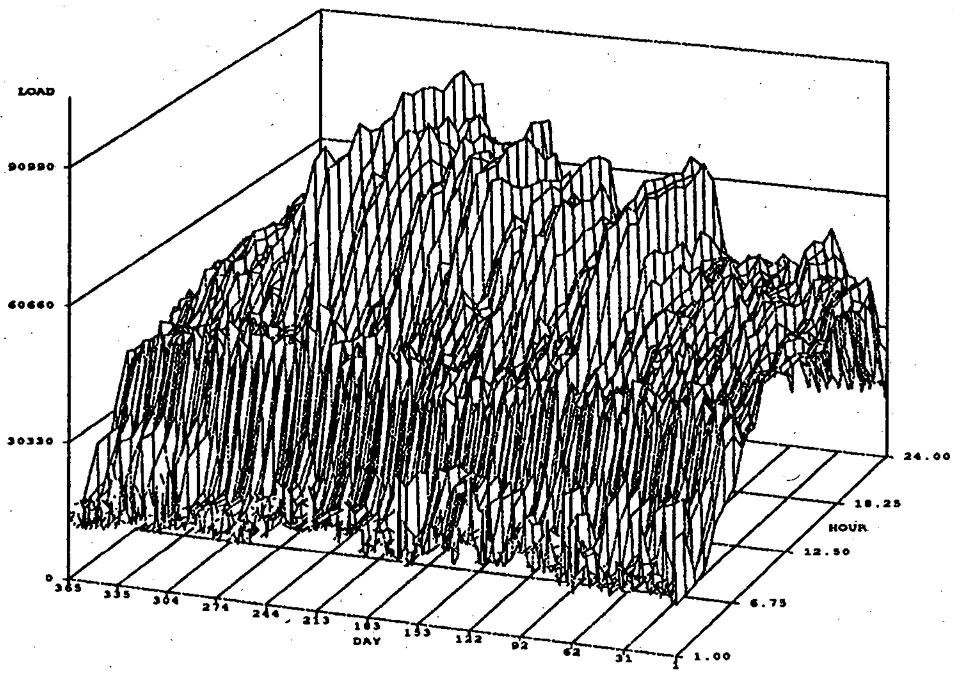


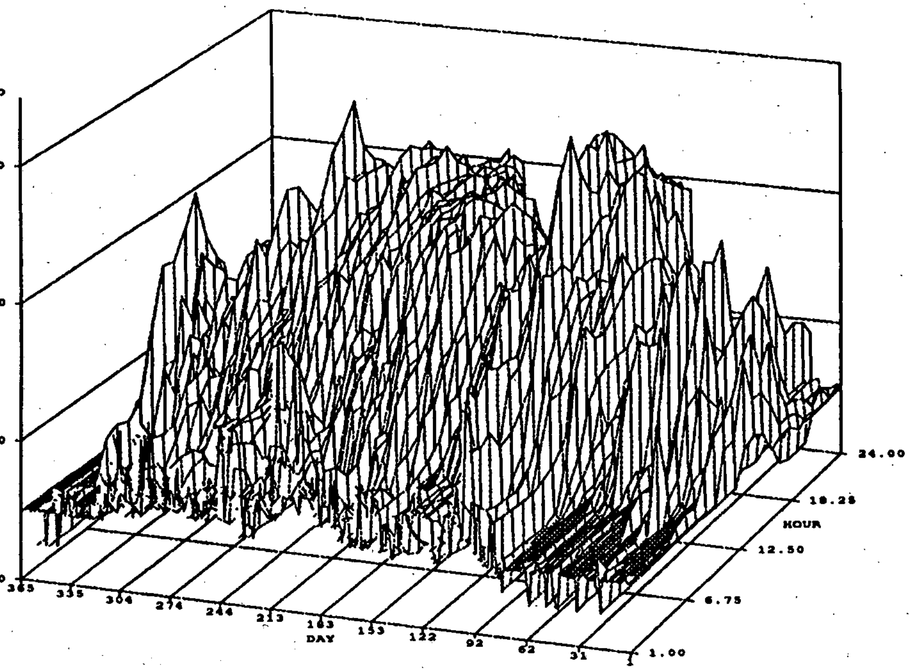
Fastfood Restaurant 7 Exhaust Fan



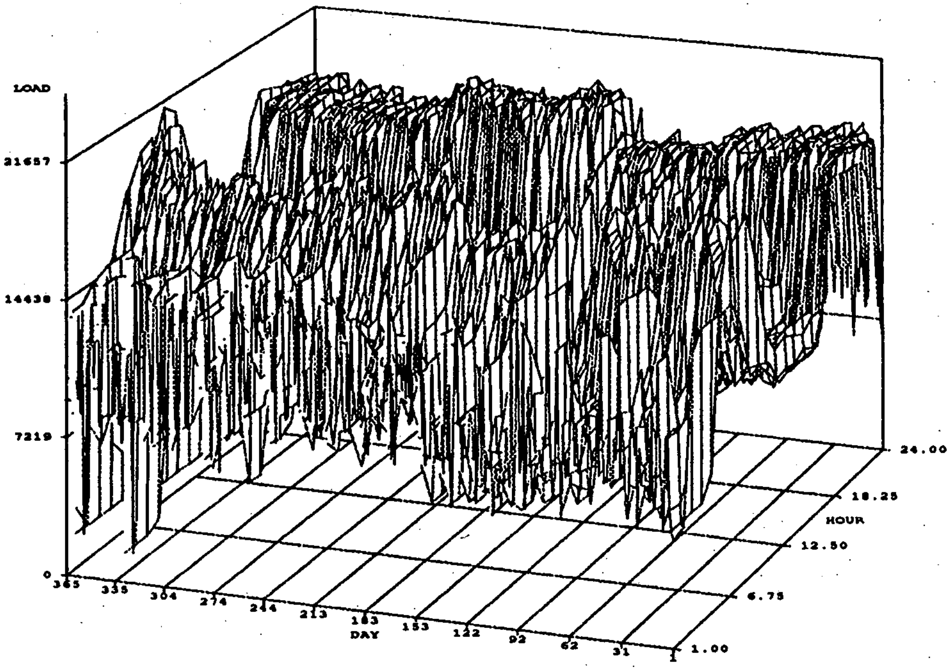
Fastfood Restaurant 7 Total



Fastfood Restaurant 11 HVAC



Fastfood Restaurant 11 Lighting



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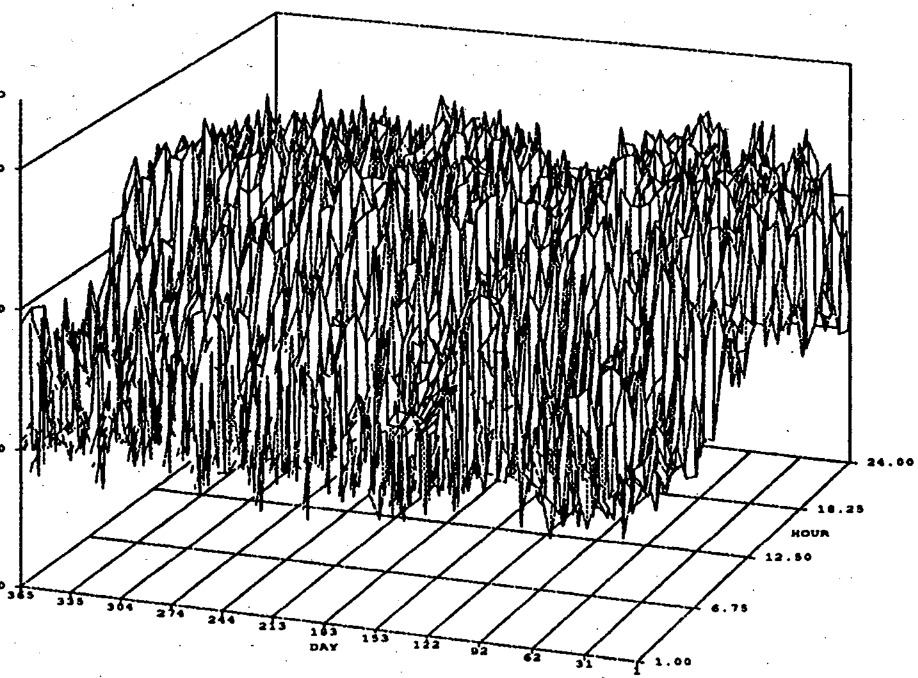
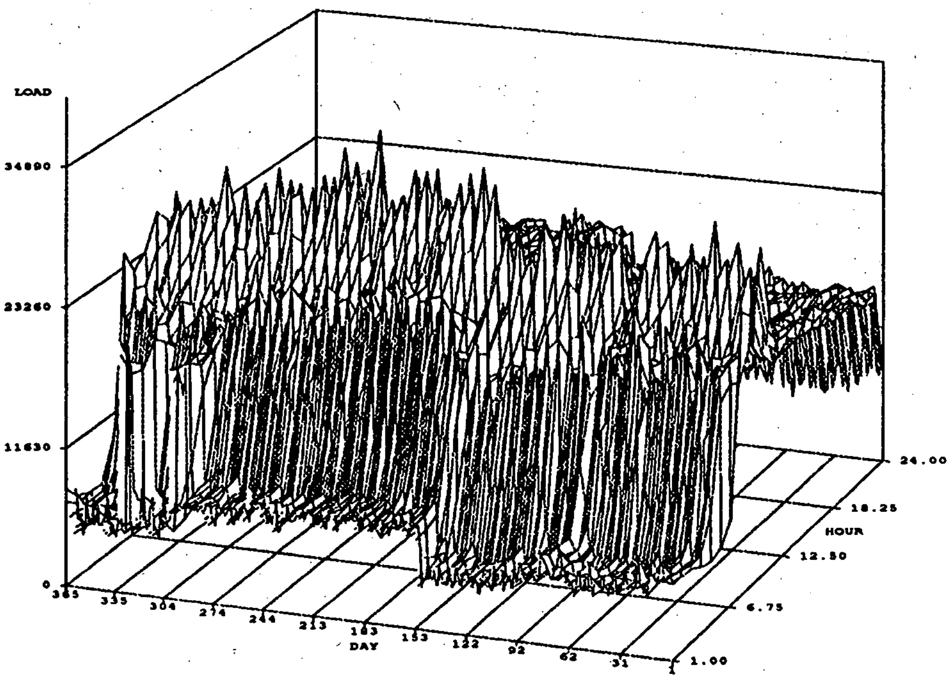
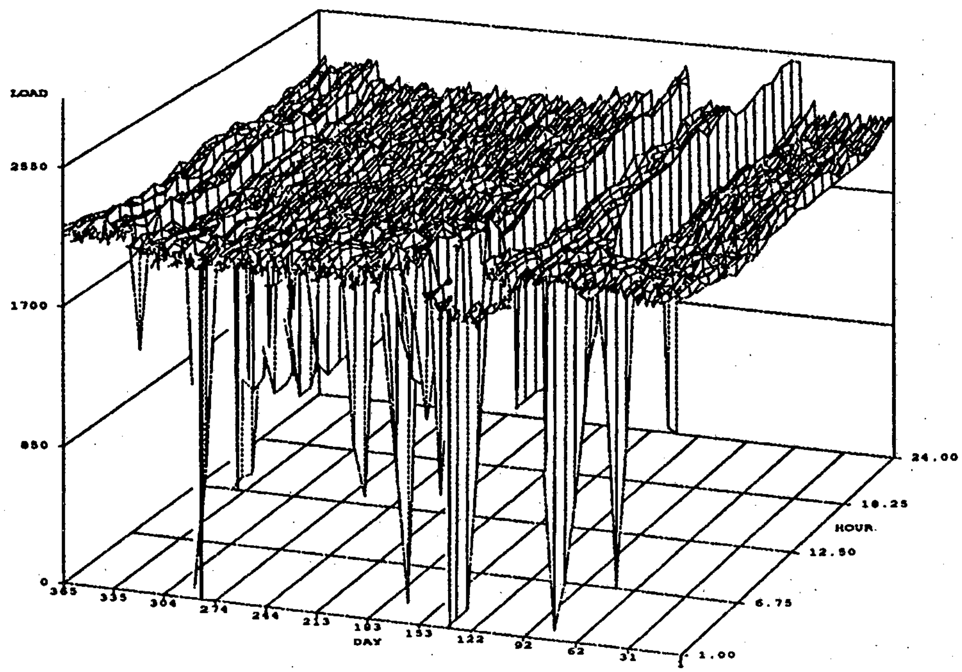


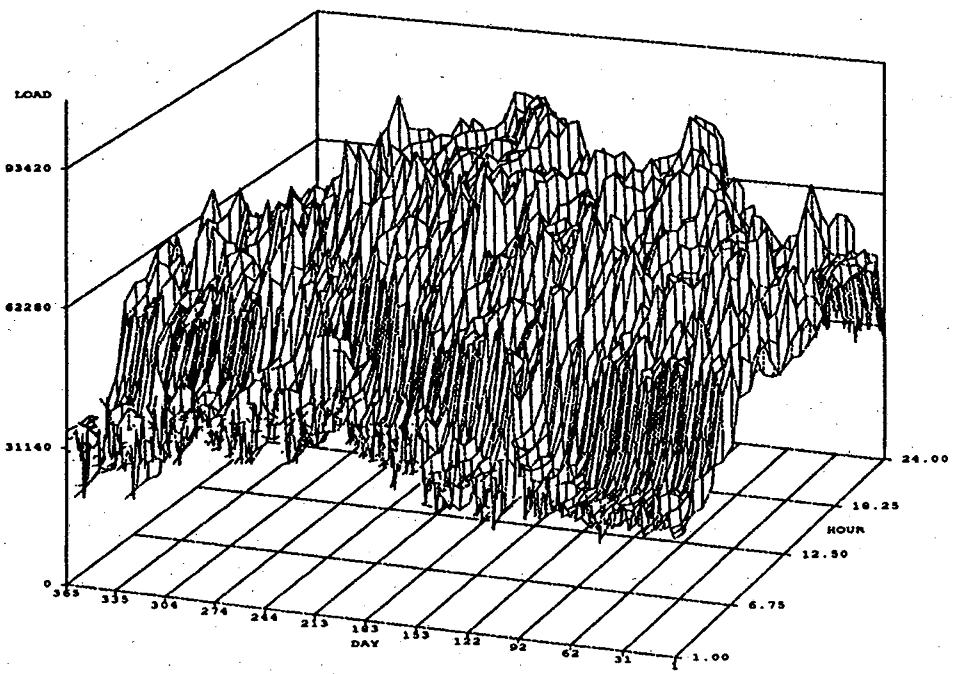
Fastfood Restaurant 11 Cooking



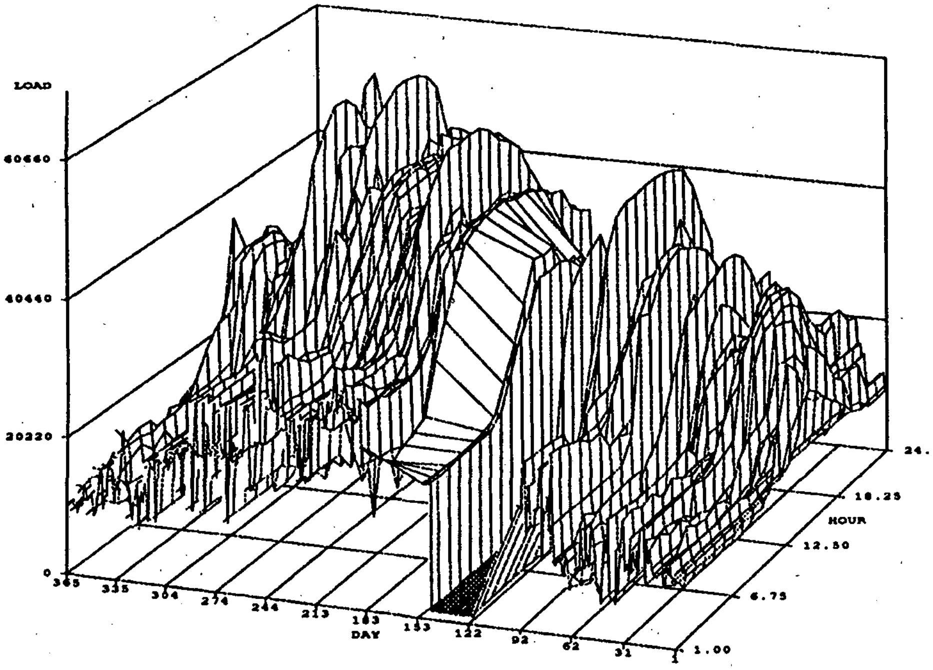
Fastfood Restaurant 11 Exhaust Fan



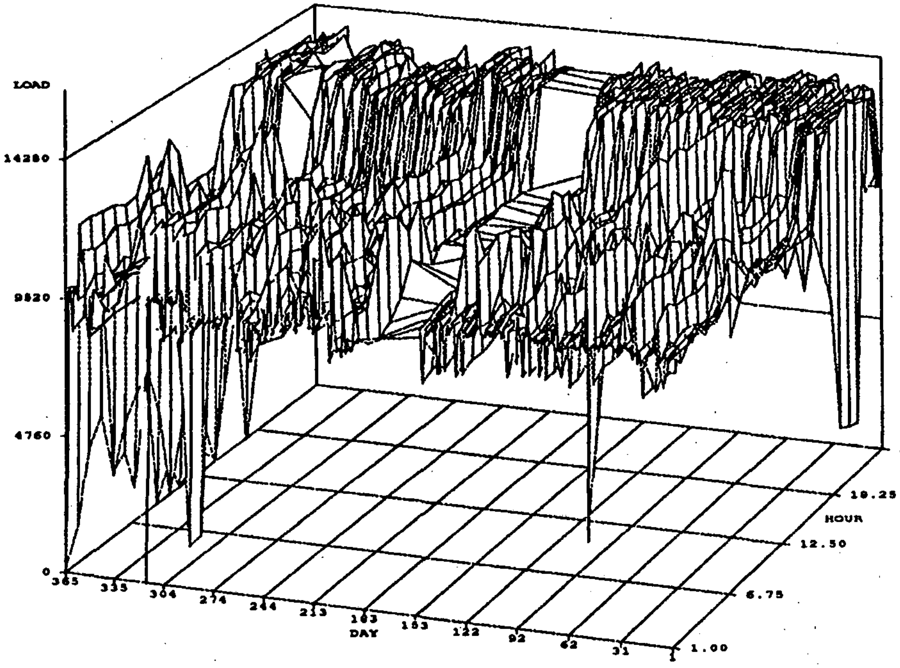
Fastfood Restaurant 11 Total



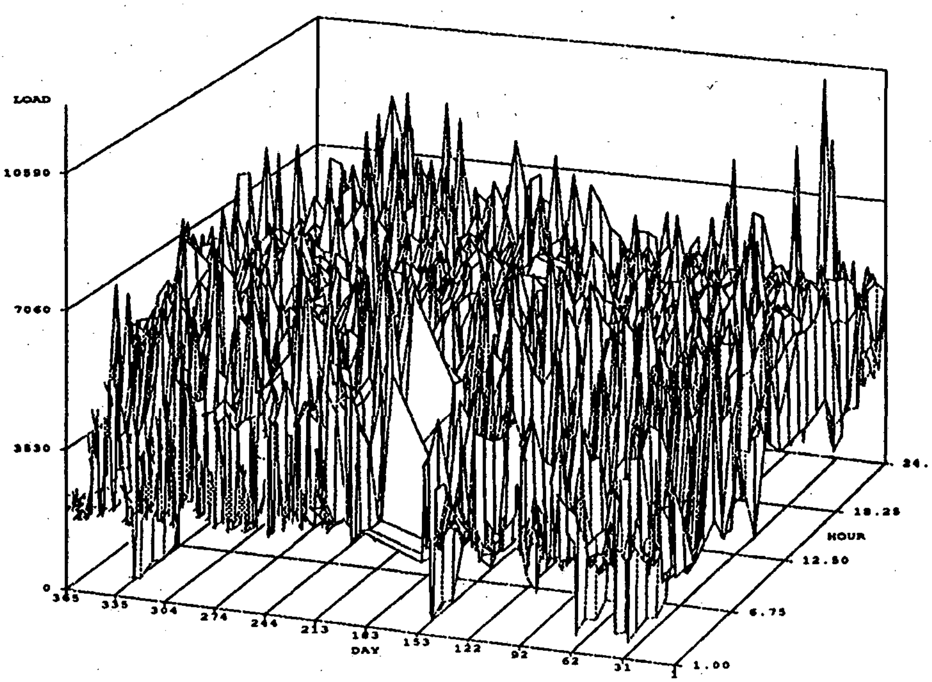
Fastfood Restaurant 13 HVAC



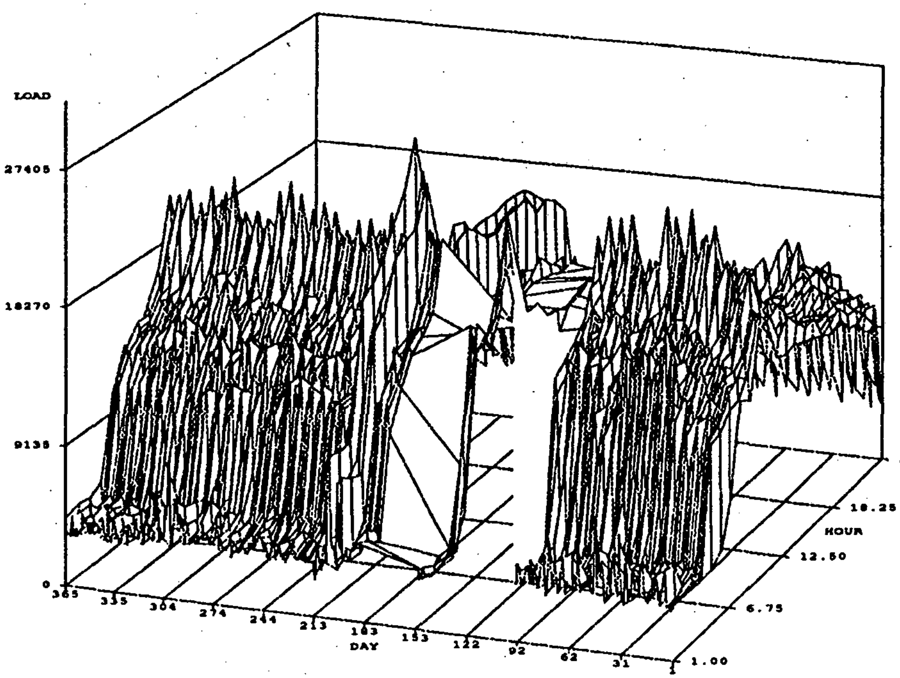
Fastfood Restaurant 13 Lighting



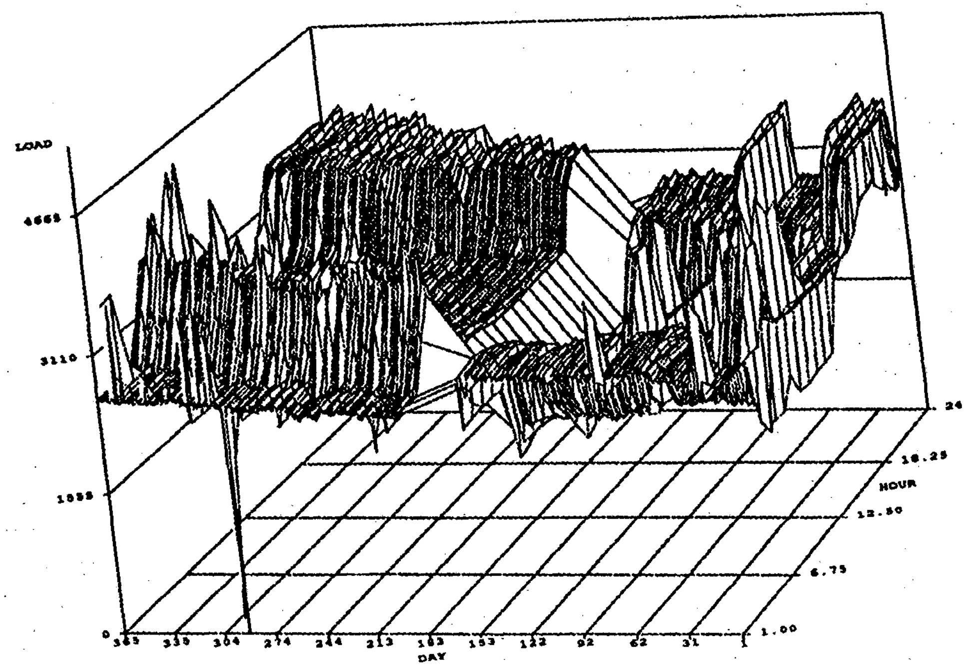
Fastfood Restaurant 13 Refrigeration



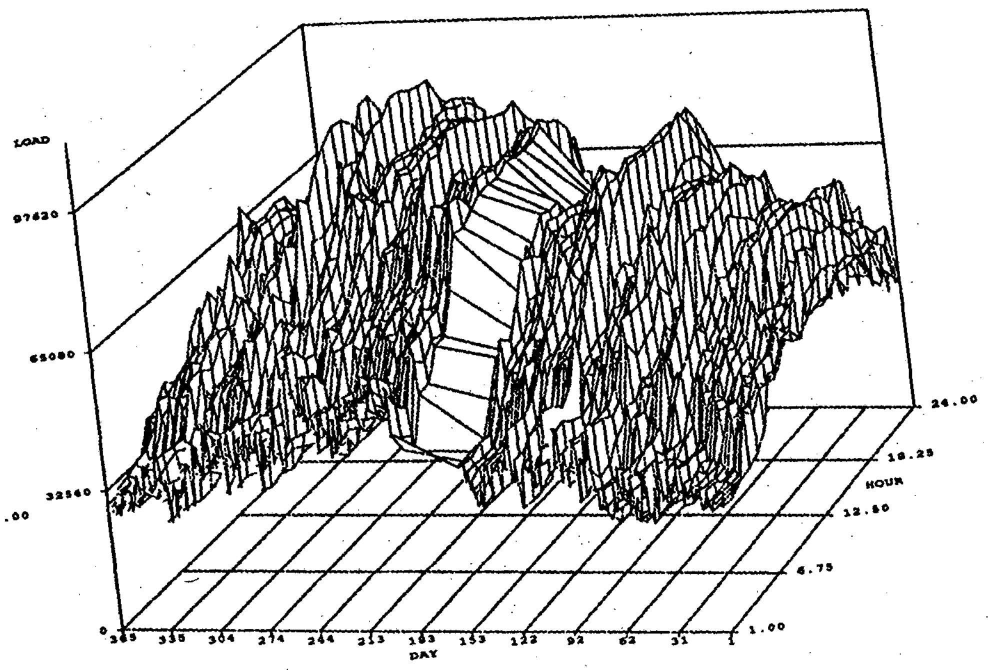
Fastfood Restaurant 13 Cooking



Fastfood Restaurant 13 Exhaust Fan



Fastfood Restaurant 13 Total



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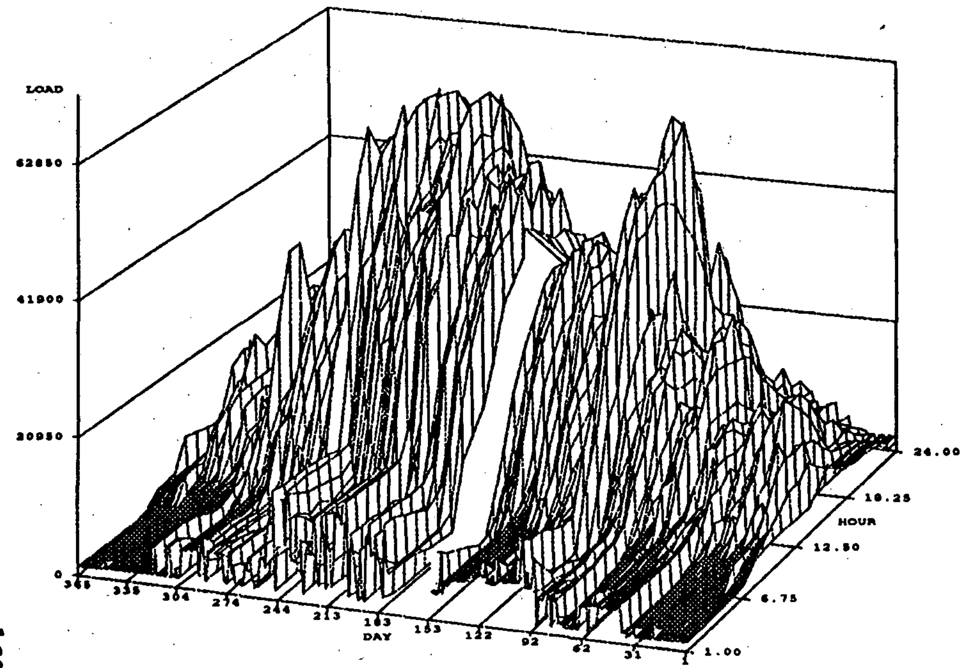
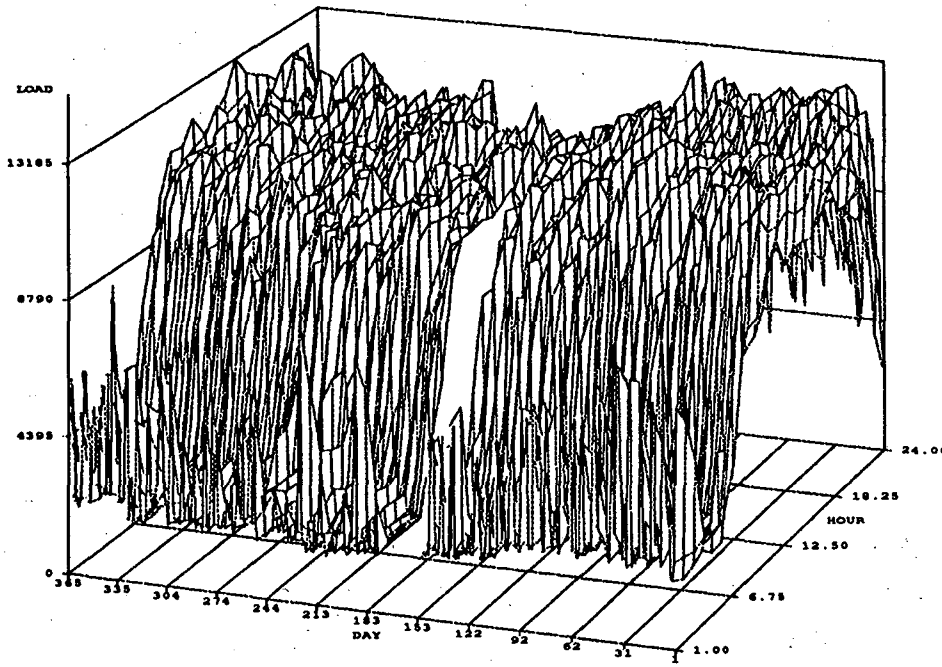
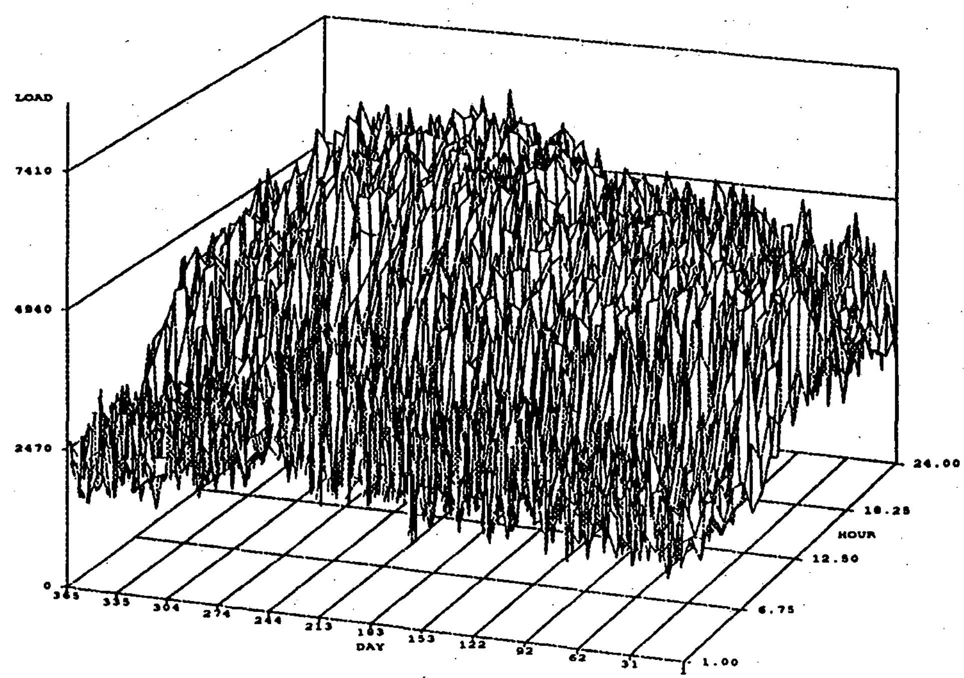


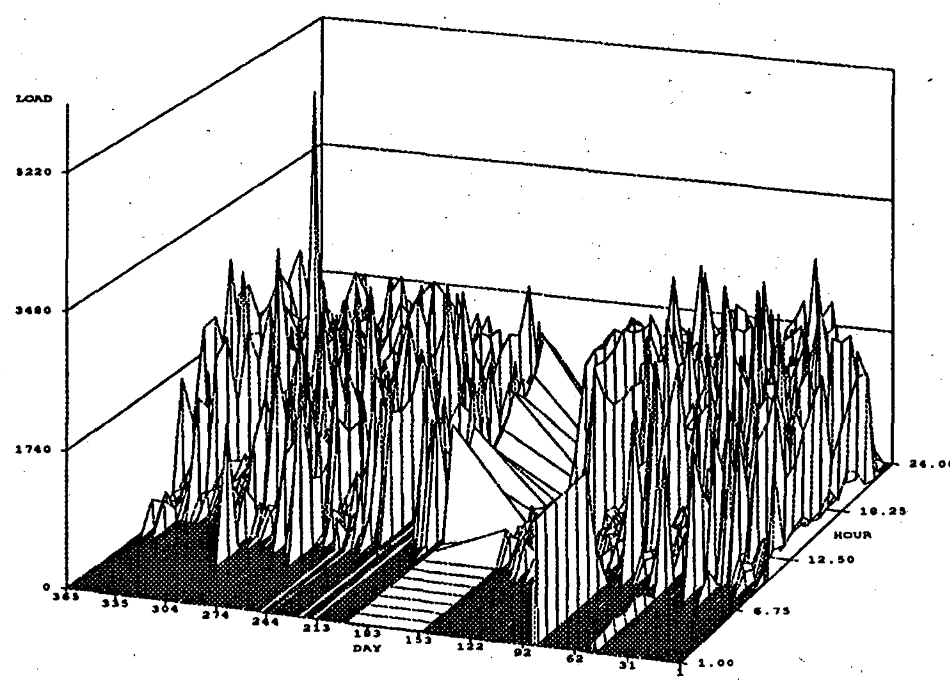
Sitdown Restaurant 1 Lighting

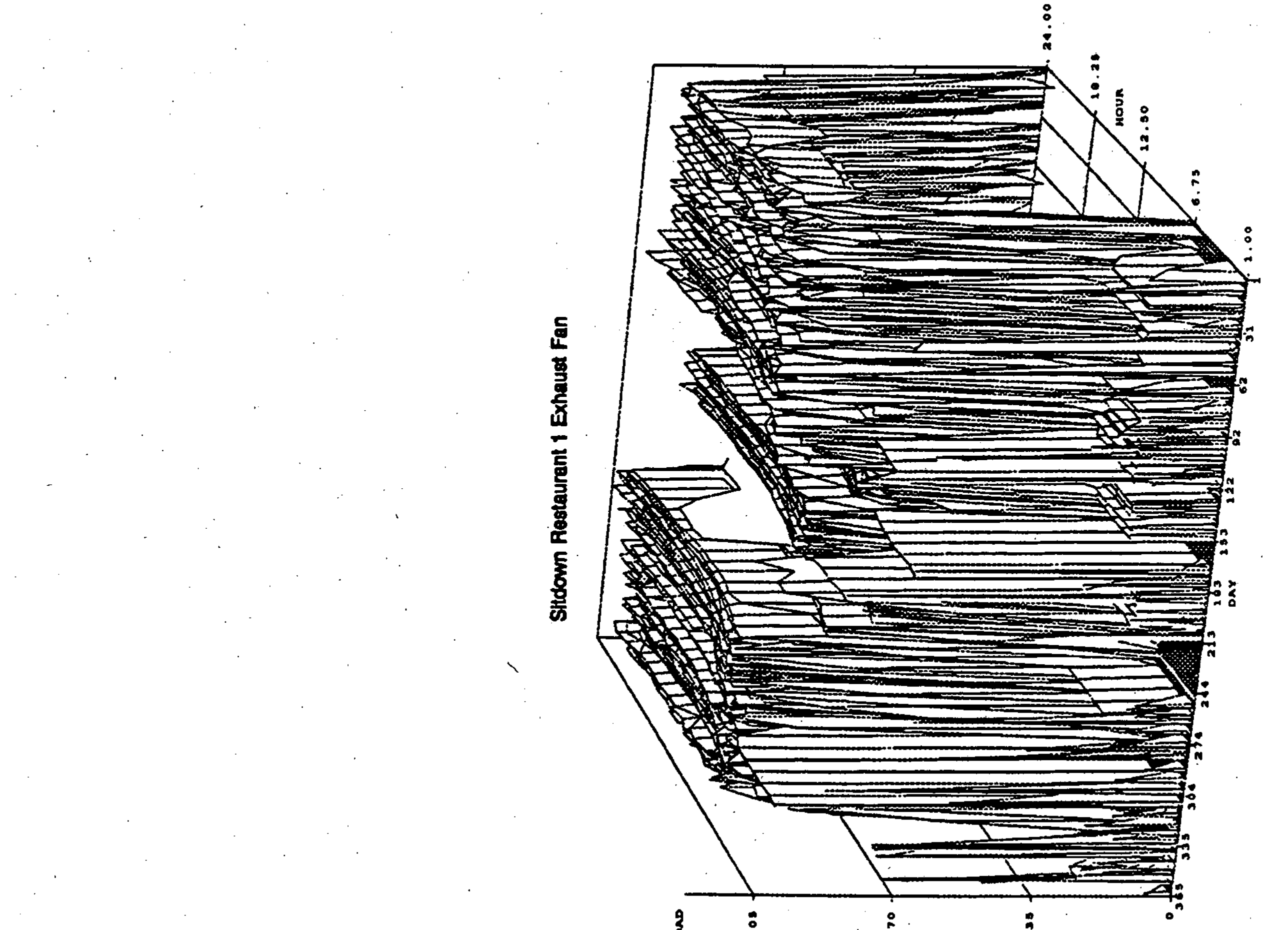


Sitdown Restaurant 1 Refrigeration



Sitdown Restaurant 1 Cooking




Sitdown Restaurant 1 Exhaust Fan
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2470
1235
0
DAY
HOUR
365
335
304
274
244
213
183
153
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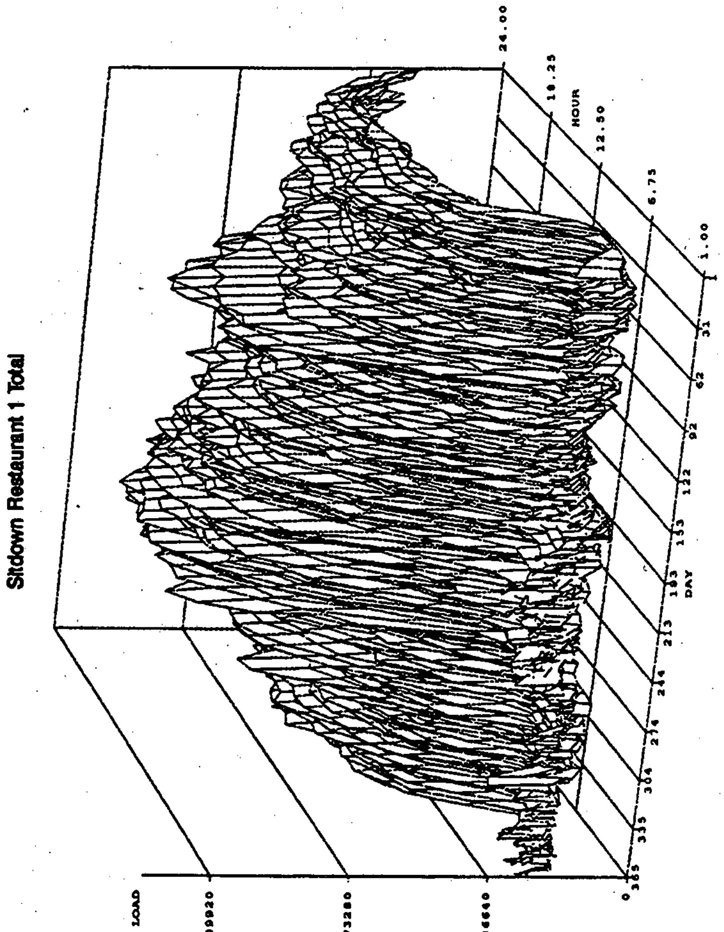
12.50
18.25
24.00


Sitdown Restaurant 1 Total
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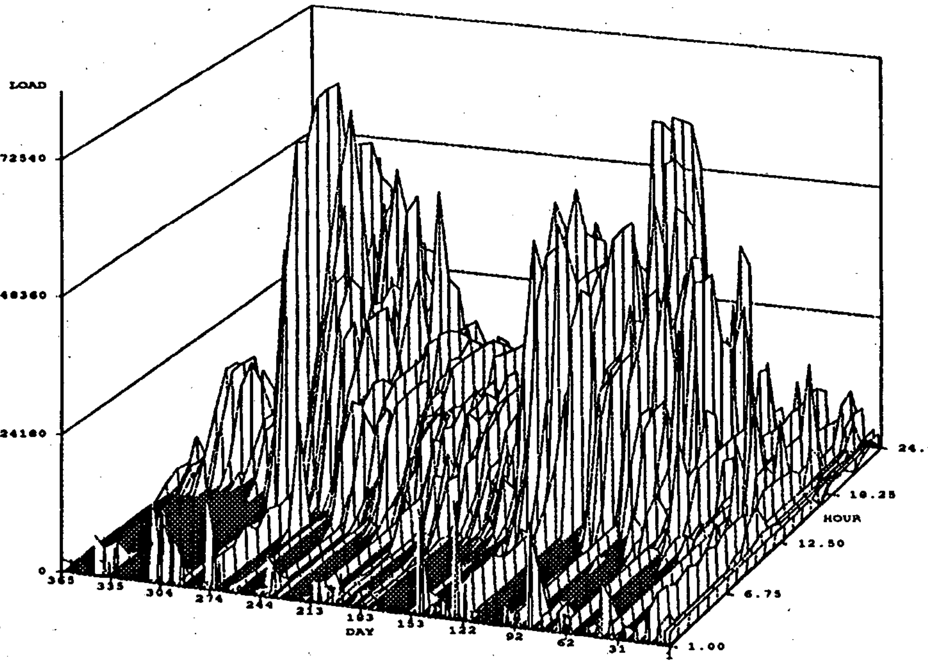
DAY
HOUR
365
335
304
274
244
213
183
153
122
92
62
31
1.00
6.75
12.50
18.25
24.00

Sitdown Restaurant 2 HVAC



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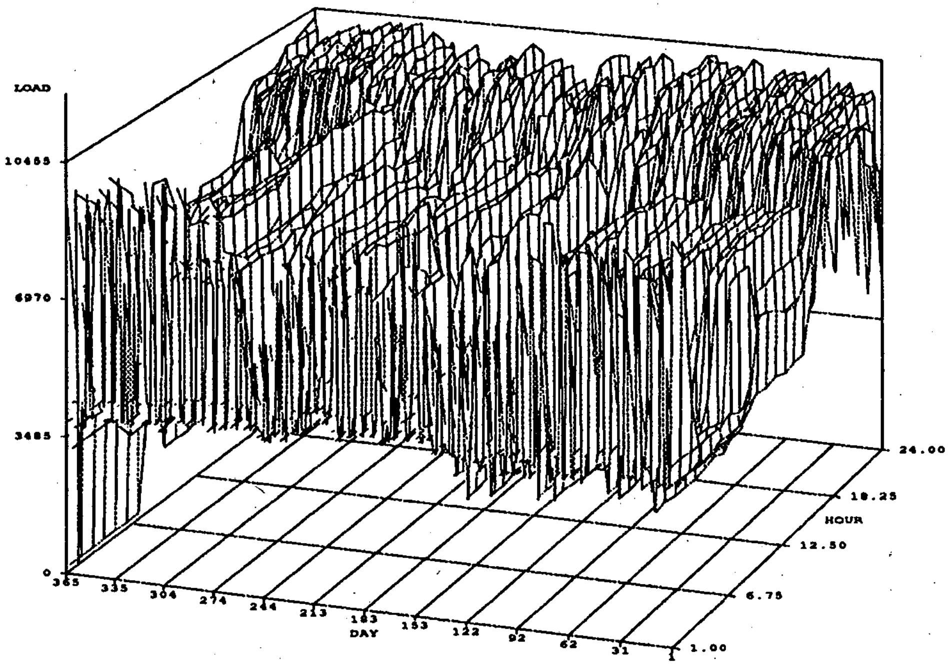

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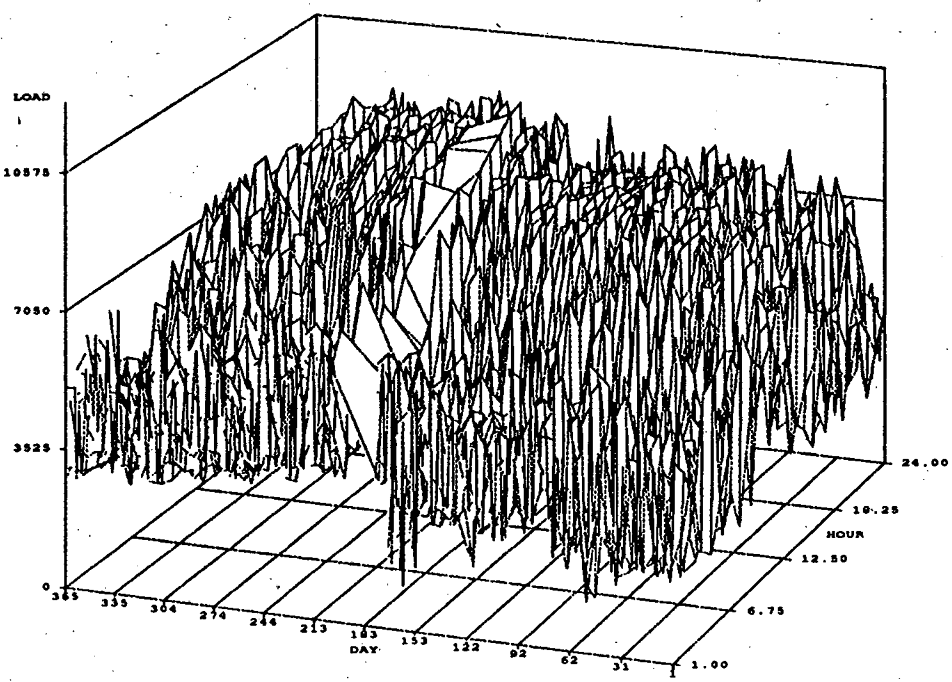
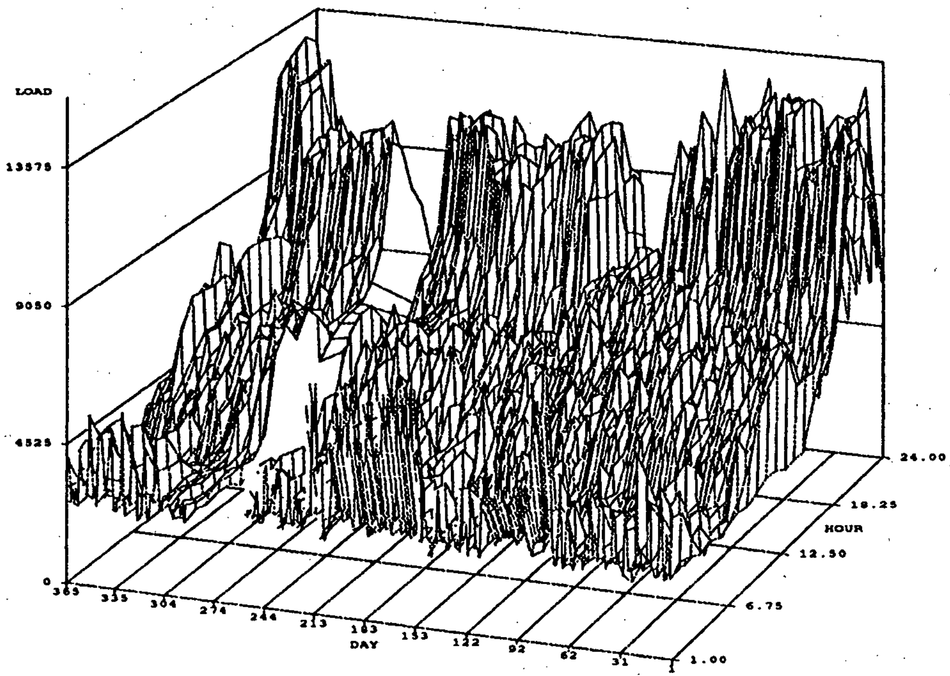


Sitdown Restaurant 2 Cooking



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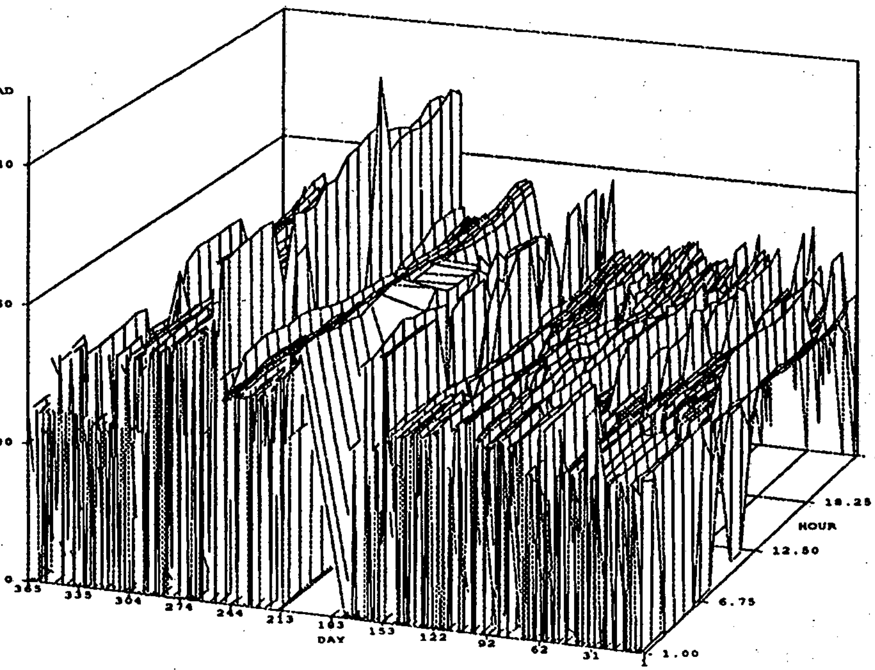

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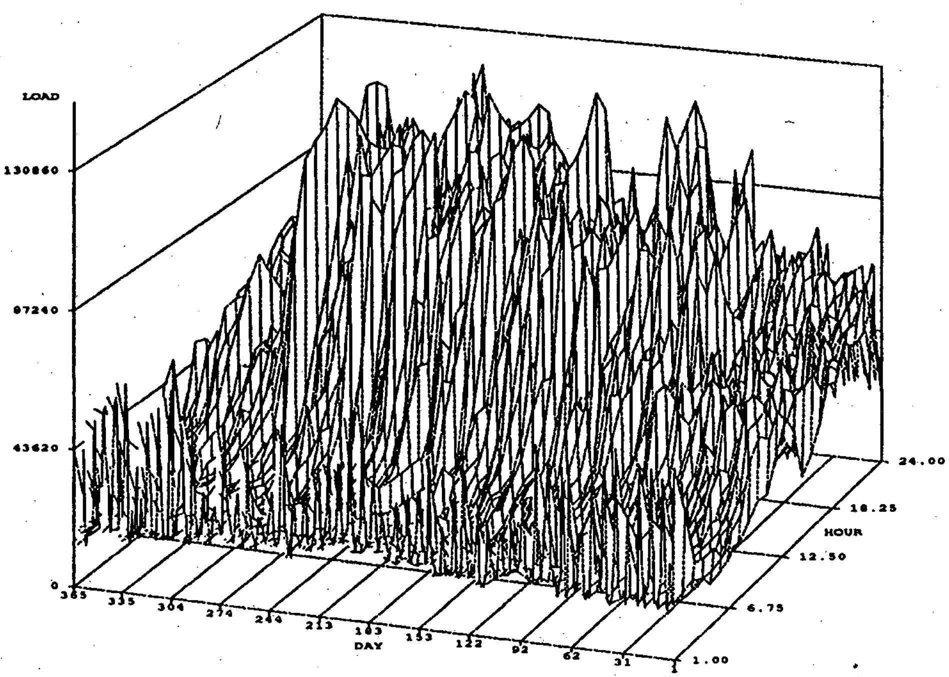
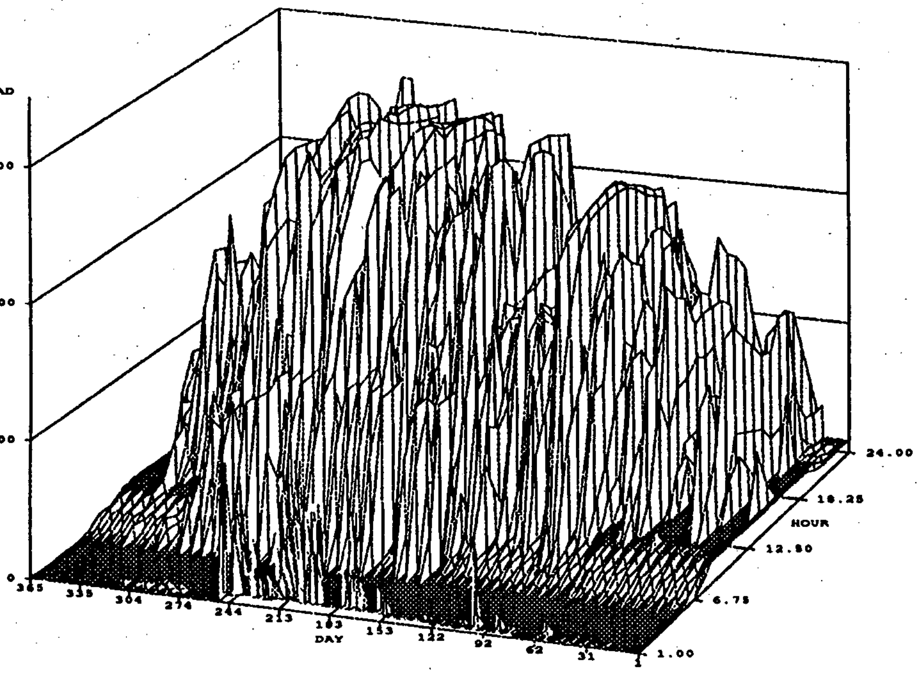
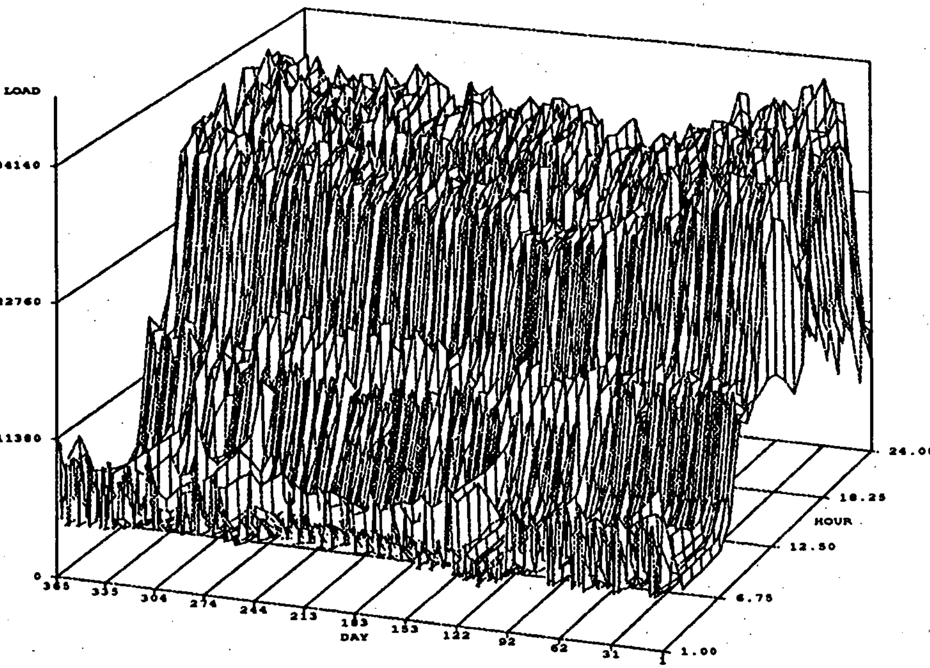


