ENERGY MANAGEMENT SYSTEMS
AS A SOURCE OF BUILDING ENERGY PERFORMANCE DATA*

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ABSTRACT

Energy performance of buildings is often estimated by computer simulation but it must also be verified with actual measured data. One of the techniques used to collect these data exploits existing in-place Energy Management Systems (EMSs). EMSs are becoming increasingly popular devices for the control of large buildings where they offer a potentially valuable means of controlling power and energy consumption. Compilation and analyses of hourly energy use, weather, and occupancy information recorded by EMSs can provide a quick and cheap method of obtaining an electrical energy end-use breakdown without actually submetering end-uses such as lighting, heating, and cooling.

The capabilities of existing EMSs as a key to end-use characterization of an industrial/commercial building in Milpitas, California, have been evaluated. Spreadsheet programs have been developed to break down the daily and hourly total building electricity use into their major end-use constituents. The calculated total building electricity use agrees with measured data fairly well (within 10%) for the daytime hours of building operation where schedules and occupancy are known. It is concluded that gathering information with even simple EMSs can be a useful, logical, and relatively inexpensive step toward understanding present energy use and revealing areas of load management and conservation.

I. INTRODUCTION

Scope

As the understanding grows in the field of energy management regarding how energy is being used in buildings, more emphasis is being placed on gathering additional information about whole building energy use, load profiles, and end-use data than is available from traditional sources [1-5]. In addition to the information available for a selected commercial building (monthly utility bills, audits), data have been collected through energy management systems to provide energy use information at more frequent time intervals and for subsets of building

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equipment.

A case-study approach is presented here for one office/industrial building in Northern California. A brief description is given of the case-study building and its EMS in particular as well as a general statement concerning the prevalence and capabilities of EMSs in commercial buildings. Daily and hourly resolution data are successively analyzed and discussed in two main contexts:

- the weather dependency of the building electricity consumption,
- the break-down of the total load into the major end-uses.

Background

Typically, the information available to an energy manager or other individual interested in a specific aspect of building performance (consultants, utilities, researchers) has come from utility billing data and building audit data [2]. Occasionally, more expensive end-use submetering experiments or computer simulation programs have also been used; the facility managers needed more information to decrease their monthly peak, or utilities wanted to better understand present energy use to optimize the use of the electricity they produce. These sources of data and their uses are quickly summarized below:

Monthly Billing Data: The most readily available information to use in understanding the energy use of most buildings has been the utility bills themselves. Several years of work with the Building Energy-Use Compilation and Analysis (BECA) databases have shown that although many trends can be observed for monthly data, many limitations exist to buildings energy research and analysis which relies on monthly utility bills for actual use information [6]. One such limitation involves the aggregation of weekday use with weekend use and daytime use with nighttime use. A call for data based on smaller time intervals than months has been made.

End-Use Submetering: End-use submetering has been used to obtain end-use information for *individual* buildings. This has been invaluable to subsequent engineering analyses, because it provides information on real building operation as well as a general understanding of the performance and behavior of different end-uses within a specified building. End-use submetering programs help to develop an "engineering common sense" as to what portions of the load are reasonable to attribute to a given end-use. However, because of the layout of many existing commercial buildings, where lighting, HVAC, equipment, etc. may all be on the same circuit, temporarily submetering these end-uses can be difficult and expensive.

Computer Simulation: Simulation techniques have made it easier to analyze 1) a building's thermal dynamics, 2) the correlation between the weather dependent end-use loads and the outside conditions, and 3) the interaction between the building and its systems. Unfortunately, in most cases, no actual measured information is available to adjust the simulation results for validation.

II. APPROACH

Energy Management Systems

For some buildings there is an alternative approach to the traditional, large-scale, costly submetering projects which have been implemented to determine electricity consumption by end-use. The extraction of data available from already in-place computerized EMSs promises to be less expensive and time-consuming. Such systems are currently included in many new commercial buildings and increasingly are retrofitted in existing ones [7]. Also, the proposed ASHRAE 90.1P standards recommend the specification of computerized energy management systems with control and recording capabilities in the design of buildings over 100,000 ft^2 [8]. Therefore, it is likely that the numbers of these systems will continue to grow.