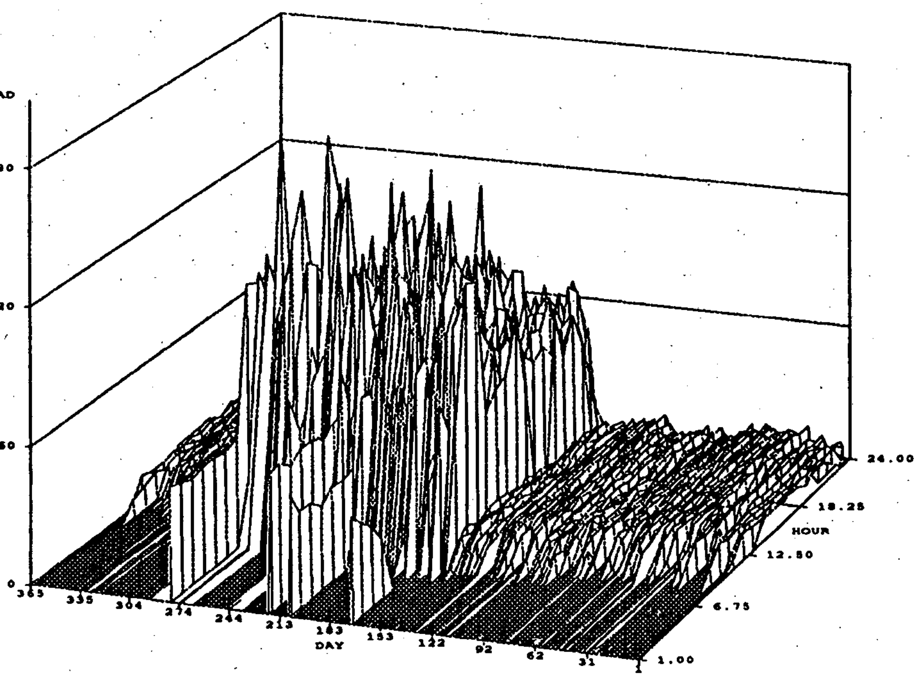
Sitdown Restaurant 3 HVAC



Sitdown Restaurant 3 Lighting



Sitdown Restaurant 3 Refrigeration



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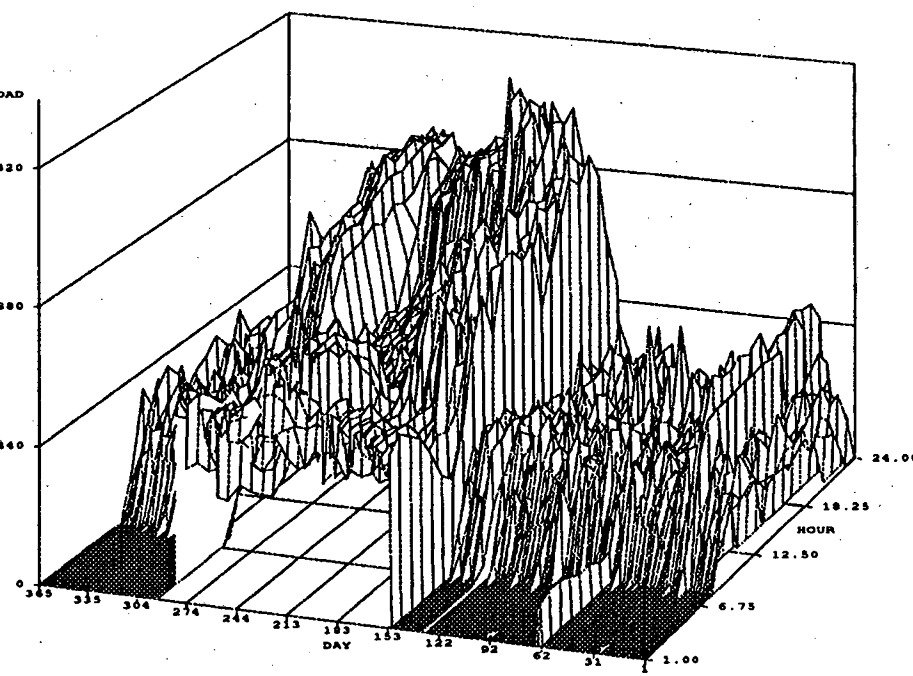
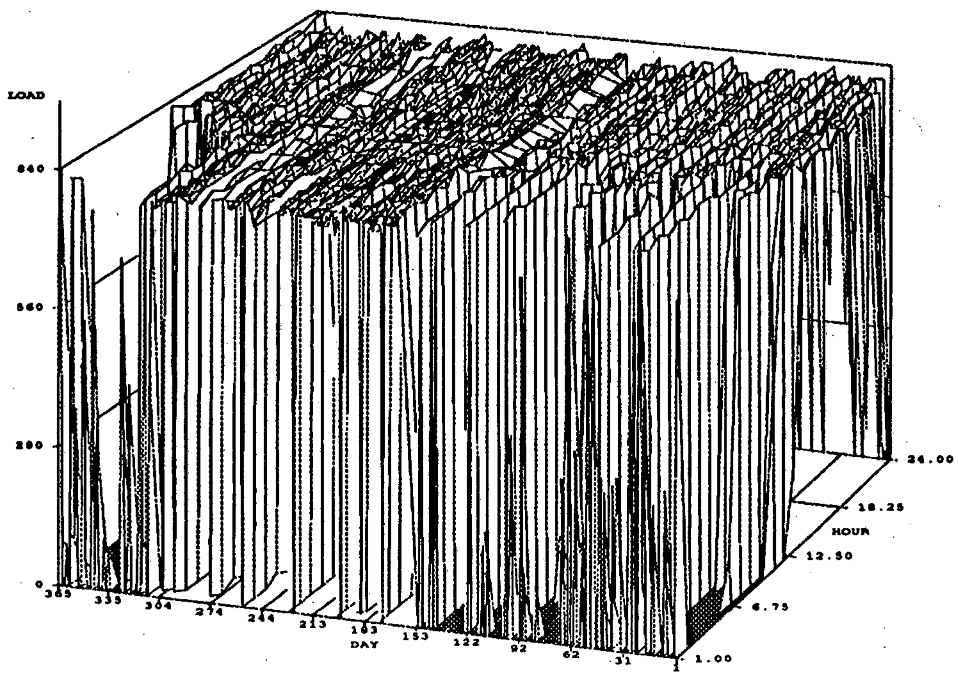


Sitdown Restaurant 3 Exhaust Fan



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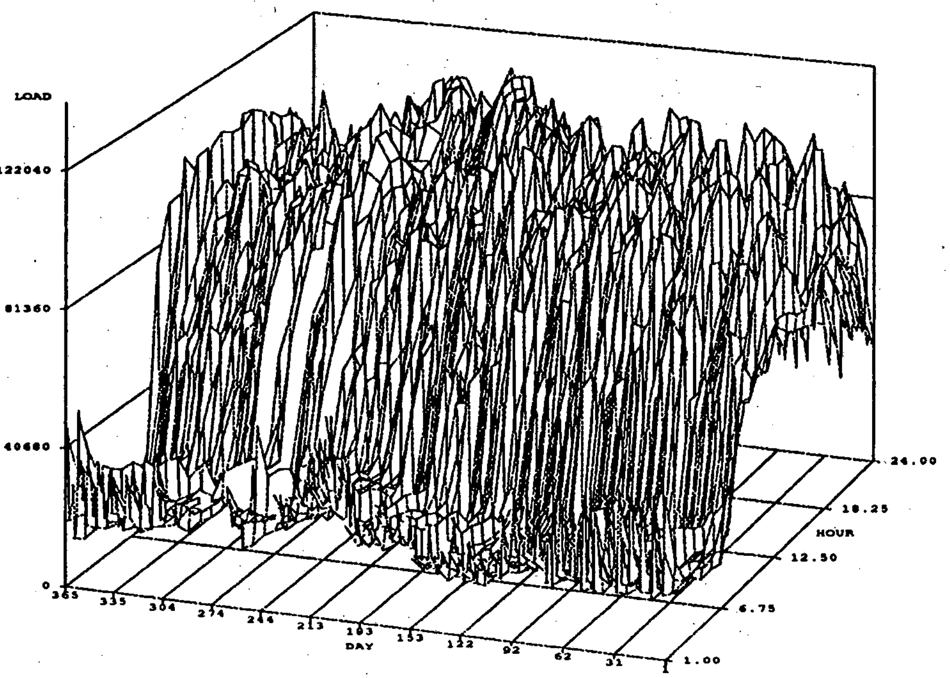
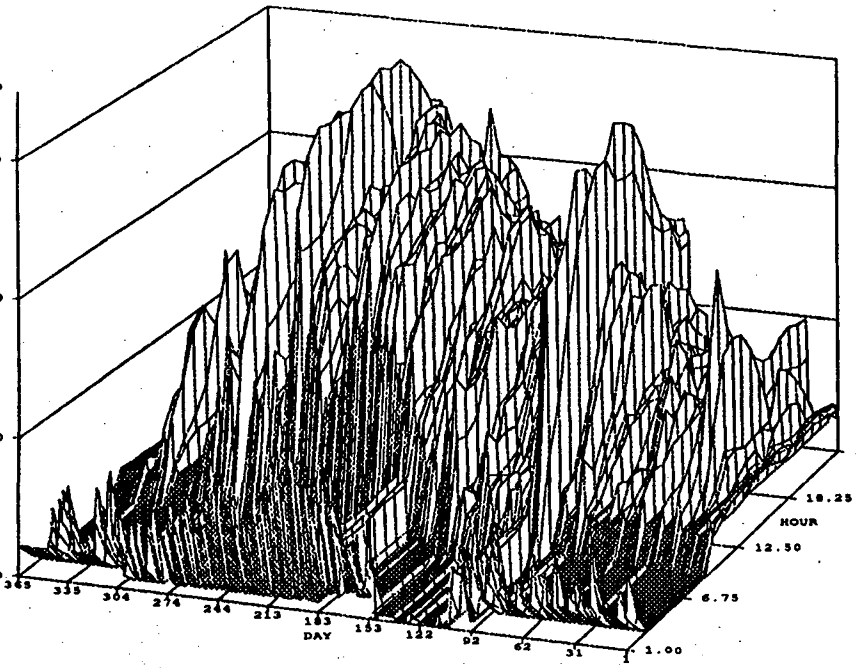
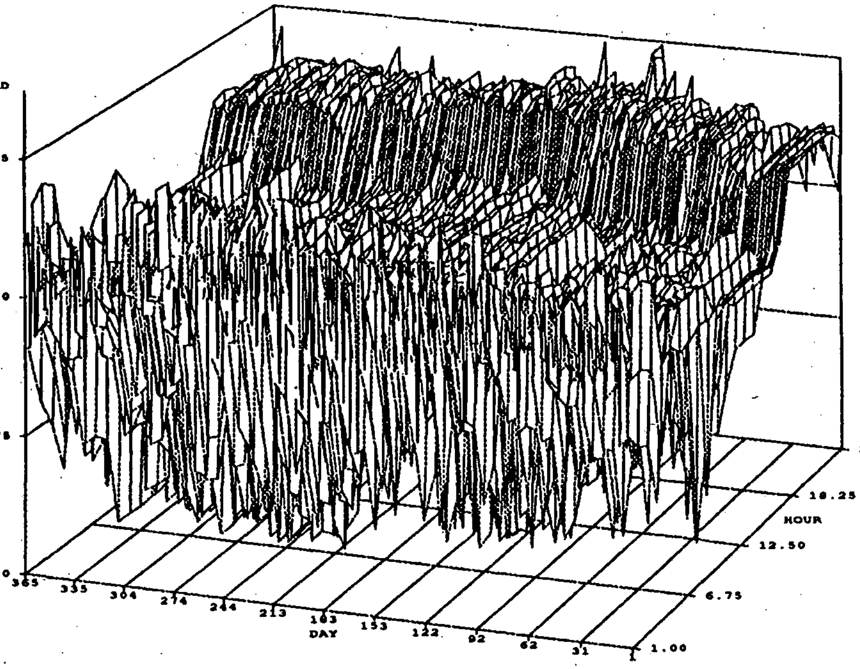


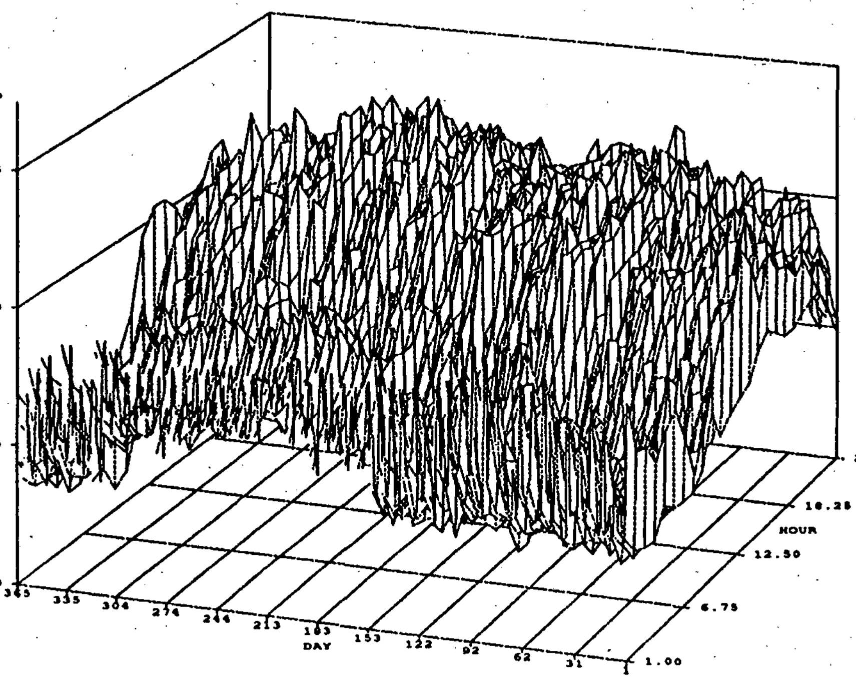
Sitdown Restaurant 4 HVAC



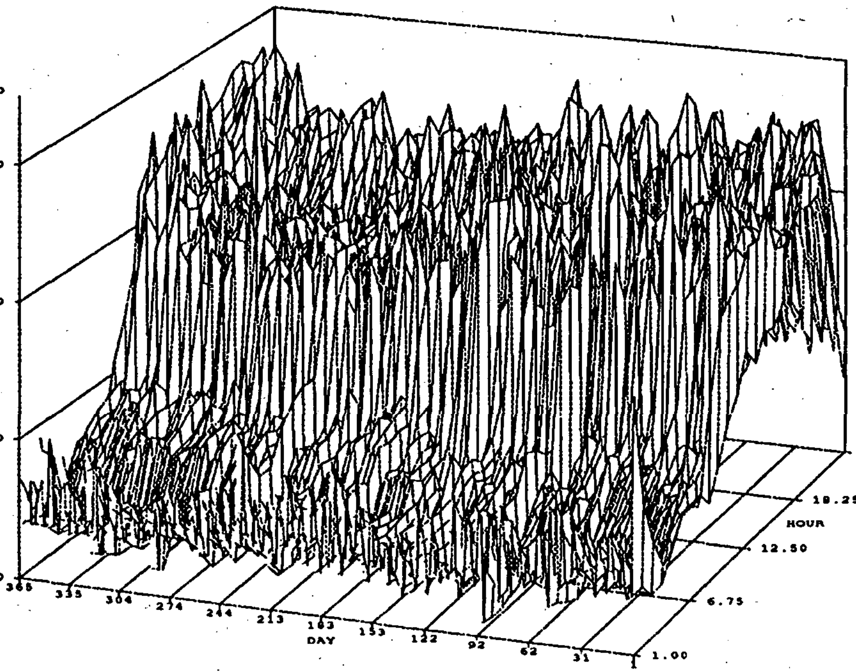
Sitdown Restaurant 4 Lighting



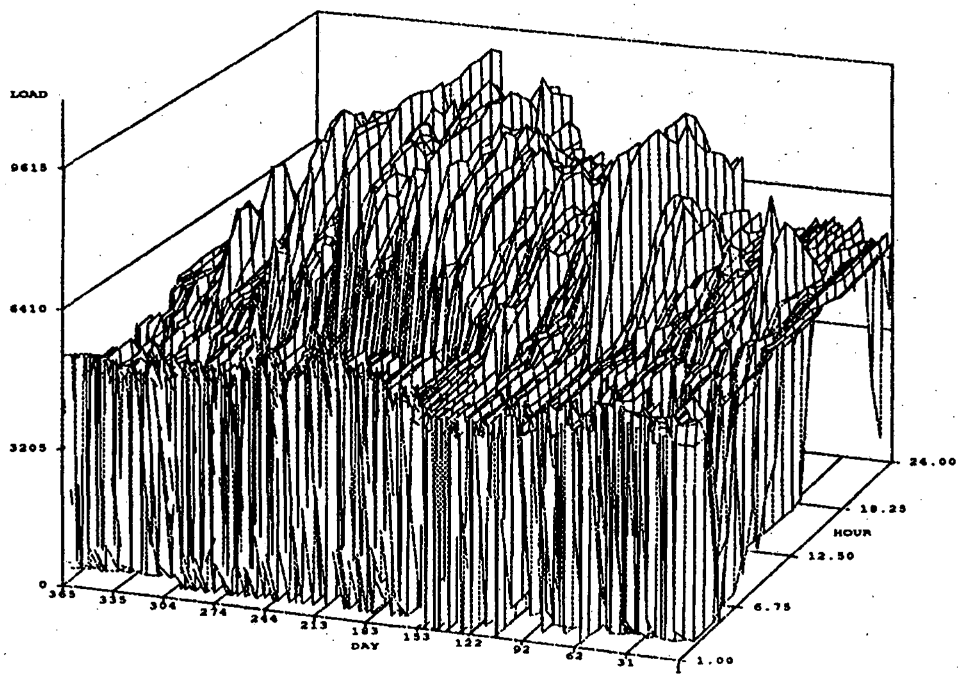
Sitdown Restaurant 4 Refrigeration



Sitdown Restaurant 4 Cooking



Sitdown Restaurant 4 Exhaust Fan



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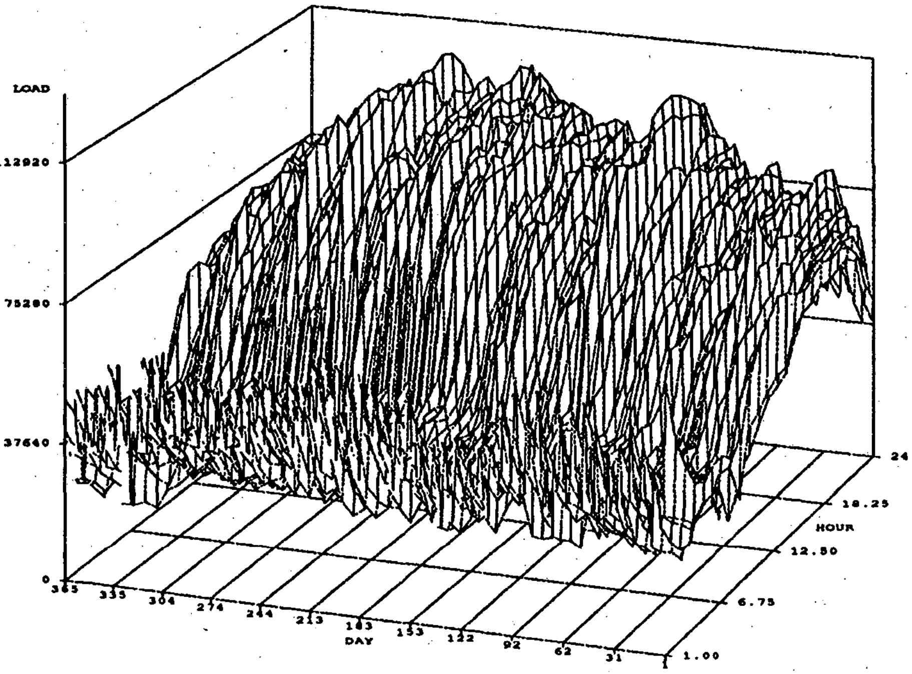
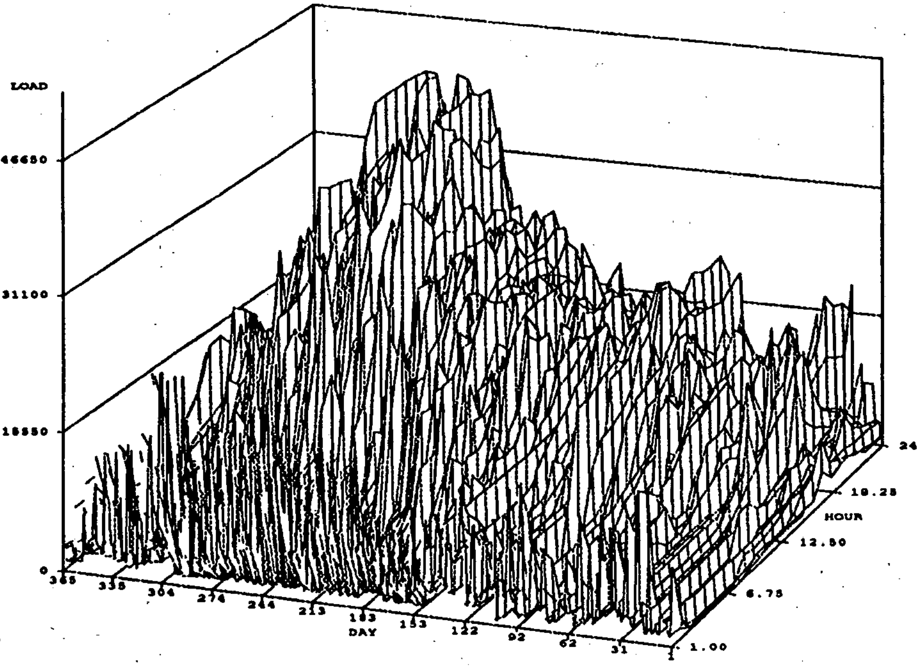
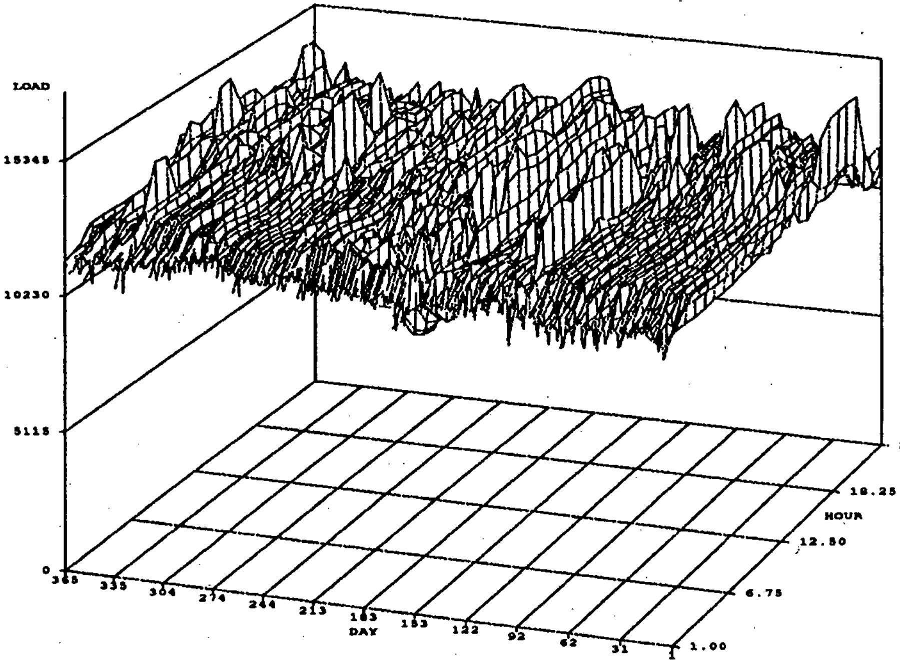


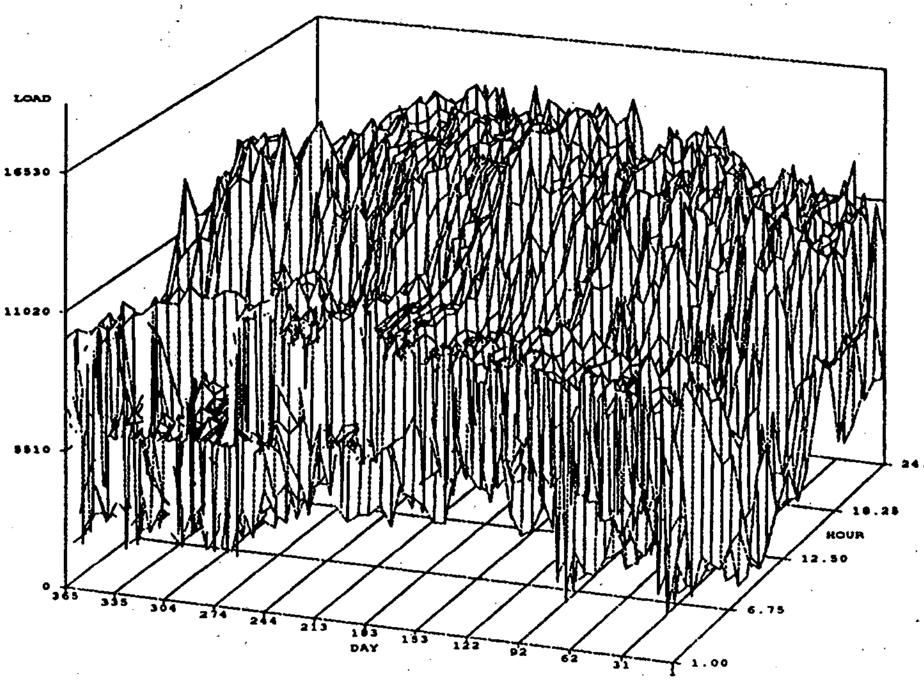
Sitdown Restaurant 5 HVAC



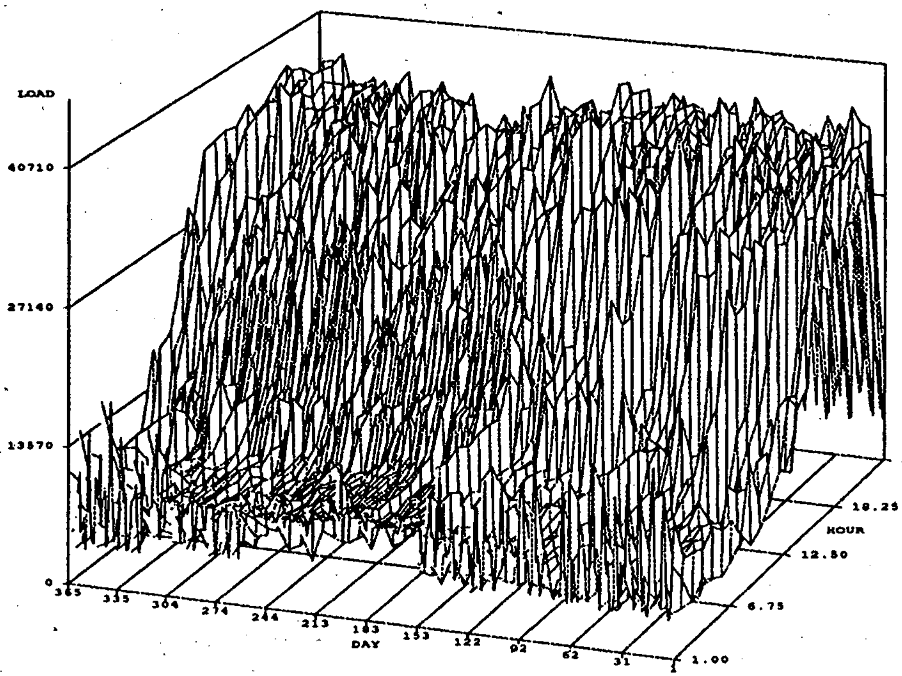
Sitdown Restaurant 5 Lighting



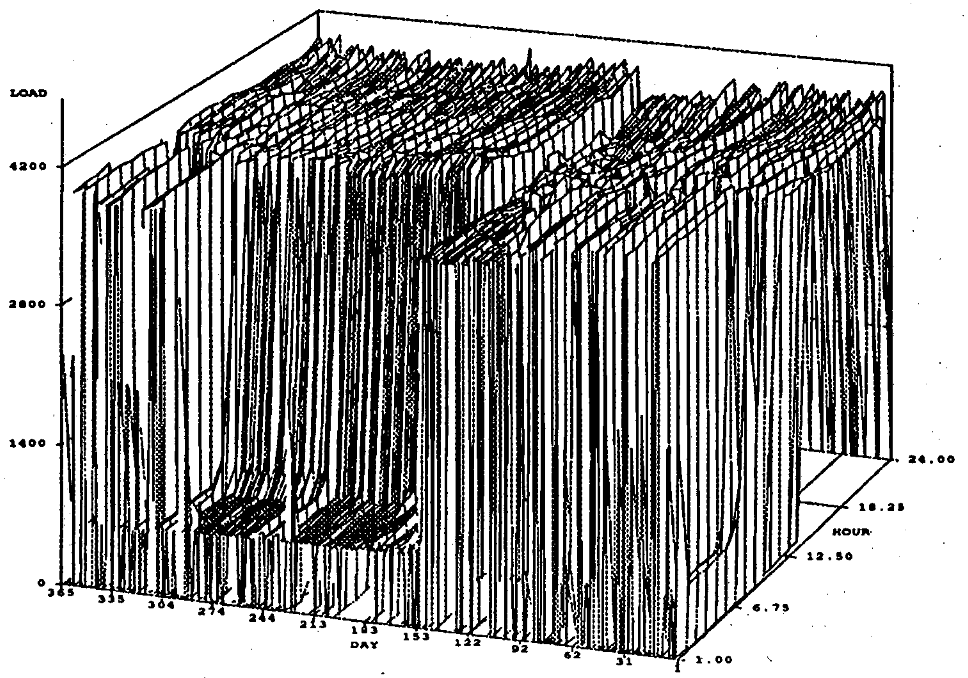
Sitdown Restaurant 5 Refrigeration



Sitdown Restaurant 5 Cooking



Sitdown Restaurant 5 Exhaust Fan



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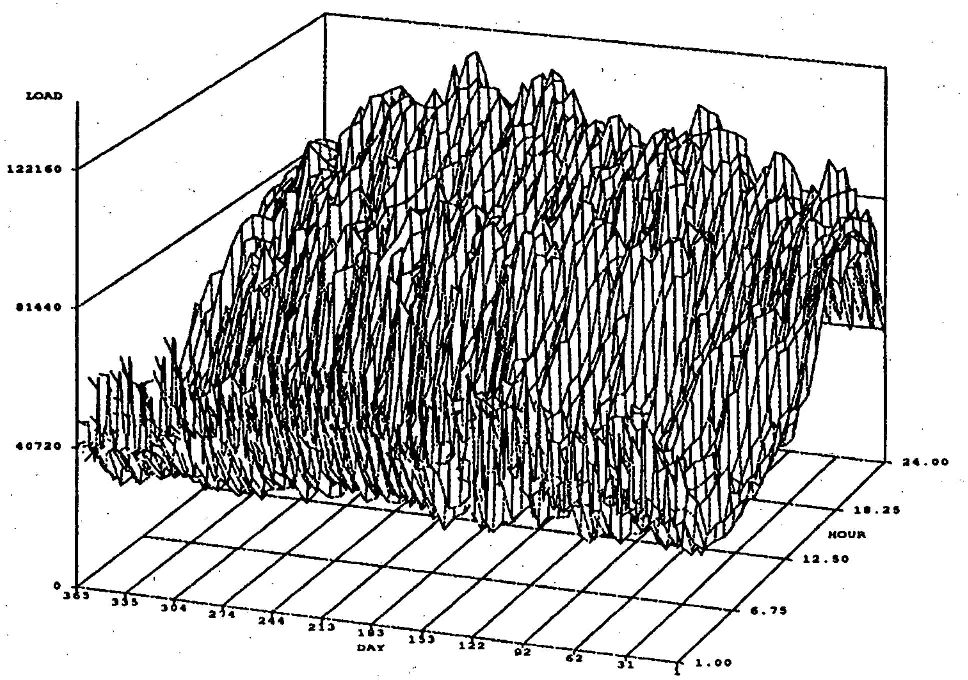
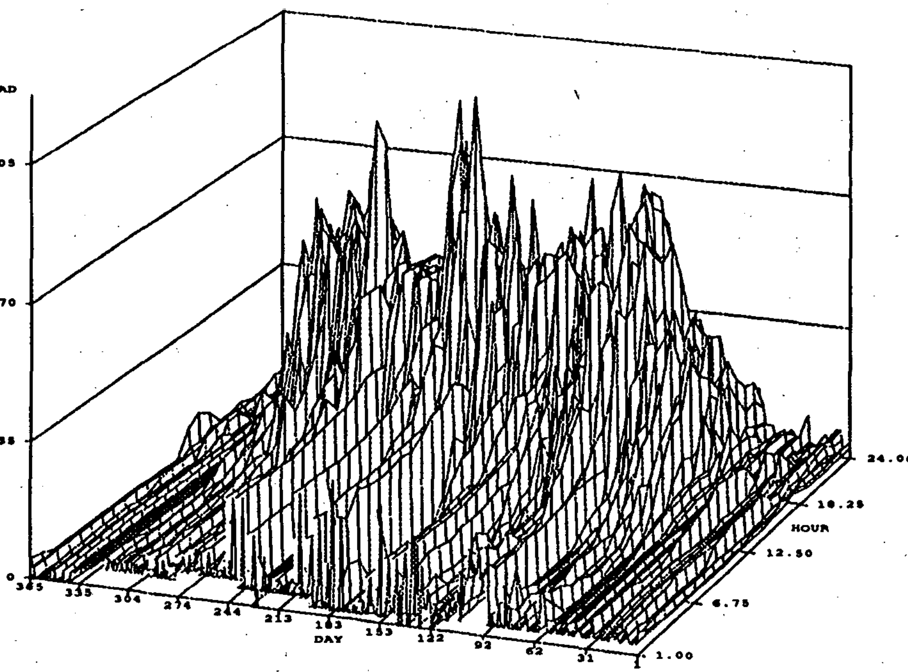
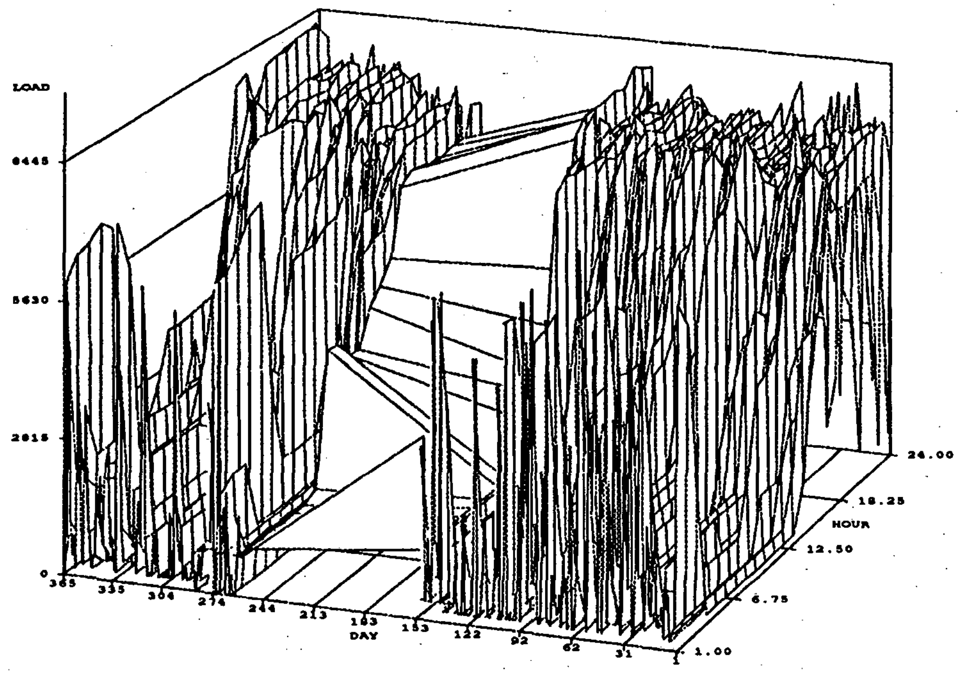


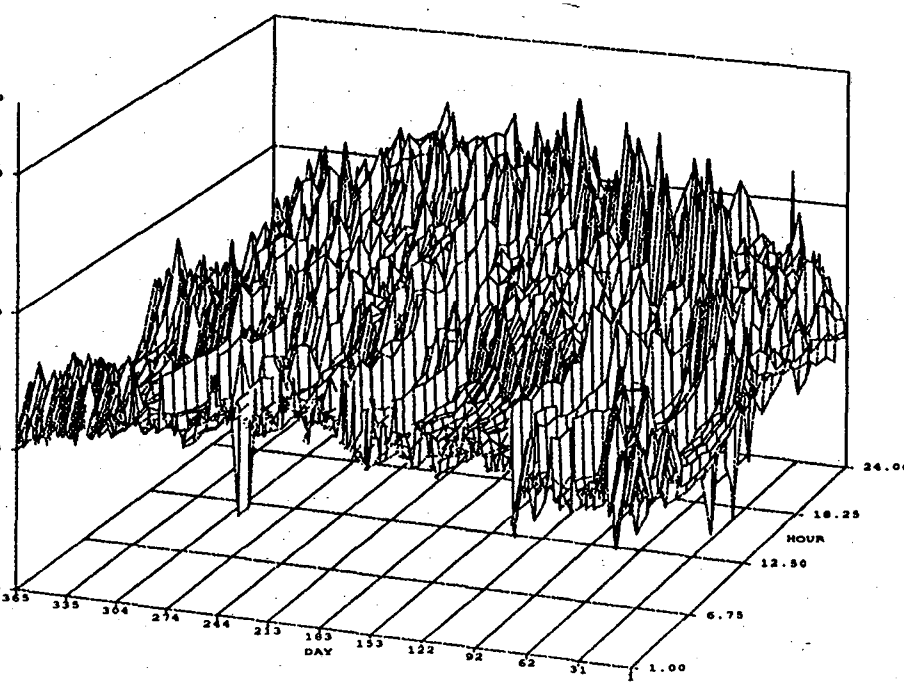
Sitdown Restaurant 8 HVAC



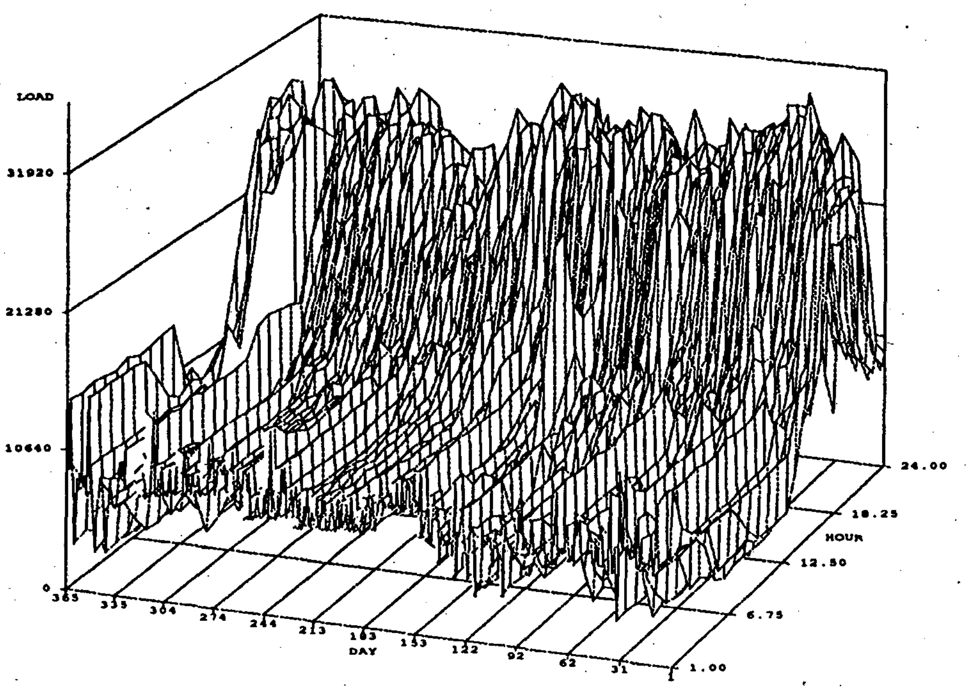
Sitdown Restaurant 8 Lighting



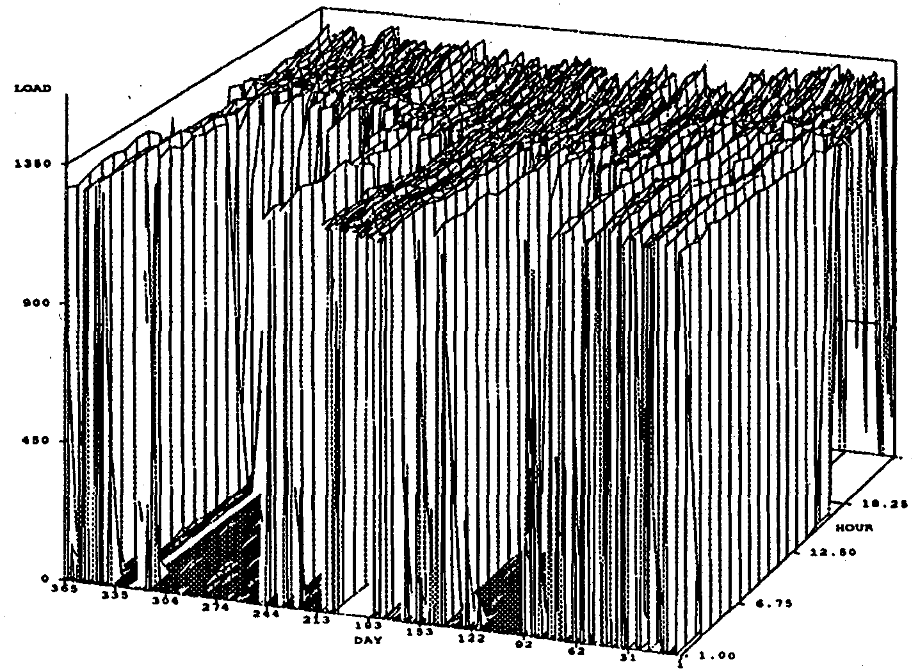
Sitdown Restaurant 8 Refrigeration



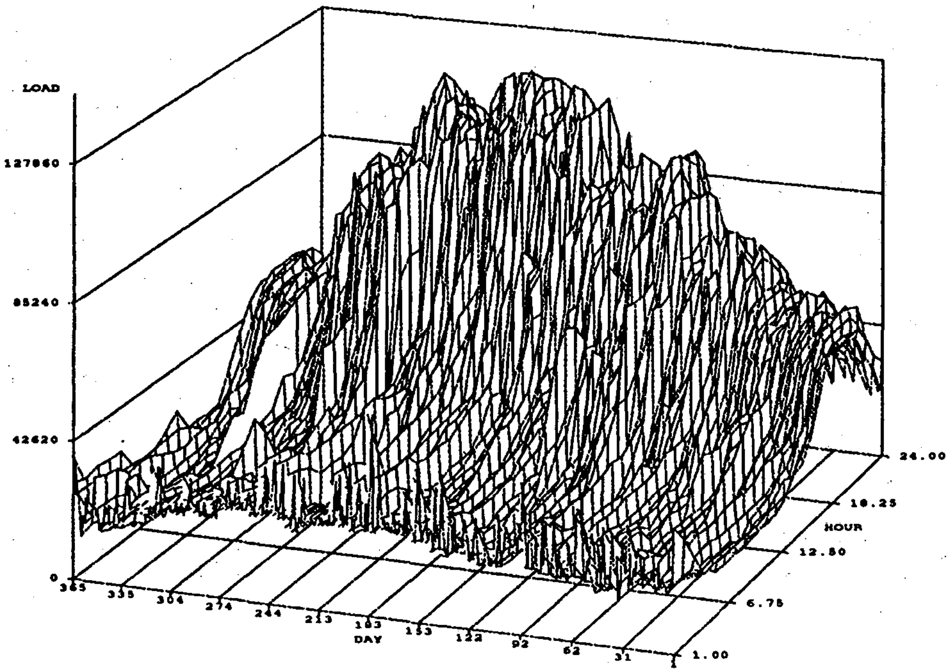
Sitdown Restaurant 8 Cooking



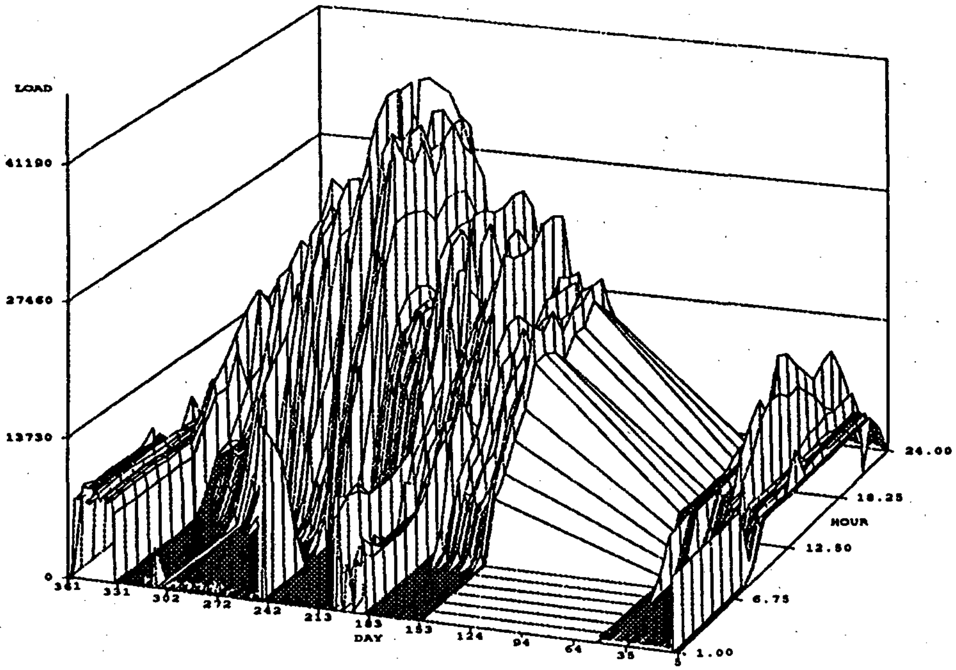
Sitdown Restaurant 8 Exhaust Fan



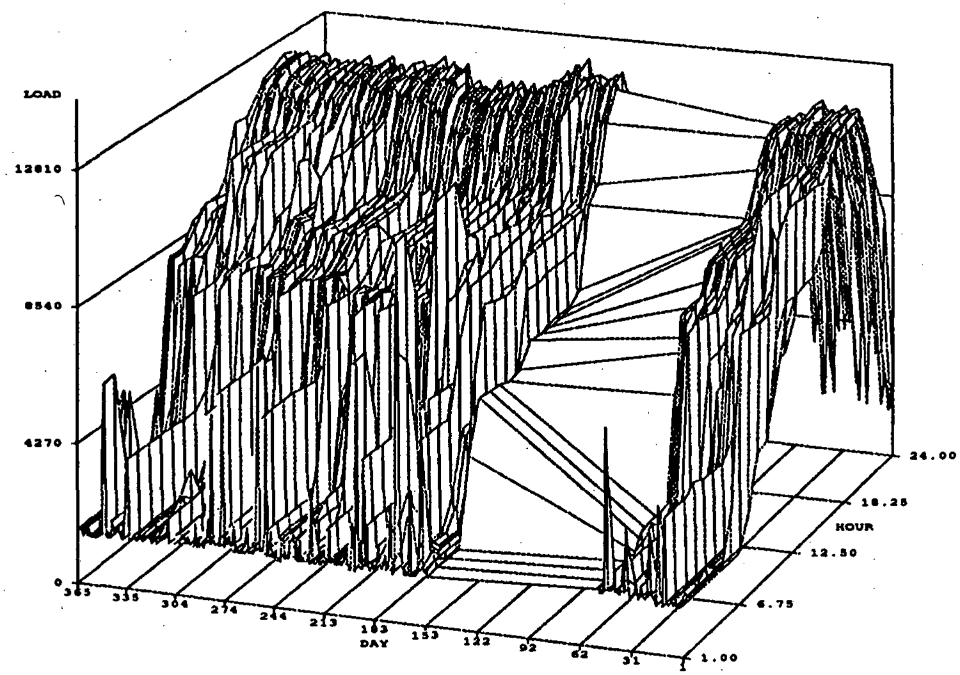
Sitdown Restaurant 8 Total



Sitdown Restaurant 9 HVAC



Sitdown Restaurant 9 Lighting



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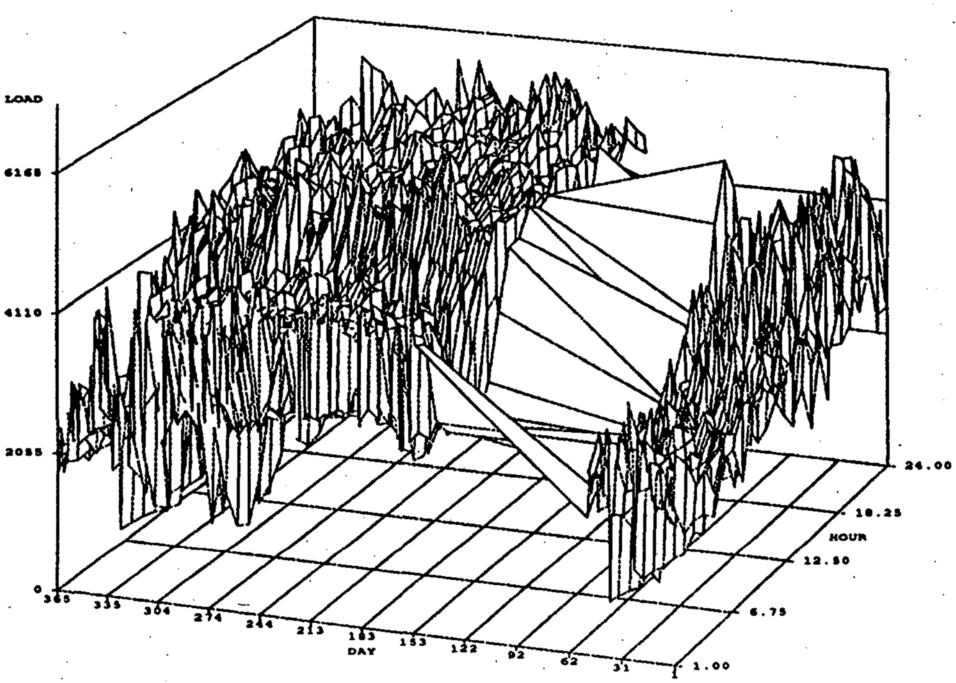
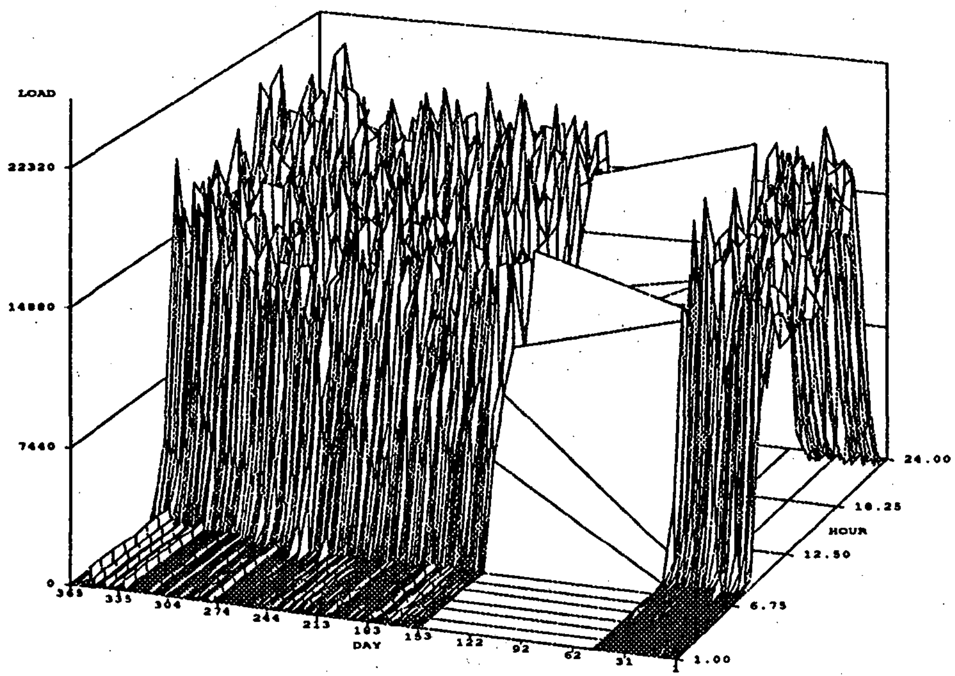
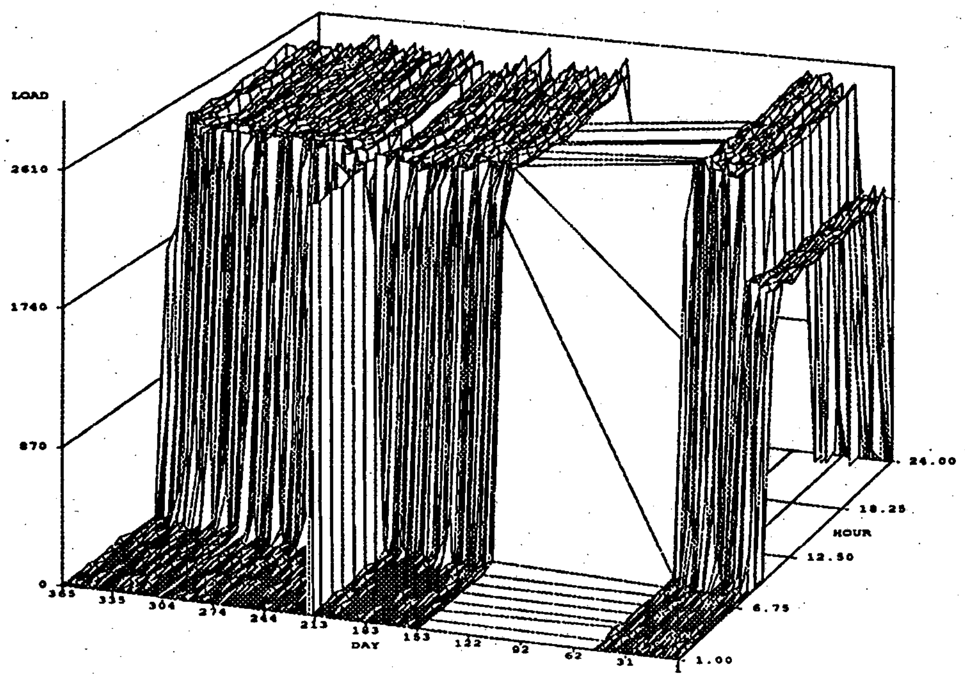