EMSs installed in commercial buildings can be categorized in the following main groups:

- sophisticated electronic time-clocks,
- microprocessor-based systems with a centralized processing unit, performing scheduling and some simple control features for 15 to 40 points, reading demand, temperatures and status for the main circuits controlled, and logging of some variables for the last 24 hours and,
- minicomputer-based systems with a decentralized intelligence (stand-alone controller with remote control units), including the same capabilities as the previous category but with more flexibility, more control points, more sophisticated load management features, and greater recording capacities.

The hourly energy use, weather, and equipment status information often recorded by an EMS may be a first key to breaking down the building's overall load profile by end-use, without directly submetering each end-use. This data provides a check with actual measured use at greater intervals than the monthly billing periods, and can be seen as a compromise between simulations and detailed continuous monitoring of a building.

It was known that *complicated* EMSs which border on real-time submetering systems, would provide valuable information for the understanding of energy use. However, it was the objective of this study to determine whether information gathered from relatively simple, *microcomputer-based systems* could be used to provide building energy data which would allow a thorough understanding of the end-uses without, in most cases, subsequent submetering. This objective was attained through a pilot study.

Pilot Study

A specific building was selected as an initial case study to explore the capabilities of EMSs as a source of building energy data. For this building the existing capabilities of the EMS to gather information have been utilized without any software or hardware modifications. The dial-up capabilities of the system were used to establish periodic computer connections between the building and our office for automatic data transfer. In addition a brief visit to the building was made to gather floor plans, general equipment information, and billing data.

We have used EMS-based data, along with audit information about occupancy and equipment, to generate an end-use breakdown for the building. Daily and hourly whole building energy use and temperature as recorded by the EMS were considered and used to revise the engineering estimates of whole building energy use in an iterative process until a final result was reached. The value of the EMS information at each step of this process has been evaluated. A more detailed discussion of the case study building, its EMS, our analyses and conclusions are presented in the following sections.

Building Description: The building considered is a 79,000 ft^2, single-story, industrial/commercial building in Milpitas, California. Medical sonic diagnostic equipment is designed and assembled (but not manufactured) here. Housed at this site are design, engineering, and administrative offices, small open laboratory areas, and large open testing and quality assurance areas. About half the floor space consists of typical office cubicles, the other half includes the shipping, quality assurance and laboratory areas. The building is five years old and is situated in an industrial park surrounded by other low buildings.

The building is generally operated on a typical business schedule from 8 a.m to 5 p.m. although operations personnel arrive about 7 a.m. and the janitors work in the evenings between 8 p.m. and 1 a.m. The nearly 300 occupants have the ability to temporarily override pre-programmed schedules for lighting and HVAC equipment for two hours at a time in the evenings. The HVAC overrides are seldom utilized. Three main package units provide air conditioning for the building and a small gas furnace provides a heating capability which is seldom if ever used, according to the building manager. Here we only consider the electrical energy used by the building, assuming the minimal gas usage to be insignificant. Other office equipment, lighting circuits, and other electrical loads will be listed in the analysis section.

EMS Description: A Trimax Powersense 830 energy management system was installed in this building in January 1985. This system is intermediate between the simple timeclock systems and the very advanced multi-featured systems. Those software capabilities of the Trimax product employed and installed at this building are highlighted below:

A. Control Strategies

- Time of day (TOD) control for 6 HVAC zones and 9 lighting zones.
- Optimum start for HVAC equipment based on temperatures and history.
- Duty Cycling to reduce the overall peak demand by cycling equipment.
- Demand Limiting to shed loads when a demand limit is reached.
- Overrides of programmed lighting and HVAC schedules via telephone.

B. Status and Data-Logging Capabilities

- Dial-up access to remotely access recorded or status information.
- Last 48 hours recording of (a) 4 zone temperatures (3 interior, 1 exterior), (b) whole building energy use, and (c) whole building peak power demand (15

minute sliding window).

- Last 34 days recording of (a) daily minimum and maximum temperatures for each zone, (b) whole building energy use for 24 hours, and (c) daily peak demand and its time of occurrence.
- Real time query of on/off status of controlled circuits, programmed schedules for these circuits, and the current values for the temperature and power.

In April 1985, we began to dial-up the building to collect hourly temperature, demand, and energy information. This method of collecting data had no effect on the operation of the EMS or the building, and required no additional effort by the building operators or staff, because we dealt directly with the computer itself. To date, 180 days of data have been collected.

III. ANALYSIS

We study the data obtained from EMS in two stages. In the first stage, we perform a sensitivity analysis on the dependency of building load to the outside air temperature. We then utilize the results of the weather sensitivity analysis in the second stage to break down the total building load into its major constituent end-uses.