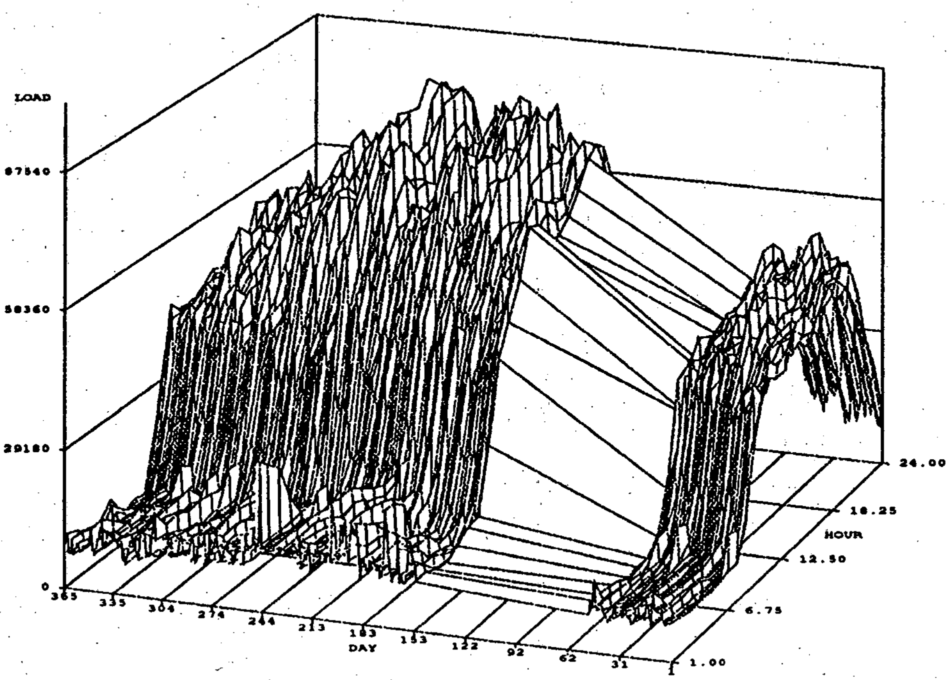
Sitdown Restaurant 9 Cooking



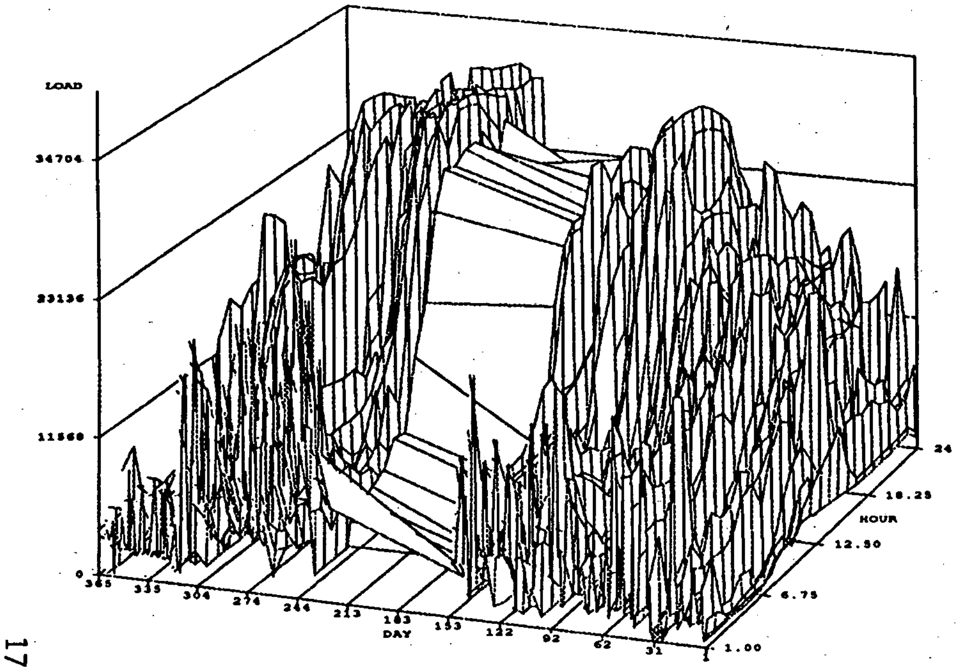
Sitdown Restaurant 9 Exhaust Fan



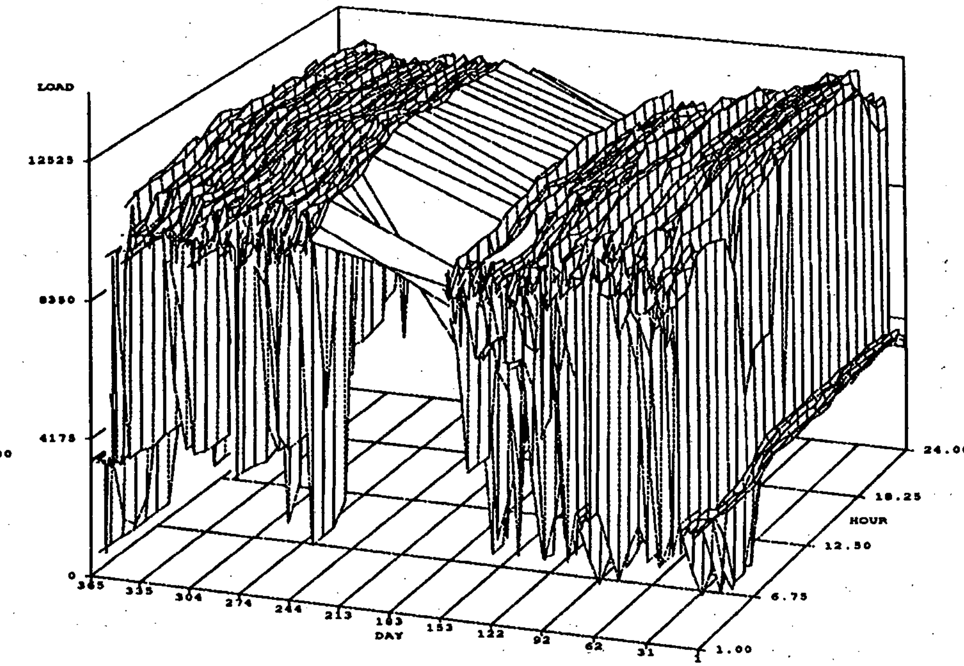
Sitdown Restaurant 9 Total



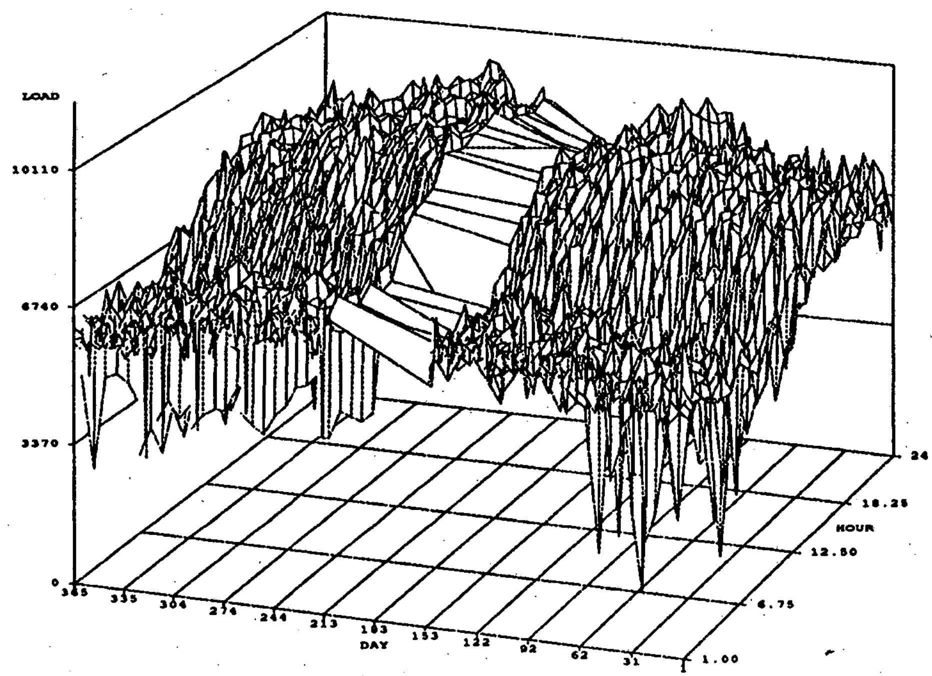
Sitdown Restaurant 10 HVAC



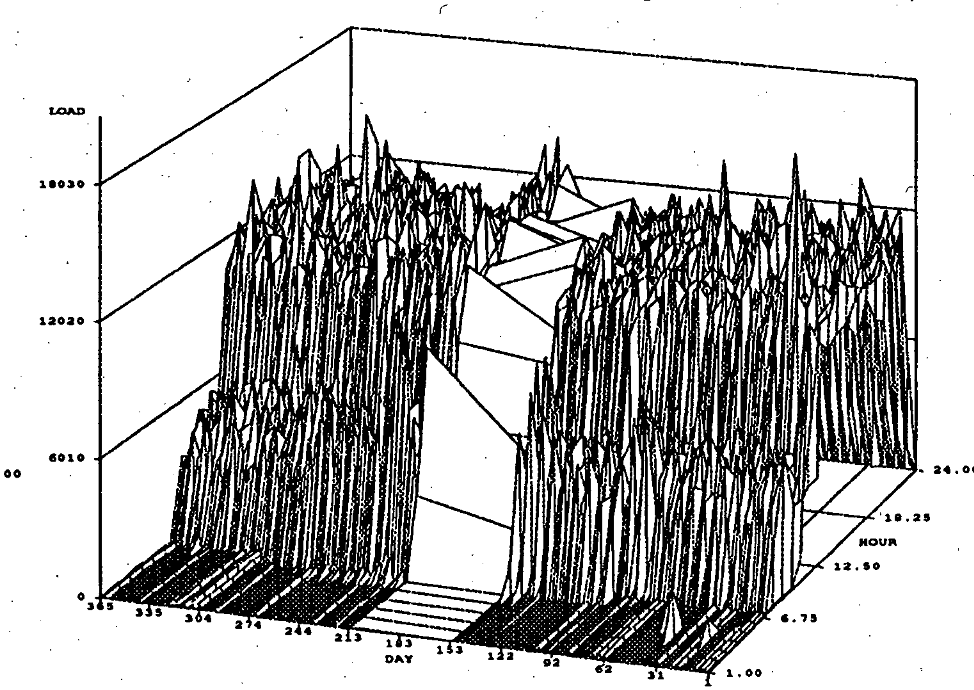
Sitdown Restaurant 10 Lighting



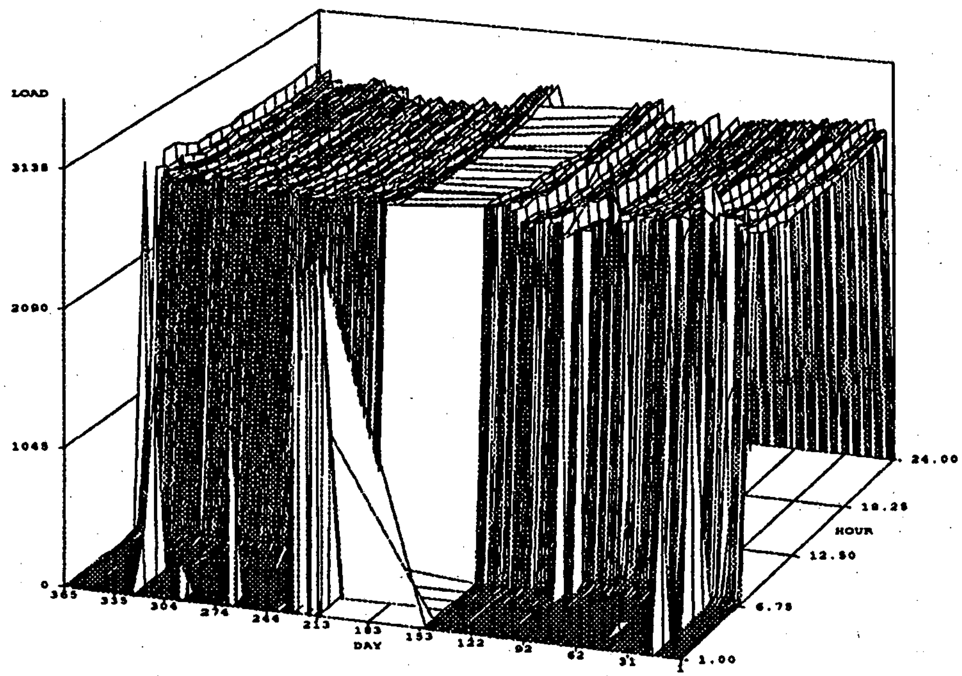
Sitdown Restaurant 10 Refrigeration



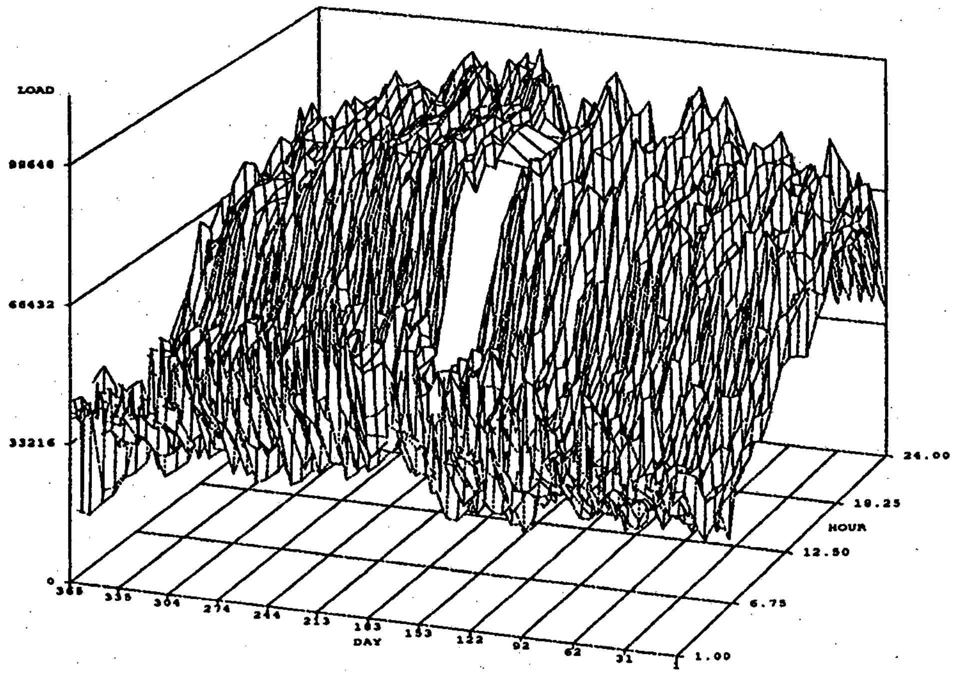
Sitdown Restaurant 10 Cooking



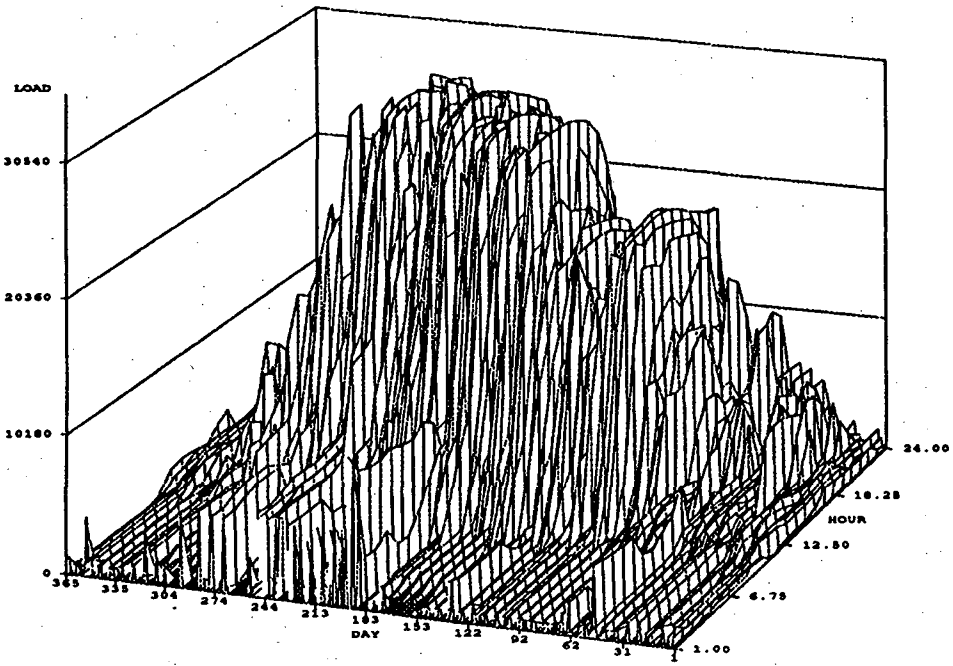
Sitdown Restaurant 10 Exhaust Fan



Sitdown Restaurant 10 Total



Sitdown Restaurant 12 HVAC



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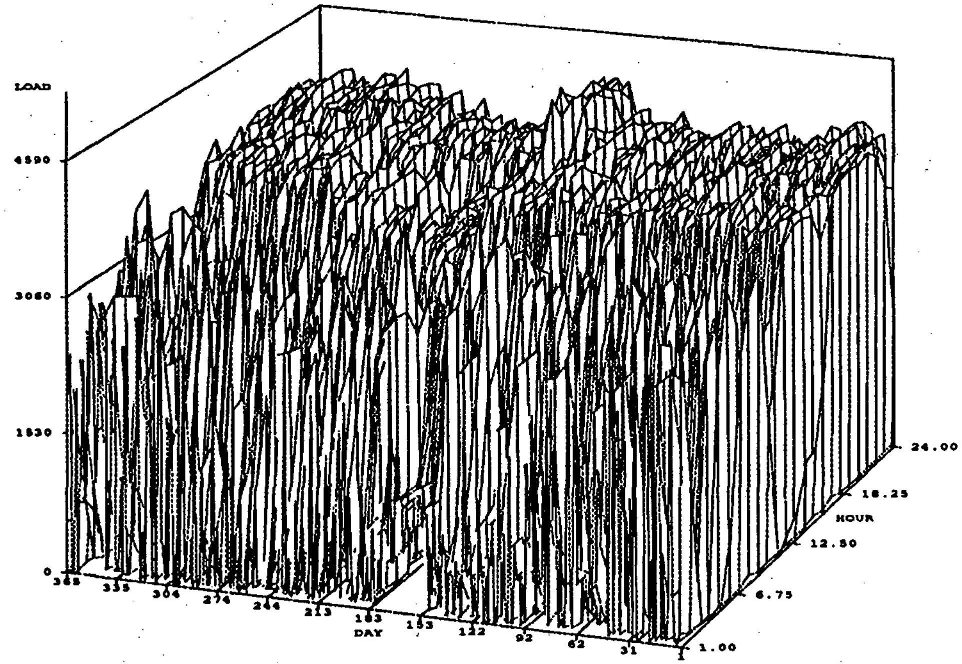

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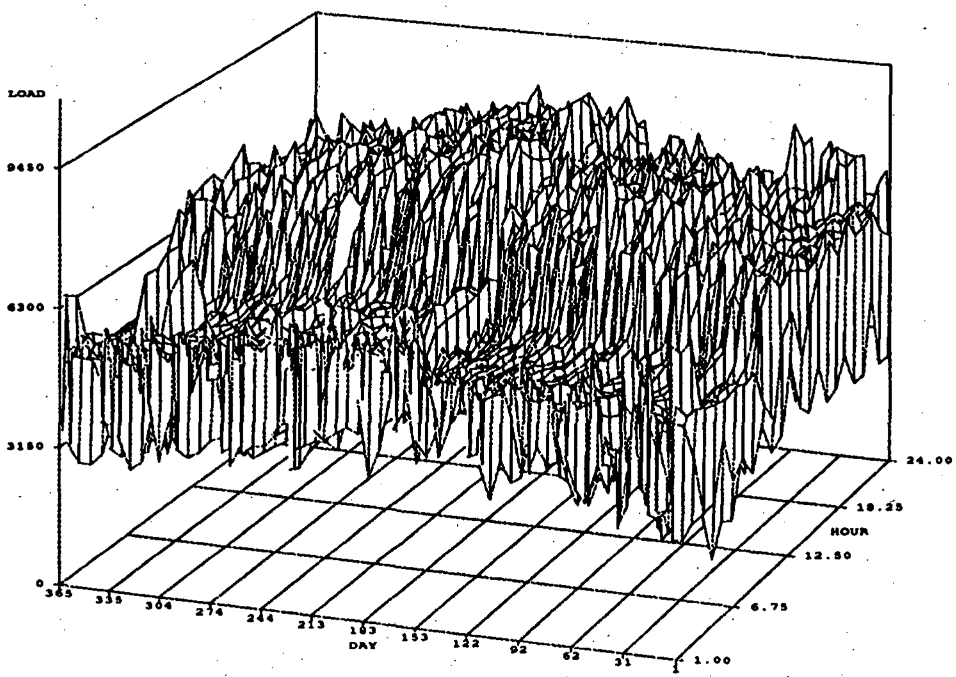

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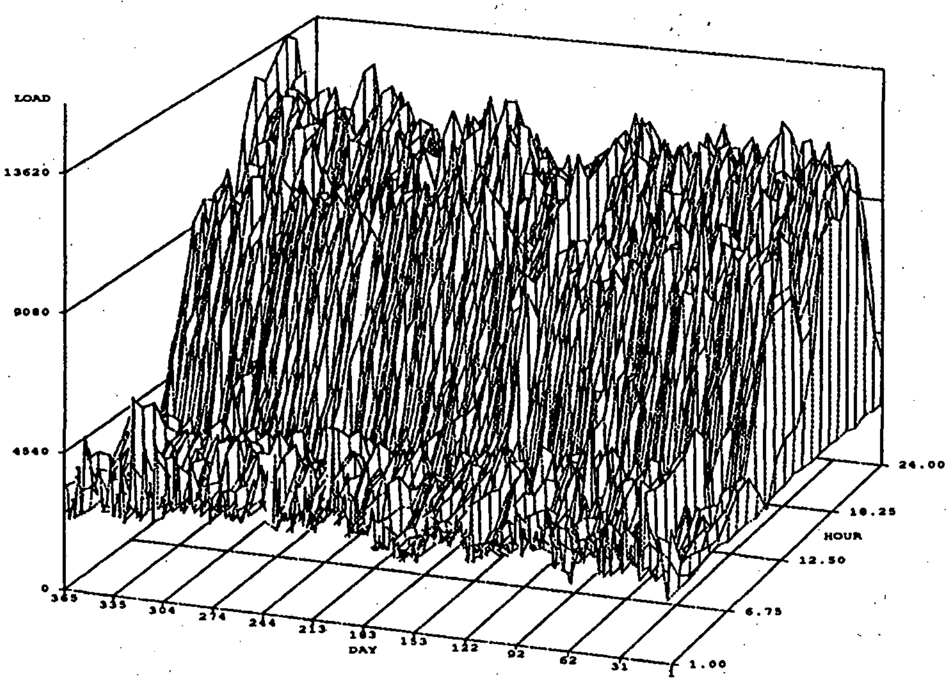
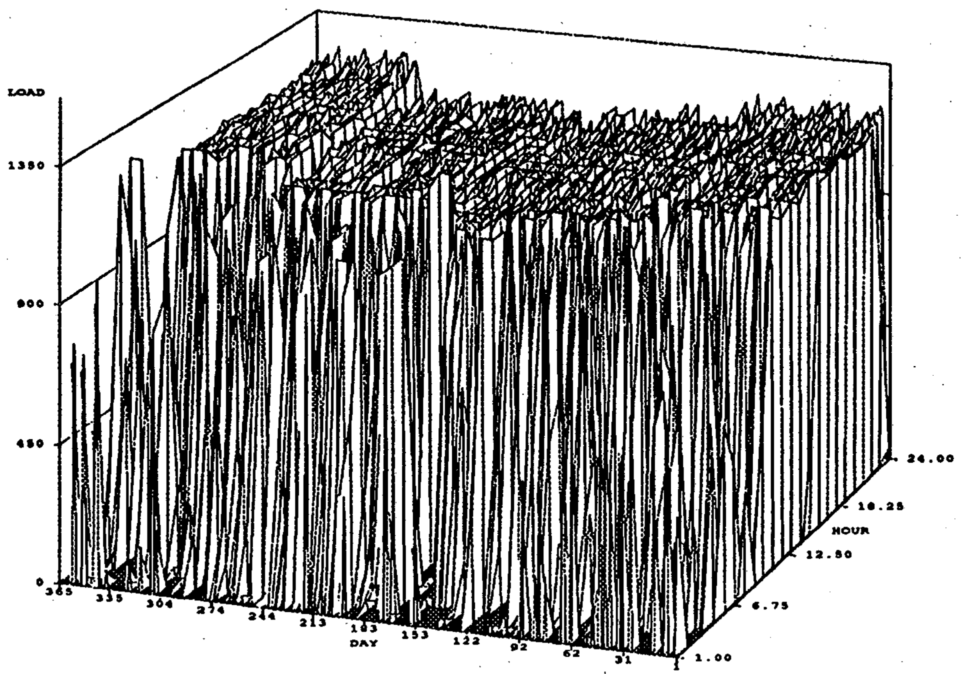
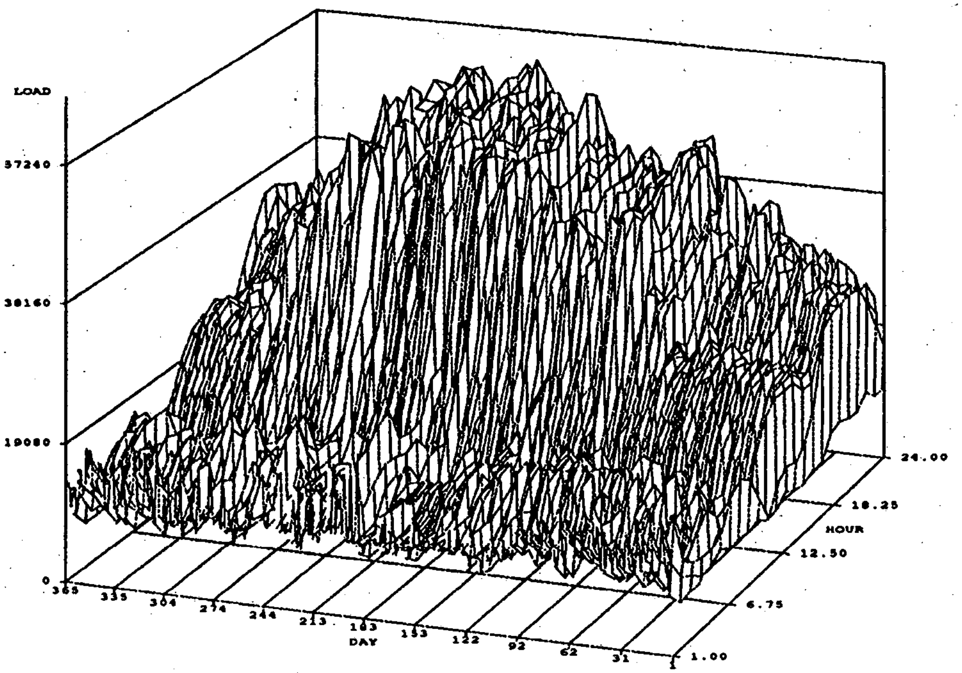


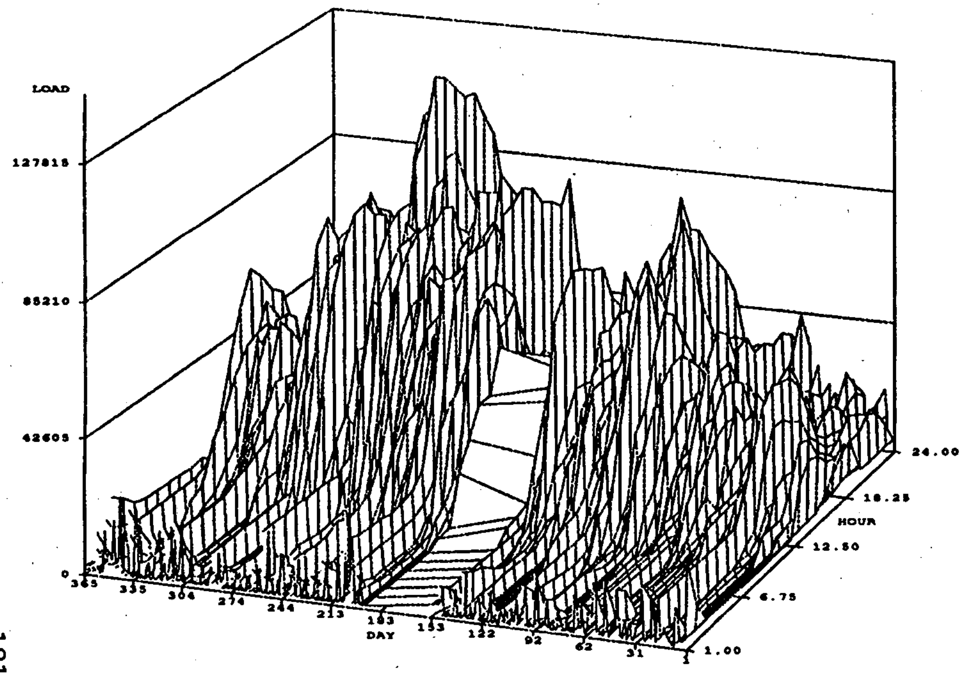
Sitdown Restaurant 12 Exhaust Fan



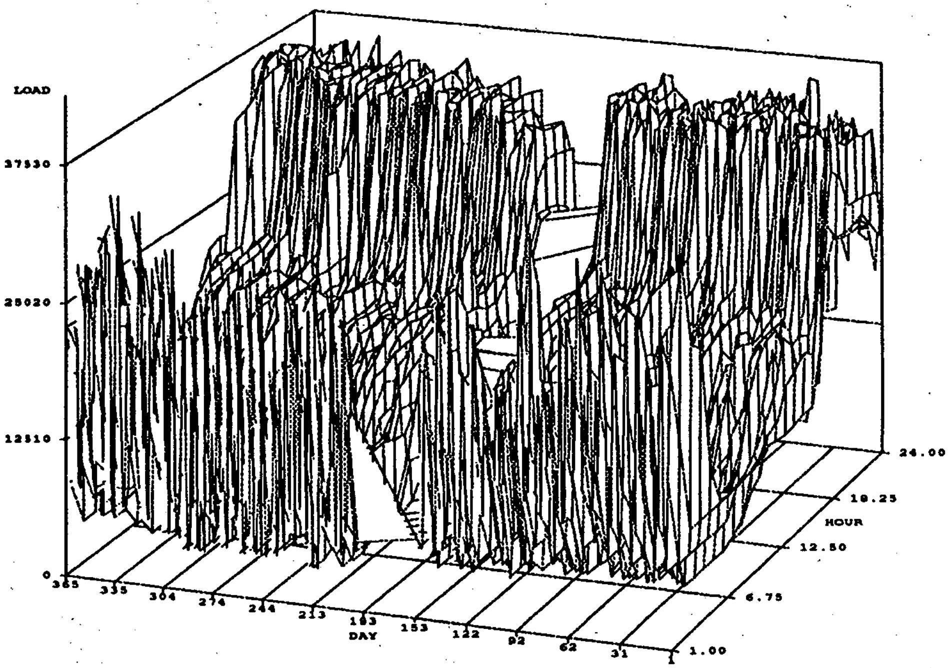
Sitdown Restaurant 12 Total



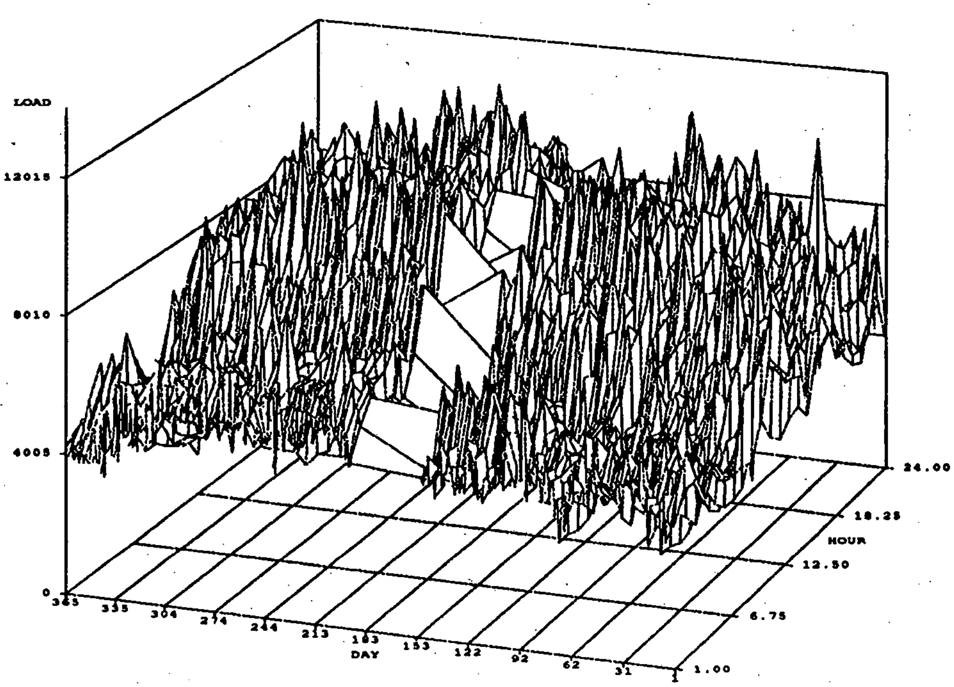
Sitdown Restaurant 14 HVAC



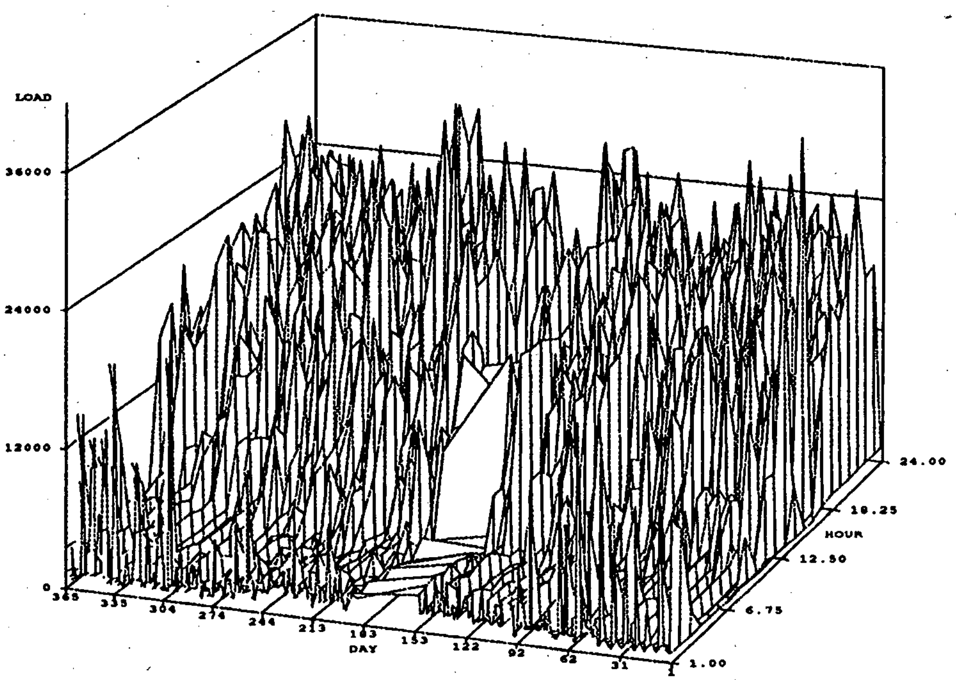
Sitdown Restaurant 14 Lighting



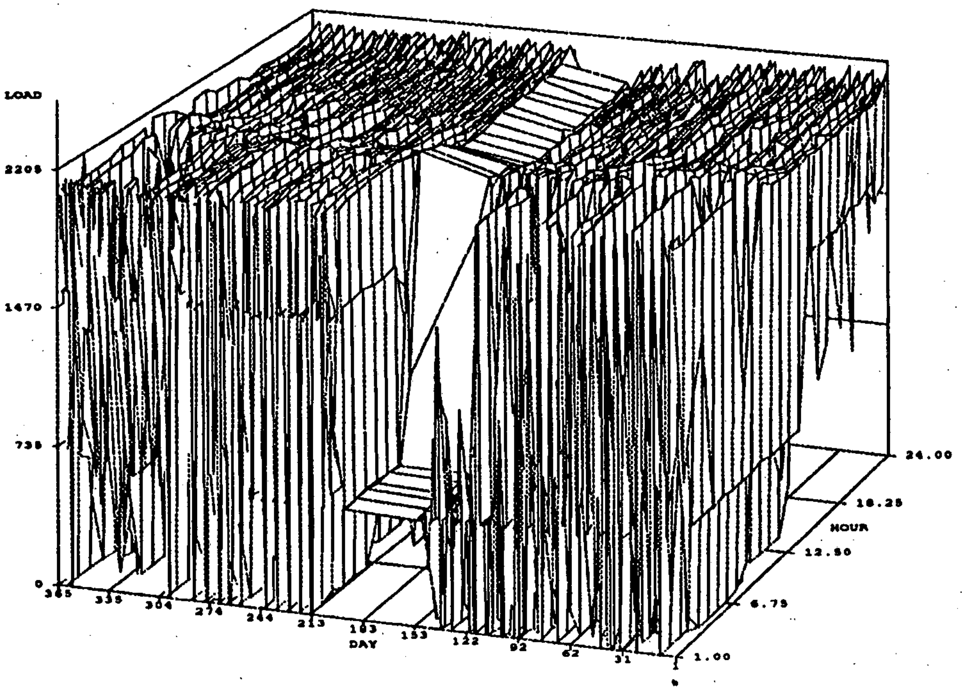
Sitdown Restaurant 14 Refrigeration



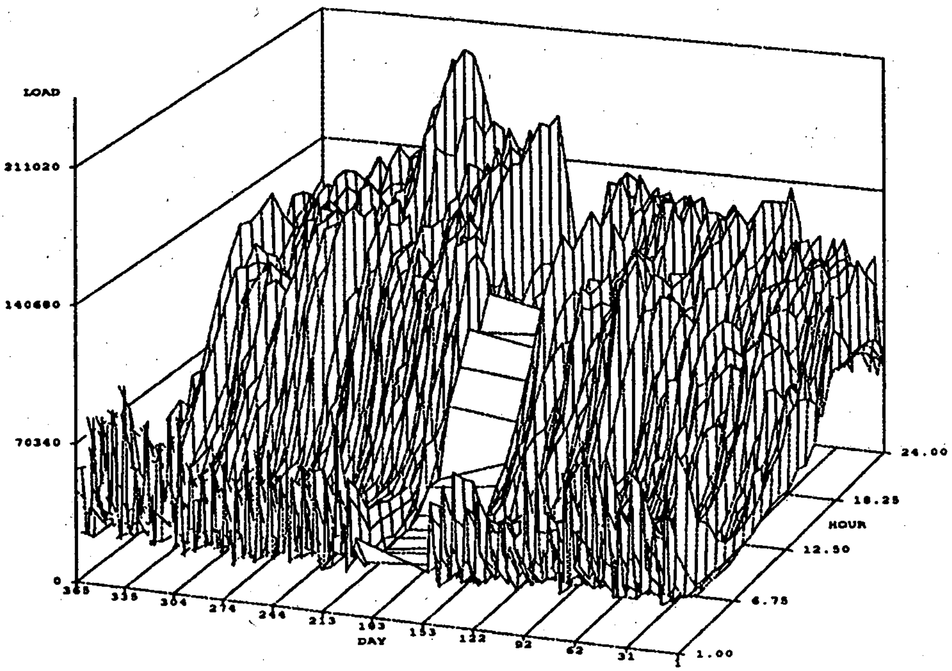
Sitdown Restaurant 14 Cooking



Sitdown Restaurant 14 Exhaust Fan



Sitdown Restaurant 14 Total



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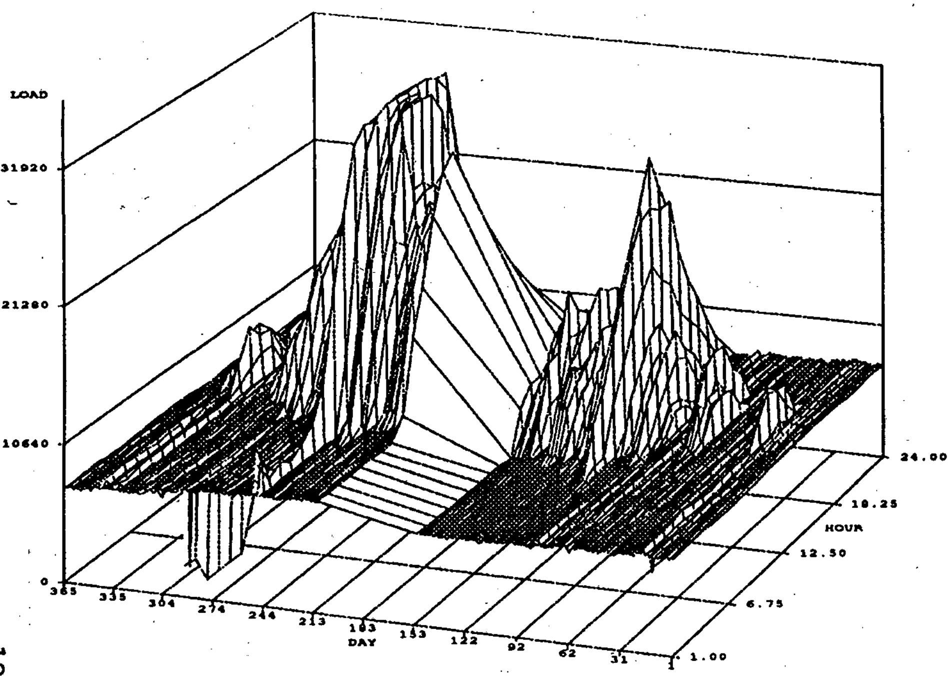
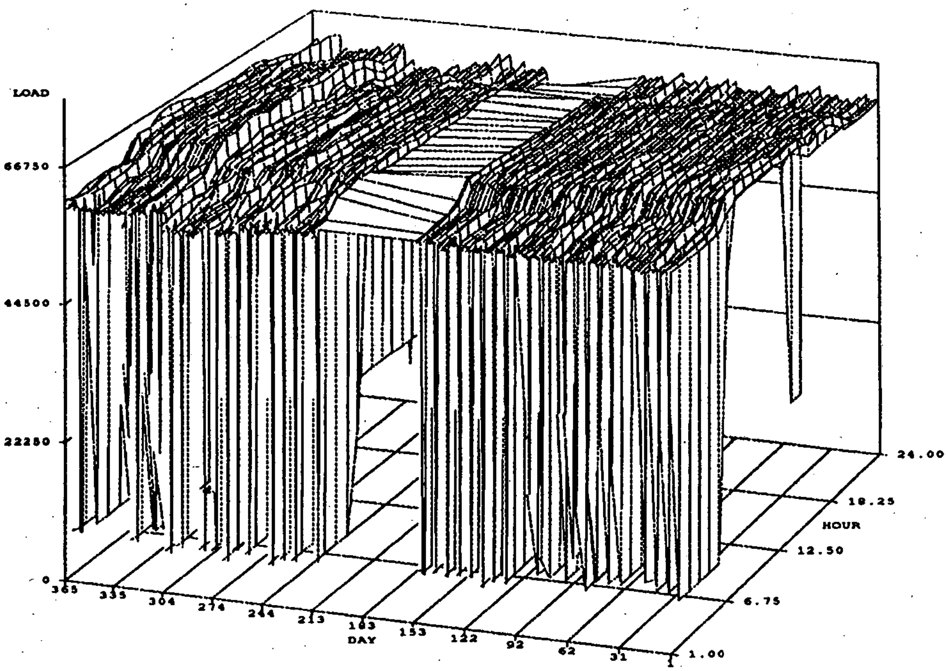


Grocery 1 Lighting



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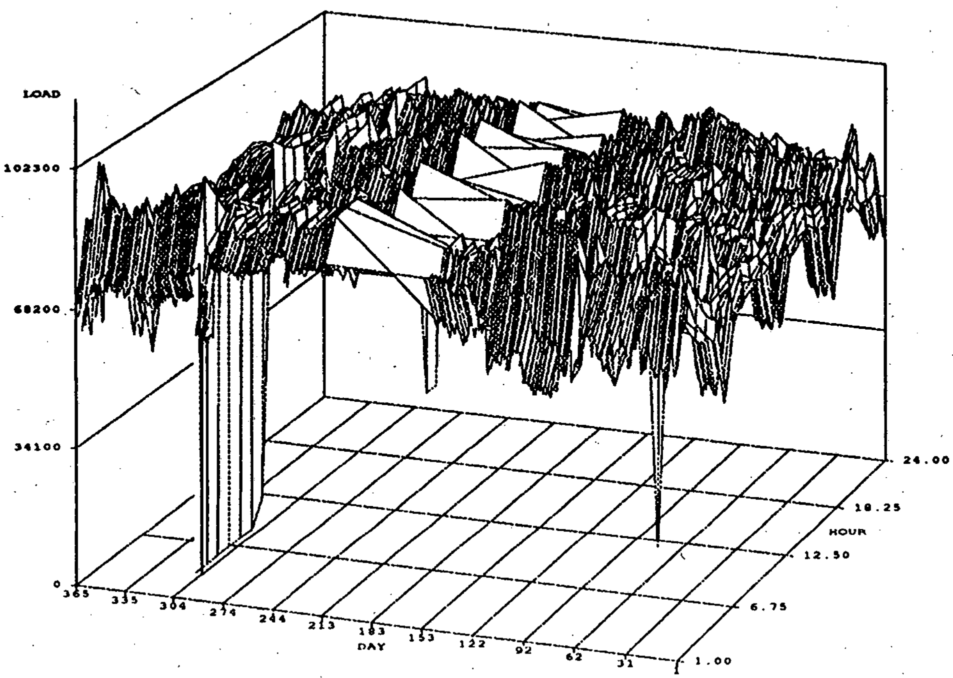
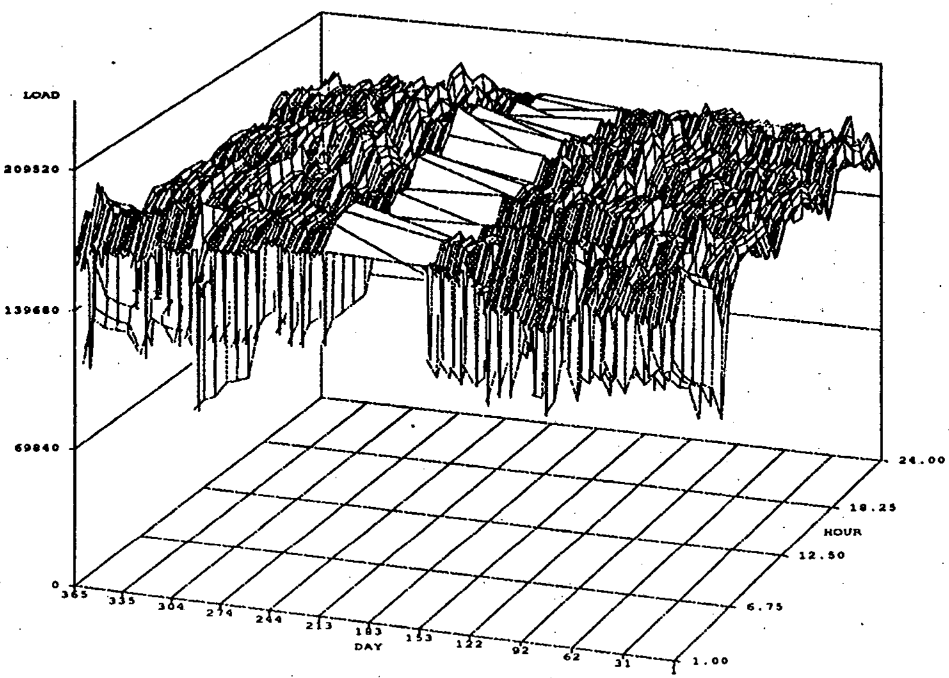


Grocery 1 Total



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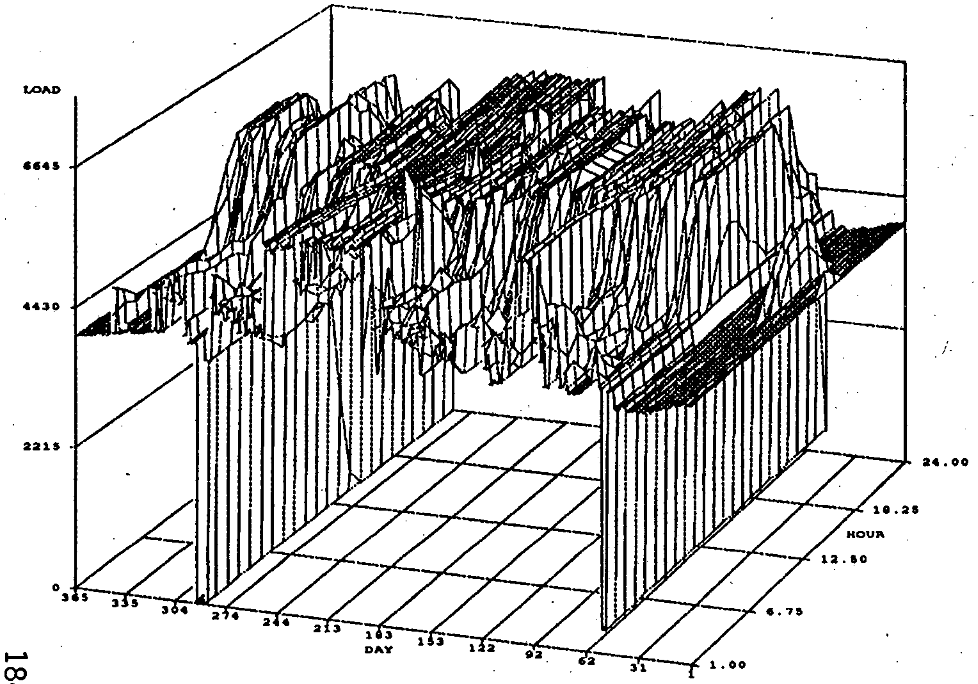

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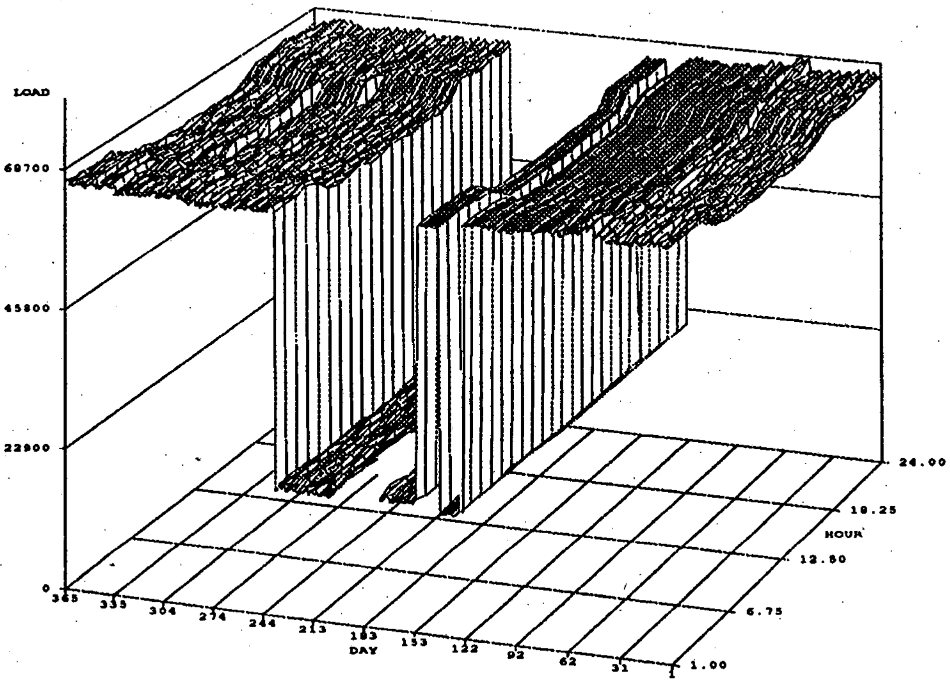

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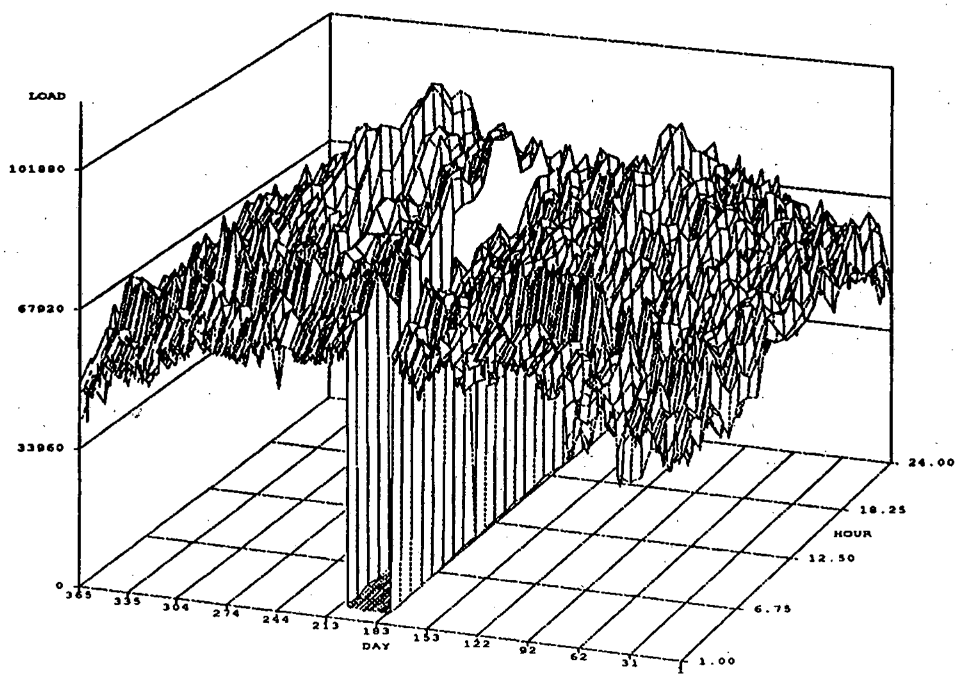

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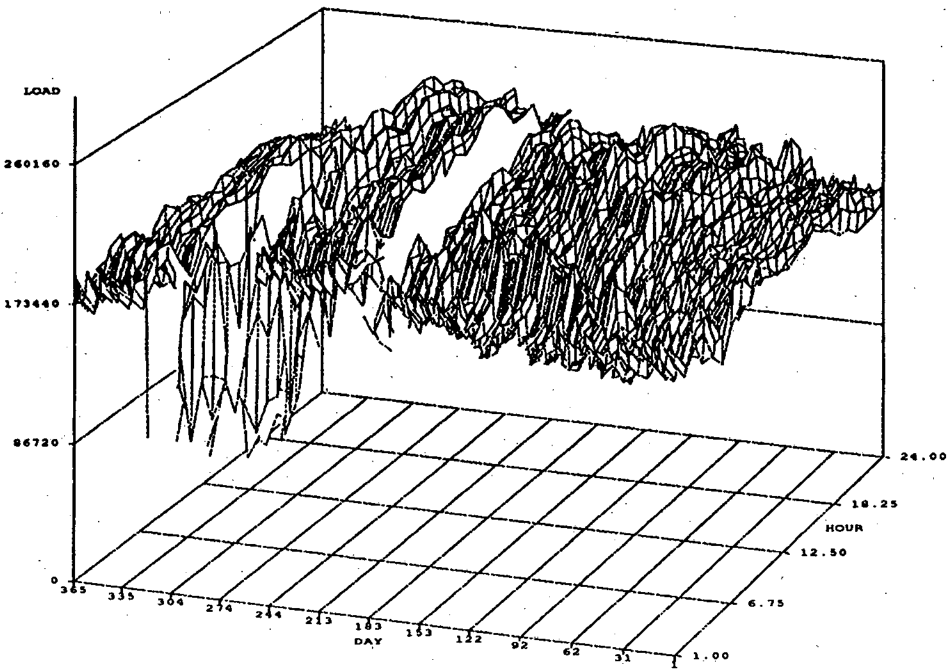

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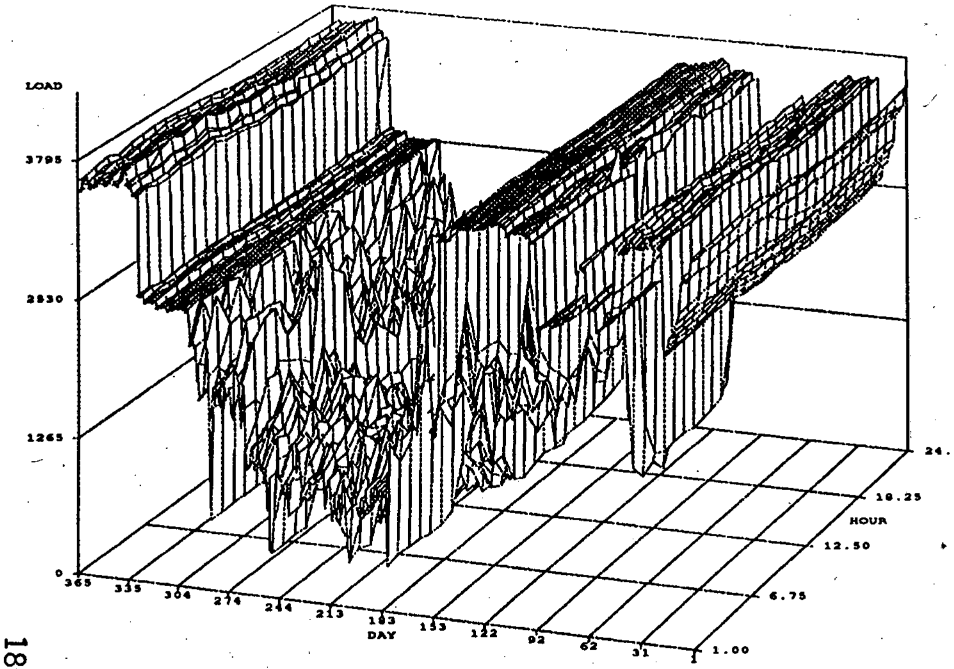

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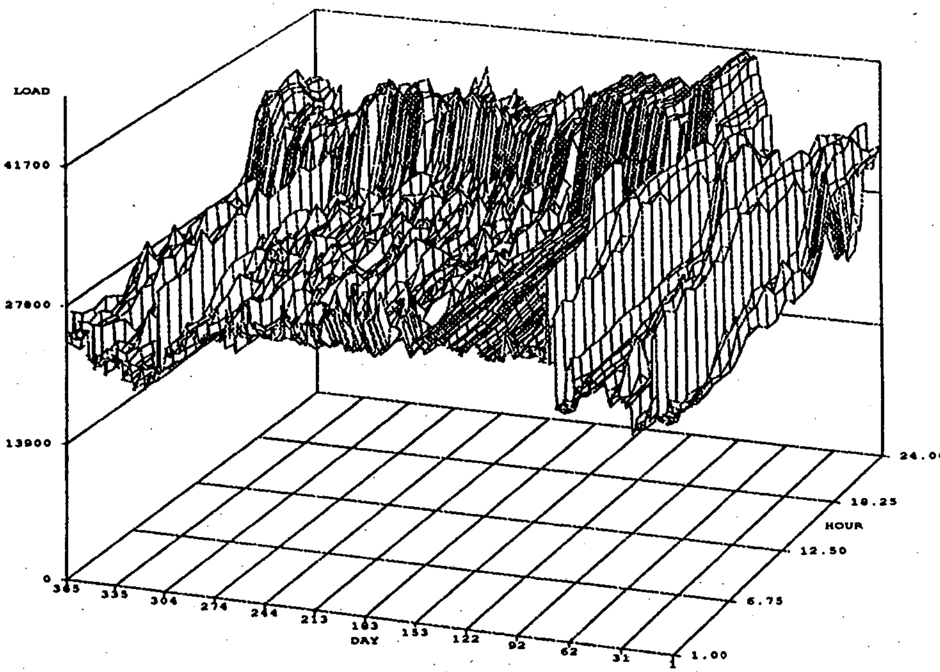

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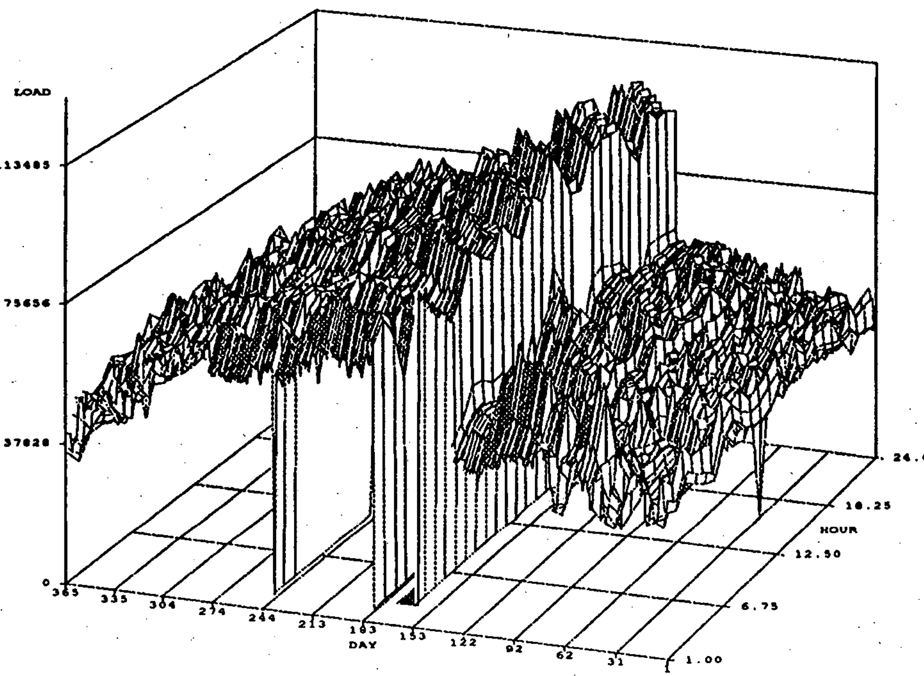

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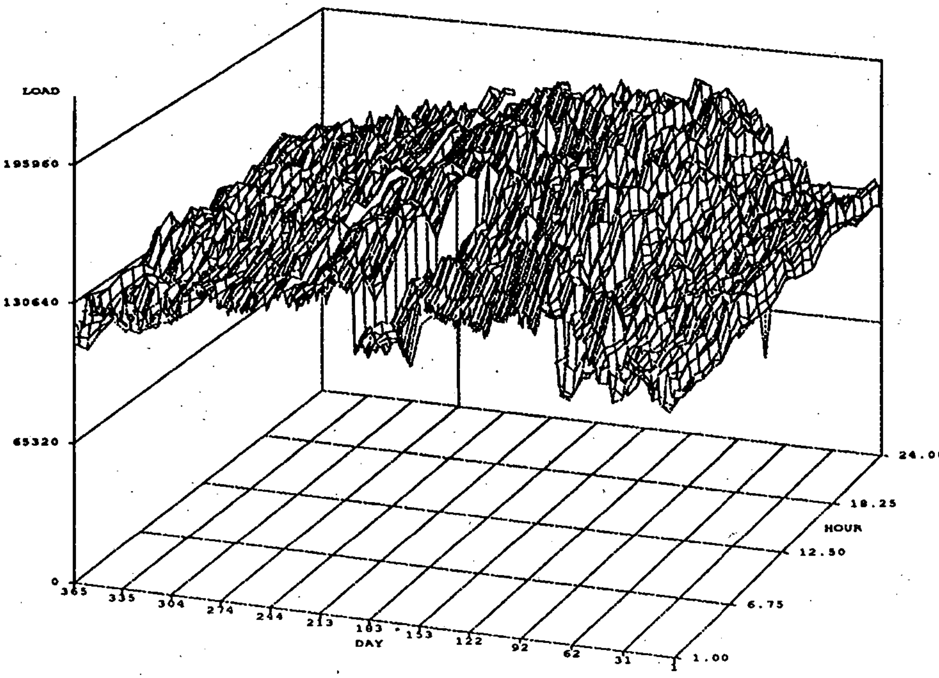

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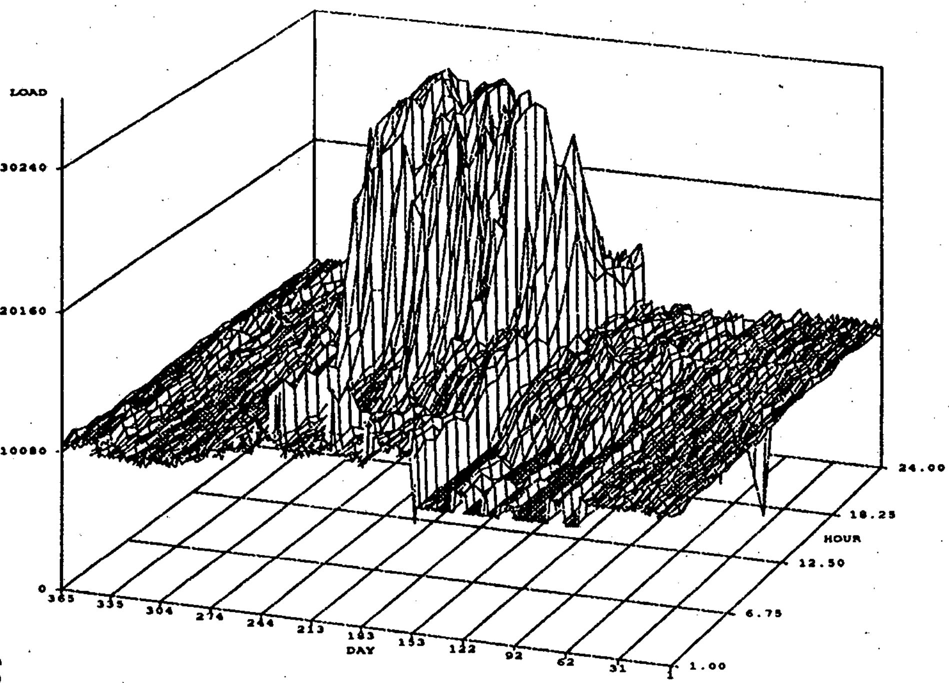

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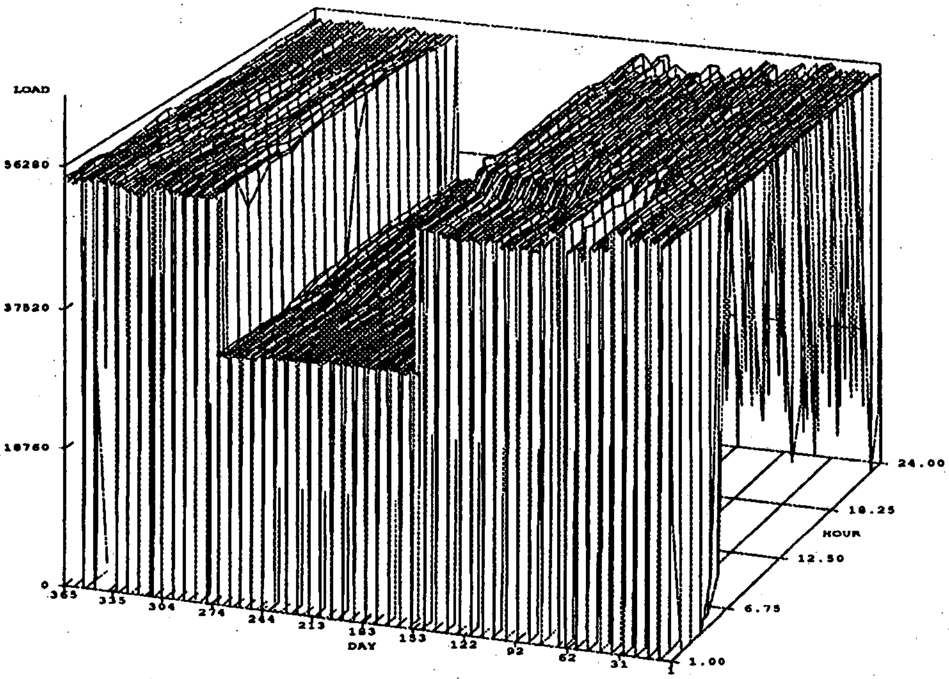

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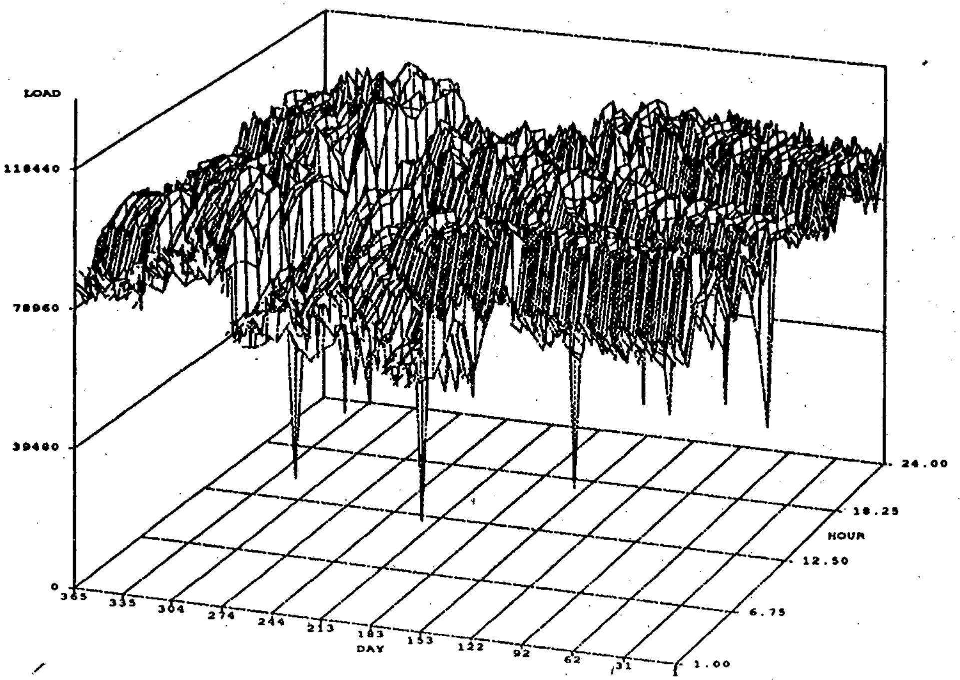

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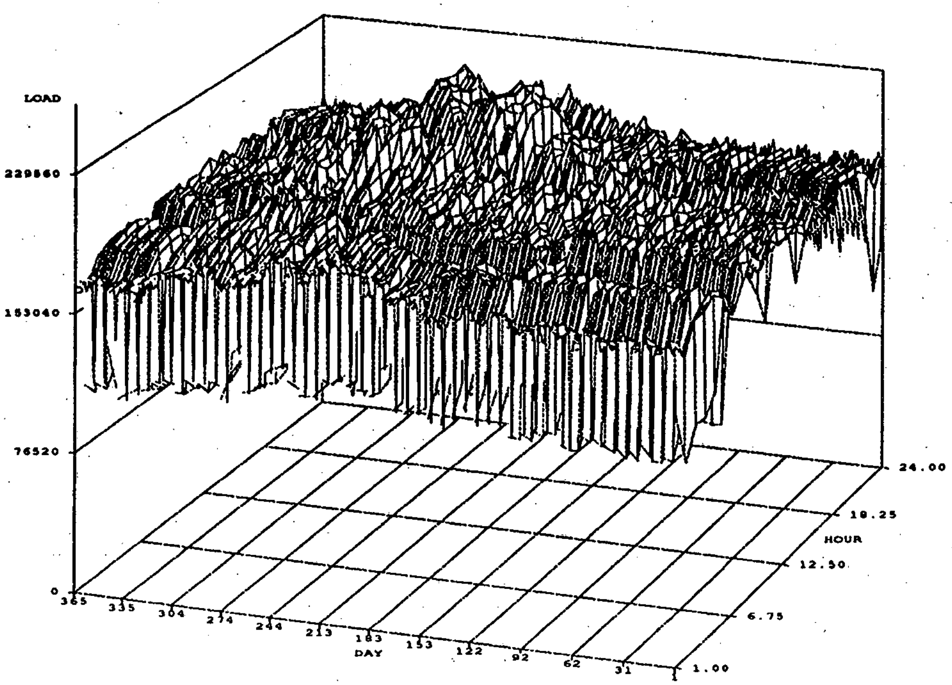

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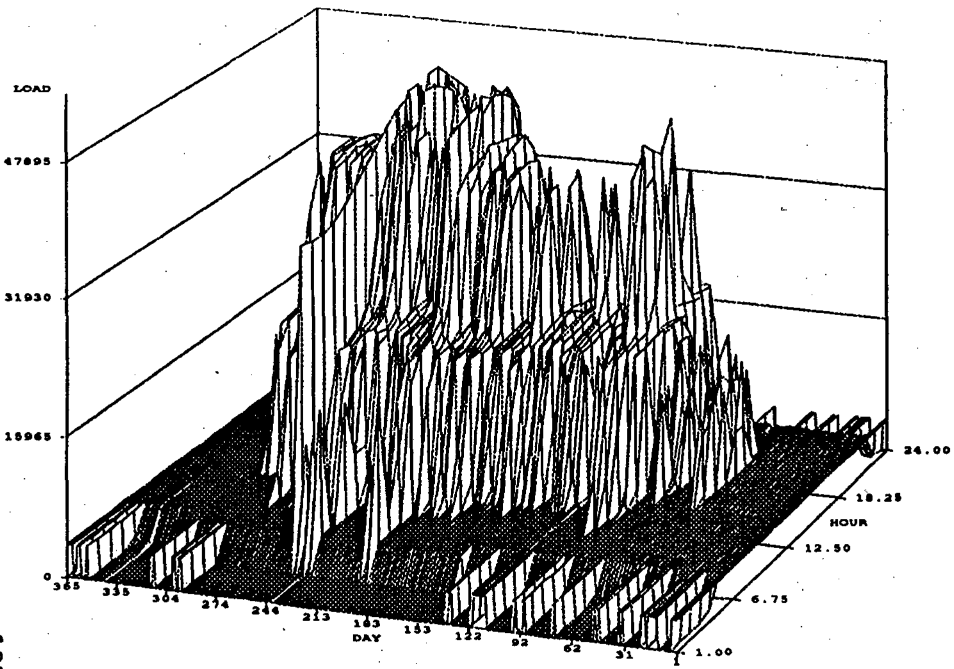

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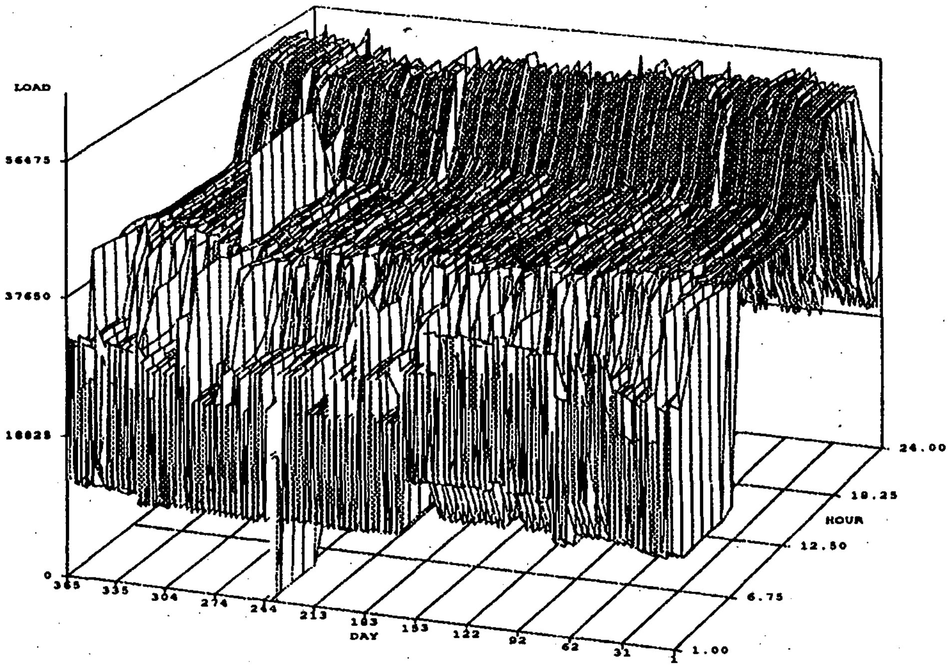

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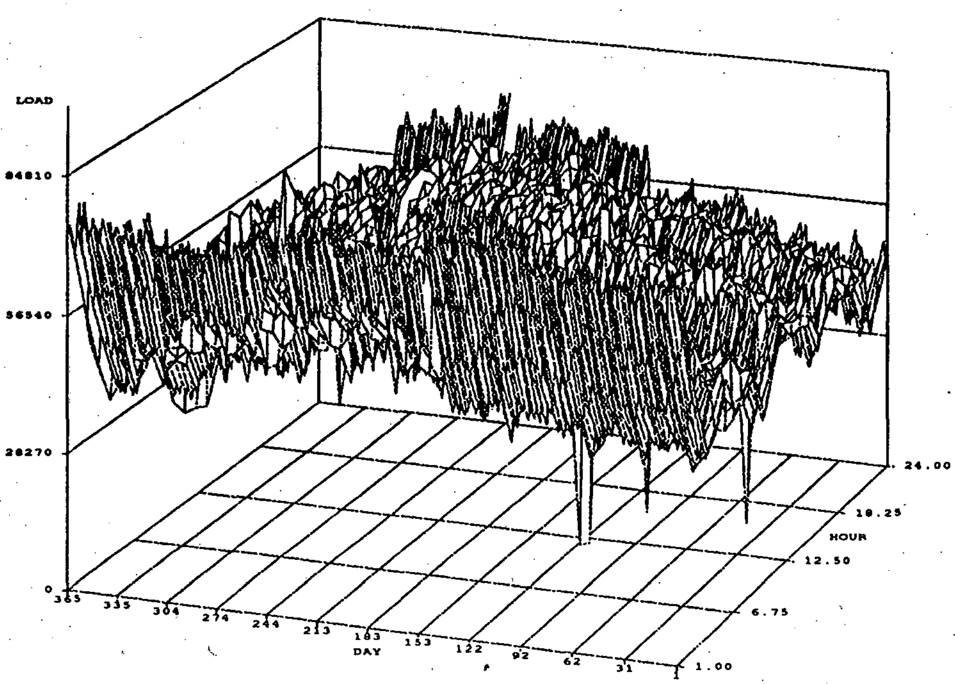

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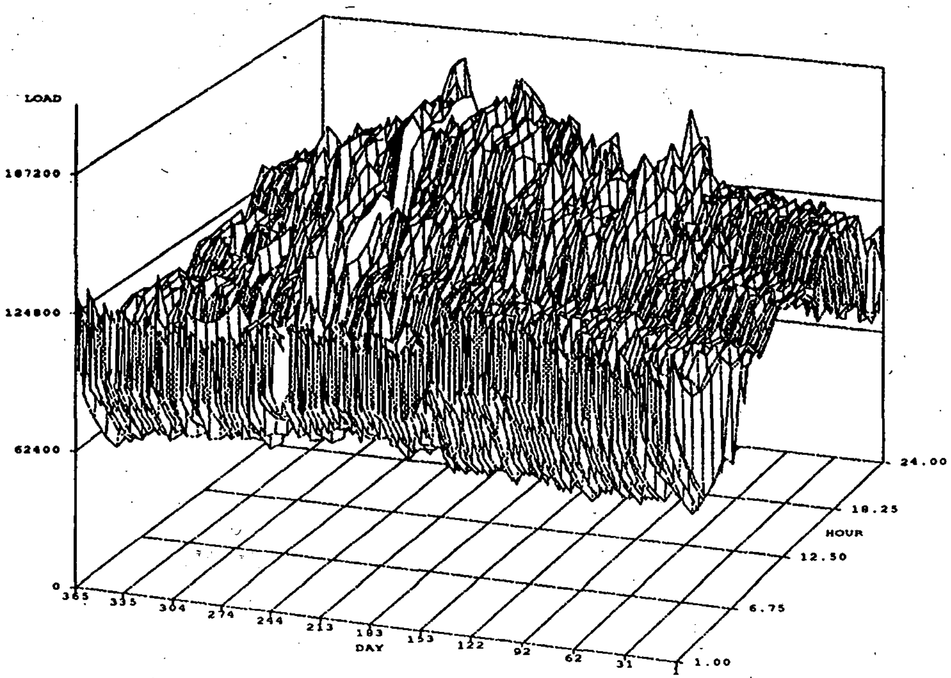

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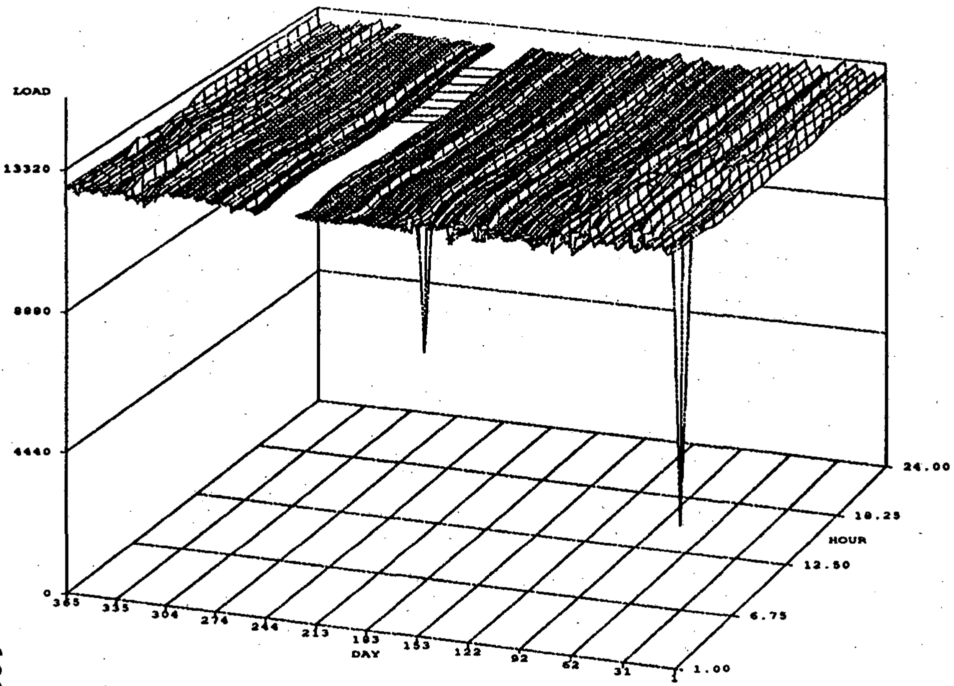

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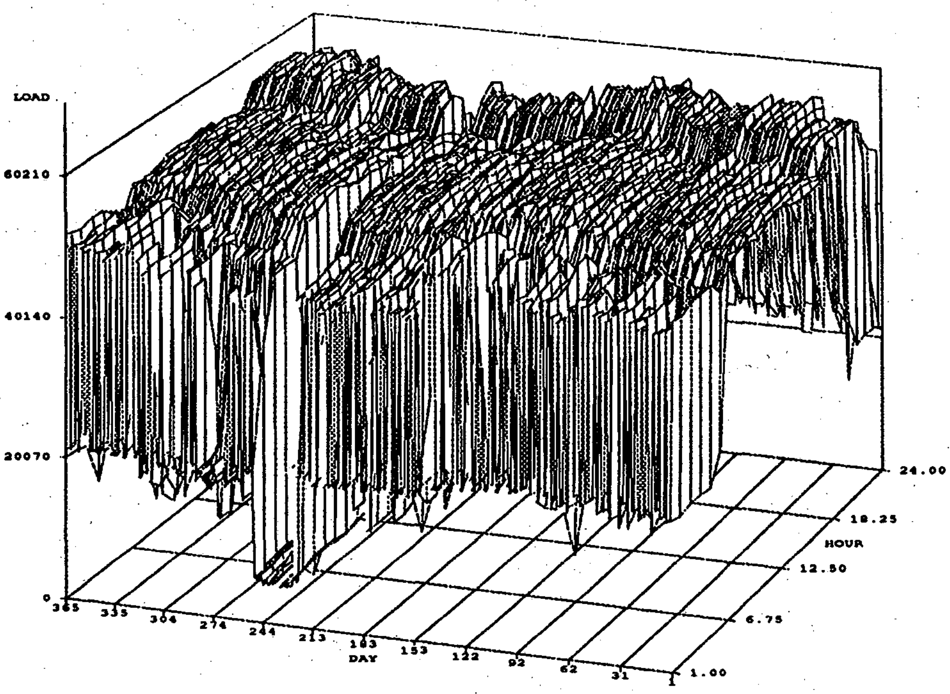

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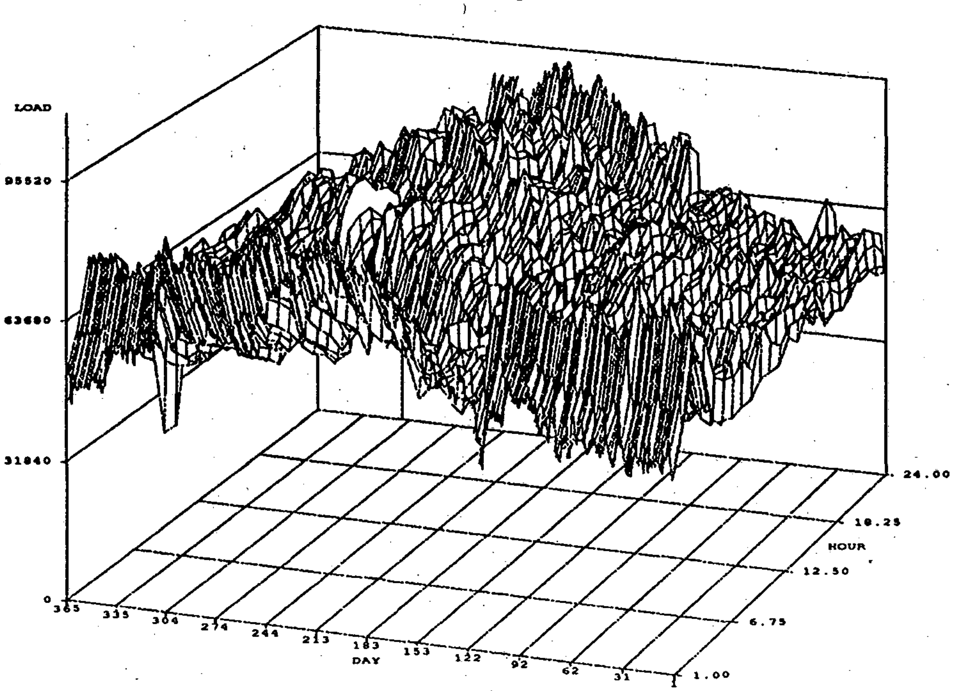

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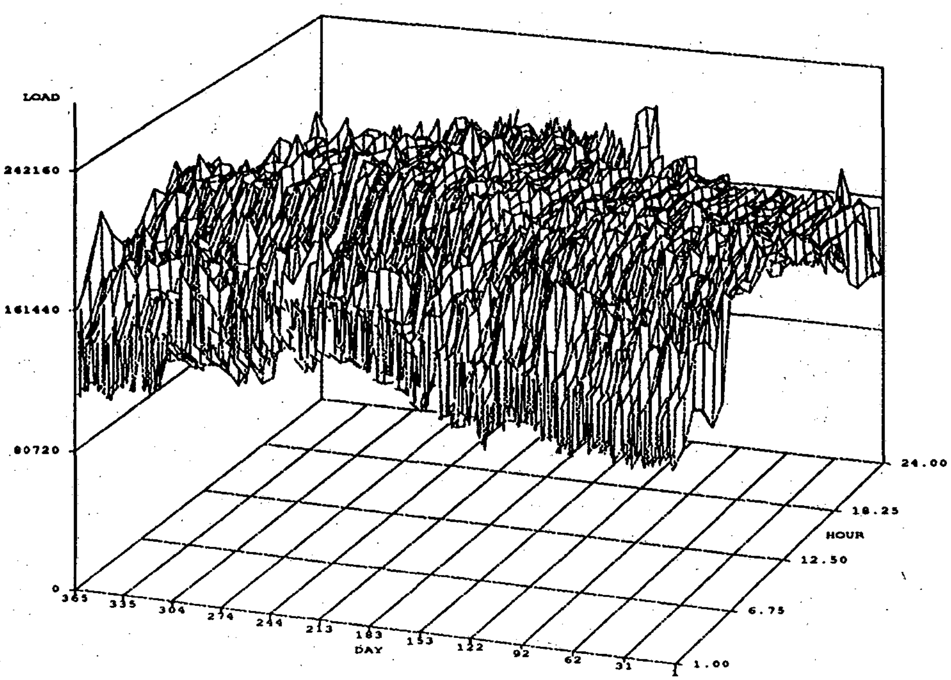

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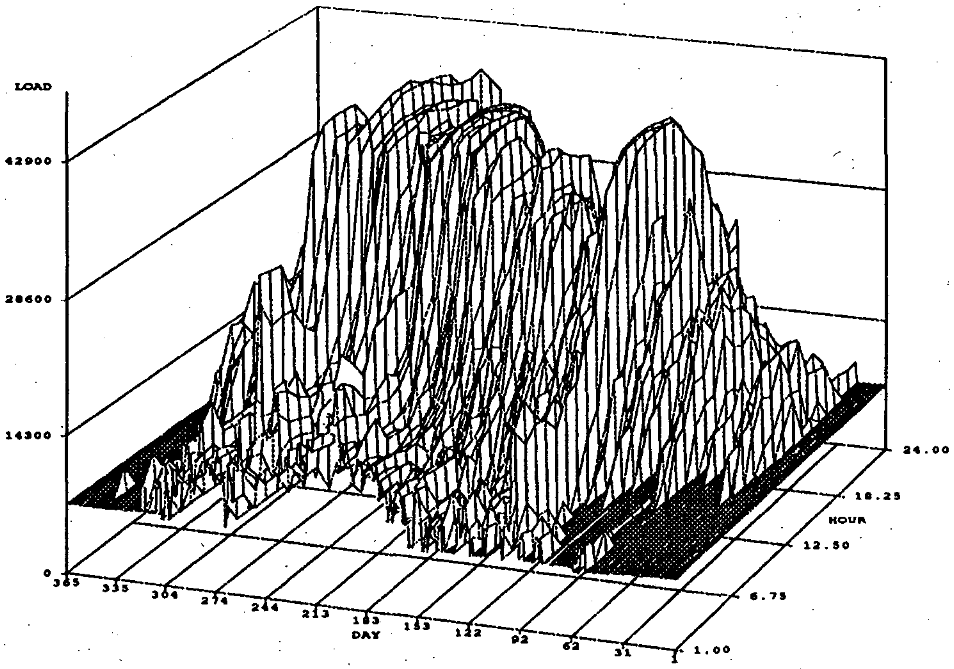

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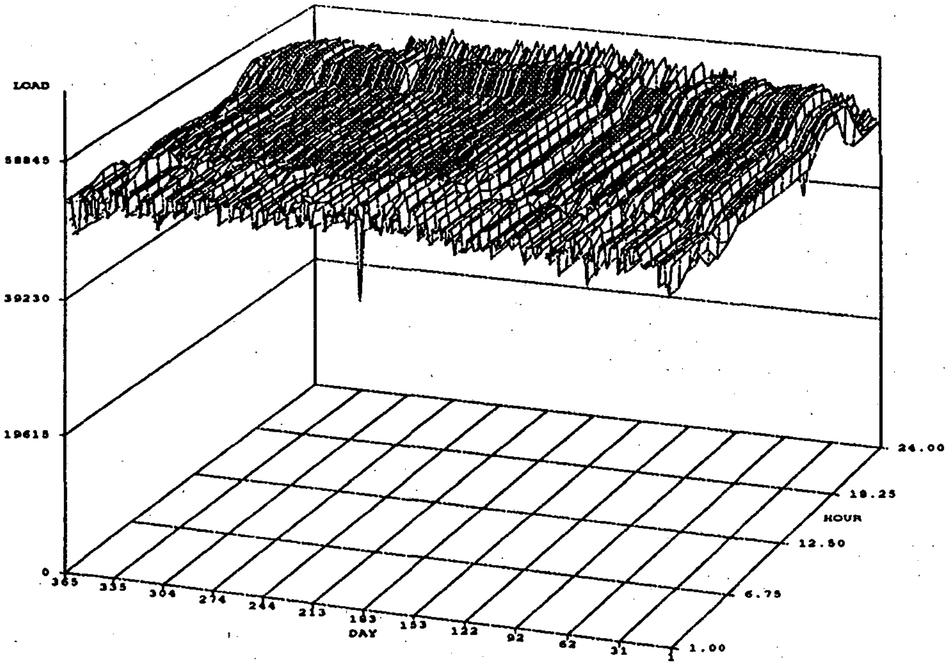

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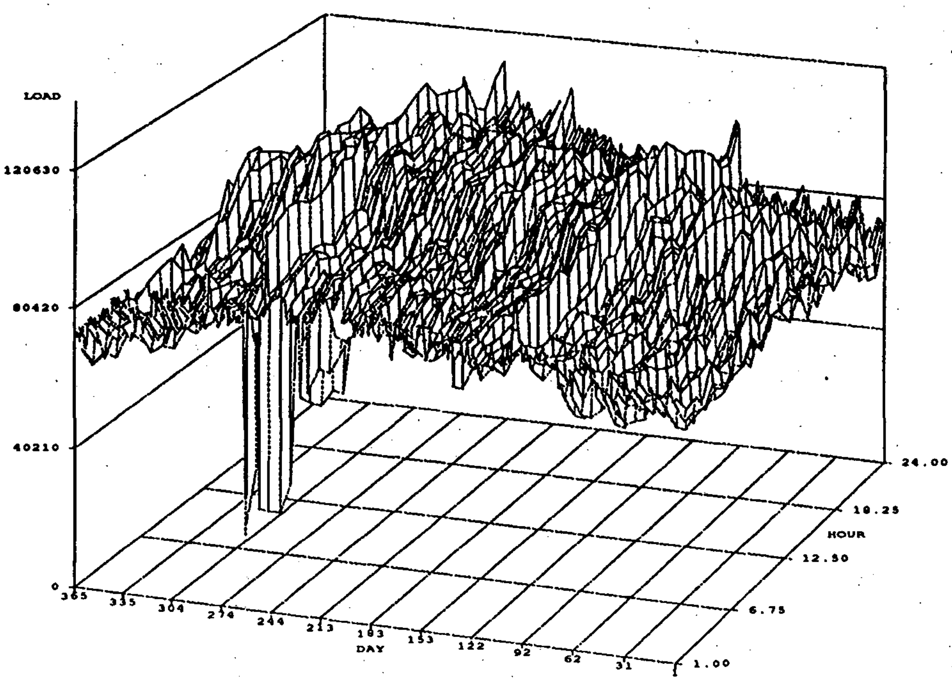

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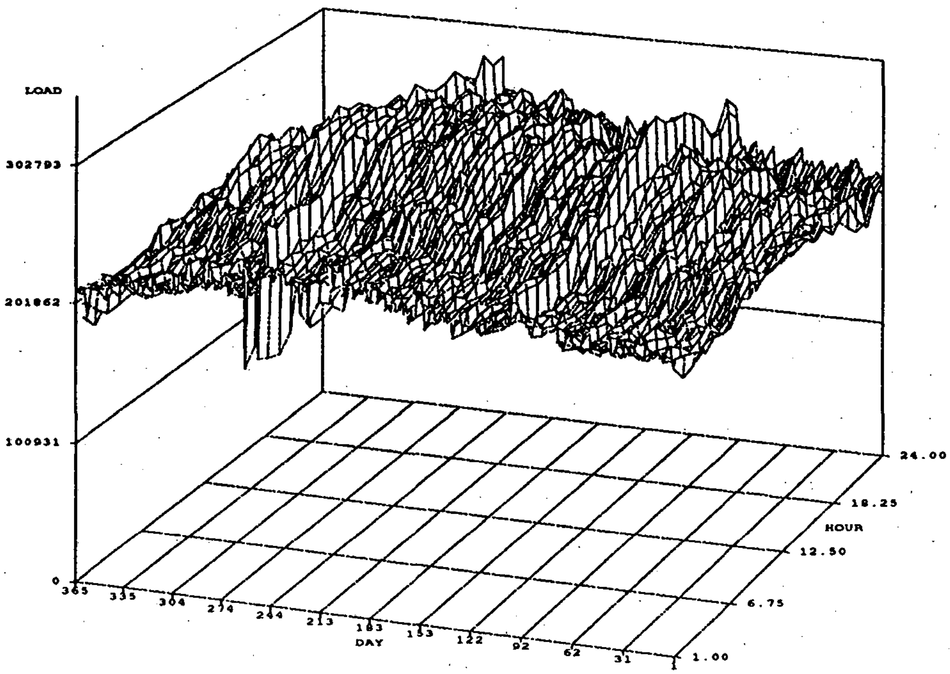

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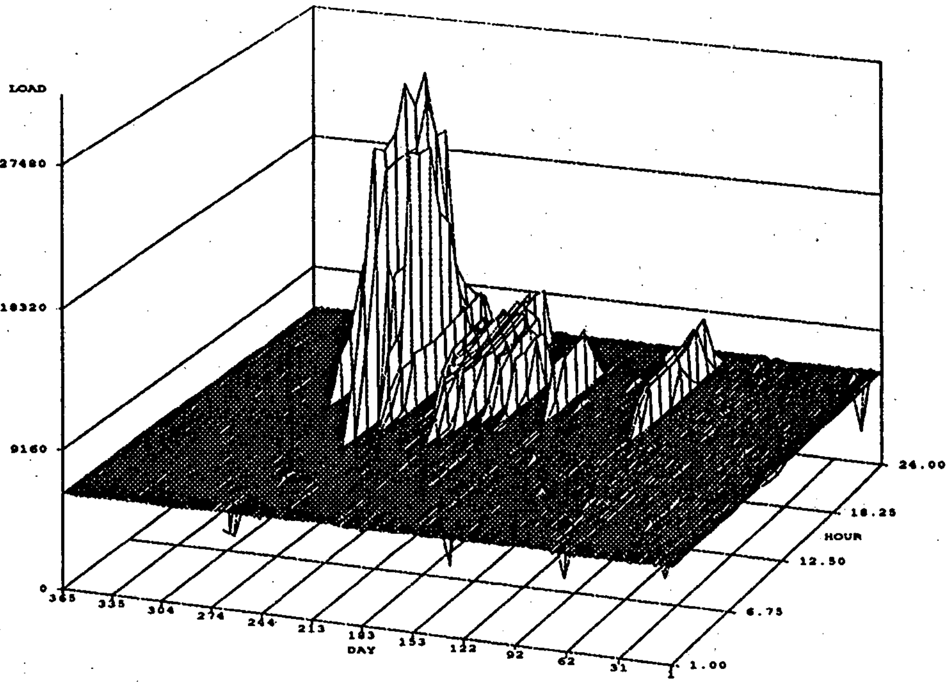

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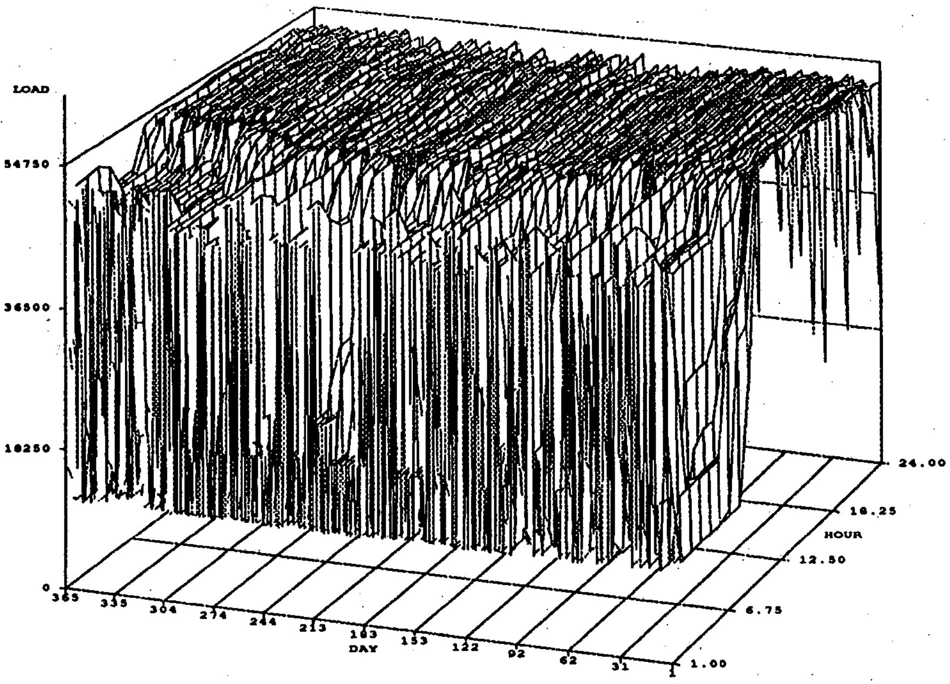

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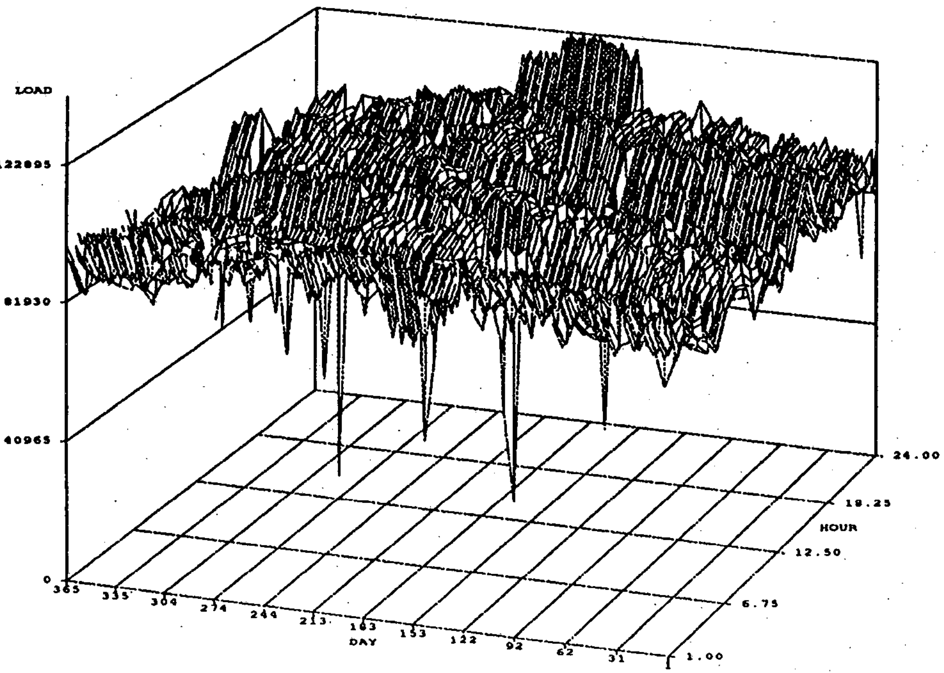

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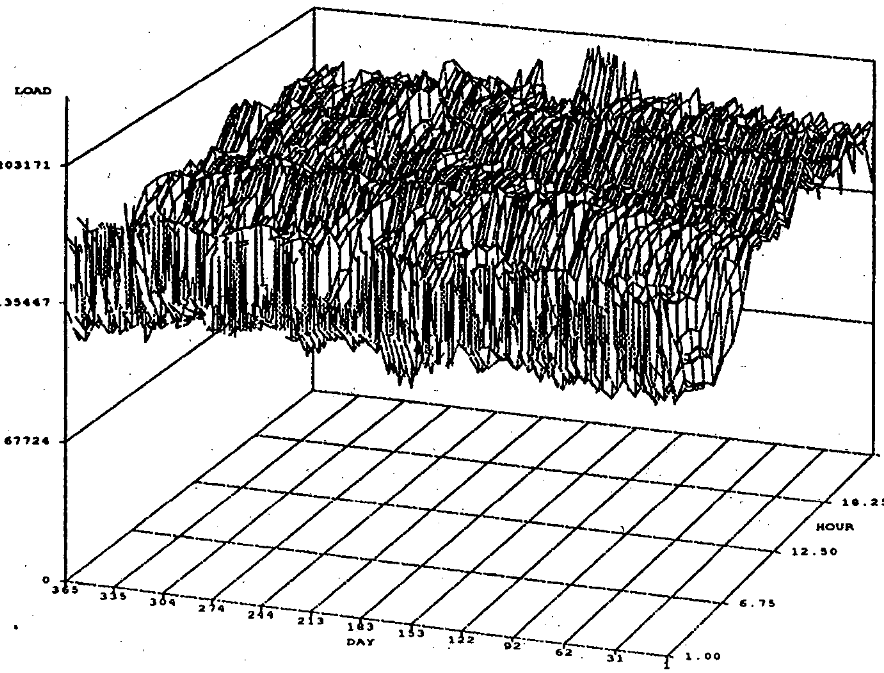

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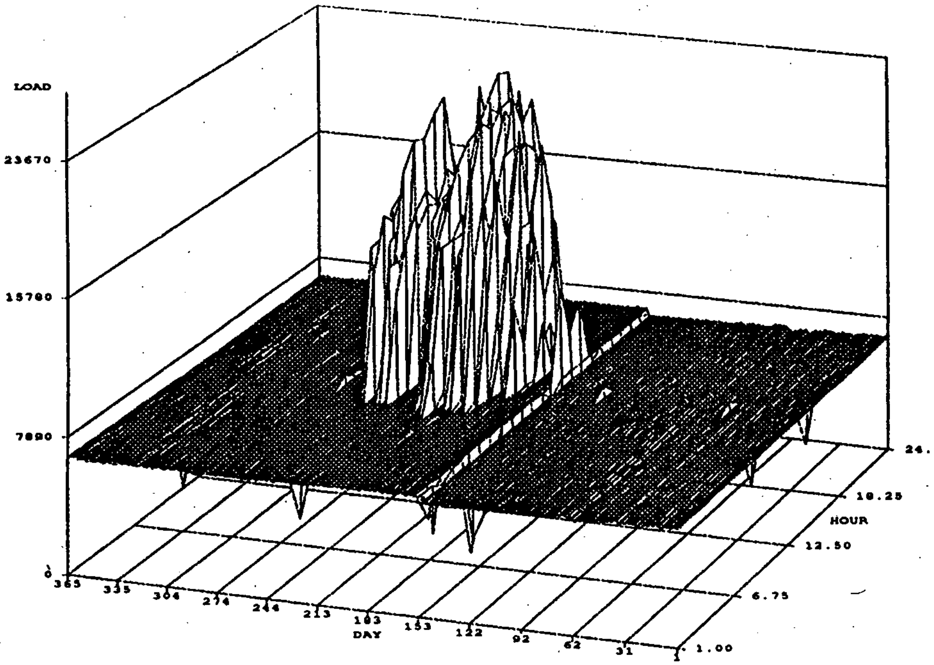