Weather Dependency

The variation of the daily peak (kW) in response to variation of the maximum daily outside temperature for 165 weekdays (Figure 2) shows a strong correlation between them. Such a strong correlation is typical of many larger buildings in relatively moderate or warm climates, especially those buildings equipped with significant internal loads such as computers and CRTs.

Scatter plots presenting average hourly demand of normal business days versus outside air temperature have been prepared. To separate the variations of demand due to changes in hourly schedules from the temperature-dependent variations, we have prepared a plot for each hour of the day. Figure 3 shows examples for hours 10 and 17 (10 a.m. and 5 p.m.). During the daytime there is a strong correlation between the hourly demand and outside temperature. At nighttime, where, in principal, all HVAC systems are turned off and the building load is mostly dominated by internal loads and lighting, there is no apparent correlation between the hourly load and outside temperature. Table 1 summarizes the results of a linear correlation for each hour of the day.

For most morning hours, the variation of the hourly demand with respect to variation of air temperature indicate two distinct patterns below and above ~68 °F (Fig. 3a, hour 10). The pattern with the lower slope represents the variation of the air conditioning loads with economizer cycle, whereas the pattern with the higher slope is representative of the loads of the units without the economizer cycle. During the afternoon, the air-conditioning units mostly operate without the economizer cycle and thus the distinction between these two patterns disappears. This is confirmed by the statistical results of Table 1.

The weather sensitivity results can be utilized to determine the contribution of the air-conditioning units to the total building electricity use. For example, at 75 °F average outside temperature at 10 a.m., about 15% of the building's total load is due to temperature-dependent end-uses such as compressors and condenser fans. The rest of the energy usage, which is not a function of temperature (minimum ventilation, lighting, manufacturing equipment, etc.), makes up a base load to which the temperature-dependent usage is added.

End-Use Breakdown

Although it was not possible to get actual measured end-use values to verify our analysis, an attempt has been made to establish an end-use breakdown using audit and EMS-generated information.

Daily data: For this detailed analysis, a simple computerized spreadsheet was created where all the major electrical equipment were listed with their nominal power ratings (collected from available inventories or blue-prints in the facility, or read from the equipment directly). Schedules available from the EMS data and deducted from the description of the activity in the building were entered with estimated capacity factors which indicate at what fraction of the total rating the equipment is likely to operate. Finally, operating hours per day for each piece of equipment was entered. Quantities in this spreadsheet were summed to estimate total electricity consumption for the day. Separate hours of operation were assumed for weekdays and for weekend days.

The calculated daily total for a weekday or weekend day were compared with an average electricity consumption for a week- and weekend day as recorded by the EMS. After the first comparison, the assumptions in the worksheet were reconsidered according to the confidence level of each piece of information collected. At this level of analysis the weather dependency was not considered.

The eventual overall discrepancies between estimated and measured energy use for a weekday were less than 10% and for a weekend day were less than 25%. Typically, the distribution was 35% for the lighting, 36% for the HVAC, 4% for domestic hot water, 3.5% for the computers, 6% for office equipment, 1.5% for cafeteria, and 14% for the manufacturing equipment.

Much can be inferred from this daily data, especially with regard to the distribution of the energy use between weekdays and weekend days. However, the hourly data offers the opportunity to reconcile at an even more detailed level. With hourly measured data, the estimated hourly results and the actual data can be compared.

Hourly data: An attempt has been made to analyze EMS-collected hourly data and to generate an hourly end-use breakdown for major end-uses in the building. An engineering loads calculation for the building has been performed using a computerized spreadsheet. This spreadsheet analysis consists of two major components: 1) an hourly building electric load calculation, and 2) an iterative methodology to reconcile the calculated load to the EMS-measured total building load. Values for daily and hourly whole-building energy use, as recorded by the EMS, were used to check the initial load calculation and to revise the engineering estimates for run-times of equipment and override assumptions in an iterative process according to our confidence in each of these assumptions.

Input to the spreadsheet came from (1) the building audit (equipment rating information and general building and occupancy information), and (2) from the EMS (HVAC and lighting schedules, and hourly outdoor temperature values). In the spreadsheet all the electrical equipment was listed with nominal power ratings. Equipment operating schedules were determined from (1) the audit (for non-programmed circuits) or (2) the EMS (for programmed, computer-controlled circuits such as lighting and HVAC). The schedules were then modified to reflect influences such as duty cycling, demand limiting, and assumptions for overrides. Separate operating hours were assumed for weekdays and weekend days.

Equipment *load factors*, which indicate at what fraction of the total rated load the equipment is likely to operate during an interval of time, were also included in the spreadsheet. These values are based on conversations with the energy consultant who installed the system and our own engineering judgement. Also, hourly temperature data from the EMS was entered to determine run times, economizer influence, and optimum start times for HVAC equipment (this includes the results developed by weather sensitivity analysis). This worksheet produced an estimate of the building electricity consumption for the day by multiplying rated load by load factor for each piece of equipment operating during each hour and summing over the 24 hours of the day.

The proposed *iterative reconciliation* methodology, described in detail in Figure 4, identifies differences between the calculated and EMS-measured hourly electricity consumption and corrects for systematic discrepancies. Typically, several iterations over several days were necessary in order to reduce the difference between measured and estimated data to an acceptable level. The initial estimates are taken from building audit data and "best engineering judgment." The end-use profiles are refined at each iteration. The discrepancy between measured and estimated electrical consumption for any single hour varies over the day and is typically within 10% during regular operating hours and 25% for evening hours. Again, this is not surprising since a larger percentage of the energy use in the evenings and at night are due to overrides and other unpredictable events.

This methodology has been applied to several weekdays and weekend days. The overall discrepancies between estimated and measured electricity use for a weekday are within 10% although the difference is somewhat larger (roughly 20%) for a weekend day. More accurate information is available on building operation practices during weekdays when there are fewer overrides of equipment and lighting schedules.

An example of estimated cumulative end-use load profiles for a summer weekday, July 19, is shown in Figure 5.a. This end-use breakdown provides an interesting portrait of the electrical energy use patterns of this building. One can see that the shape of the predicted curve is determined by the HVAC in the middle of the day when the magnitude of the discrepancy is the greatest. This implies that the assumptions related to the dependency of the HVAC energy on outdoor temperature should be examined in greater detail. Even though the absolute magnitude of the discrepancy is greatest here, the percentage of the discrepancy is less than it is in the evening hours. Electrical end-use patterns do not appear to vary greatly from day to day.

Once the hourly values have been reconciled for a day, the components that make up each end-use are separated to generate an hourly or daily end-use breakdown. The significance of the manufacturing and testing equipment (34%), the lighting (32%), and the HVAC (22%) for a single weekday, July 19, can be seen in the daily end-use breakdown of Figure 5.b. The large percentage attributed to the manufacturing equipment can be expected in this facility where industrial and office activities are integrated. Note that the energy usage for manufacturing and testing equipment was underestimated with the daily analysis. Close examination of the hourly spreadsheet (not presented here) has shown that of the energy used for HVAC, 40% of the load is represented by the ventilation load and the other 60% is due to compressor and condenser fans.

This preliminary analysis of EMS-based data has helped to determine some major characteristics of the electricity consumption in this building including typical values for energy use, peak power and typical outdoor temperature ranges over a day. The distribution of the energy use between weekdays and weekend days has been ascertained, and a better understanding of the relationship between outside temperature and energy and power use has been developed. Finally, an end-use breakdown has been prepared for the building which can point to areas of possible conservation and load management.

IV. DISCUSSION

It is important to consider the type of EMS used for this form of a data collection effort. Because the data collection equipment is an integral part of the EMS, if the EMS is not functioning or has no memory backup, data may be lost.

The temperature sensors have to be properly installed. Even though the outside temperature sensor in the case study building appeared to be well shielded, its consistency with the closest weather station must be and has been verified.

The case study and the associated EMS used for this study are not necessarily ideal for developing and refining a new method. Ideally, we should have actual end-use and time-of-use data on the same building. However, many conclusions can be drawn about the work done with this building, and there are prospects for applying this method to both more complicated systems and situations.

V. CONCLUSION

Our work suggests that EMS-derived data may offer important advantages, in terms of cost and effort vs data quality, compared with conventional approaches now being used to analyze end-use performance in large buildings. Of course, using EMSs for performance monitoring is not equally promising in all commercial buildings nor for all data needs. There must be a computerized EMS already in place, with appropriate sensing, data storage, and communication capabilities. However, we feel that these systems are already becoming standard equipment, especially in buildings larger than 100,000 square feet.