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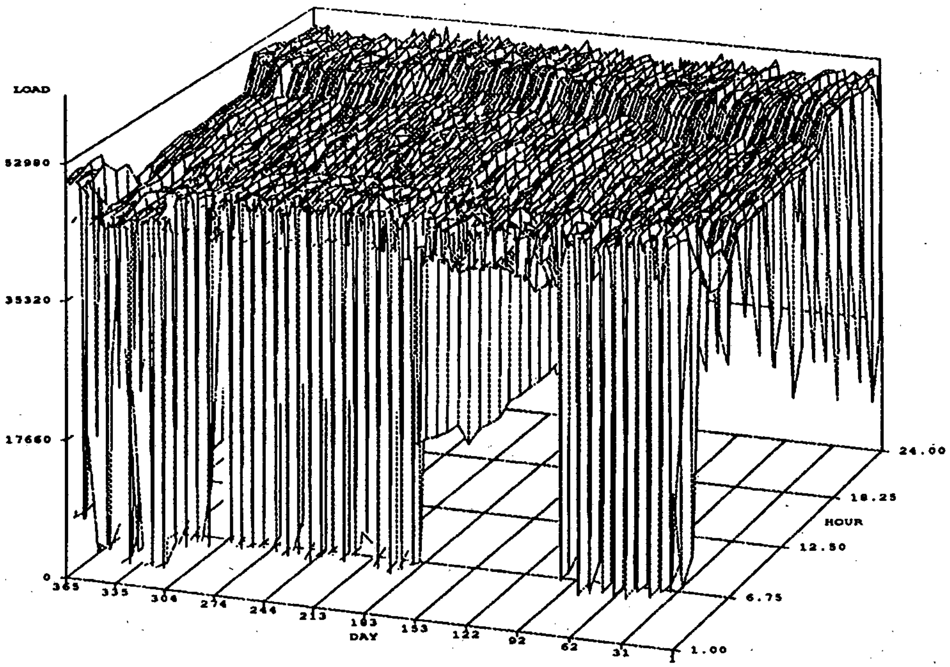

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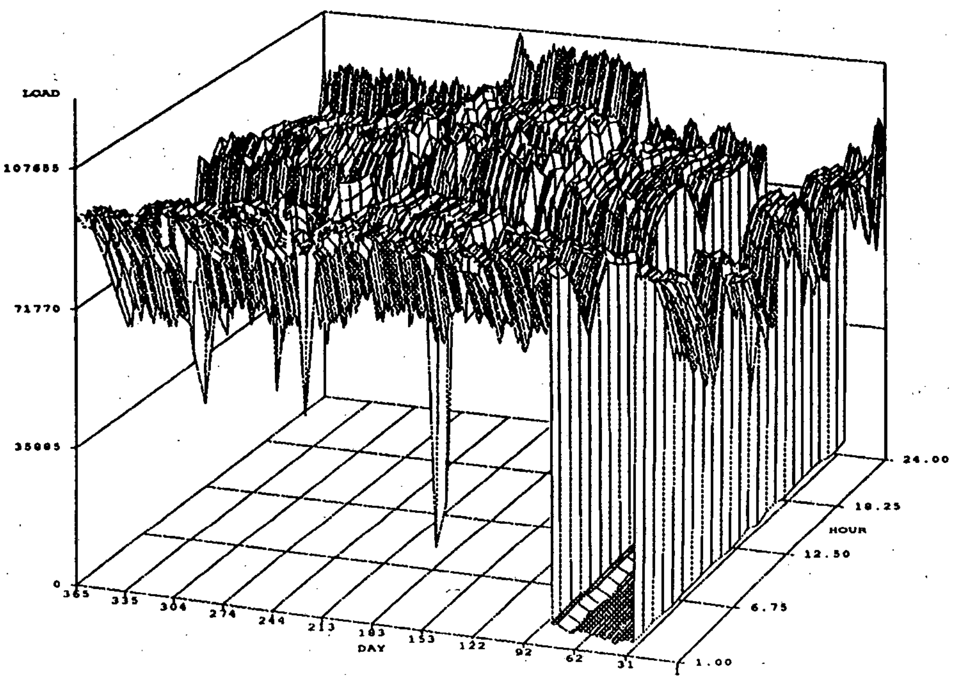

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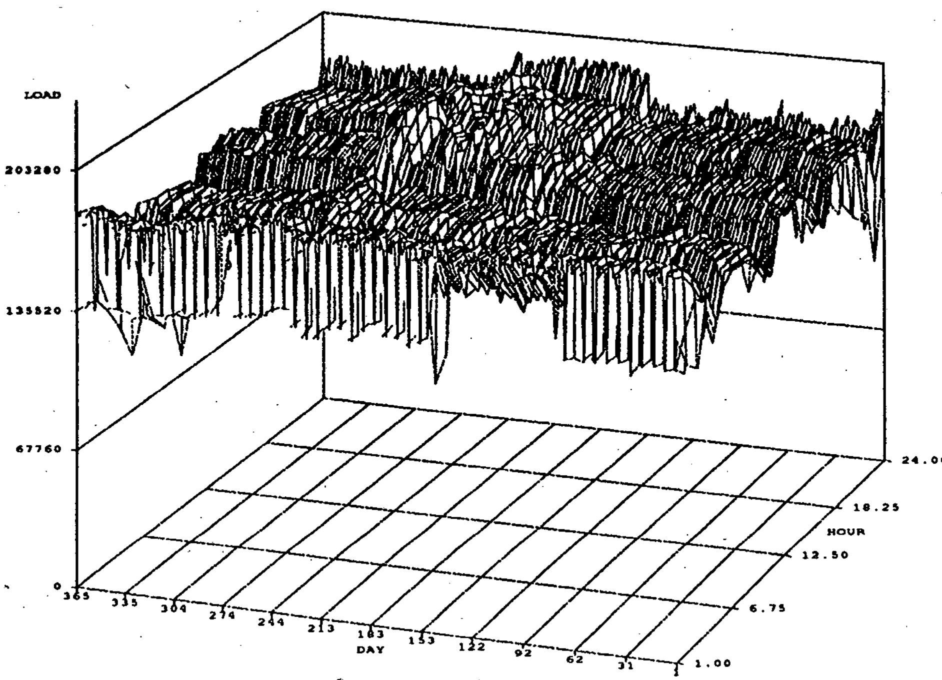

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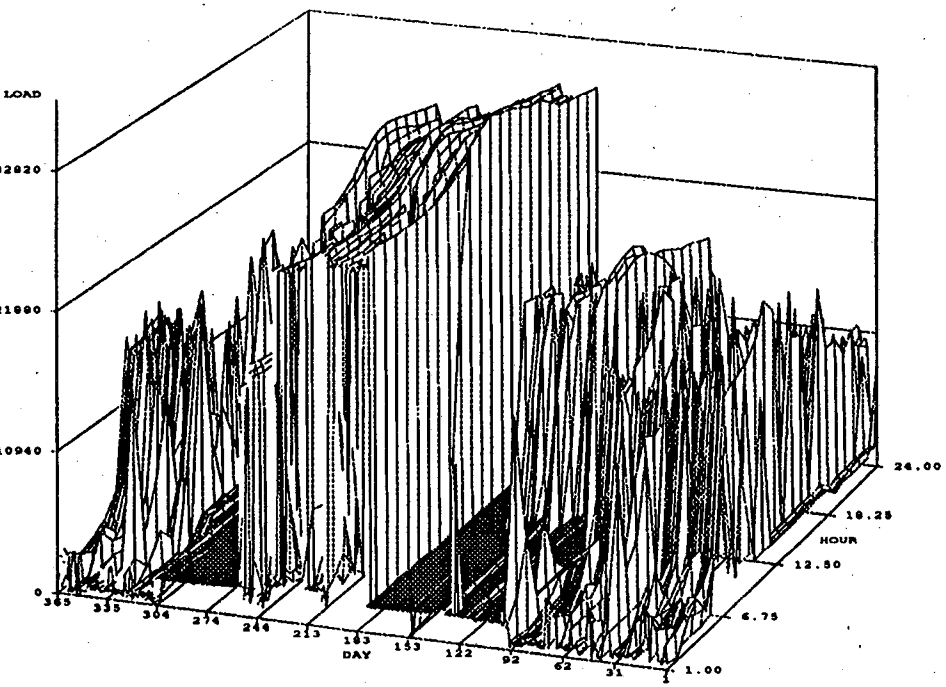

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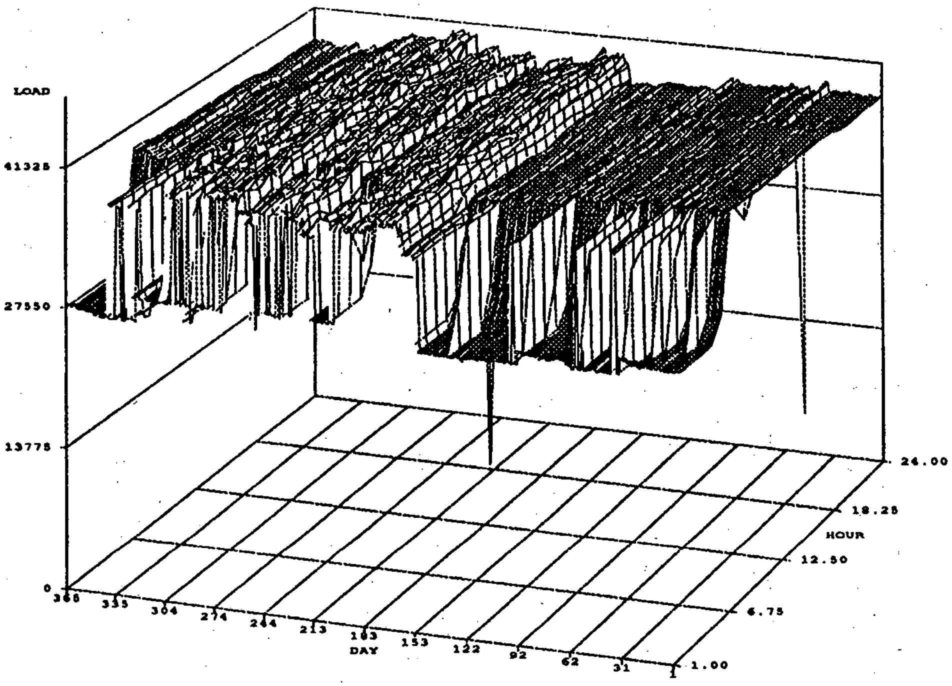

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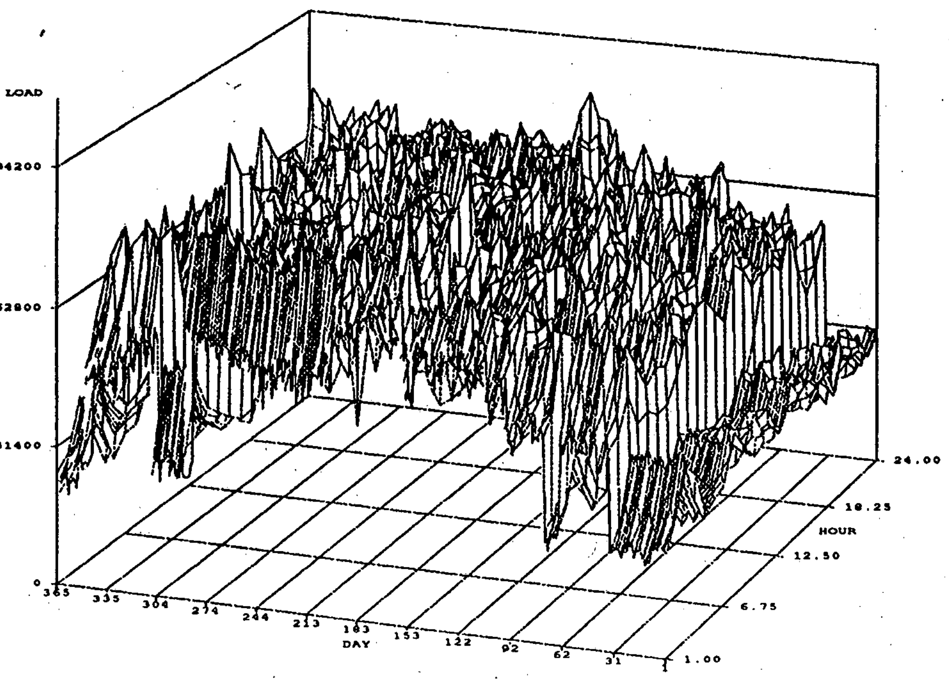

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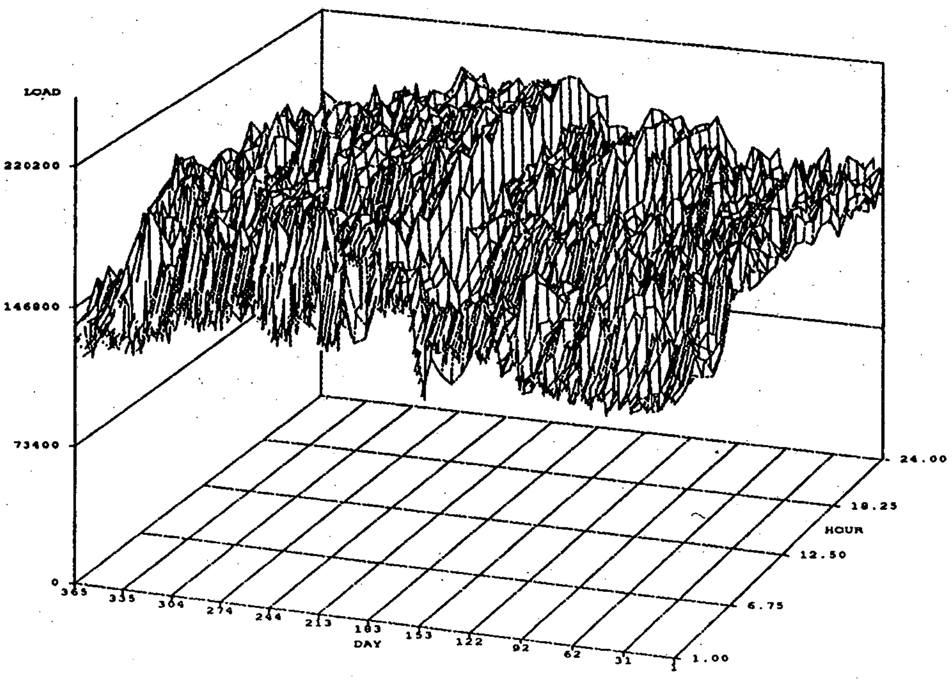

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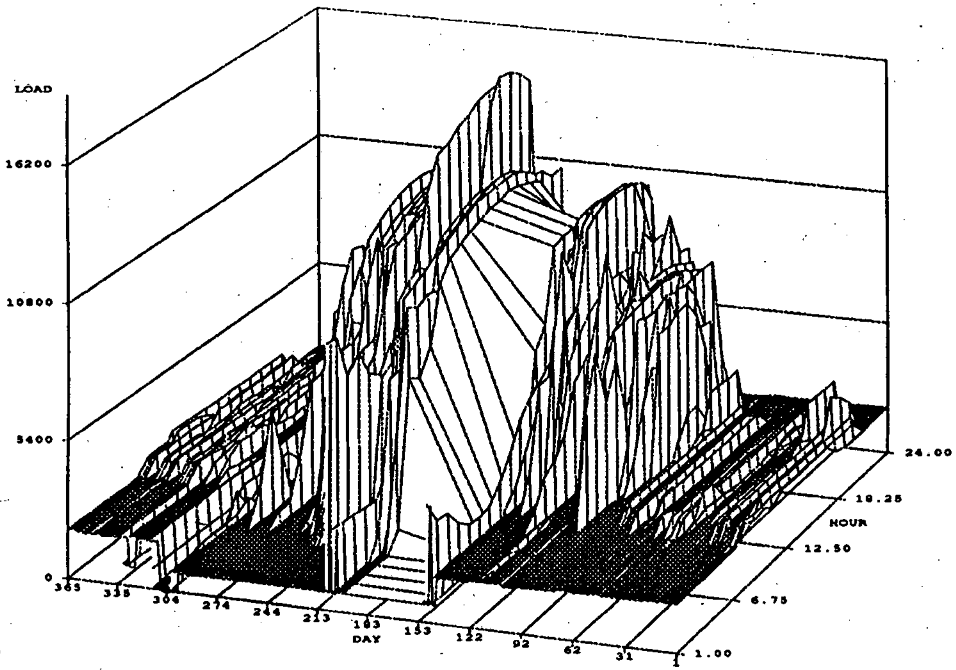

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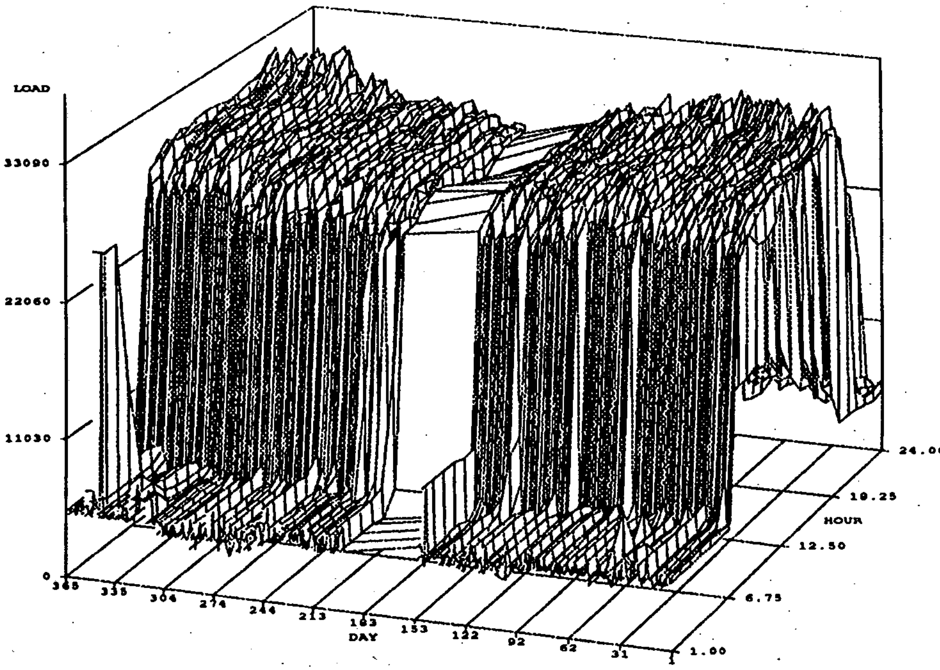

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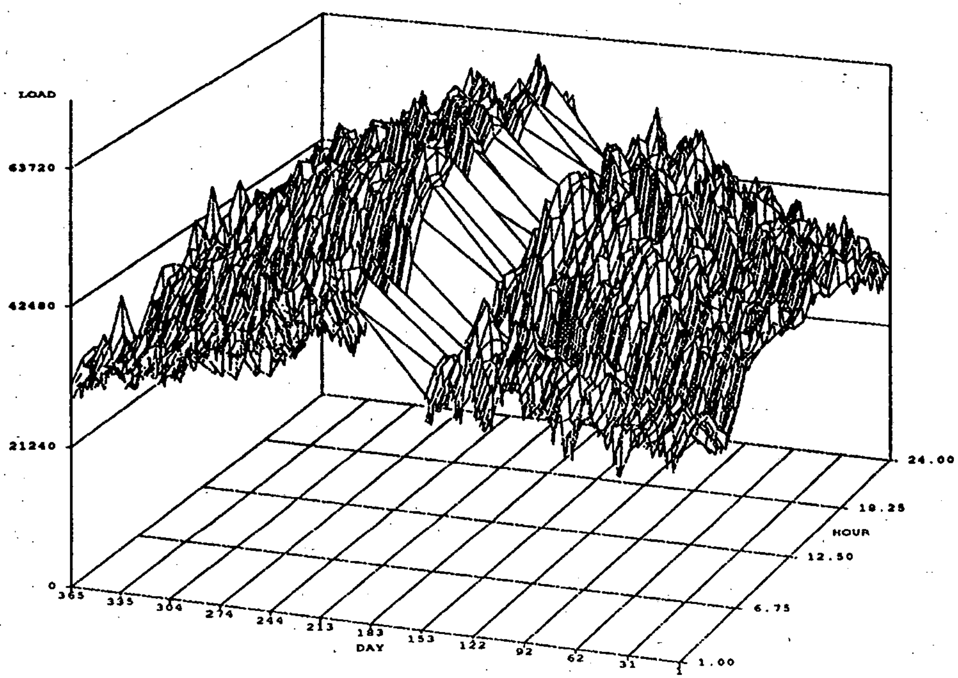

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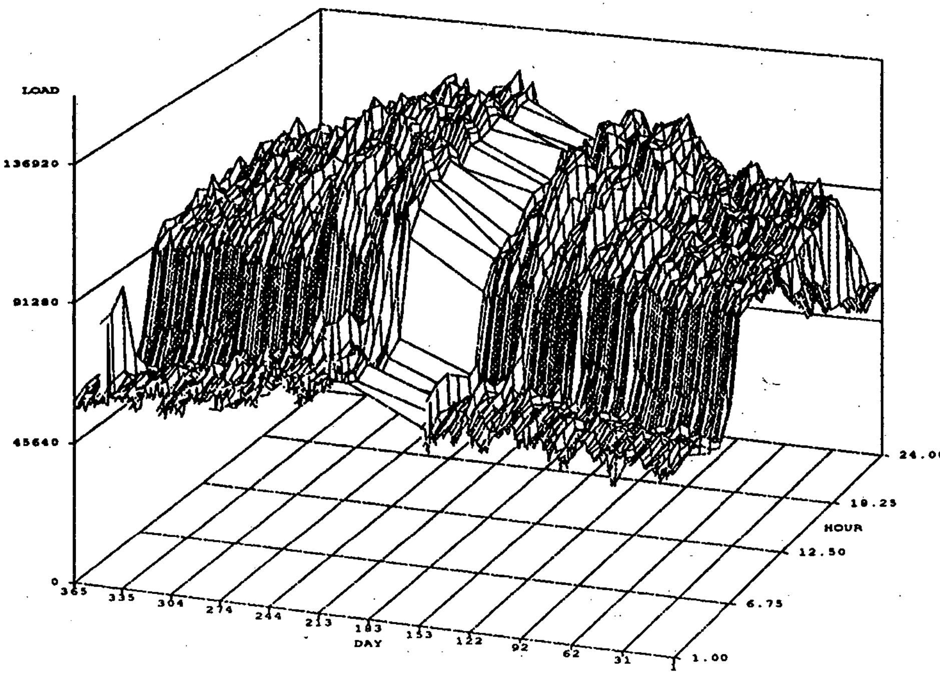

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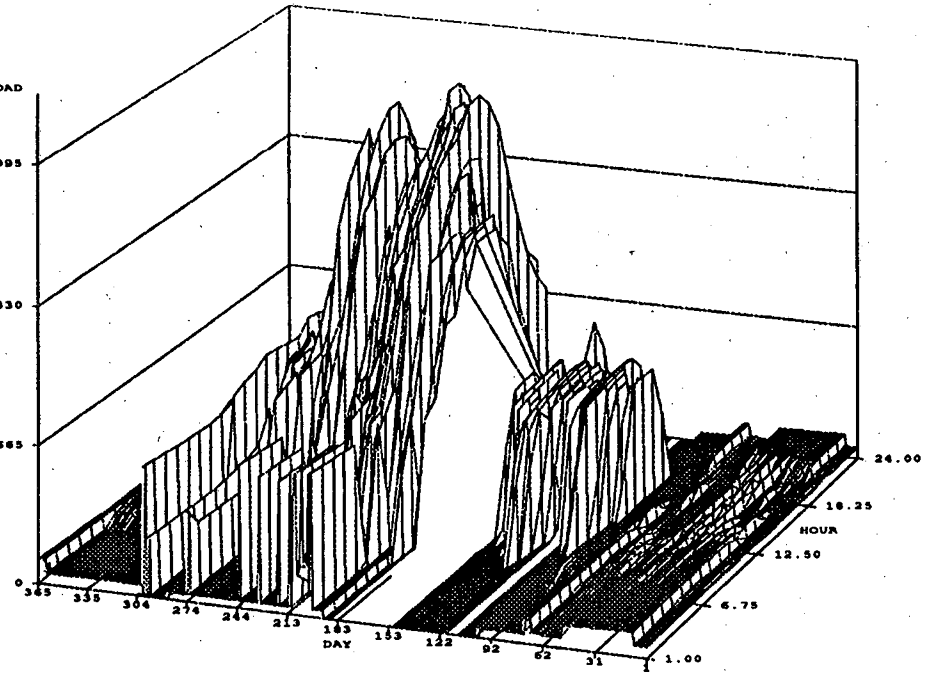

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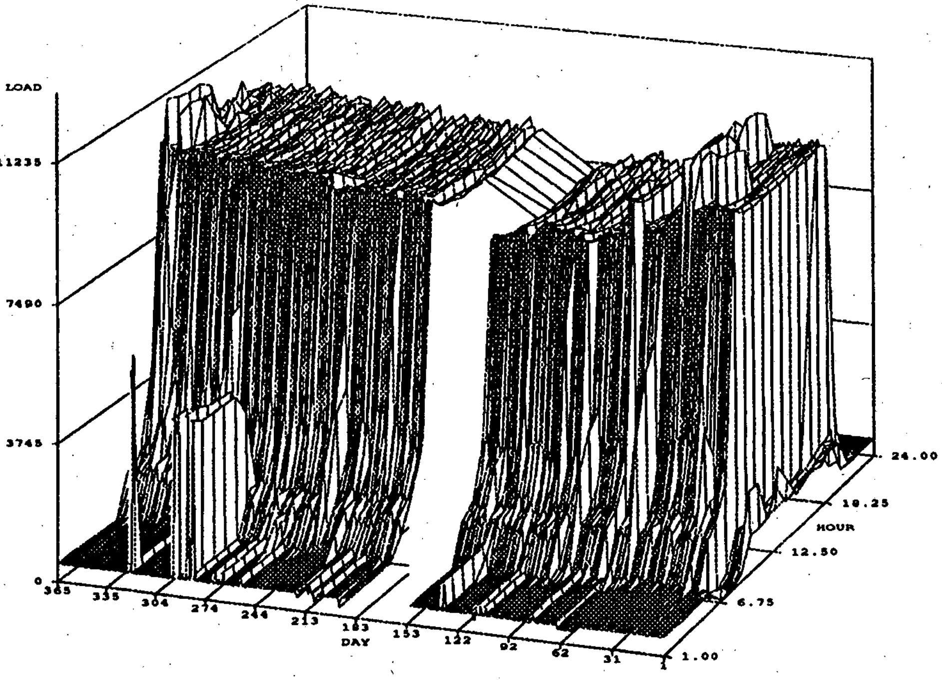

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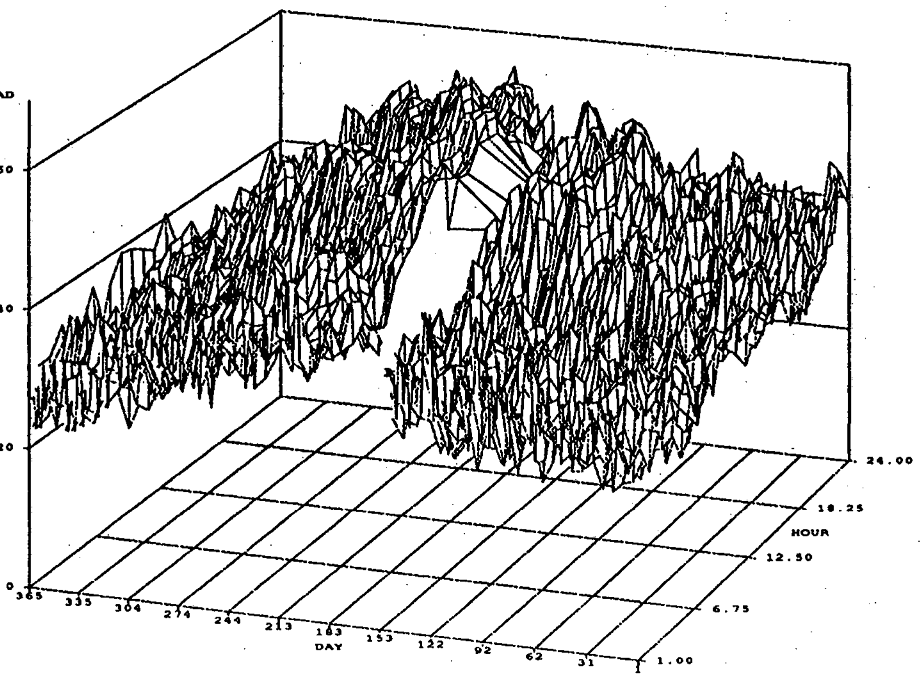

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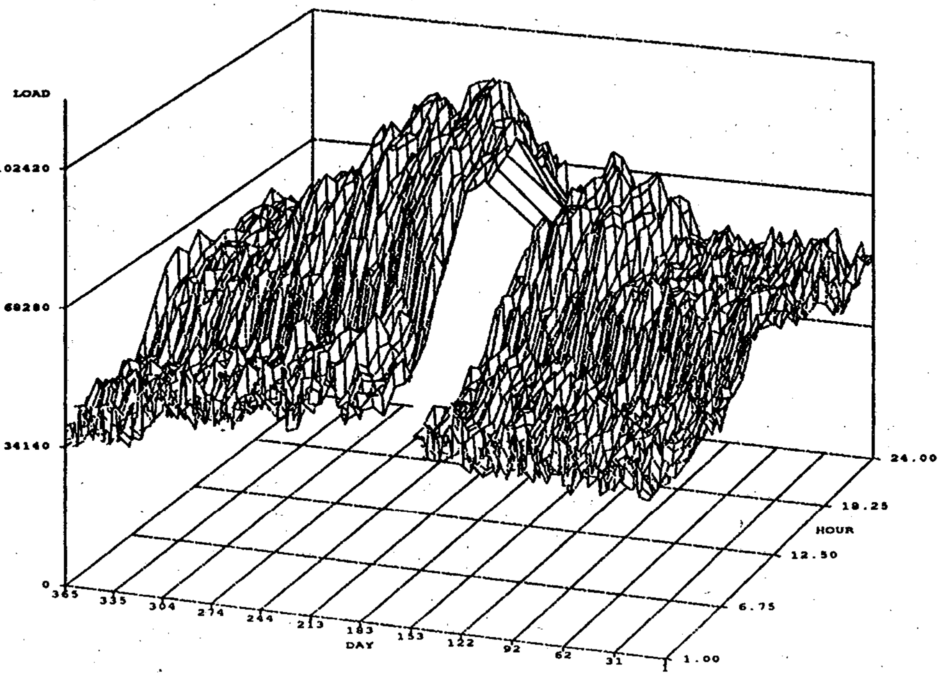

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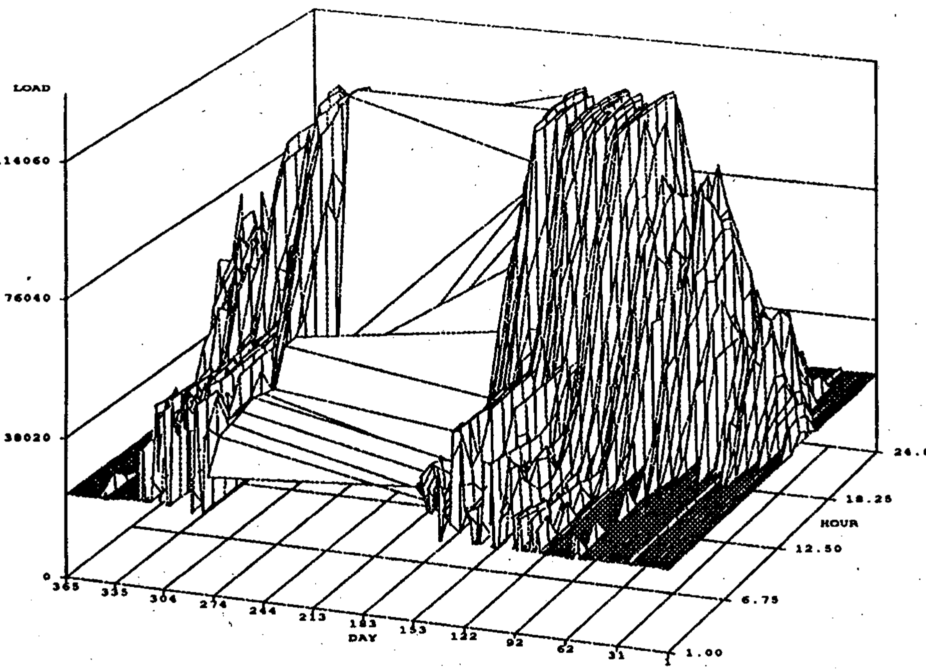

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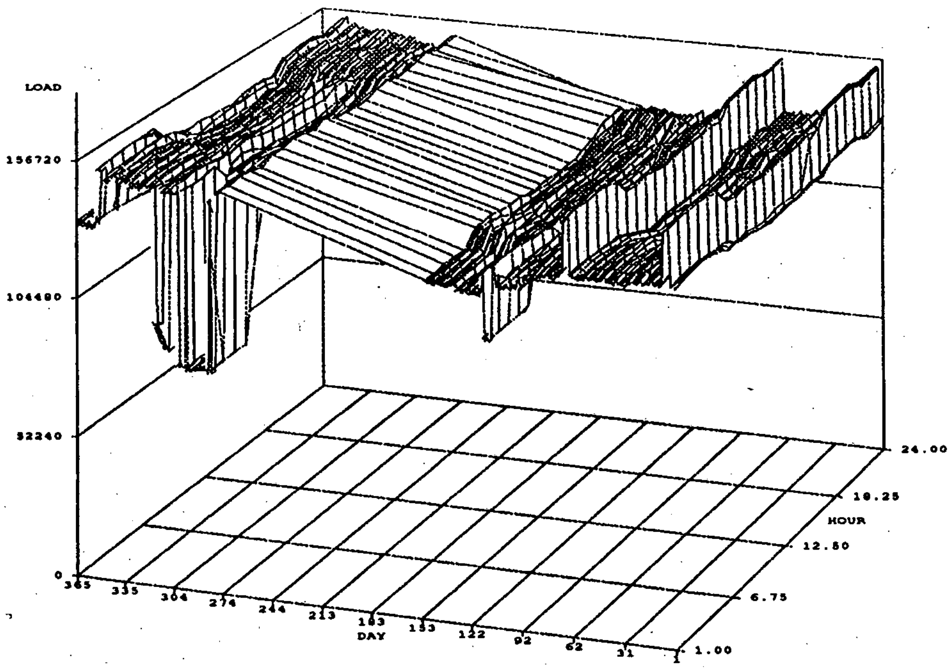

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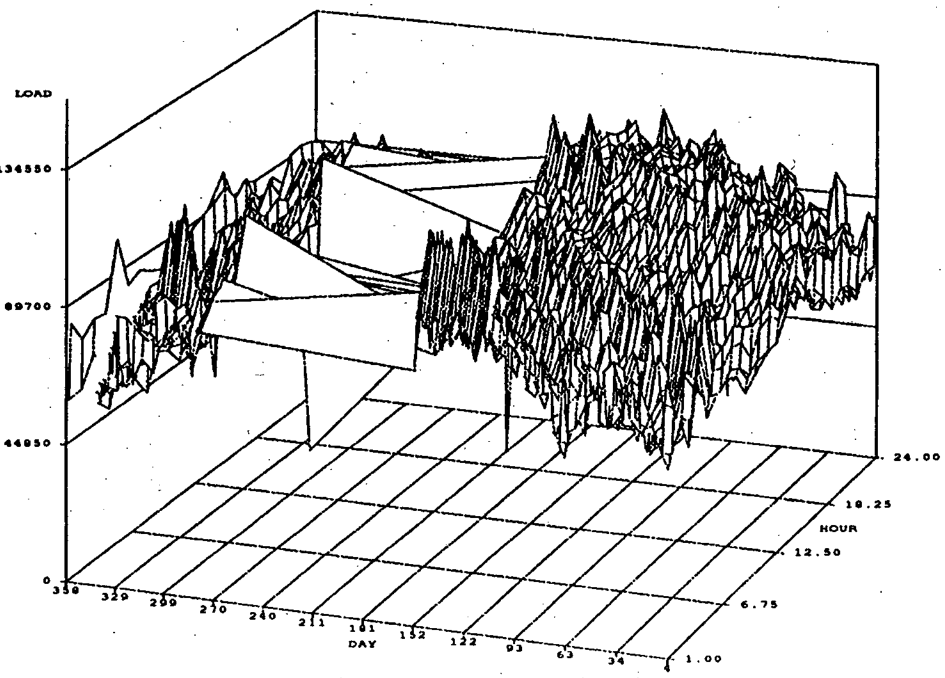

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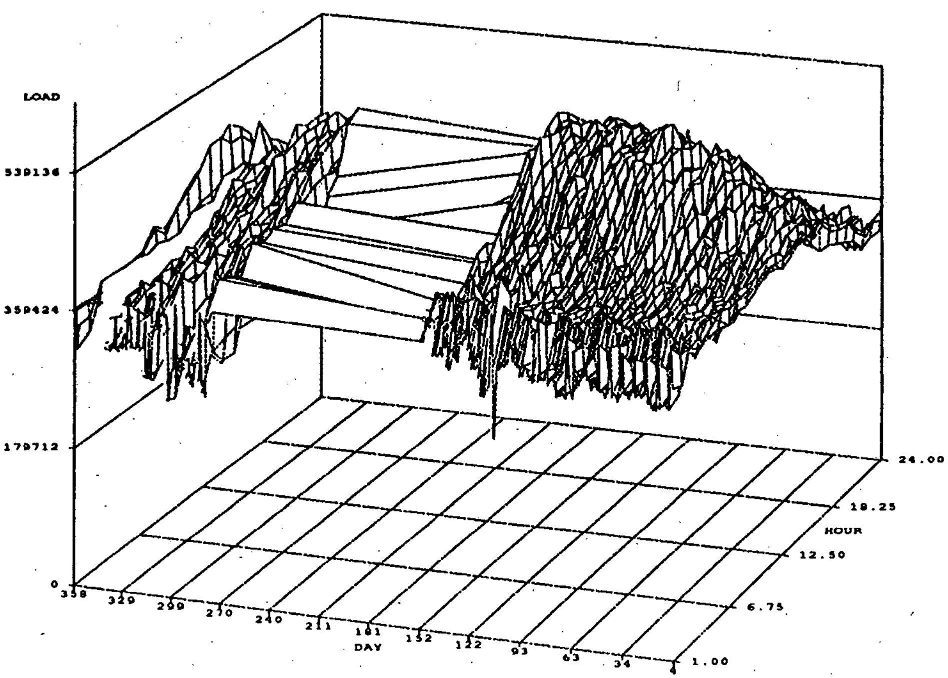

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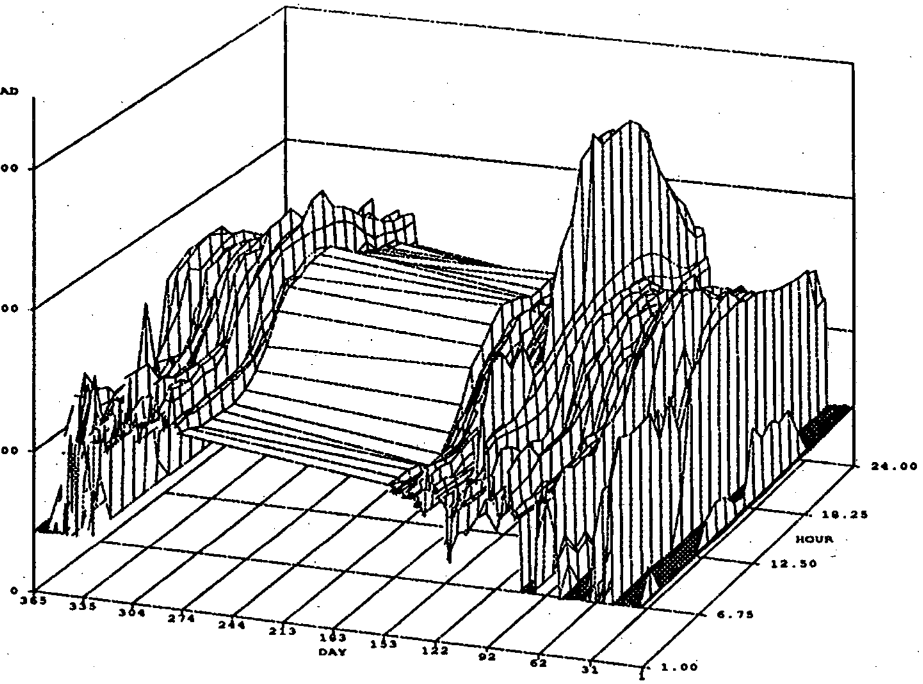
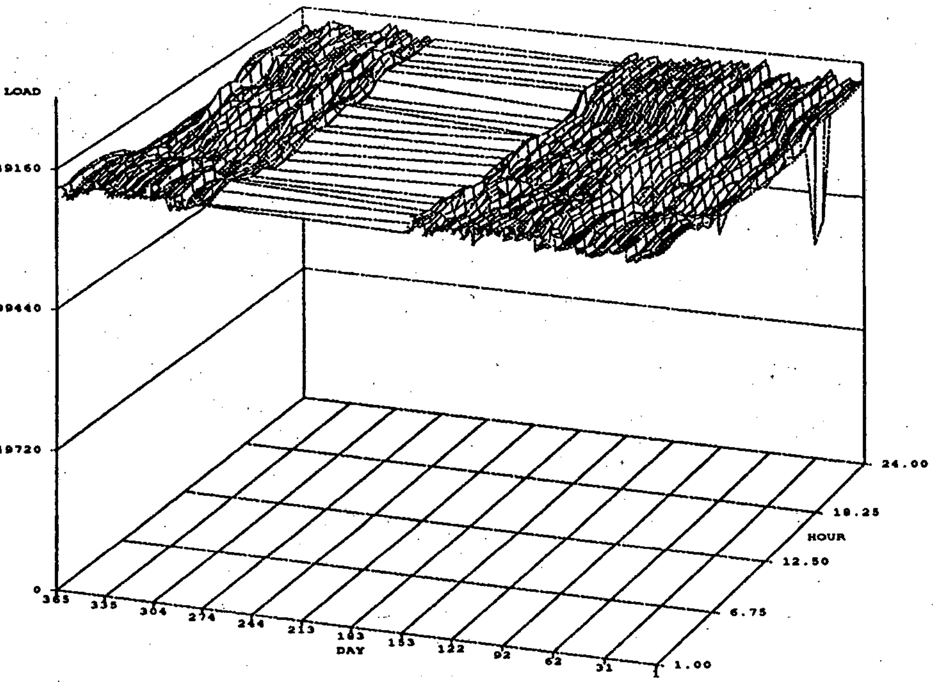


Grocery 14 Lighting



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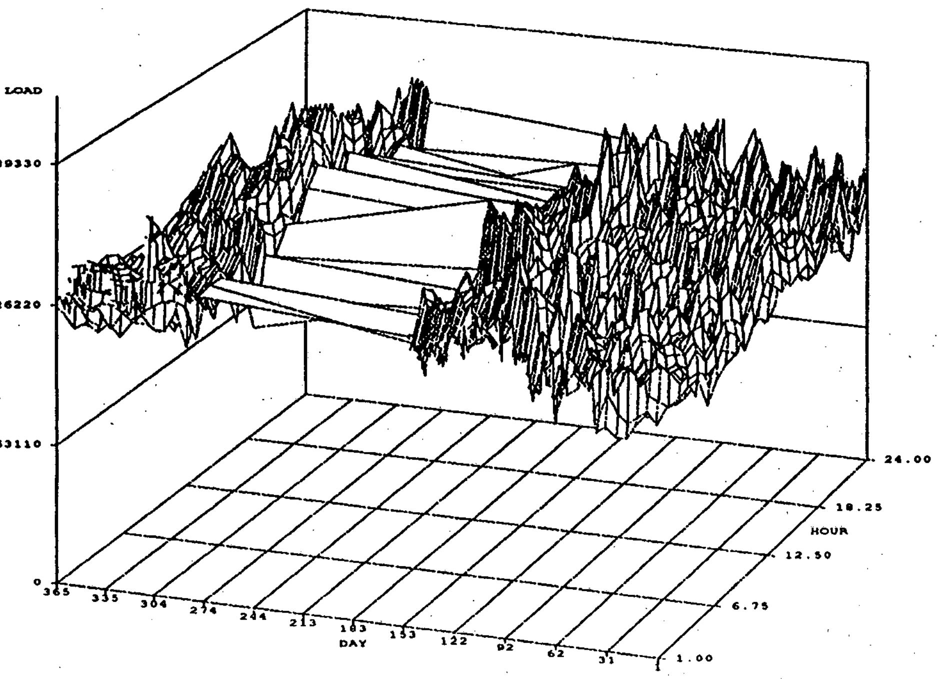

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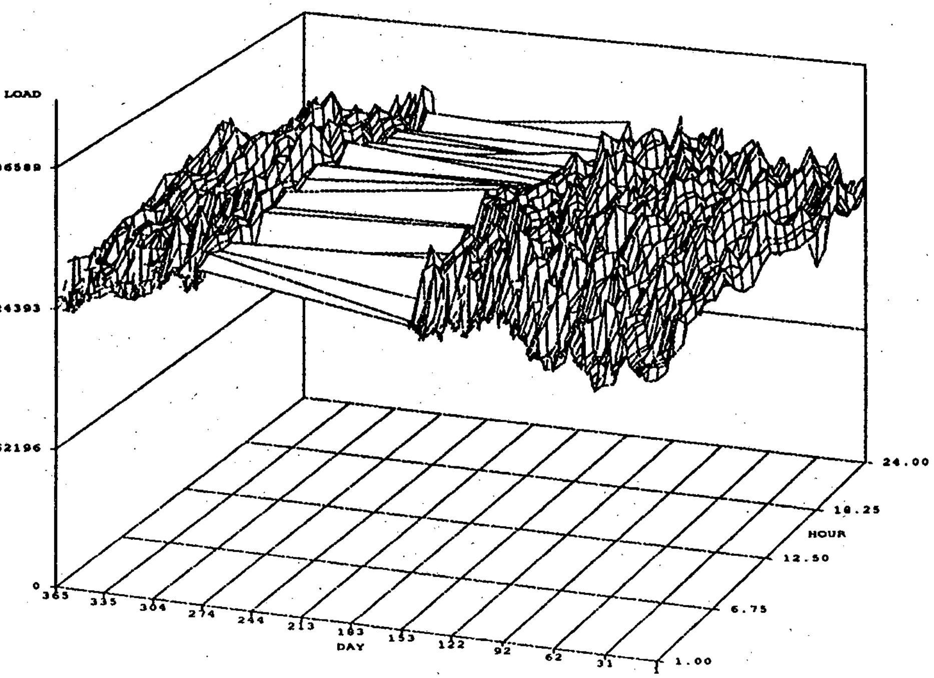

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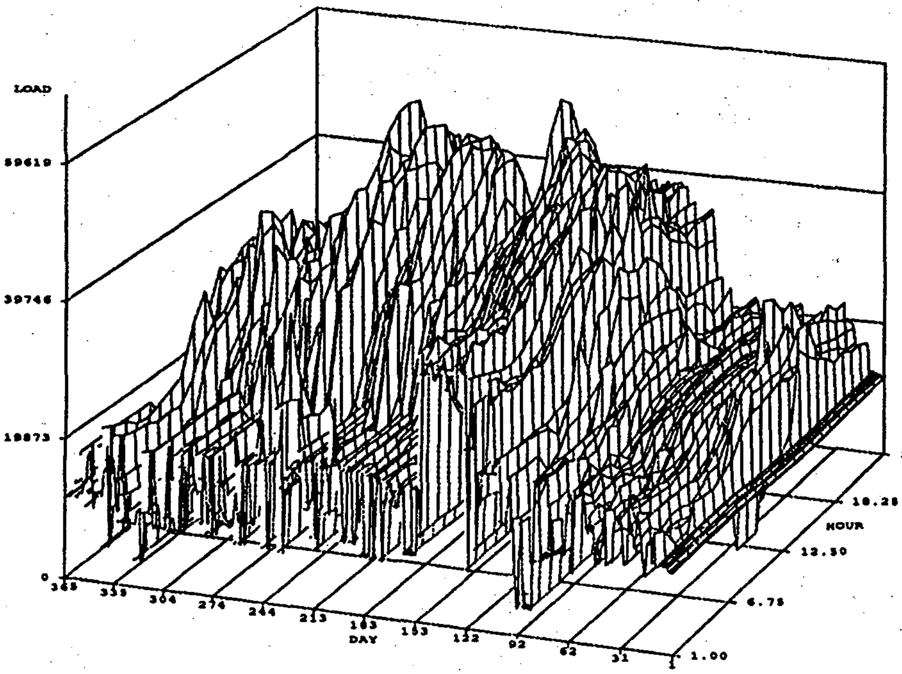

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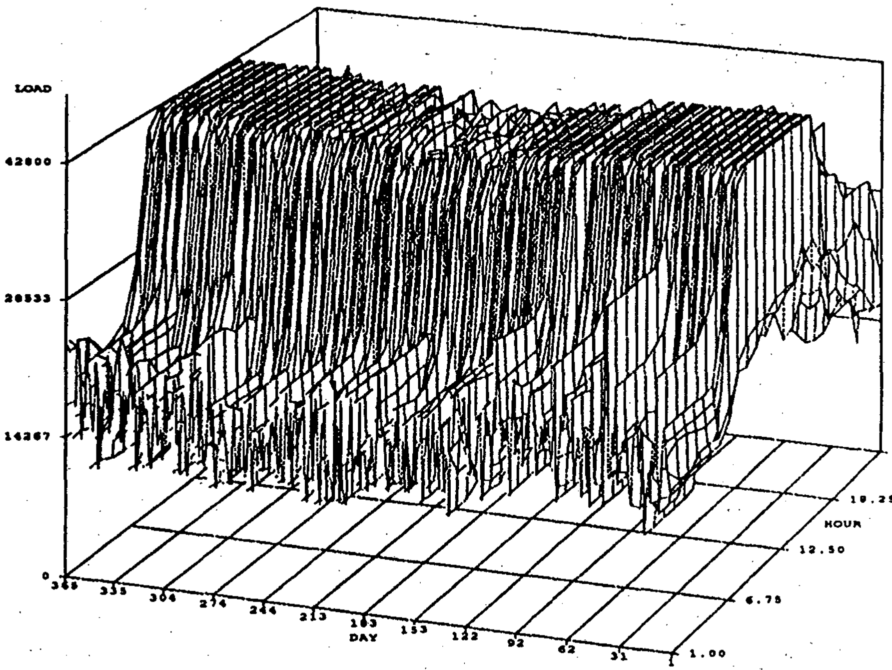

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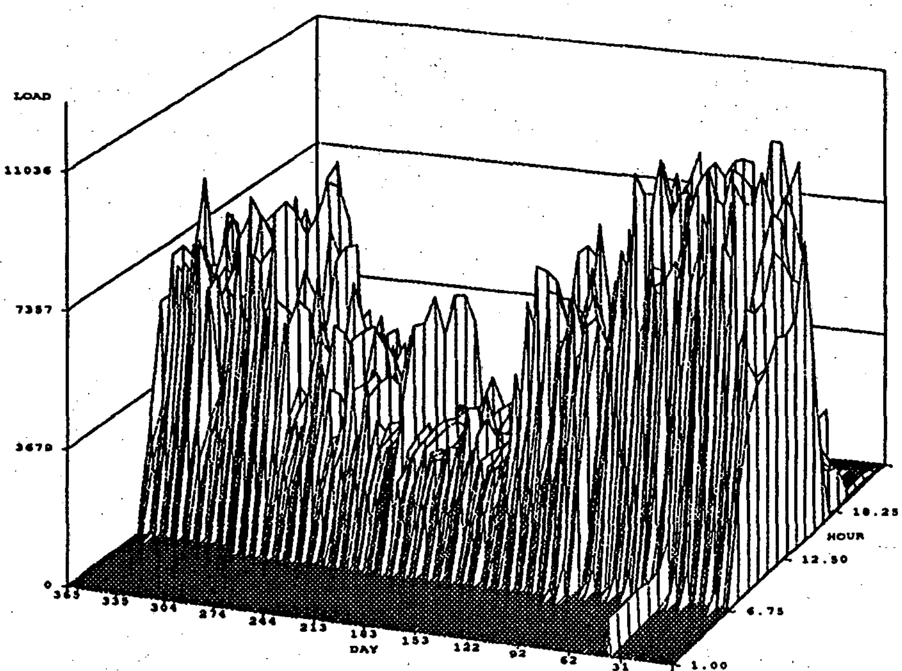

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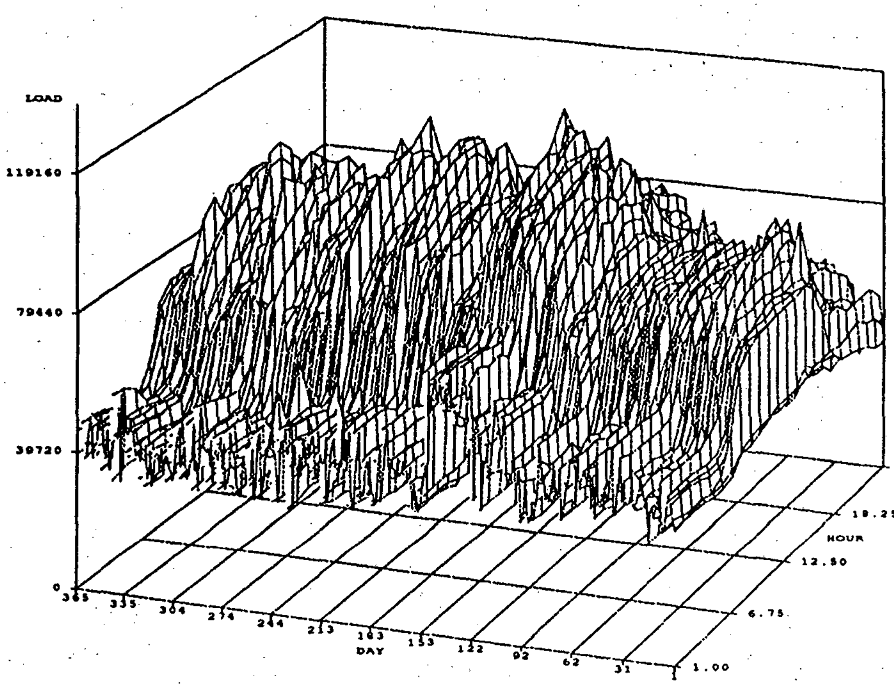

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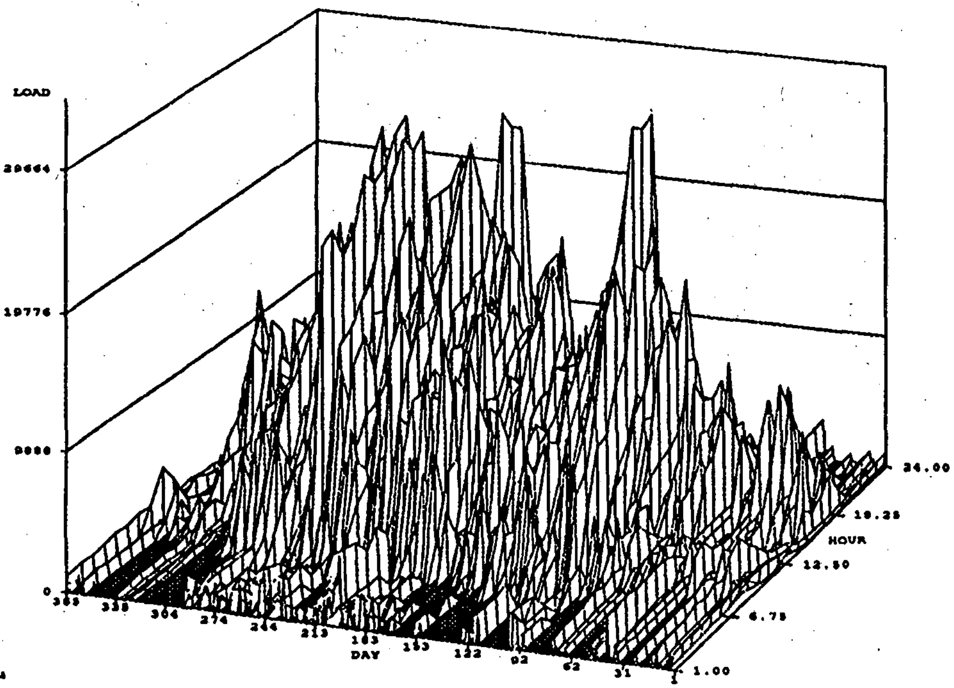

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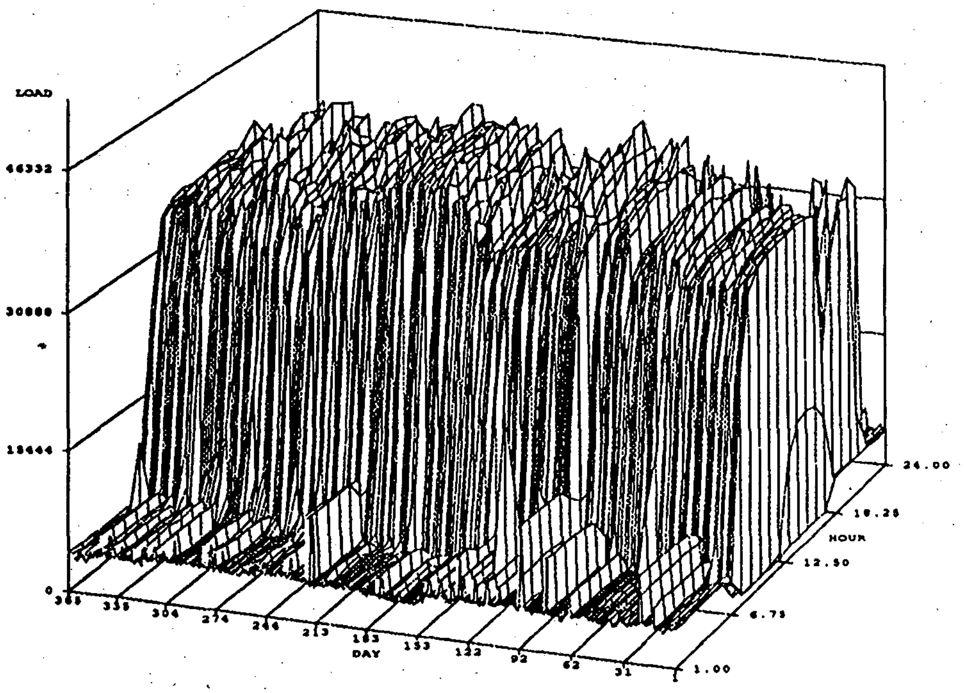

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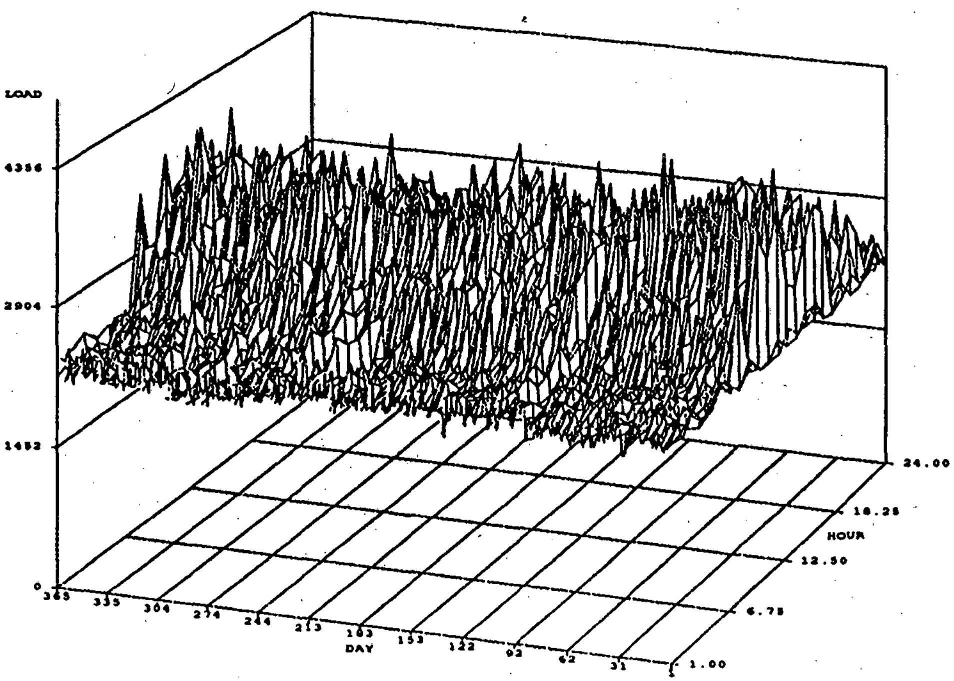

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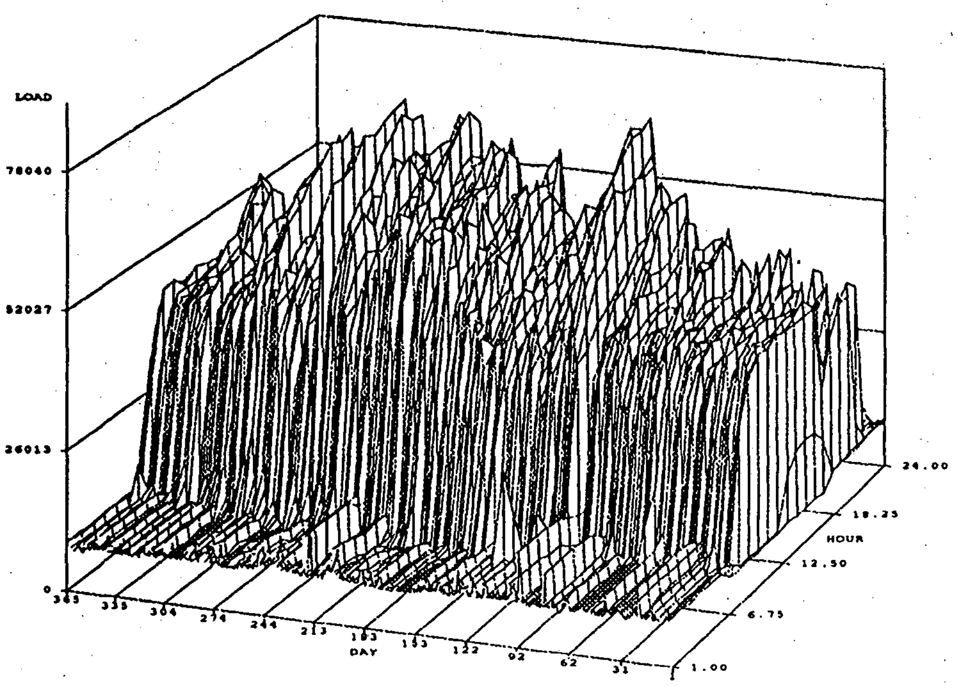

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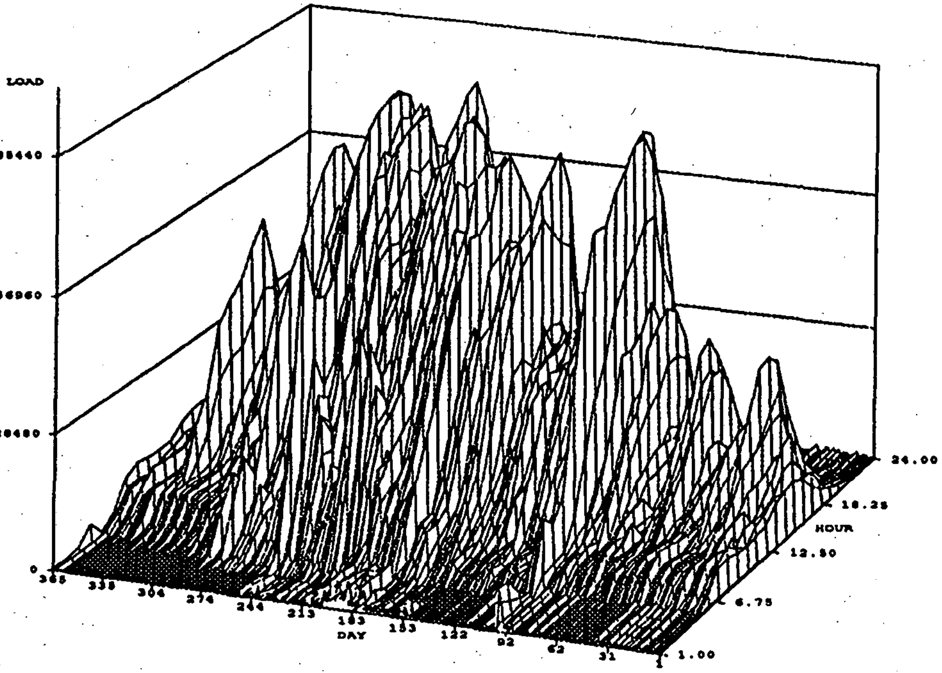

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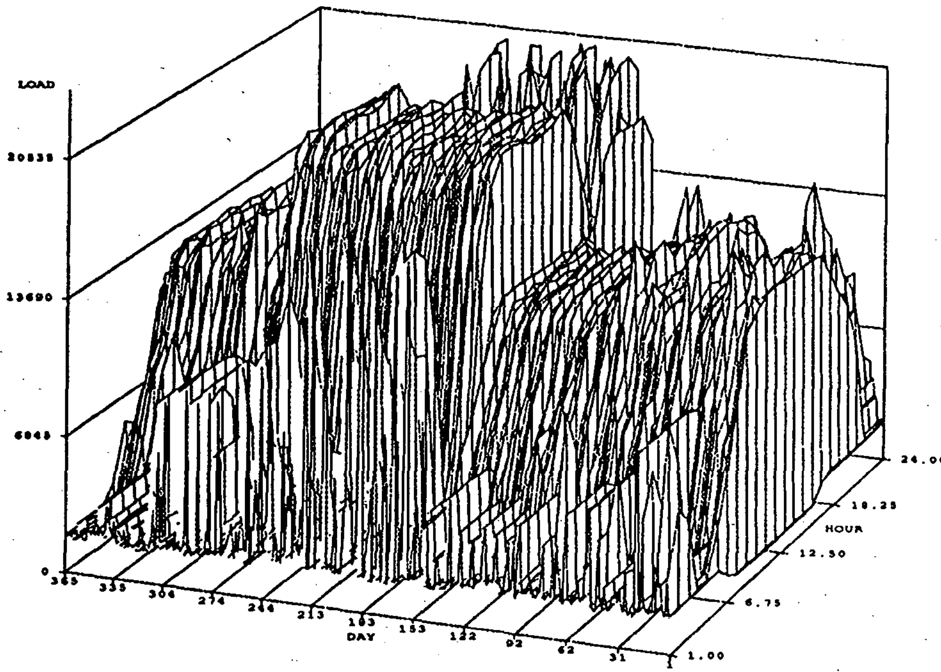

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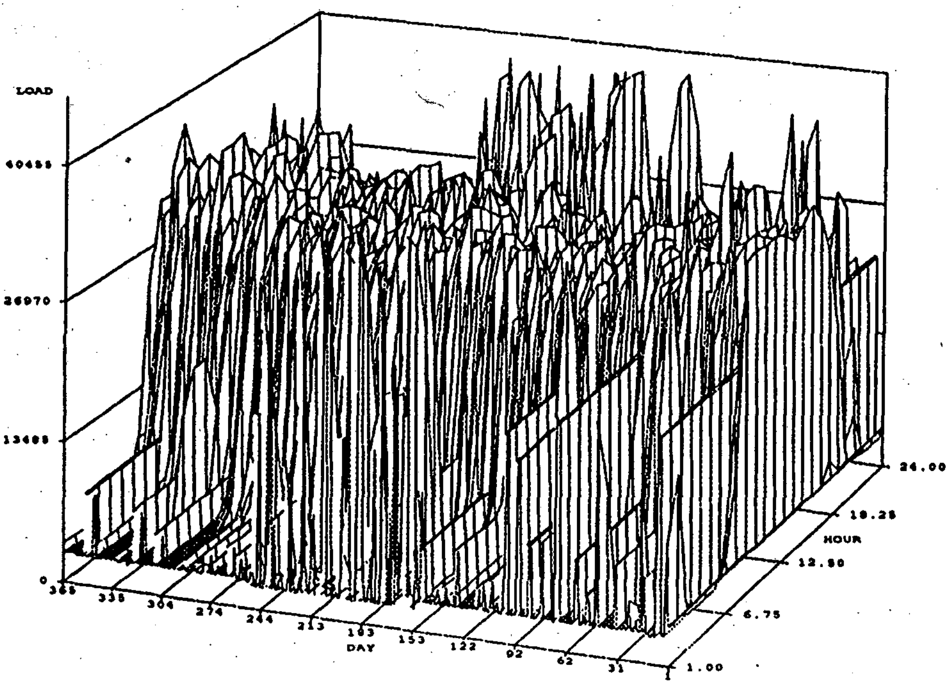

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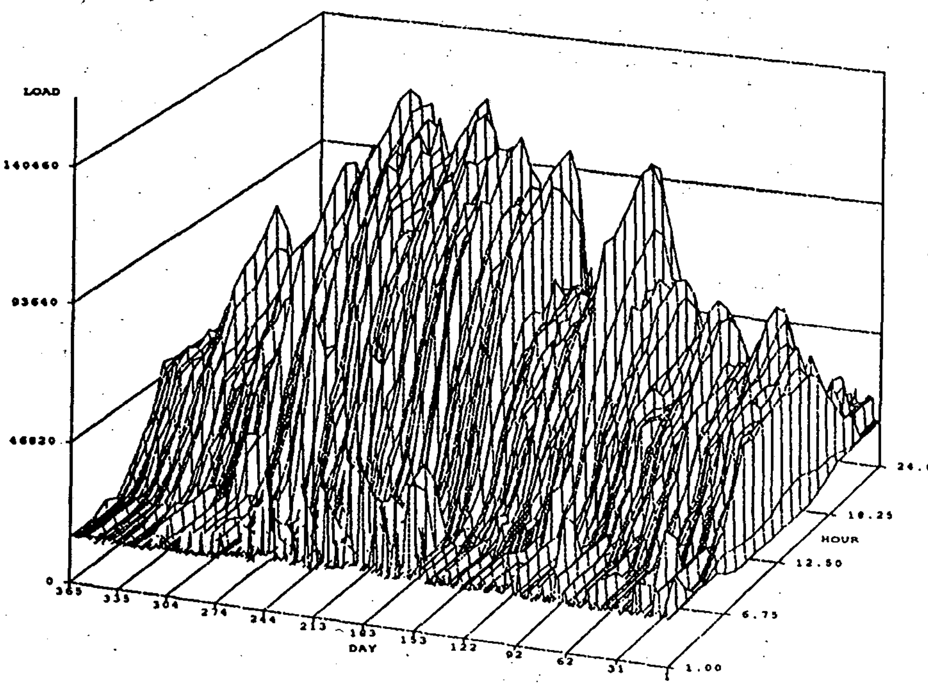

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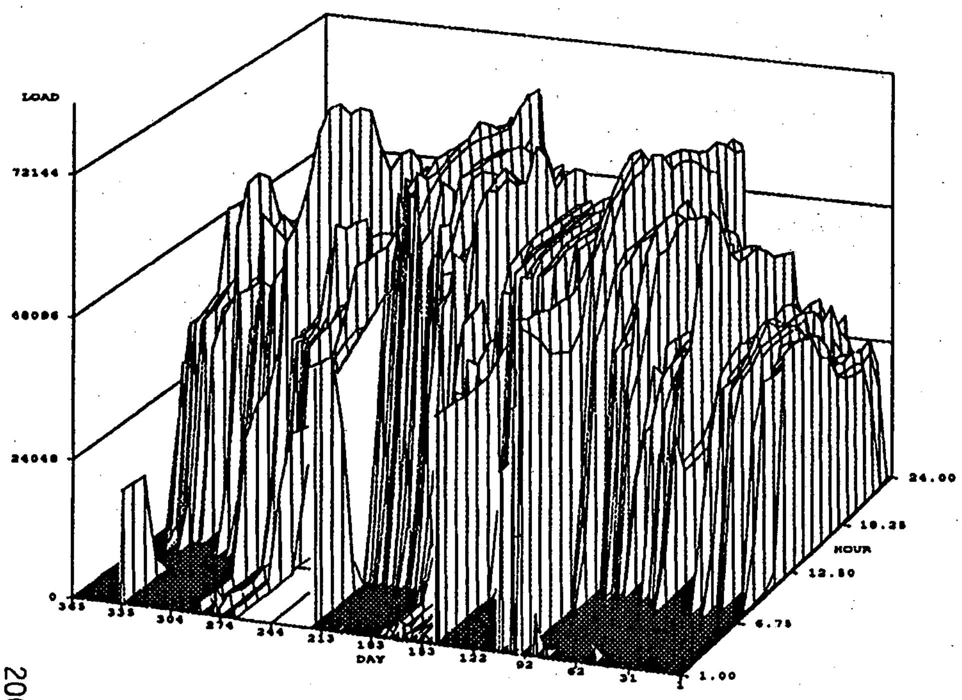

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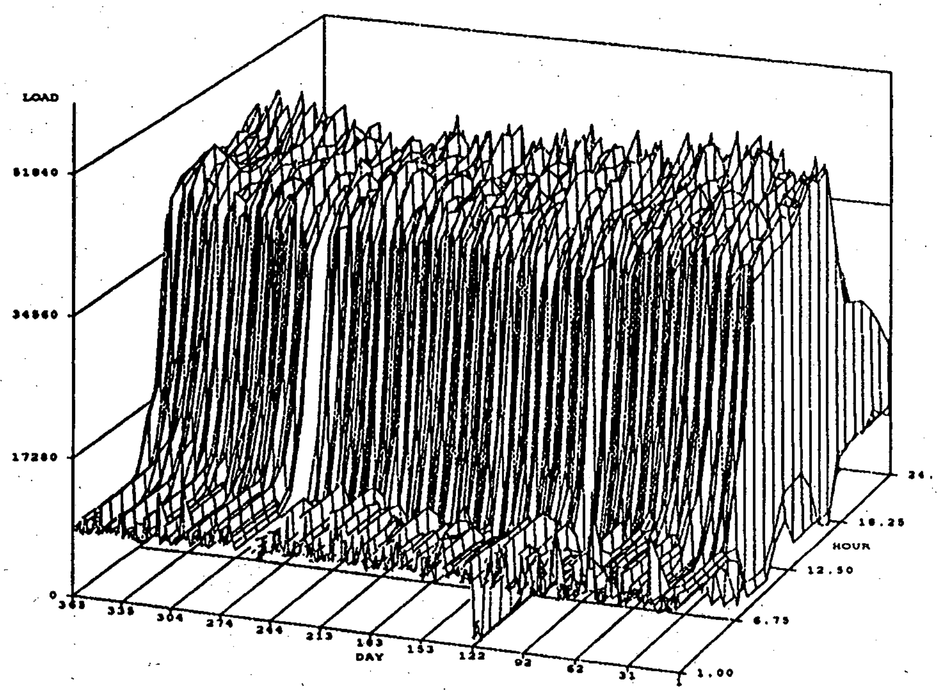

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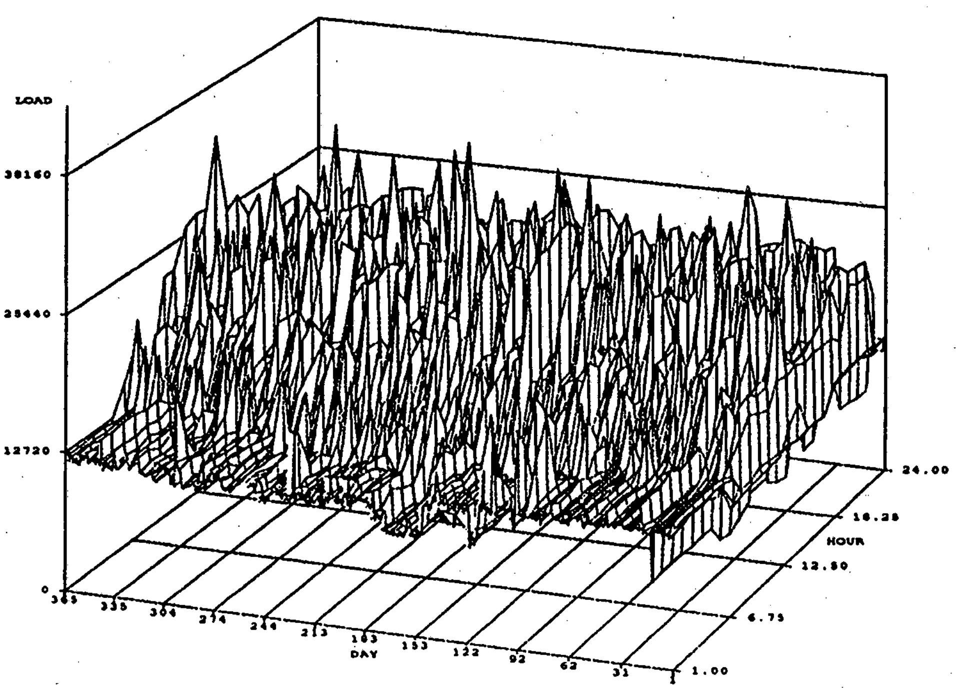

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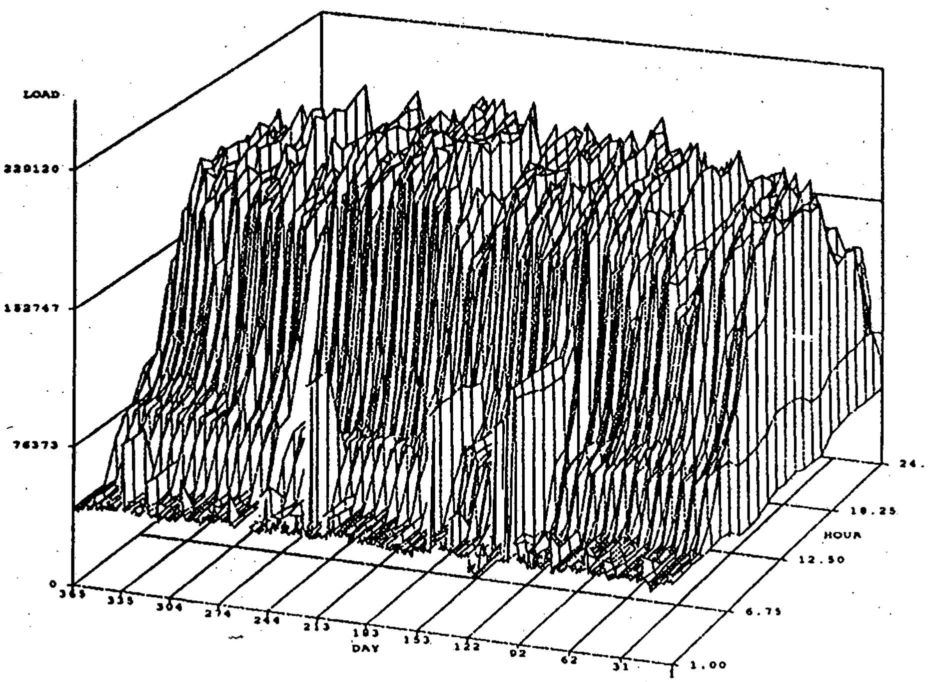

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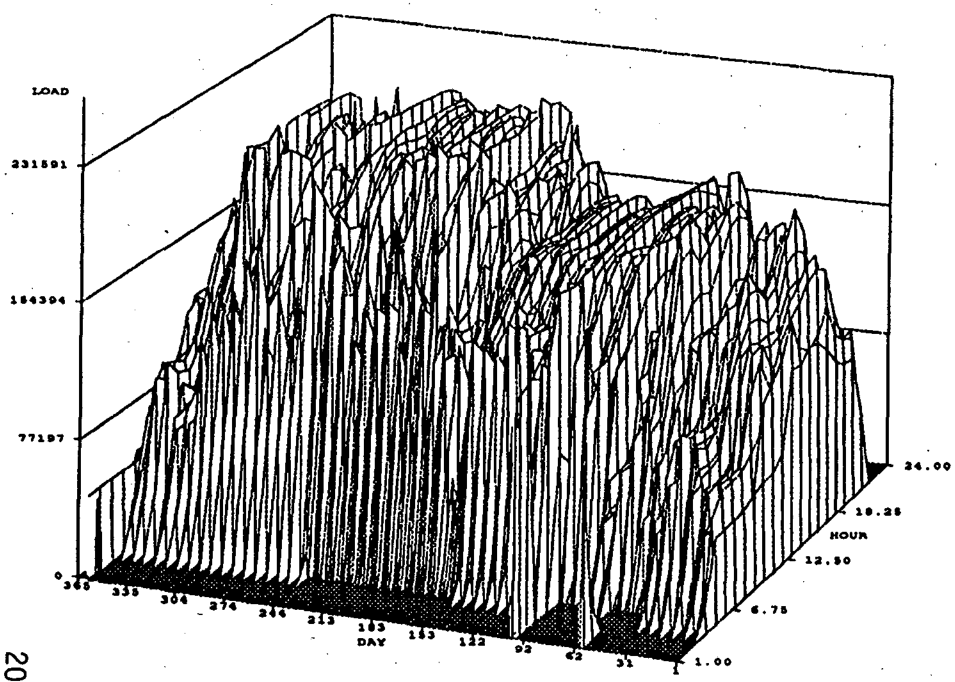

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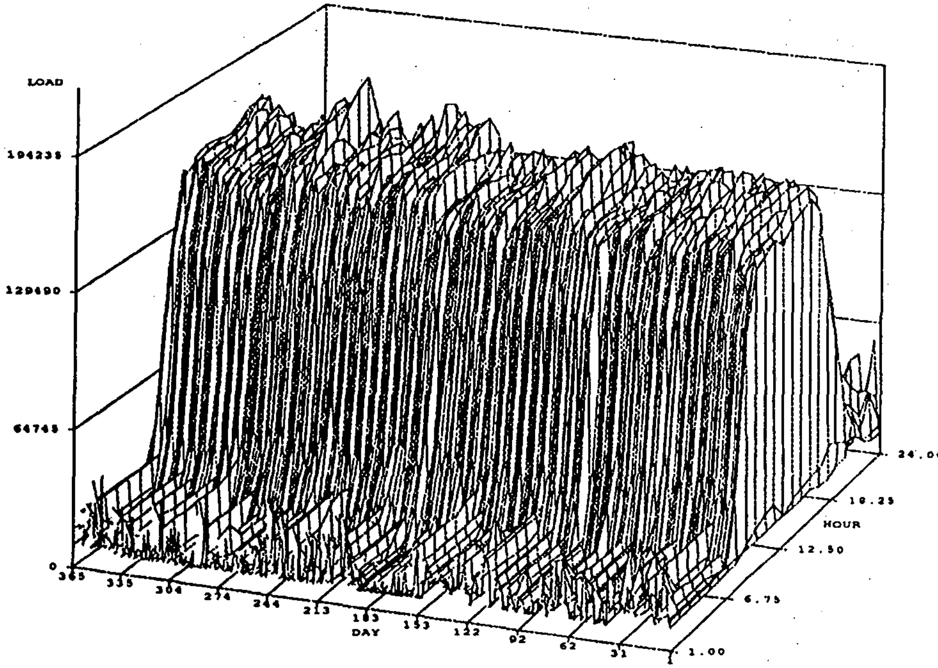

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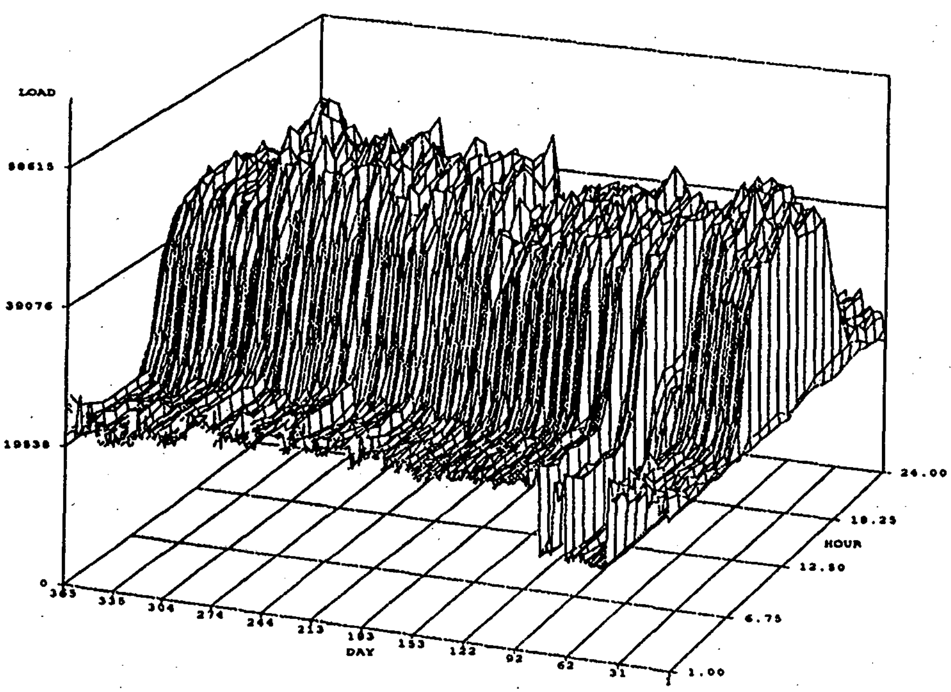

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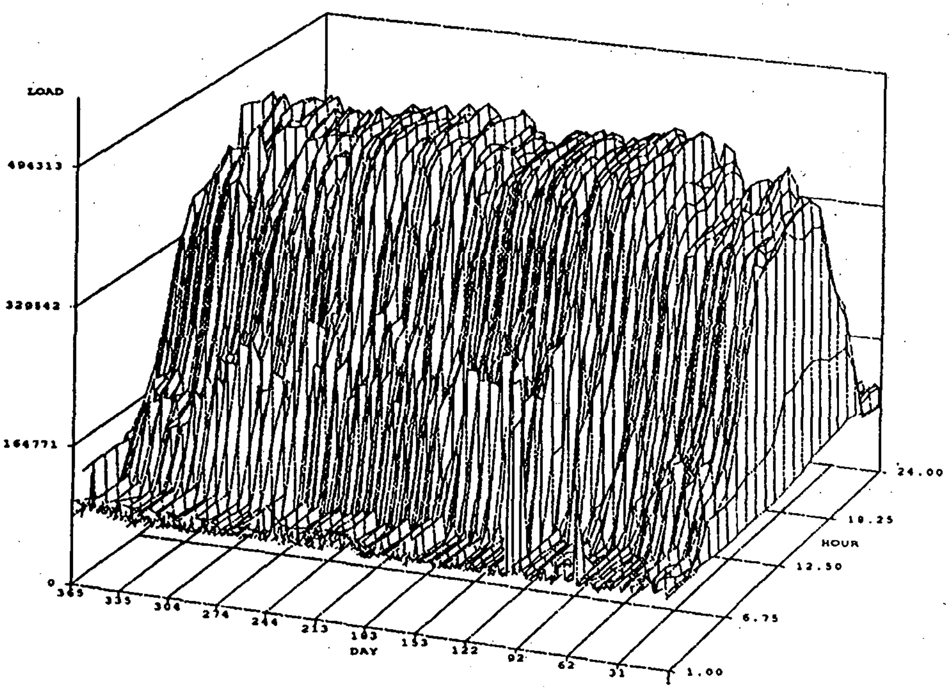

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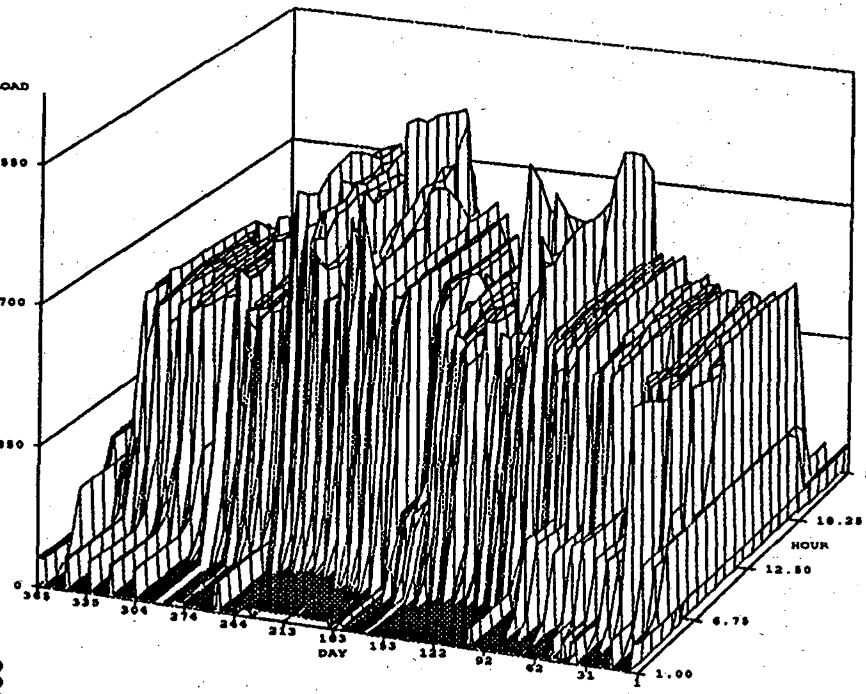

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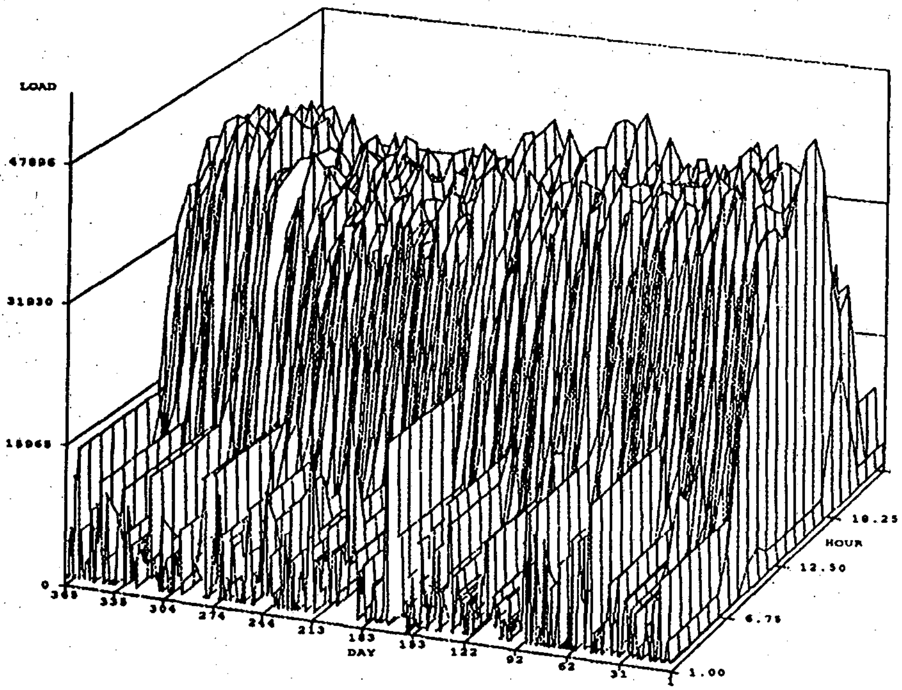

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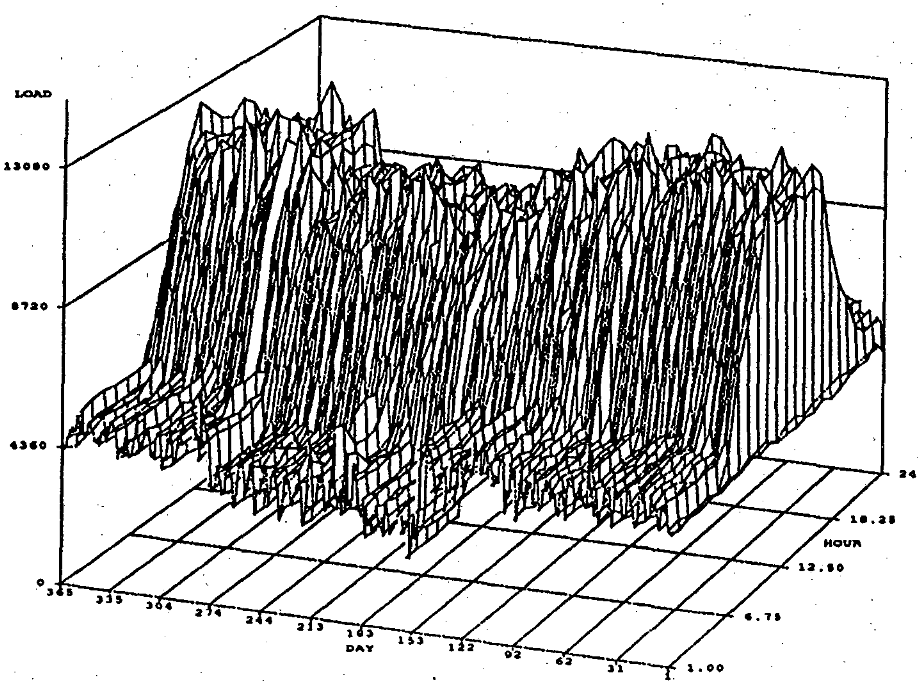

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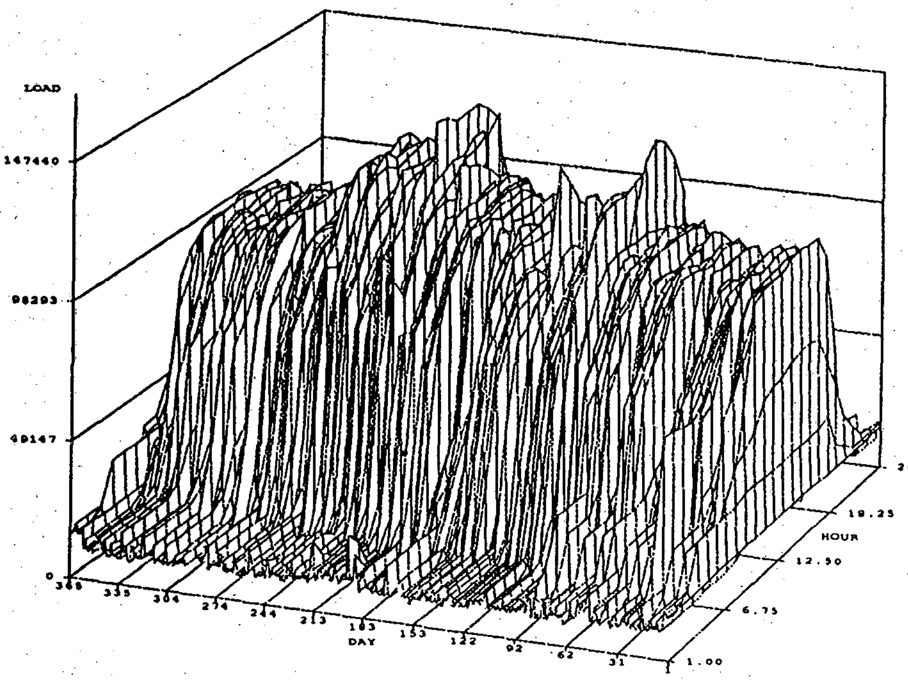

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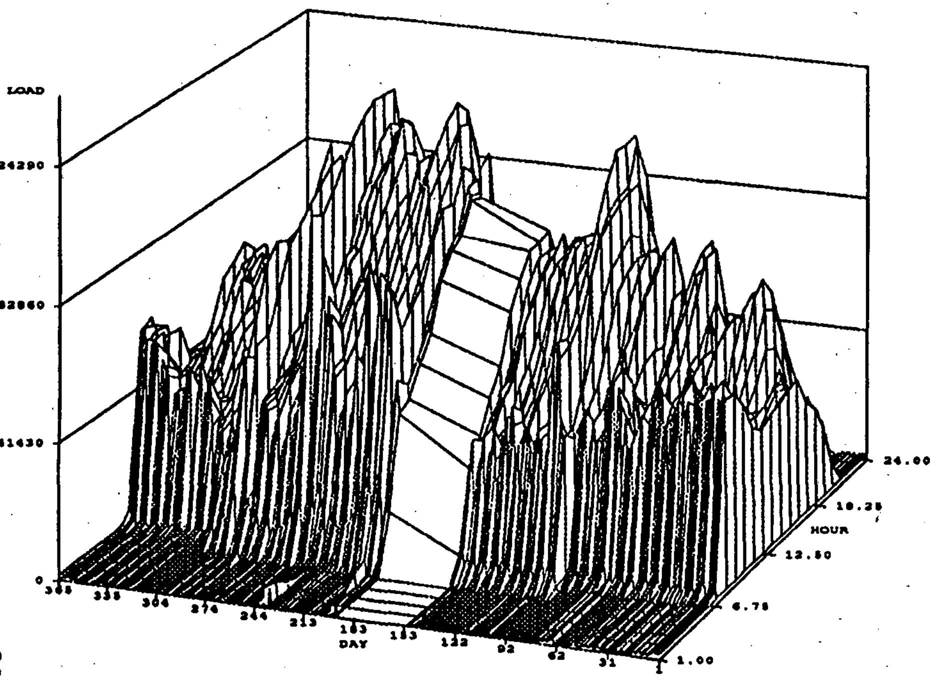

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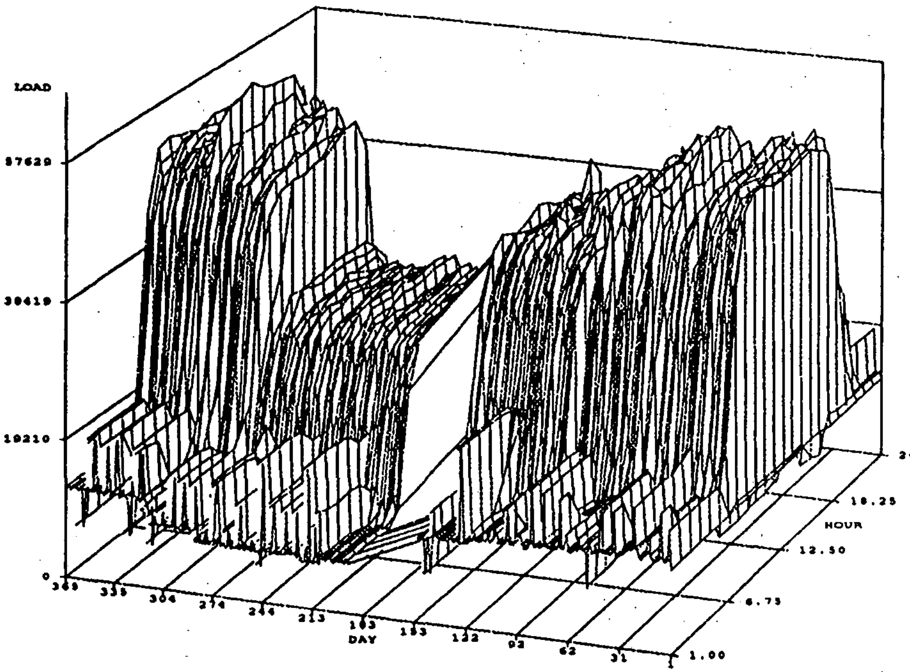

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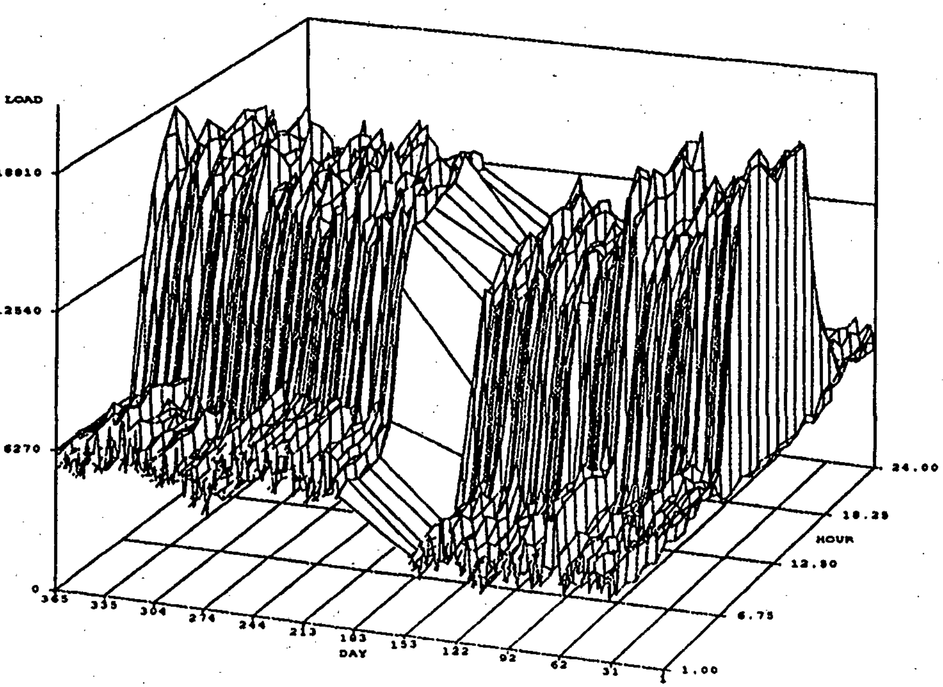

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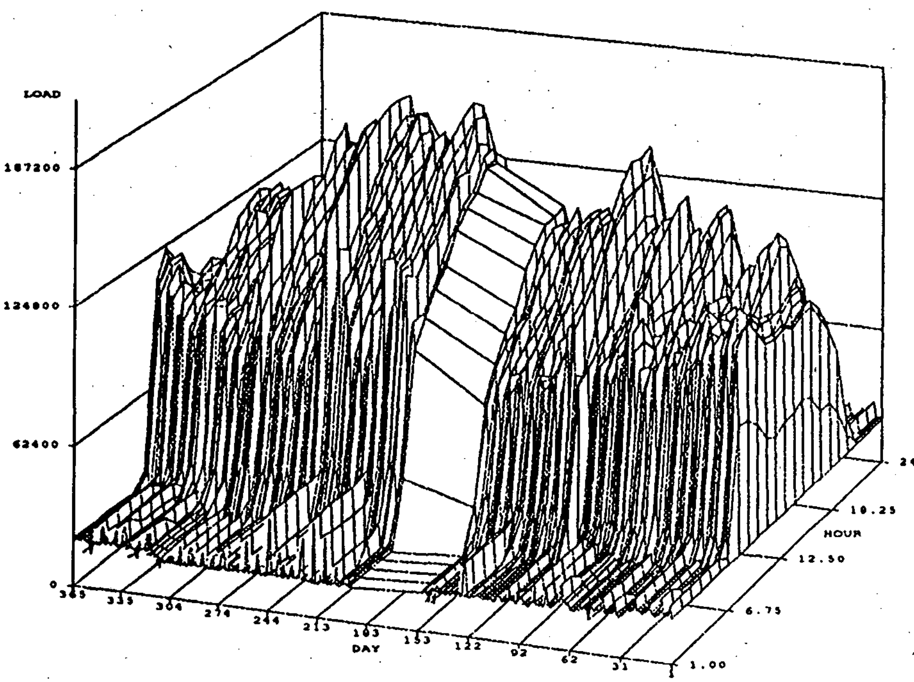

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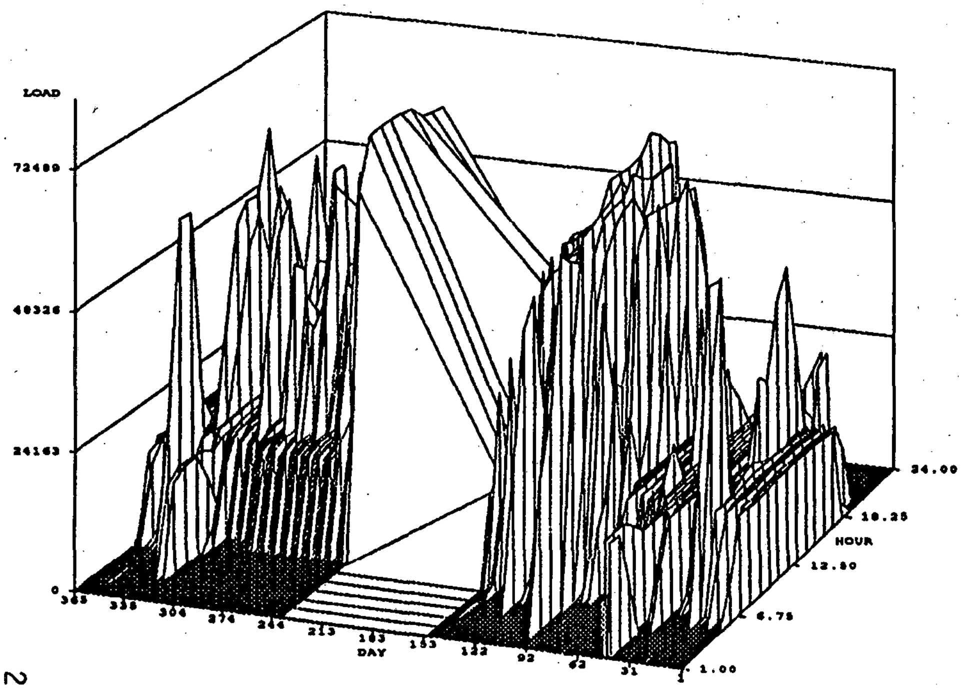

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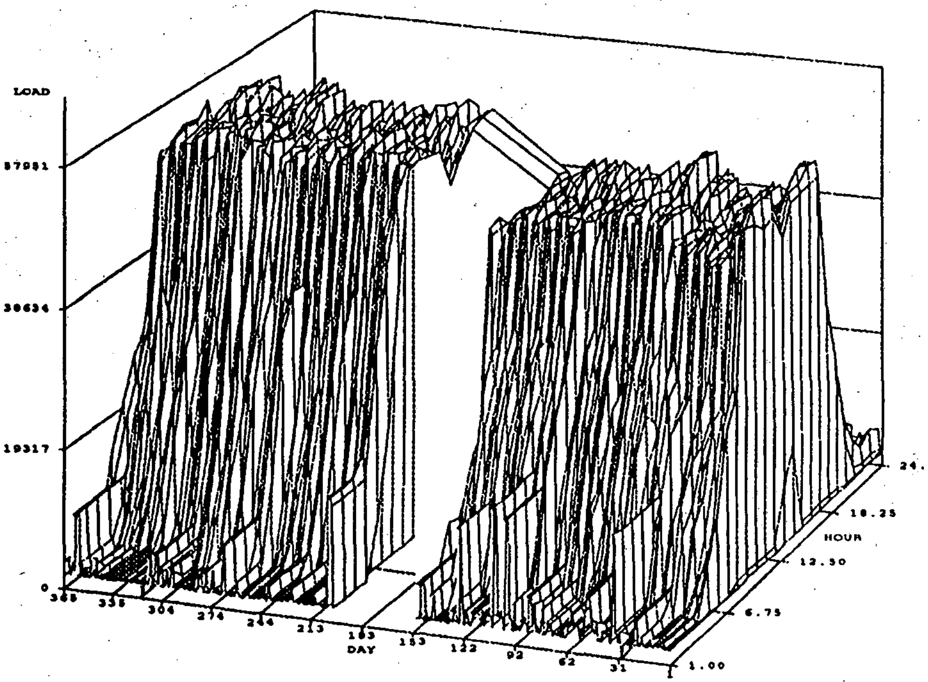

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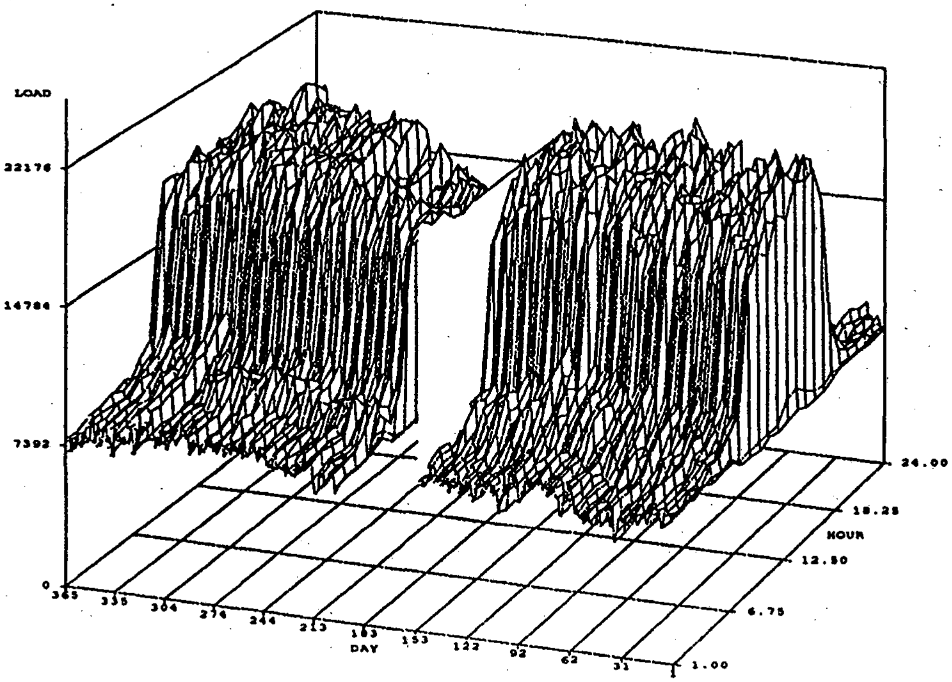

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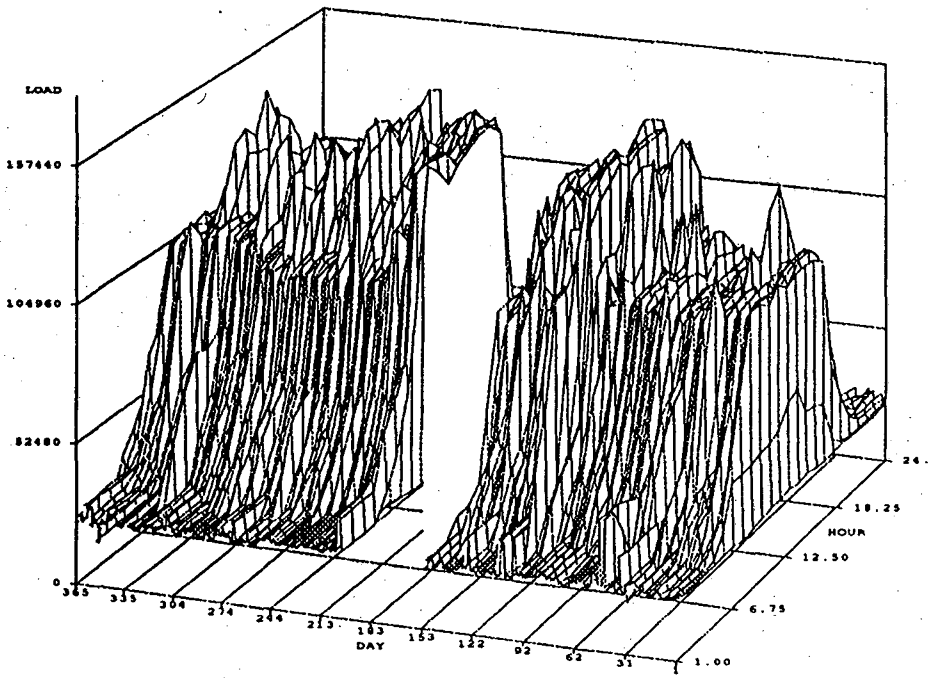

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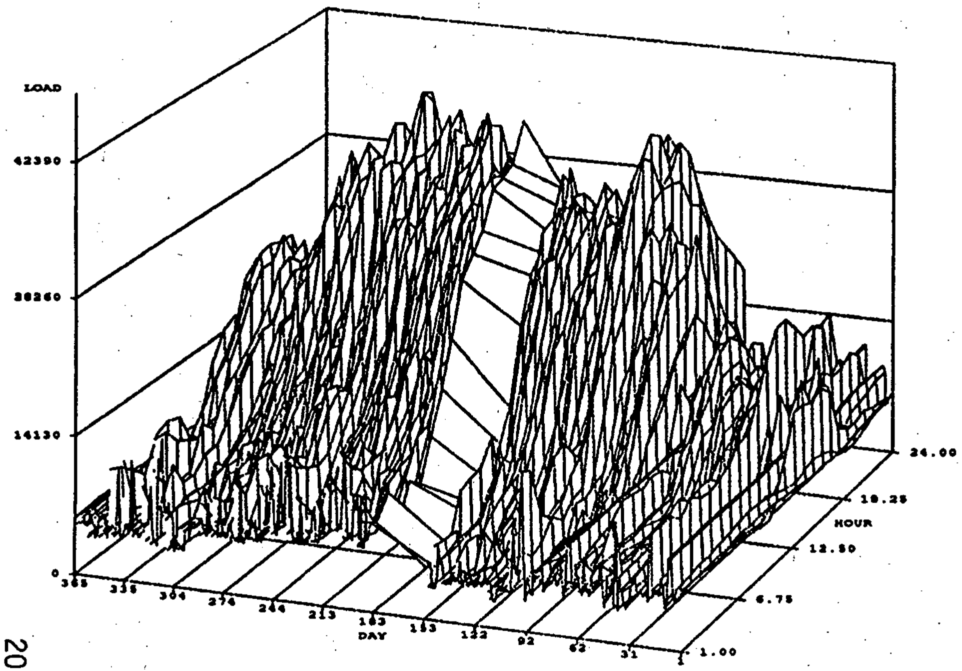

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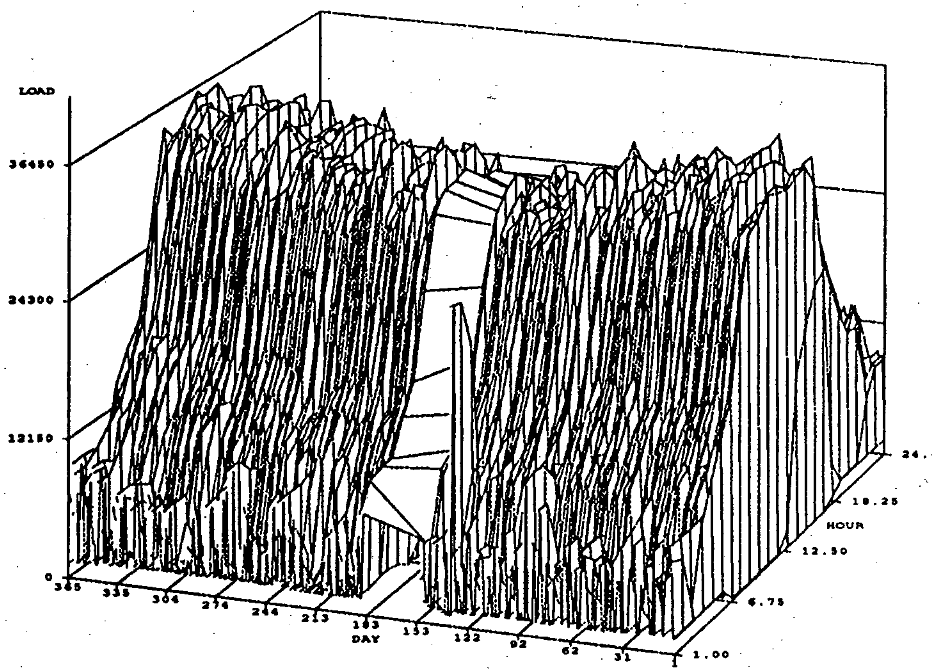

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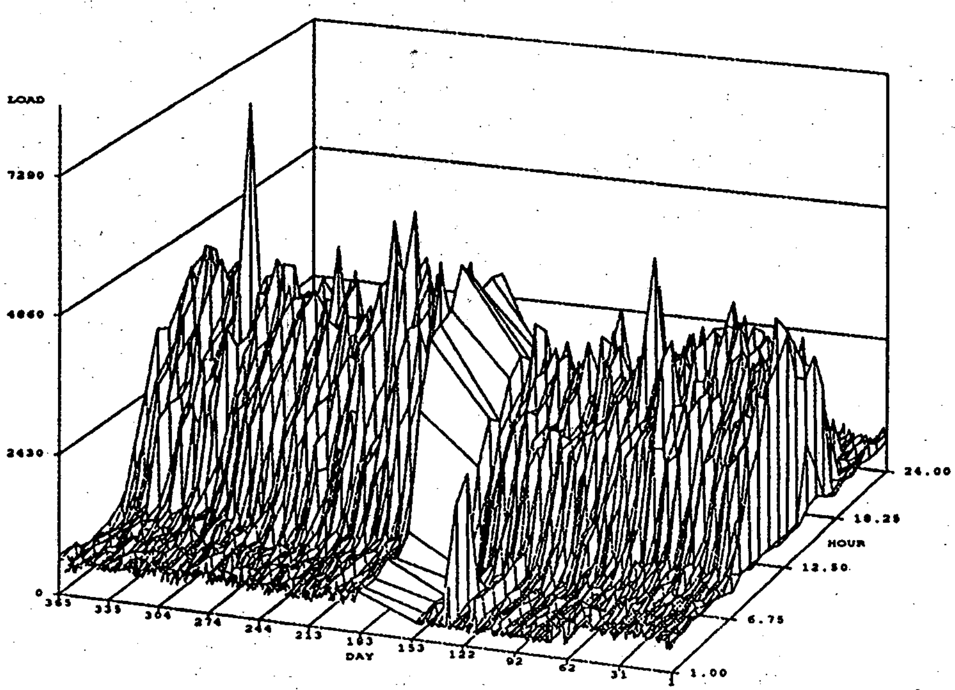

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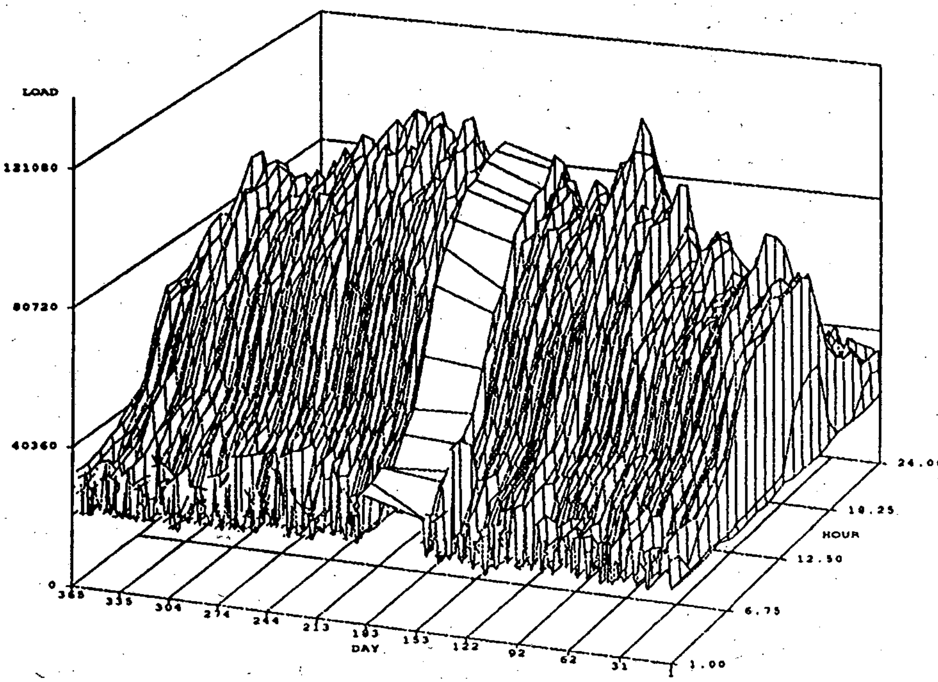

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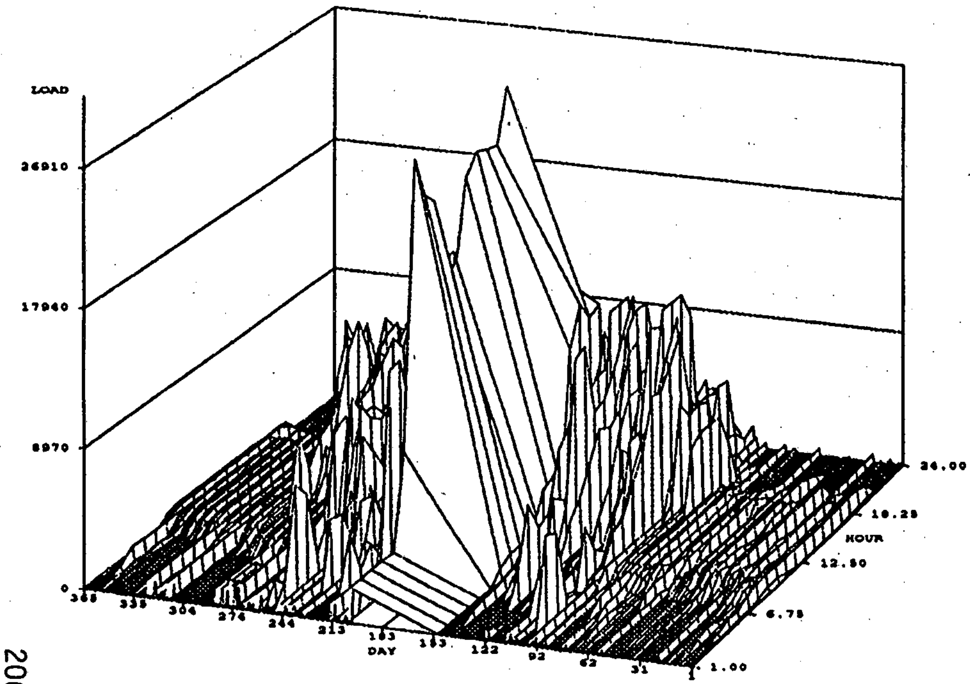

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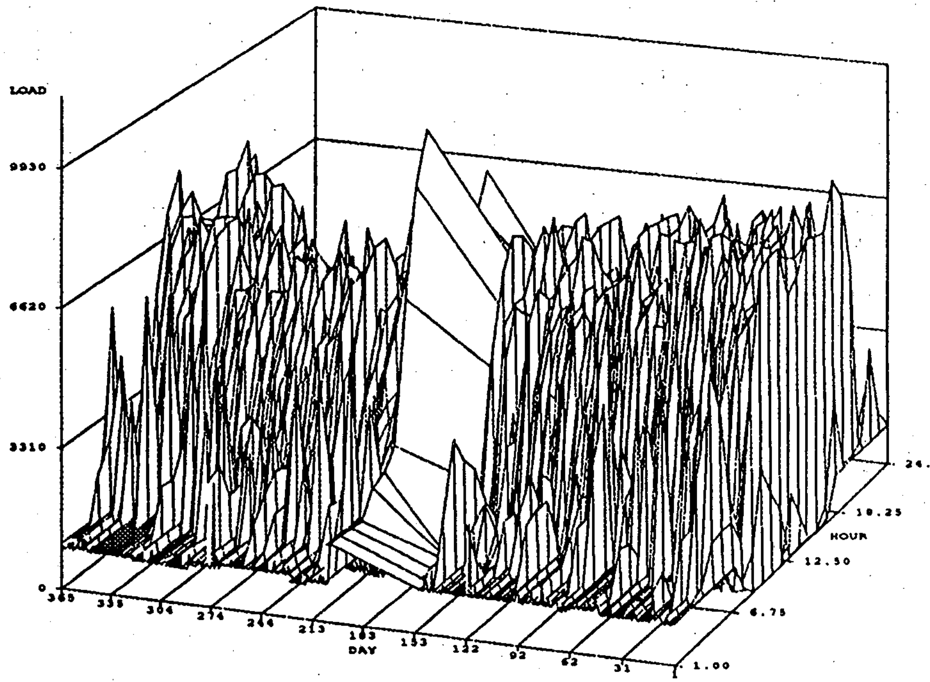

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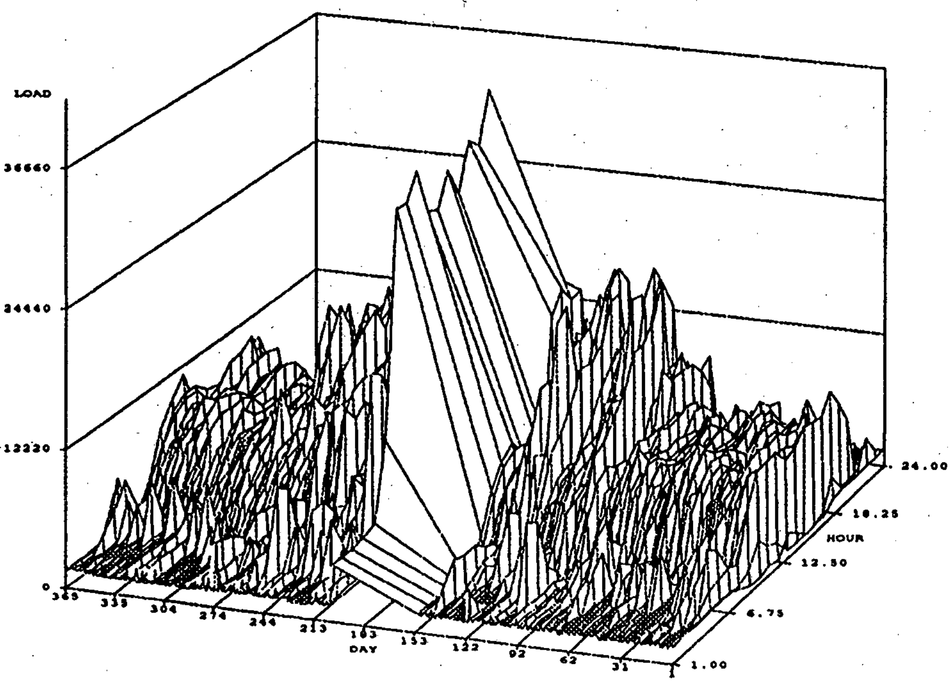

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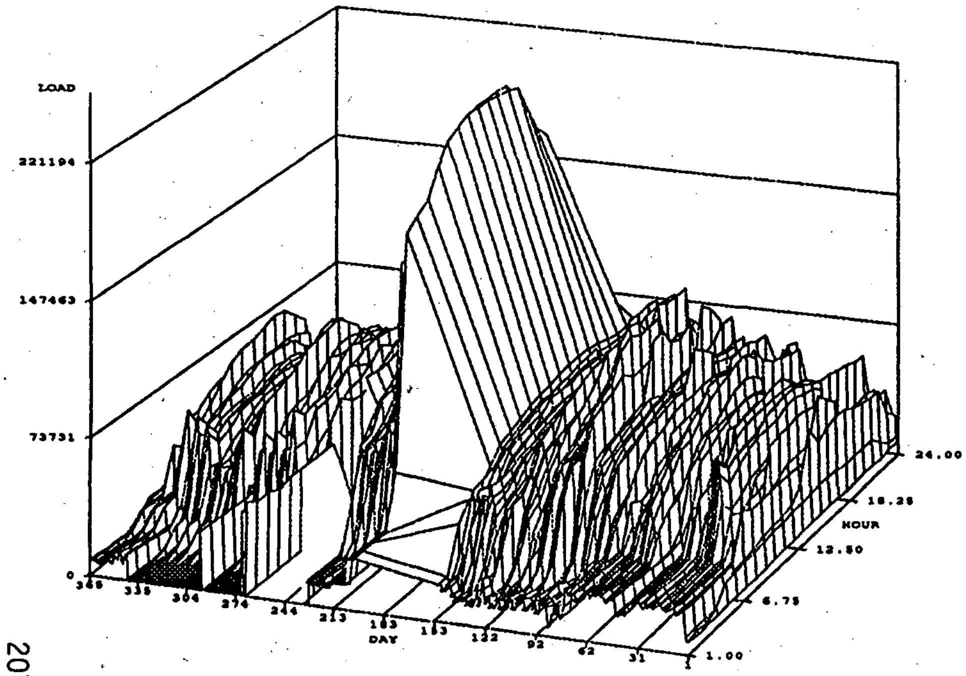

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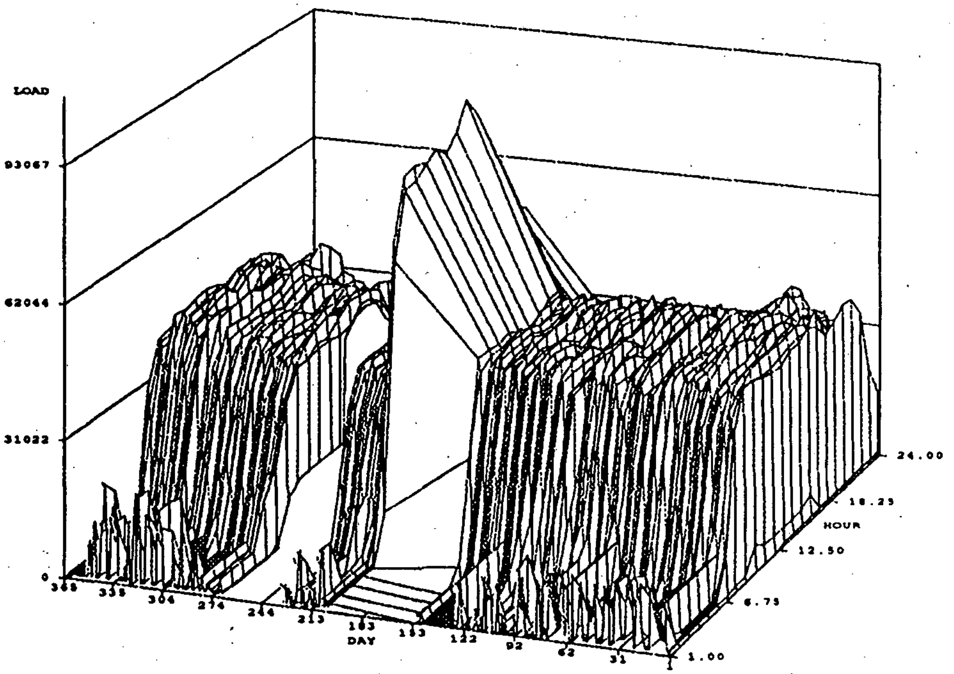

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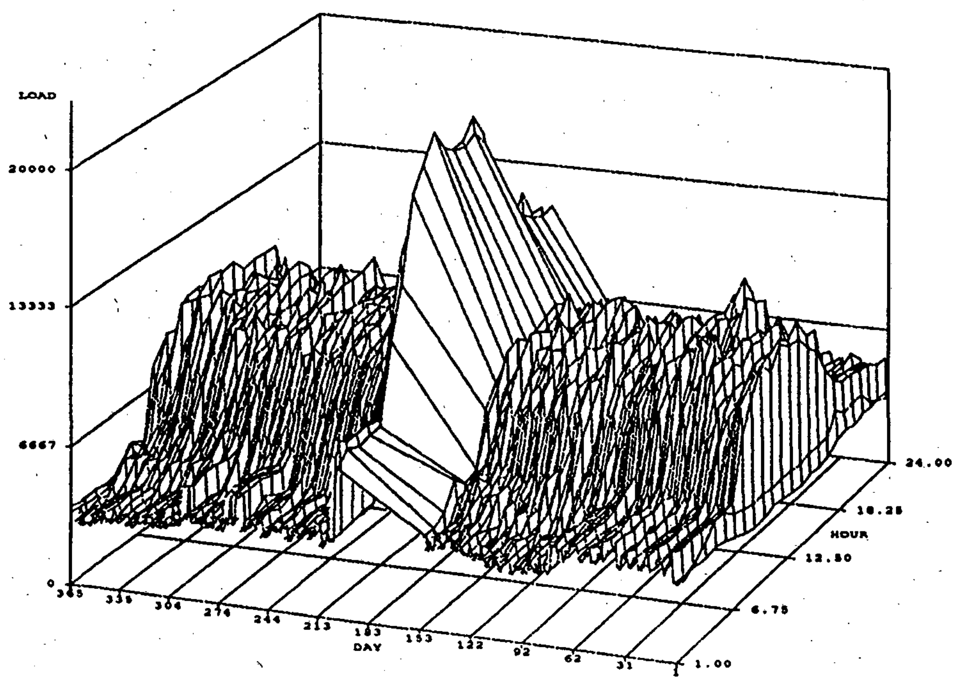

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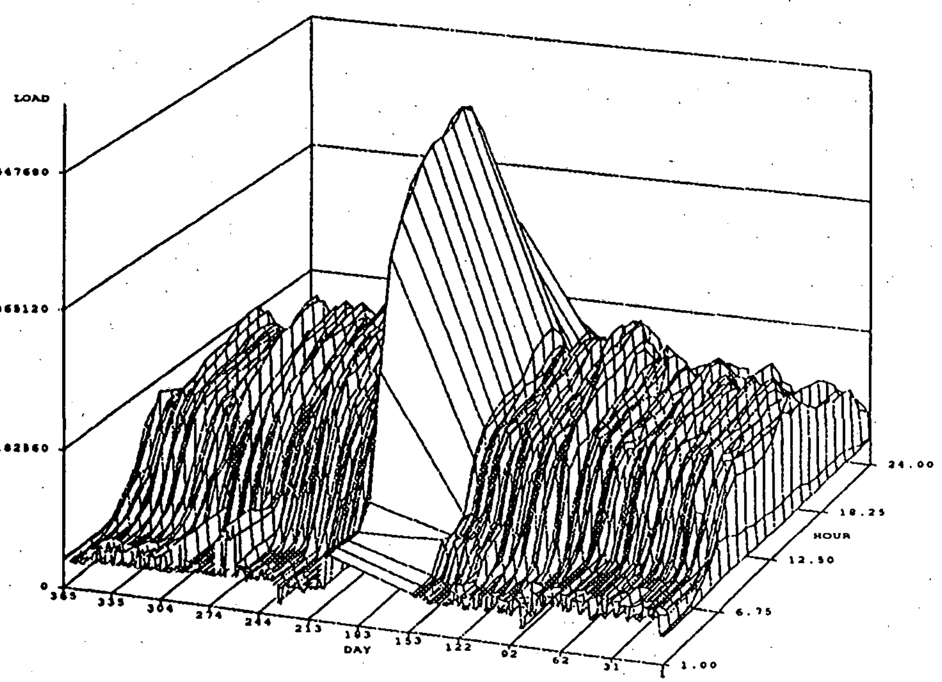

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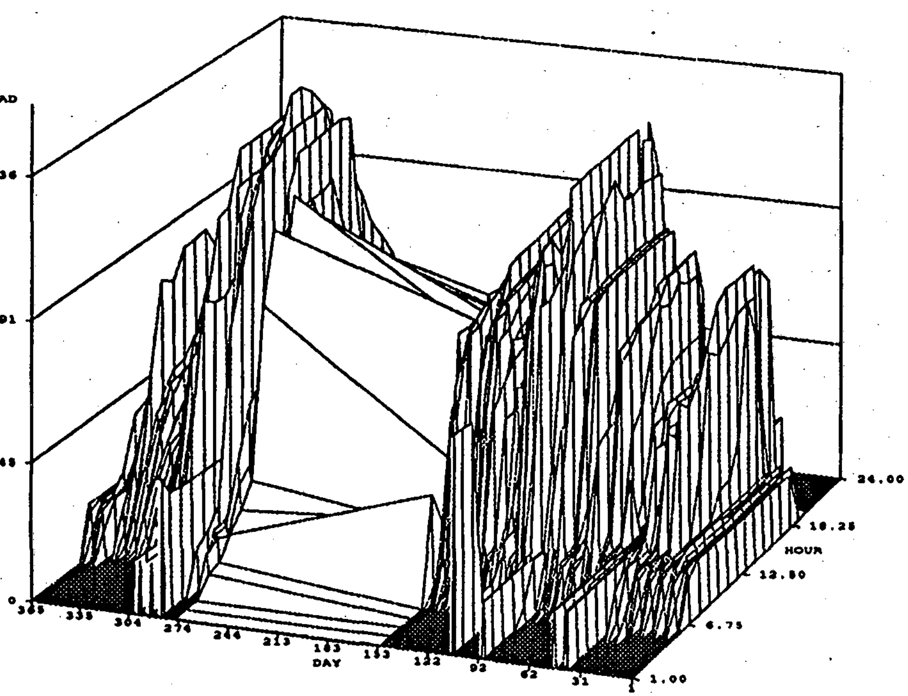

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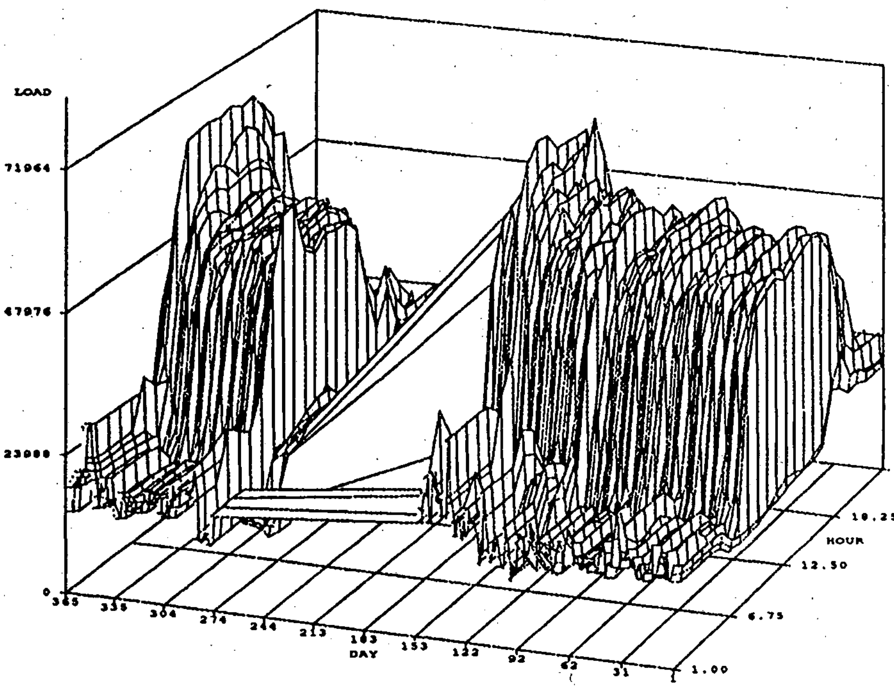

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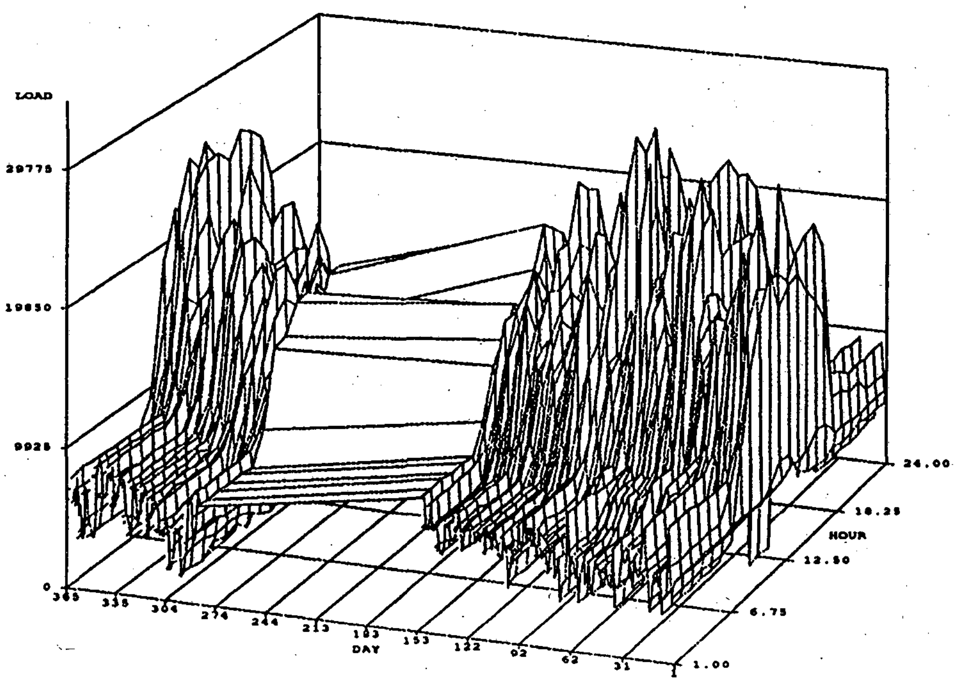

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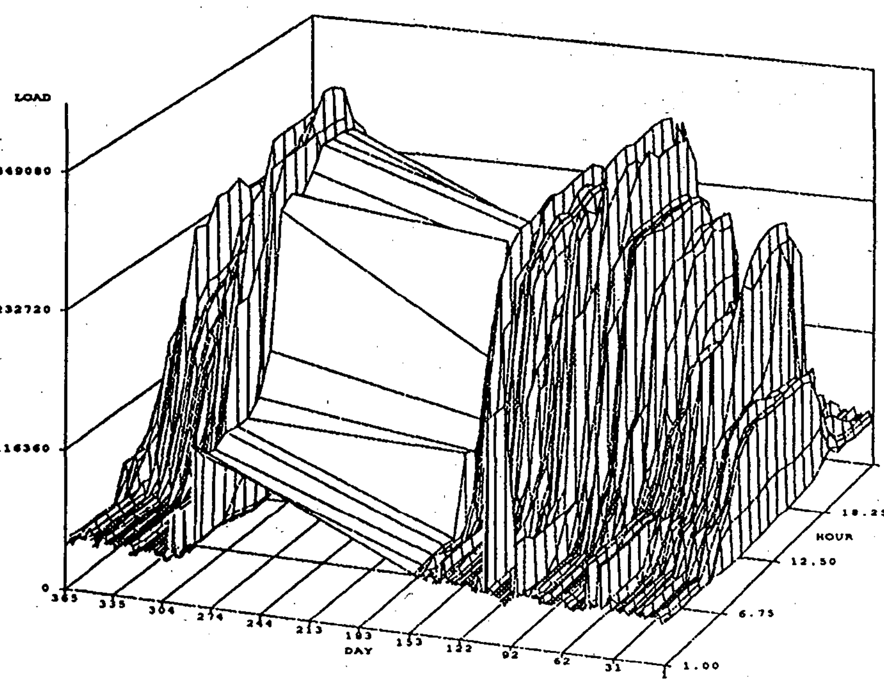

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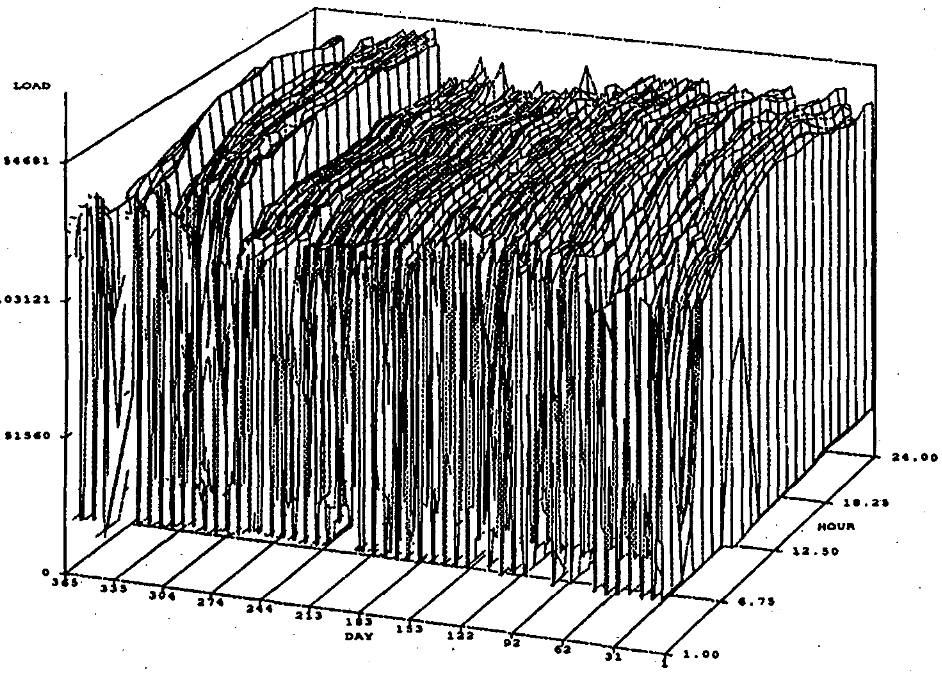

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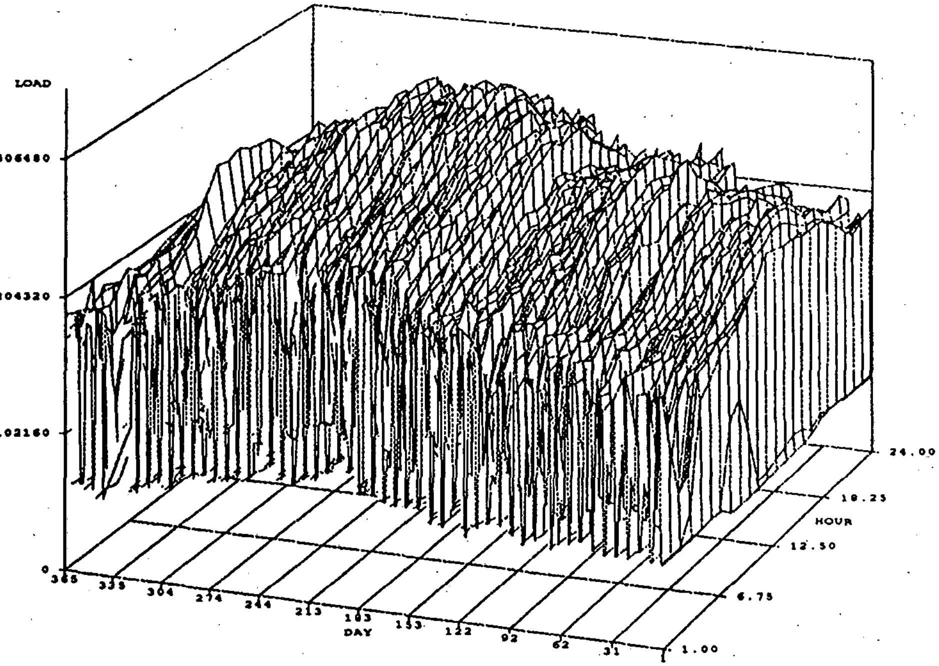

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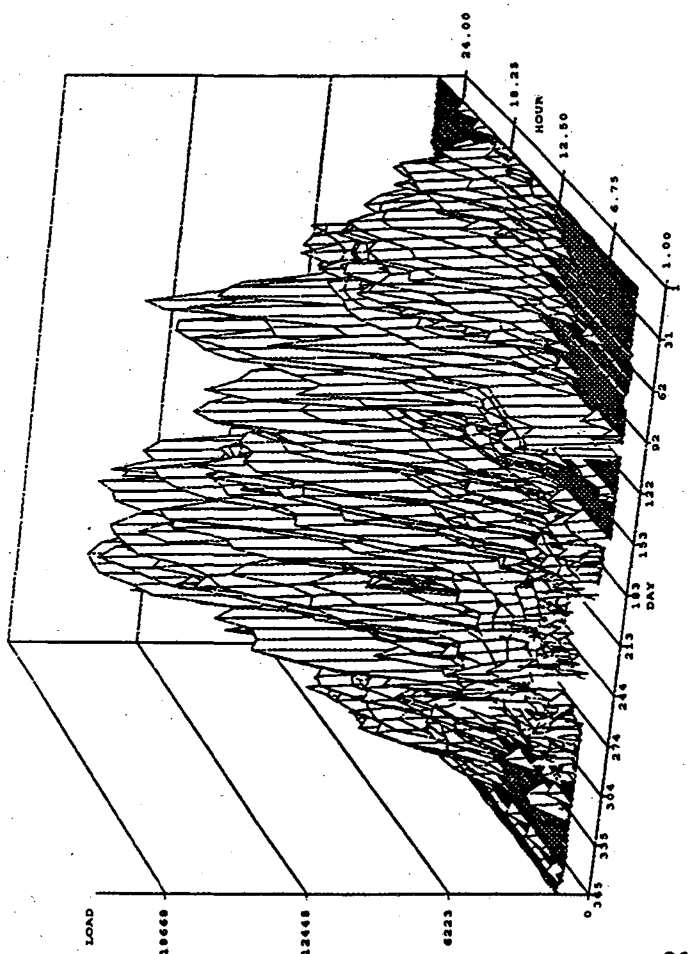

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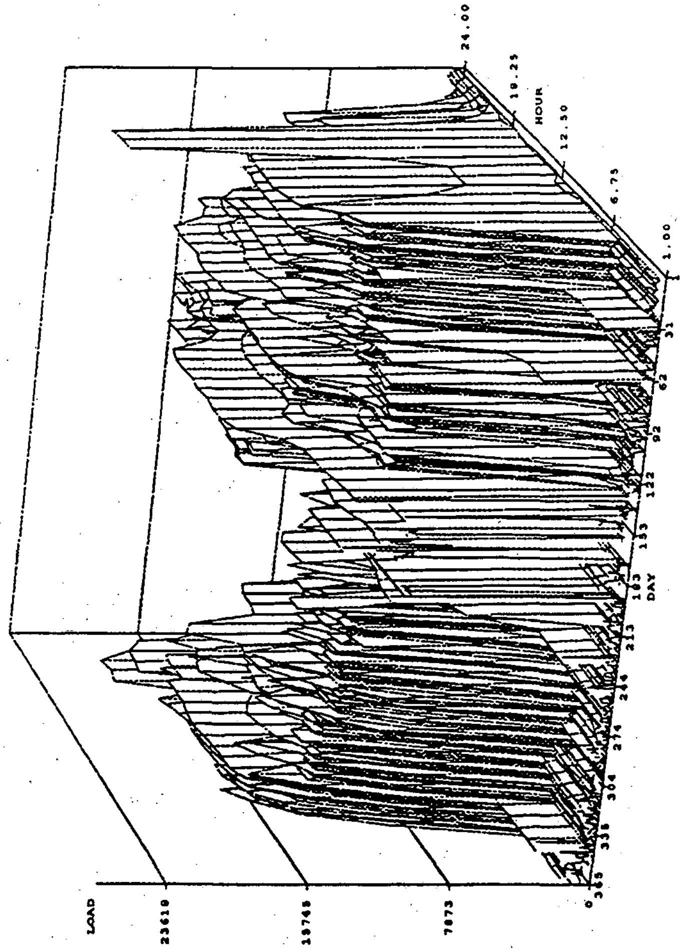

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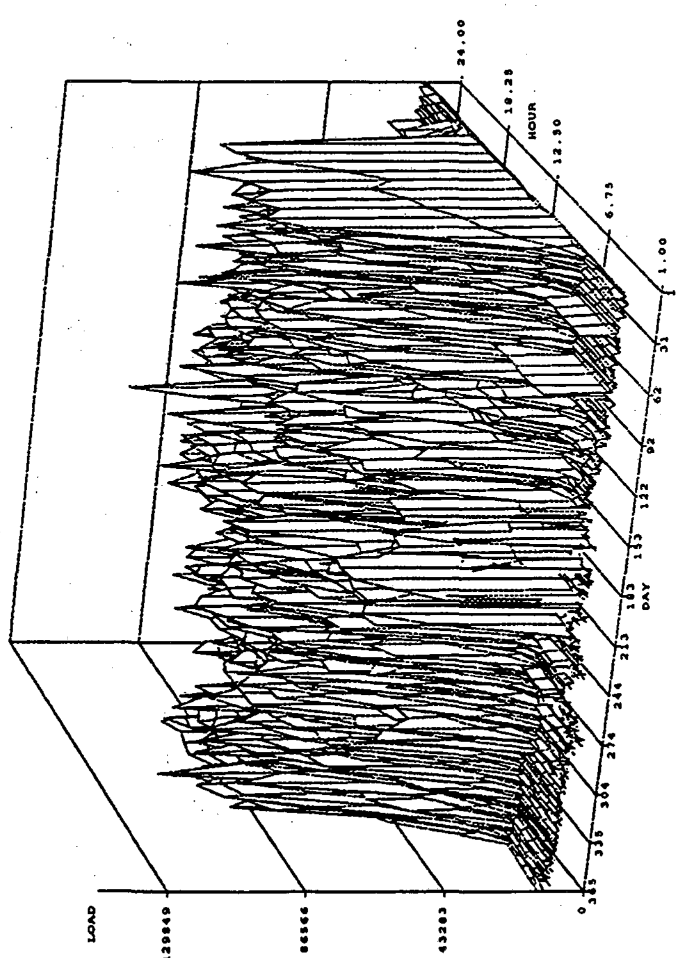

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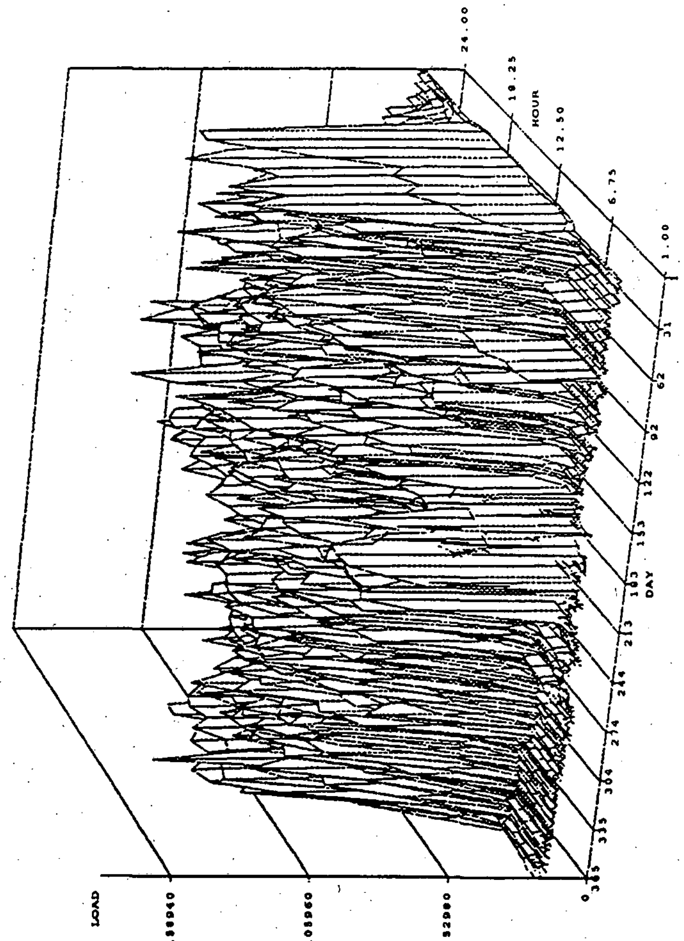

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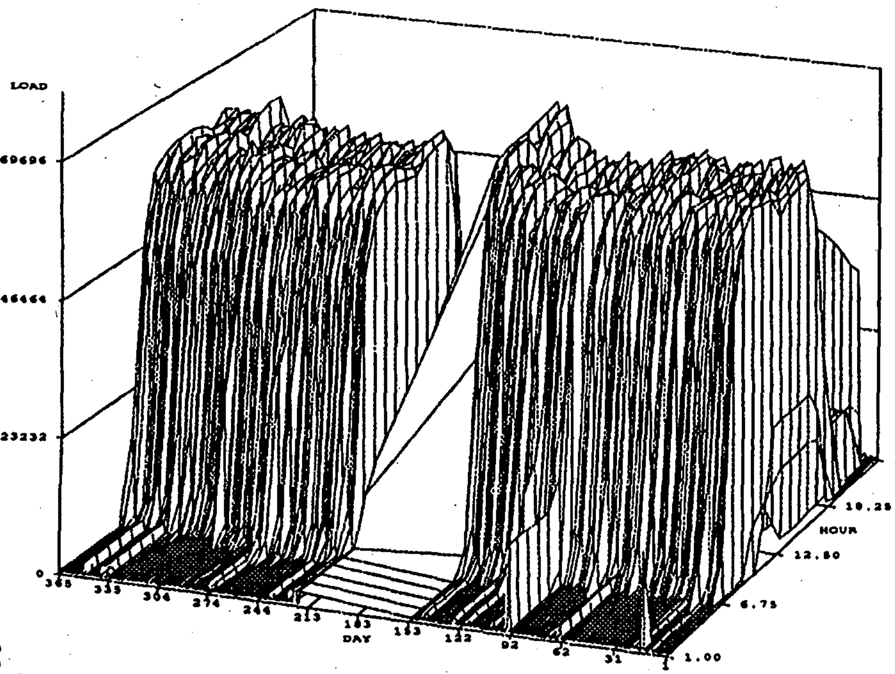

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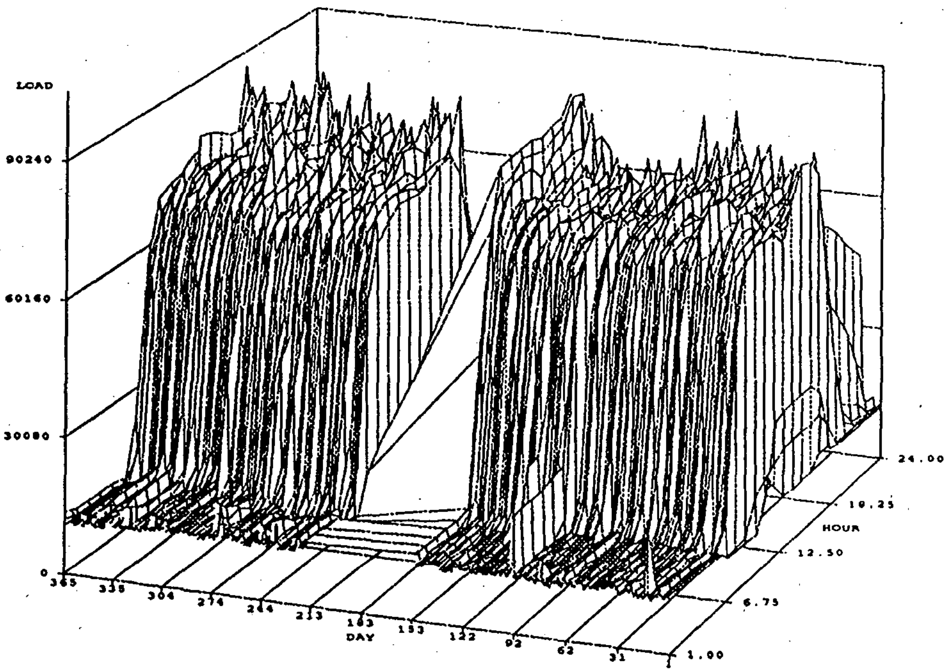

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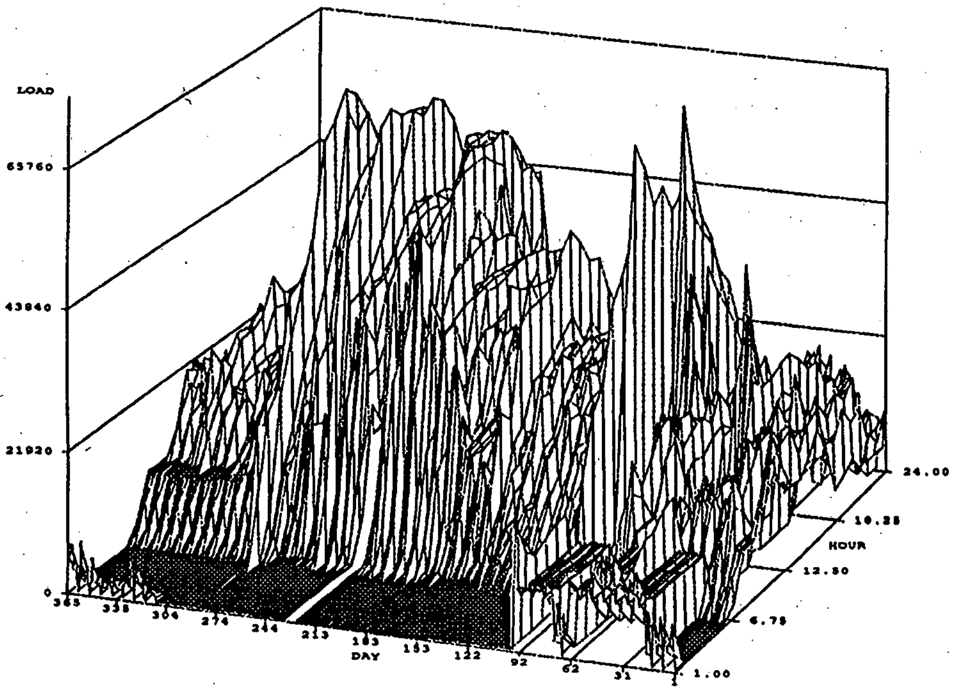

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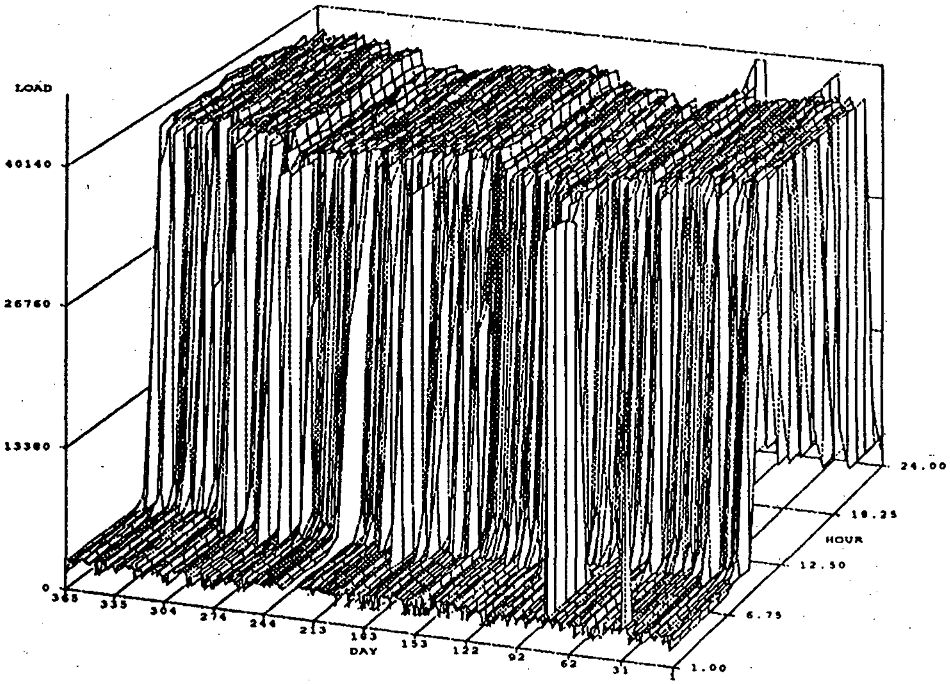

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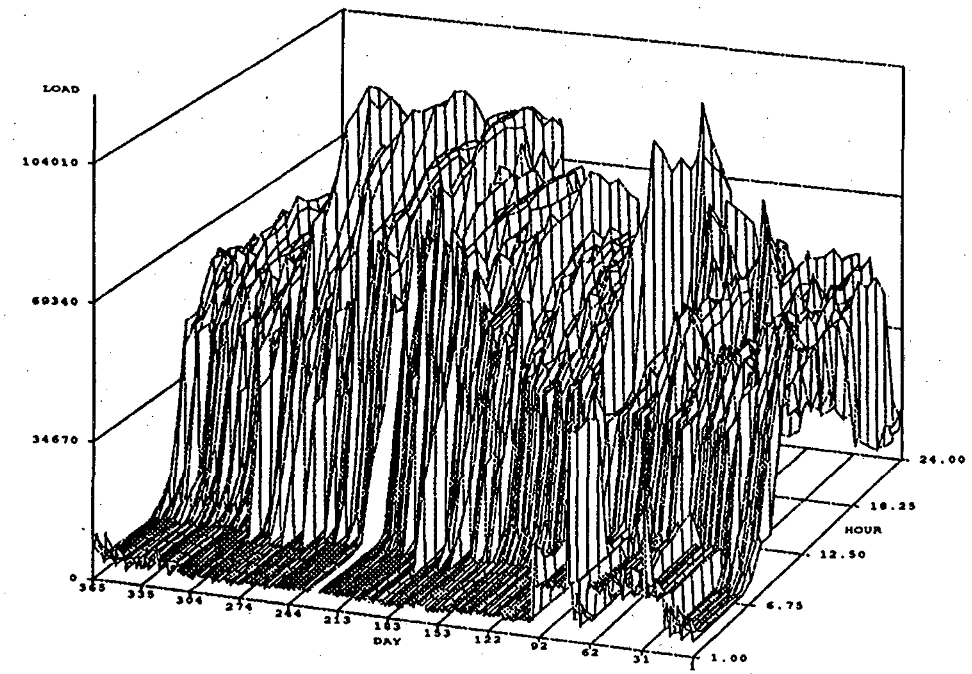

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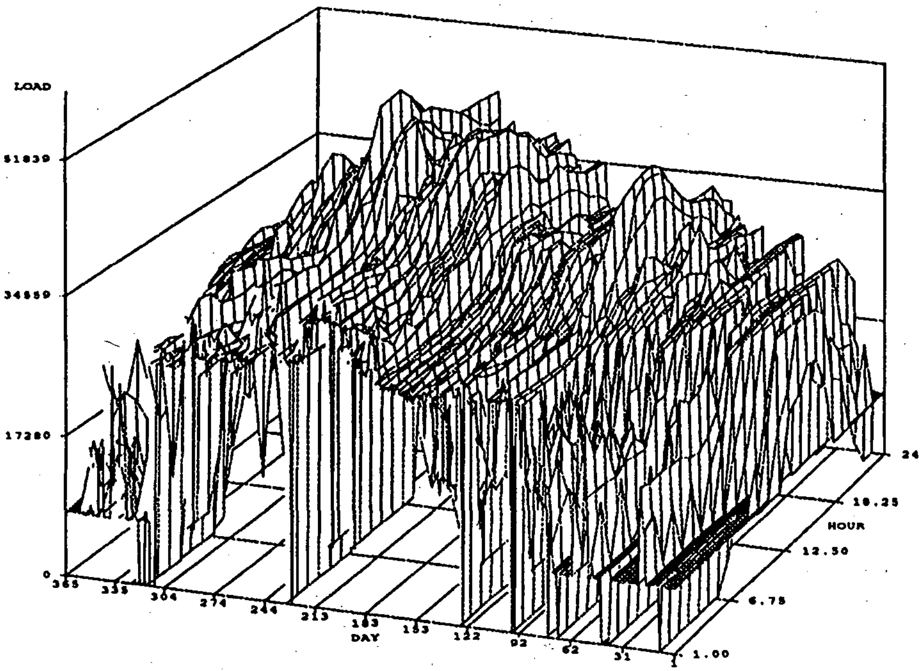

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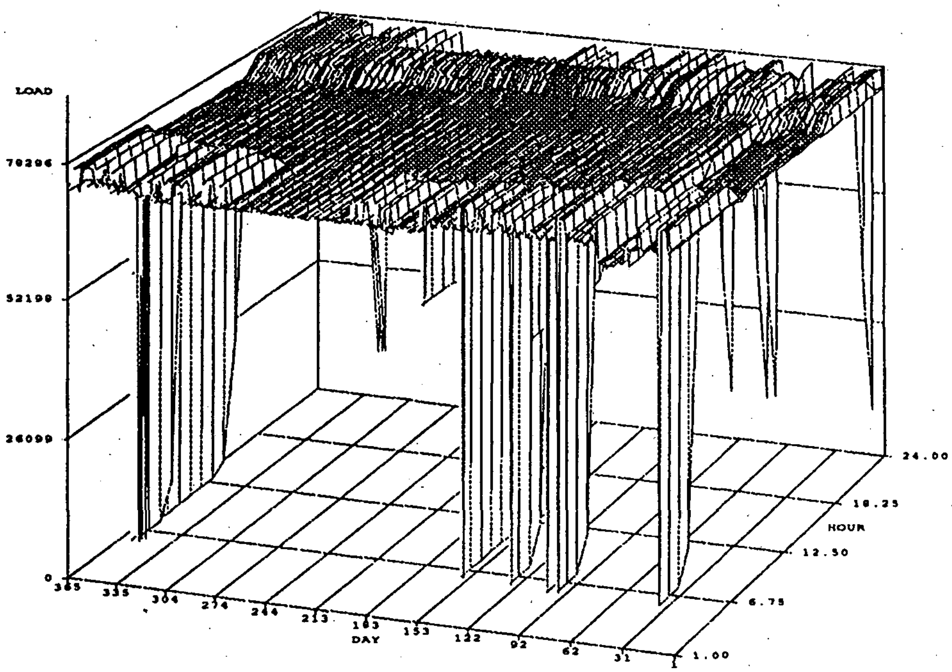

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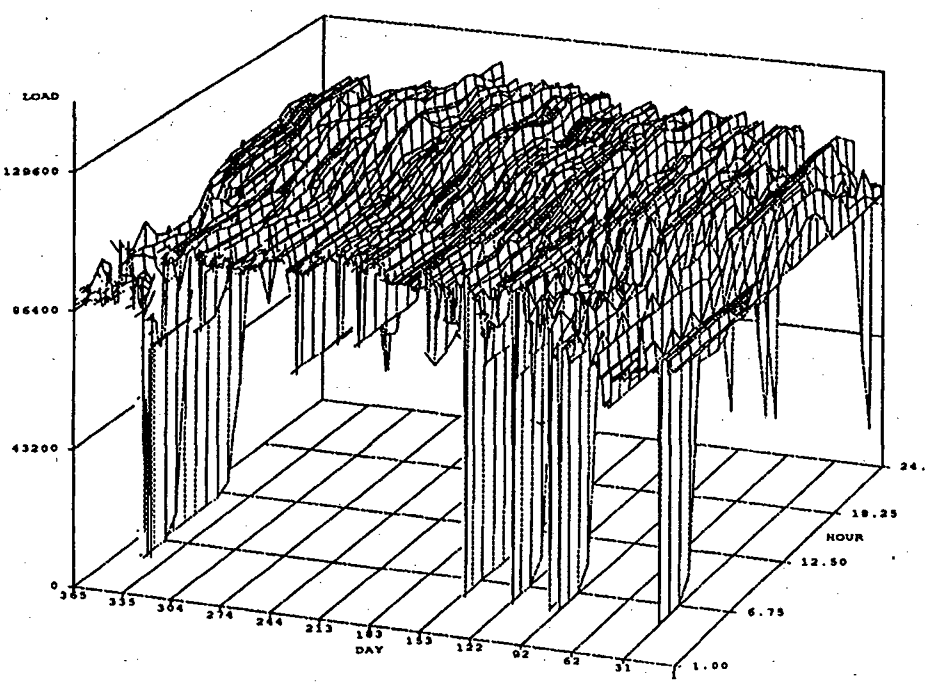

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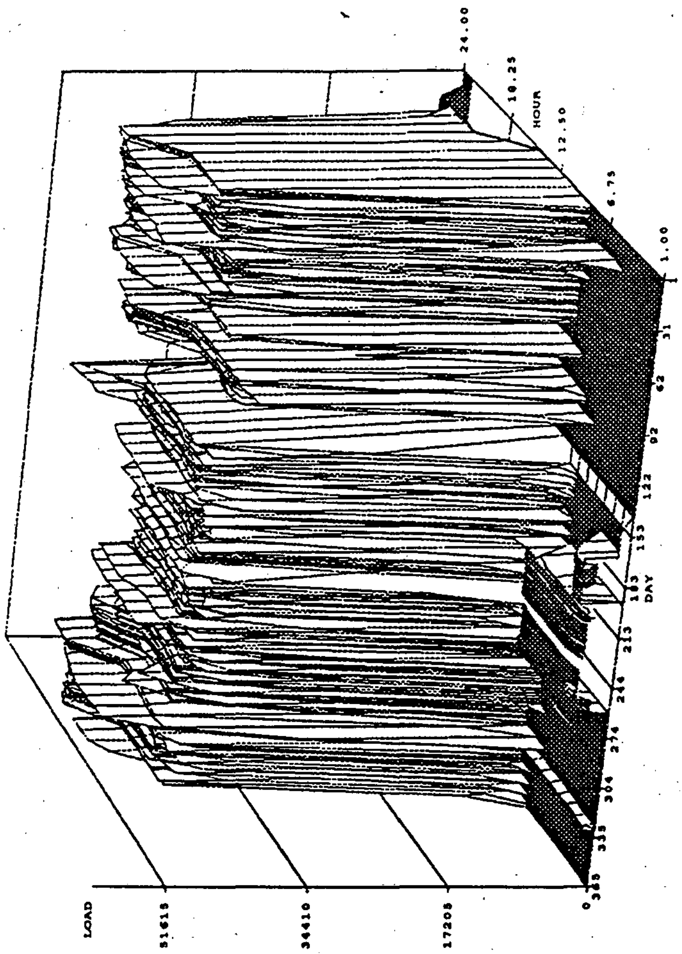

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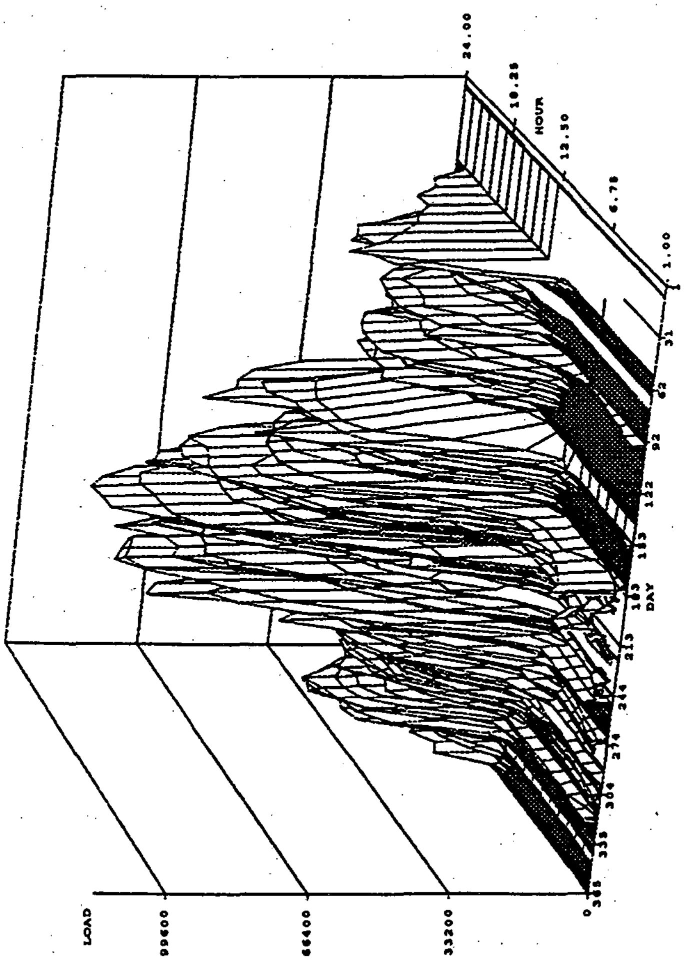

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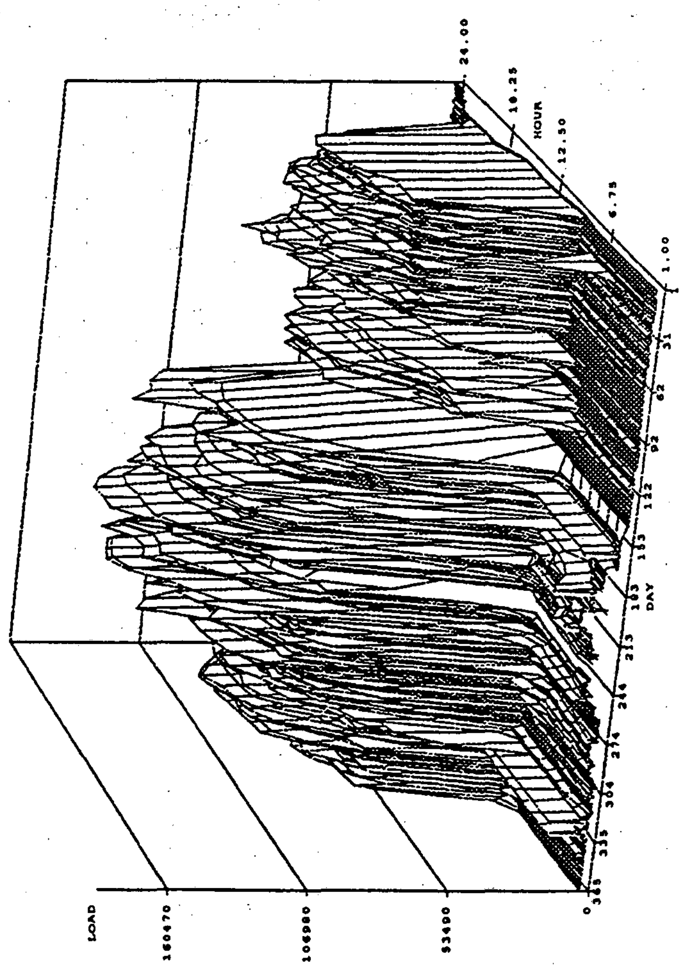

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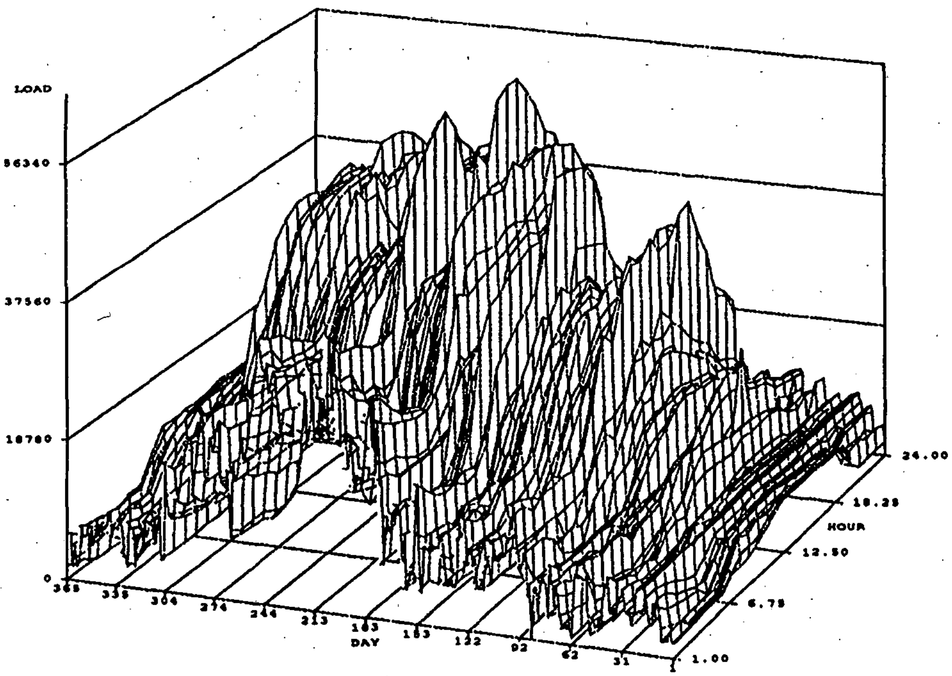

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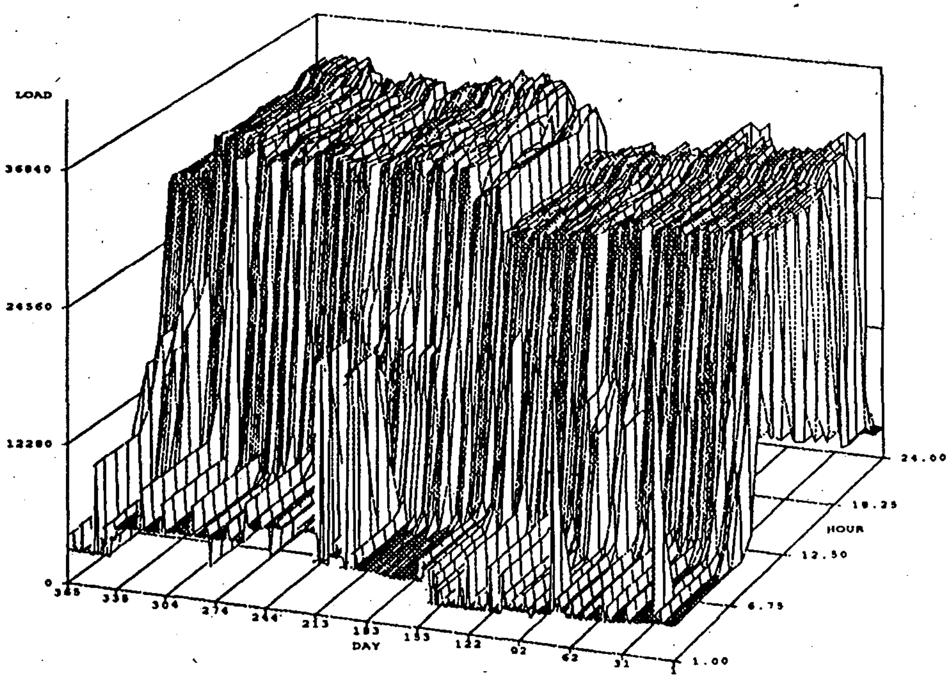

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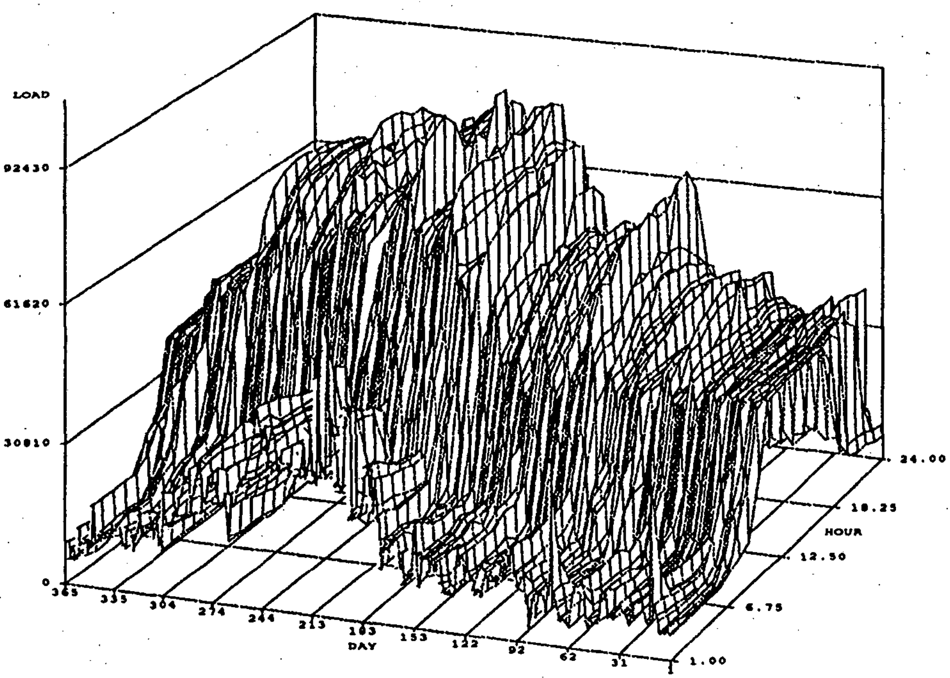

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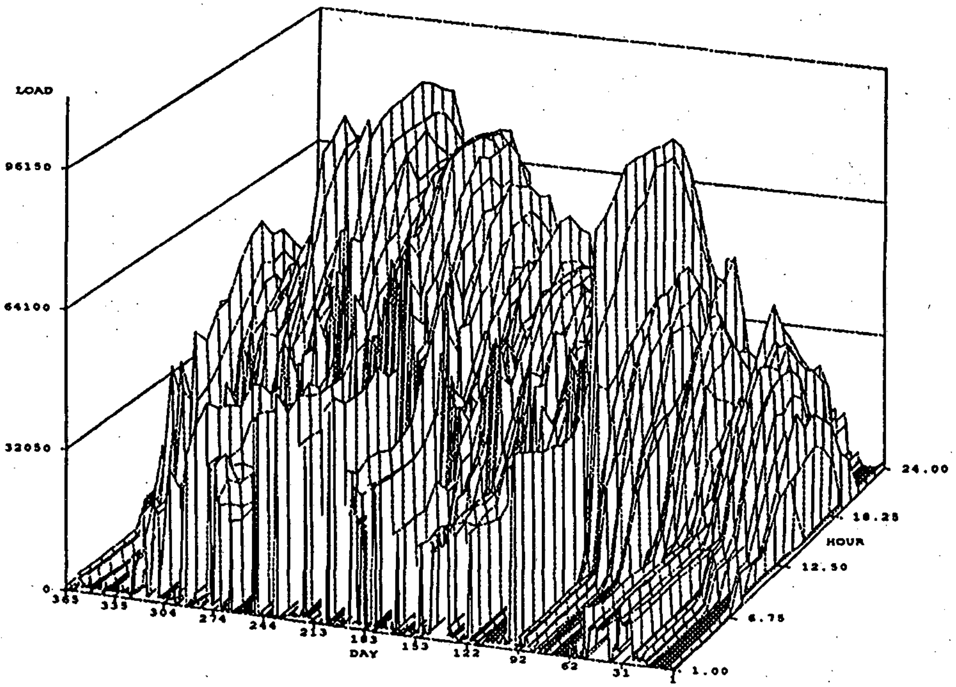

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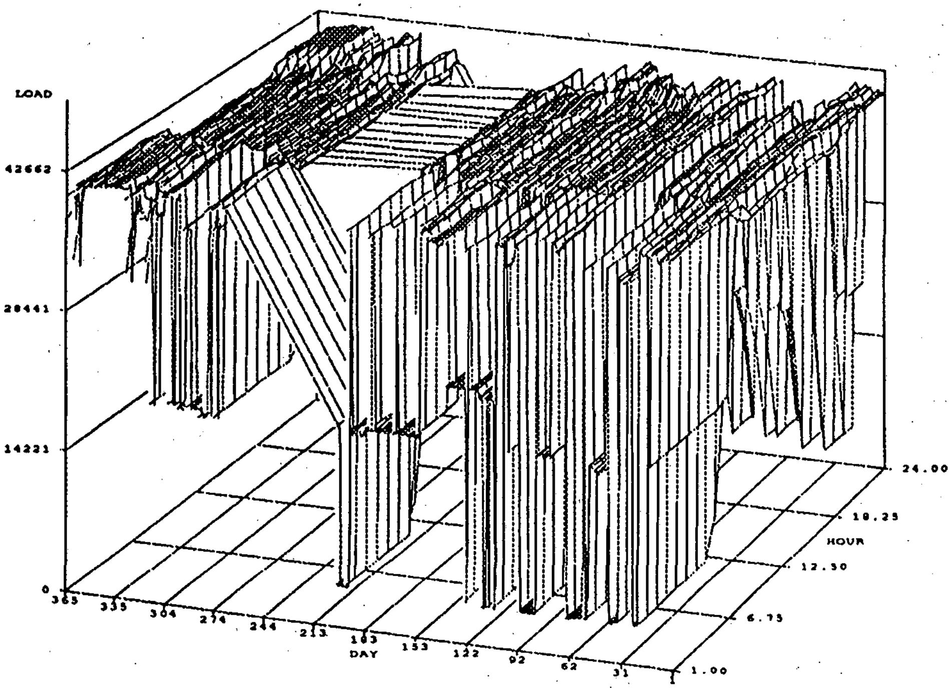

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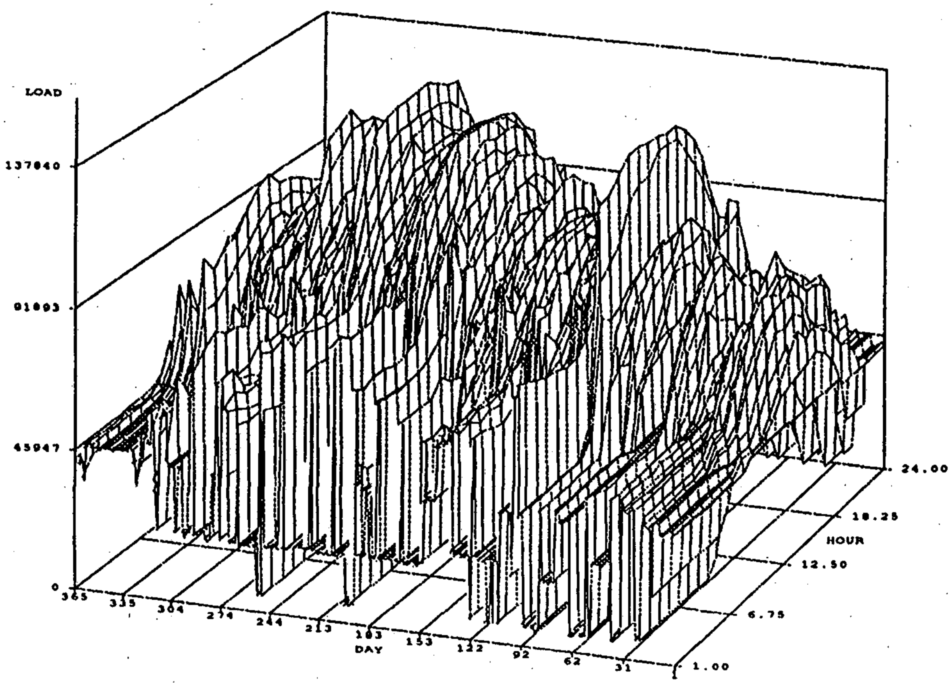

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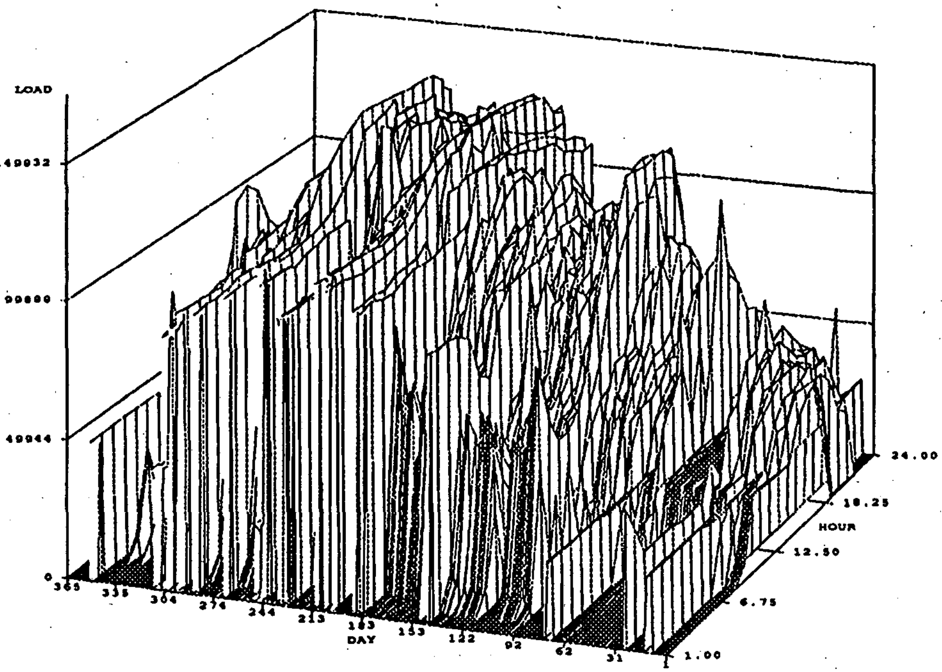

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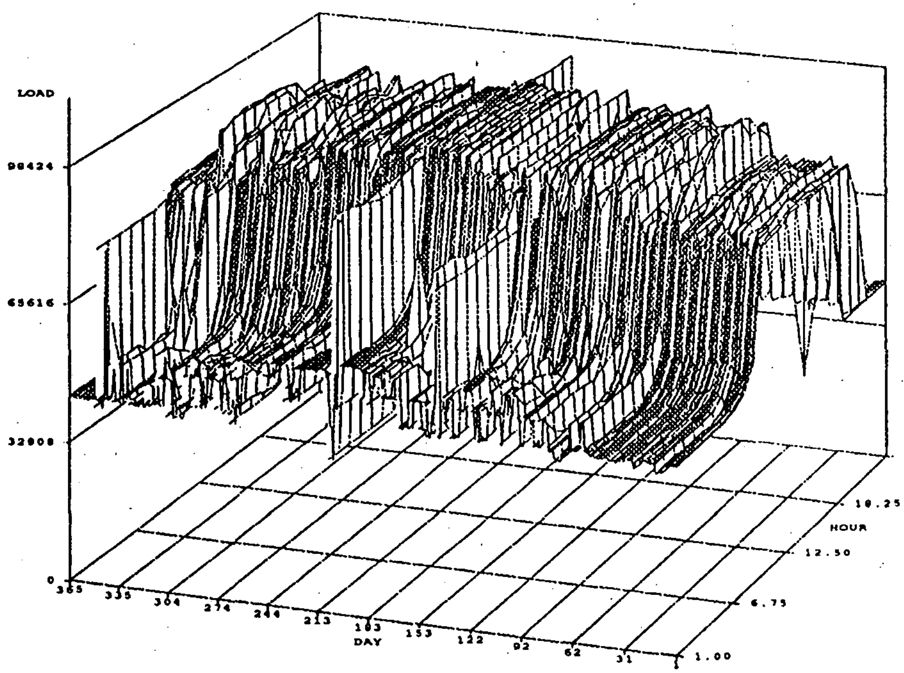

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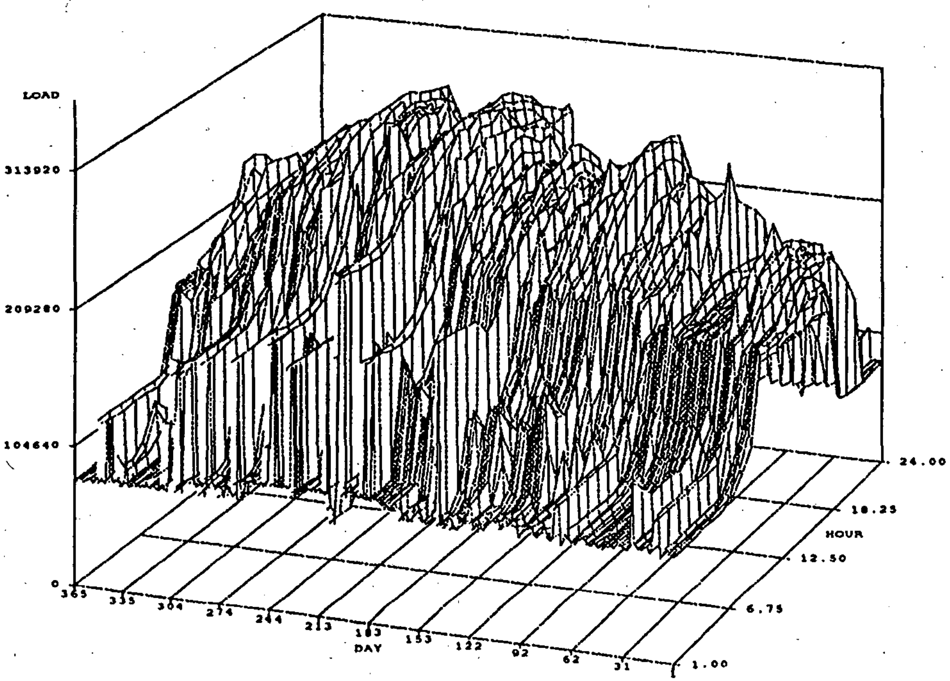

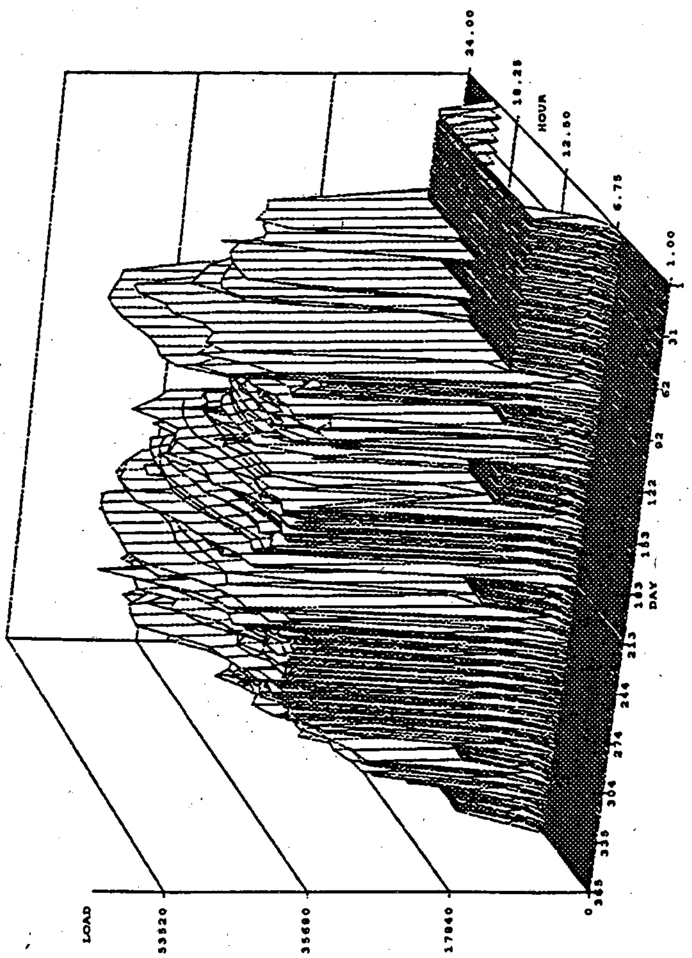

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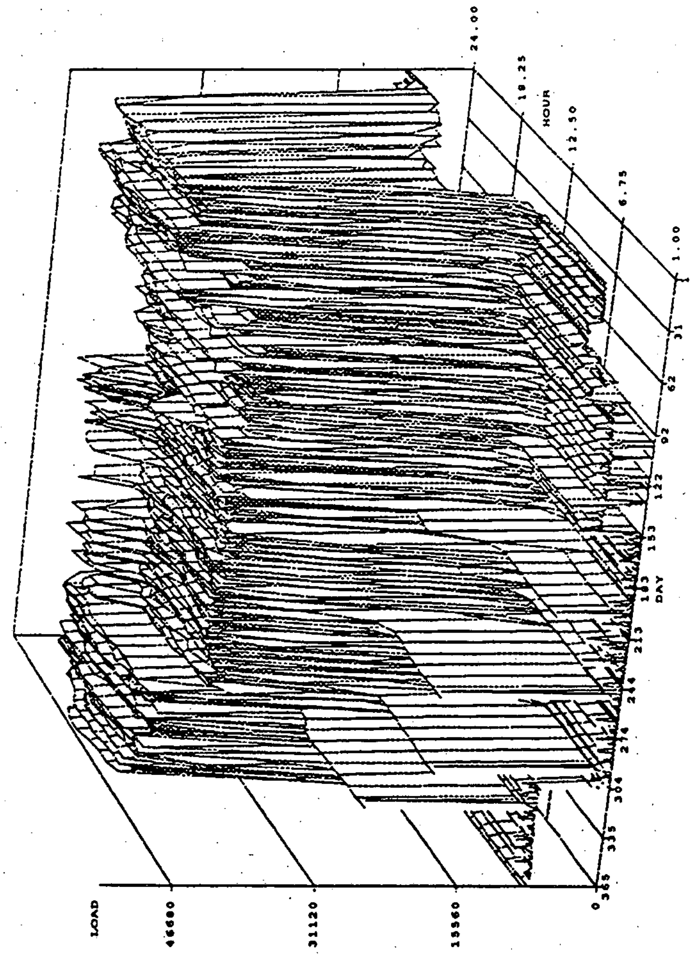

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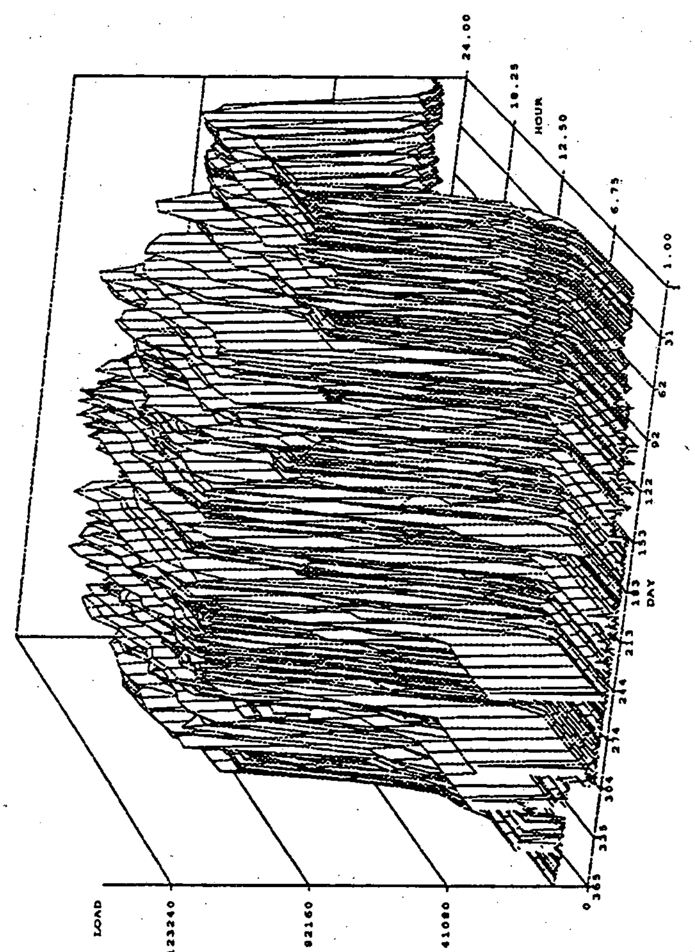

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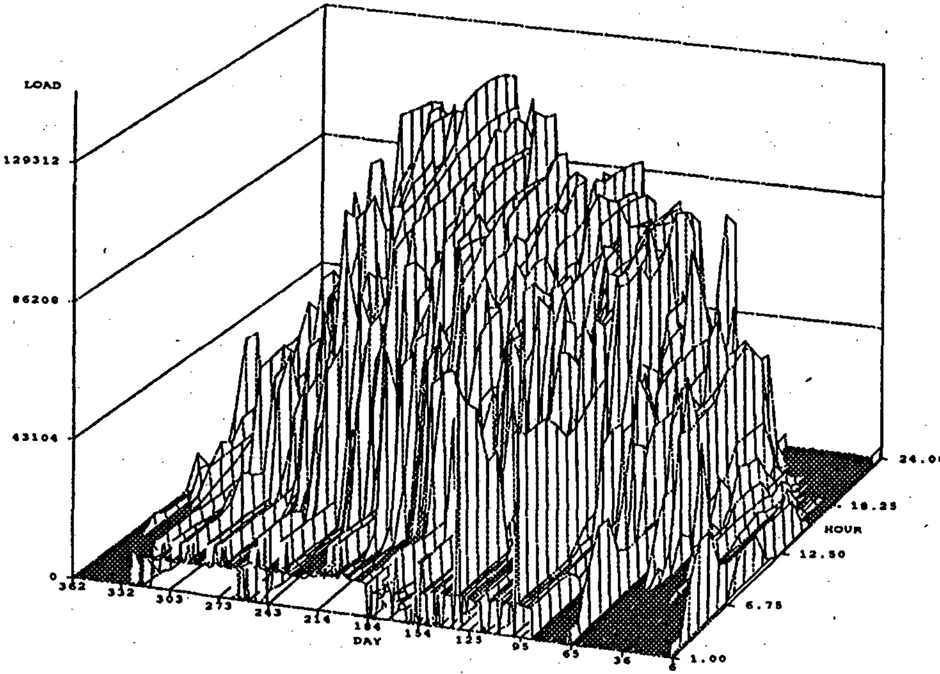

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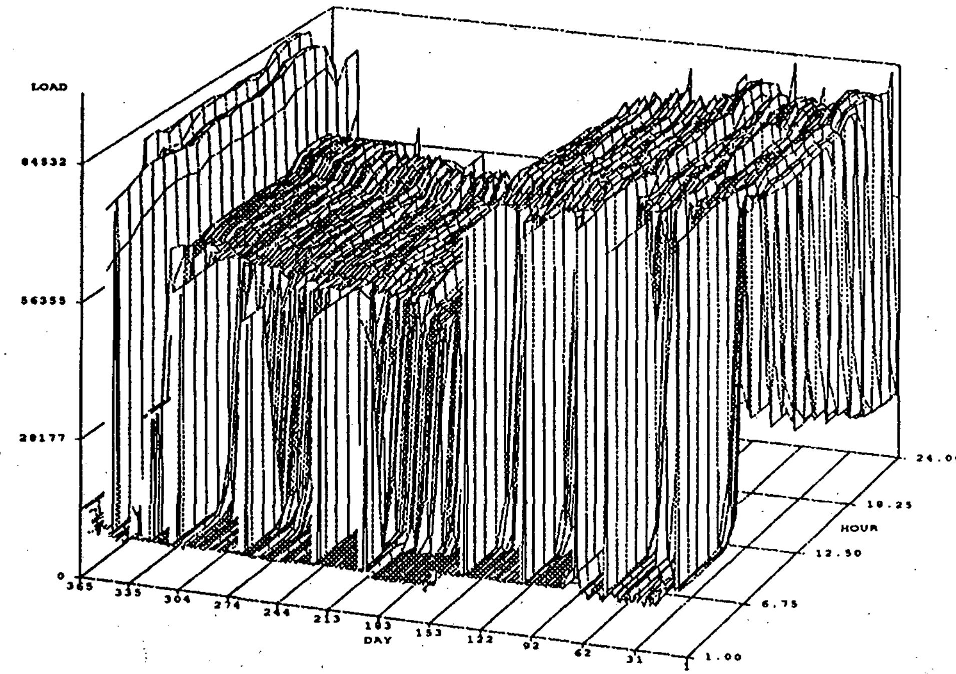

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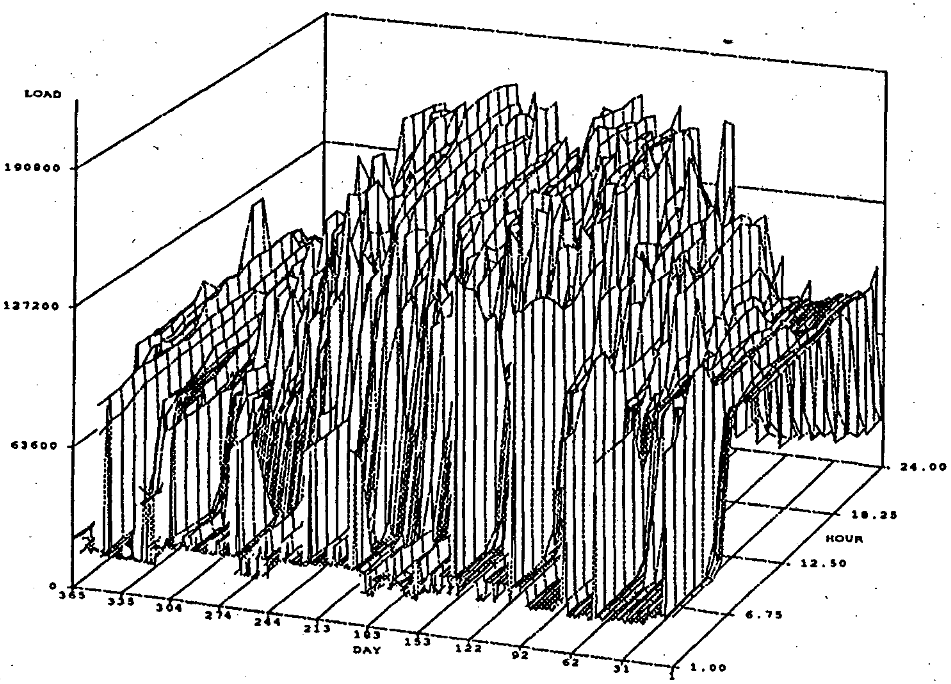

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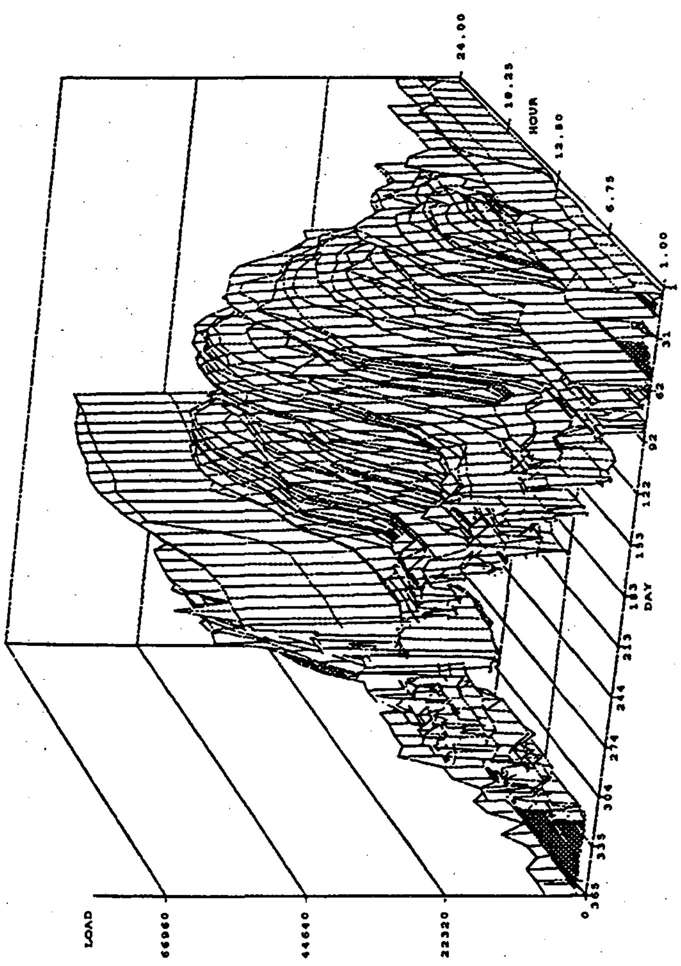

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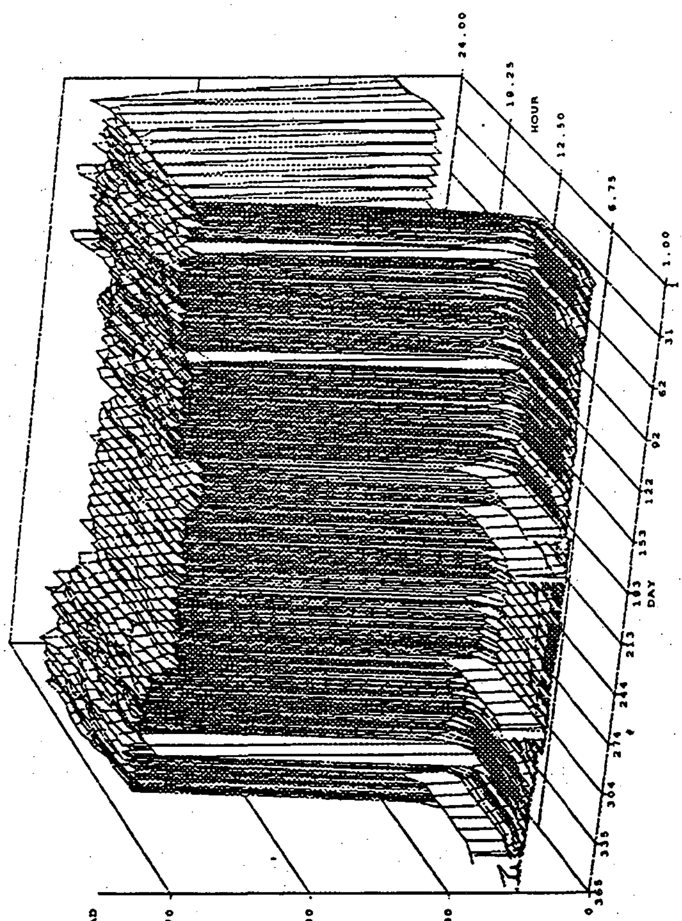

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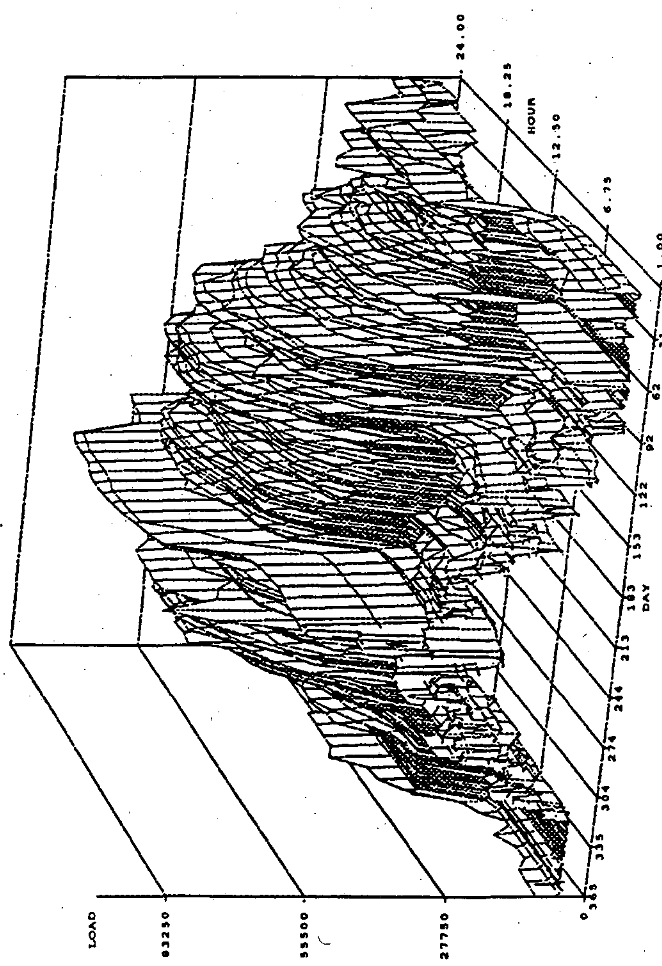

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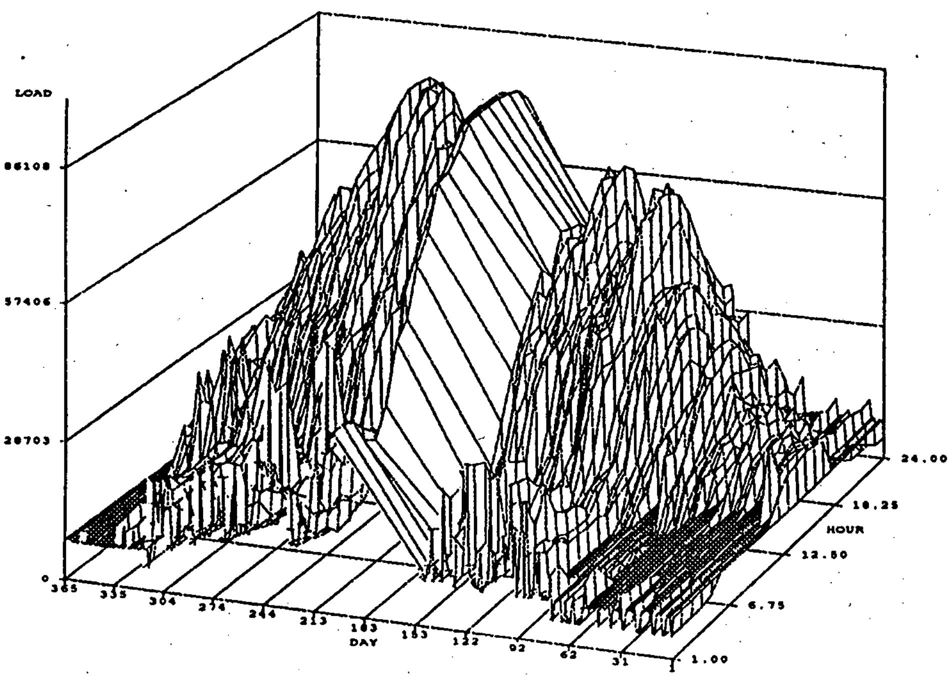

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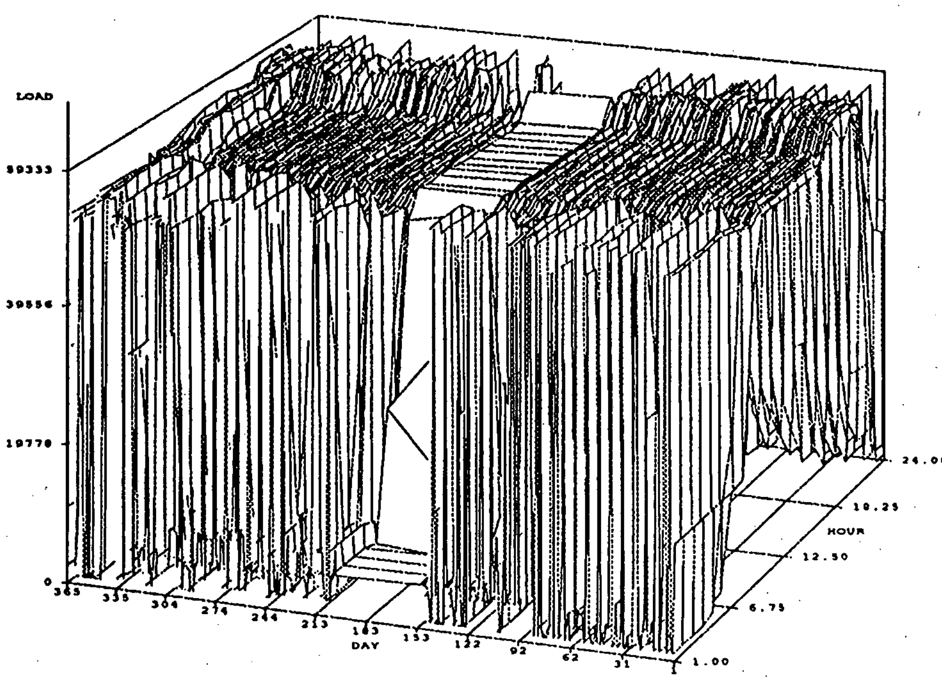

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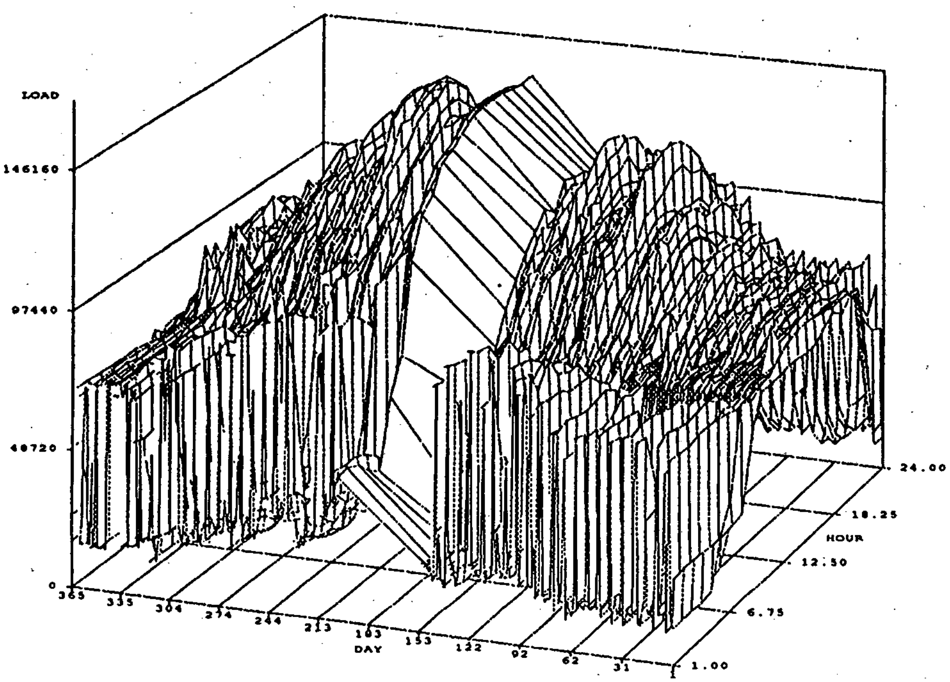

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