It is possible to take advantage of the data available from even a simple EMS to determine some operating characteristics of a commercial building, especially to understand the way the electricity is used. Hourly EMS data help to indicate the weather dependency of the energy use in the building and can be used as a constraint on load profile estimations, where they are invaluable in establishing an accurate end-use breakdown.

It should be noted that this work is only a first attempt to exploit EMS data. In the future, this approach will be tested with more buildings, including some with submetering to cross-check the results and validate the general method. We also hope to explore buildings in other climate zones and with other major interior activities. Finally, we would like, in future studies, to quantify the benefits and drawbacks of simplified versus more sophisticated EMSs as the principal source of data.

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```
STATUS,CHECK,CHANGE, OR HISTORY?  STATUS     ←

12:52P DLS TUESDAY  5/14/85

TIMER:  0:00   SETPOINT NO.: 1
PRESENT DEMAND:  420   PREDICTED DEMAND:   432   SETPOINT LEVEL:   450

CKT
NO. STATUS
--- ------
  1  ON
  2  ON
  .  .
  .  .
 21  ON
 22  ON
```

```
STATUS,CHECK,CHANGE,' OR HISTORY?  CHECK     ←

ALL,SCHED,TIMER,DU/CY,HOL,SET,MIN,PRIOR,PEAK,OPT,TEMP,TDC,TSP,STD,DLS, OR ALARM?


CKT SCHED OPER-
NO.  NO.  ATION  MON    TUE    WED    THUR   FRI    SAT    SUN   SPEC 1 SPEC 2
--- ----- ----- ------ ------ ------ ------ ------ ------ ------ ------ ------
 1    1   ON    6:30A  6:30A  6:30A  6:30A  6:30A
          OFF   6:30P  6:30P  6:30P  6:30P  6:30P

 2    1   ON    6:30A  6:30A  6:30A  6:30A  6:30A
          OFF   5:00P  5:00P  5:00P  5:00P  5:00P

 3    1   ON    6:30A  6:30A  6:30A  6:30A  6:30A                       6:30A
          OFF   7:00P  7:00P  7:00P  7:00P  7:00P                       7:00P
 .    .   .       .      .      .      .      .                           .
 .    .   .       .      .      .      .      .                           .

ZONE
 NO. TEMP
---- ----
  1   94
  2   72
  3   77
  4   73
```

```
STATUS,CHECK,CHANGE, OR HISTORY?  HIS     ←

INTERVAL,DAILY, OR OVERRIDE/SHED?  INT

                                                     12:56P DLS TUESDAY
                        48 INTERVAL ENERGY HISTORY

  TIME   PEAK KWH  ZONE1 ZONE2 ZONE3 ZONE4 ZONE5 ZONE6 ZONE7 ZONE8
 ------- ---- ---- ----- ----- ----- ----- ----- ----- ----- -----
 12:00A  430  418   90    71    76    73
 11:00A  408  398   91    71    76    74
 10:00A  406  399   84    70    76    74
  9:00A  372  359   74    71    76    73
  8:00A  331  315   65    72    77    73
  7:00A  262  194   54    72    78    73
    .     .    .     .     .     .     .
    .     .    .     .     .     .     .
    .     .    .     .     .     .     .
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INTERVAL,DAILY, OR OVERRIDE/SHED?  DAILY     ←

                                                     12:57P DLS TUESDAY
                               34 DAY ENERGY HISTORY

              TIME         TIME TIME
               OF    KWH    IN   IN   ZONE1 ZONE2 ZONE3 ZONE4
DATE PEAK    PEAK   USED  SHED ALRM MN MX MN MX MN MX MN MX
---- ----  ------  -----  ---- ---- -- -- -- -- -- -- -- --
 513  466   304P   6243     0    0 44 99 71 79 76 79 72 76
 512  146  1032A   2338     0    0 40 91 71 79 75 80 71 78
 511  278  1021A   3700     0    0 43 87 71 73 75 79 71 76
 510  408   240P   5887     0    0 48 78 71 74 75 78 70 73
 509  415   134P   6292     0    0 41 77 71 74 75 79 70 74
 508  420   243P   6331     0    0 41 81 71 73 75 79 70 74
  .    .     .      .       .    .  .  .  .  .  .  .  .  .
  .    .     .      .       .    .  .  .  .  .  .  .  .  .
  .    .     .      .       .    .  .  .  .  .  .  .  .  .
```

Figure 1. Example of information available from the EMS report. The information includes a status report, a check report with schedules and zone temperatures, and a history report.

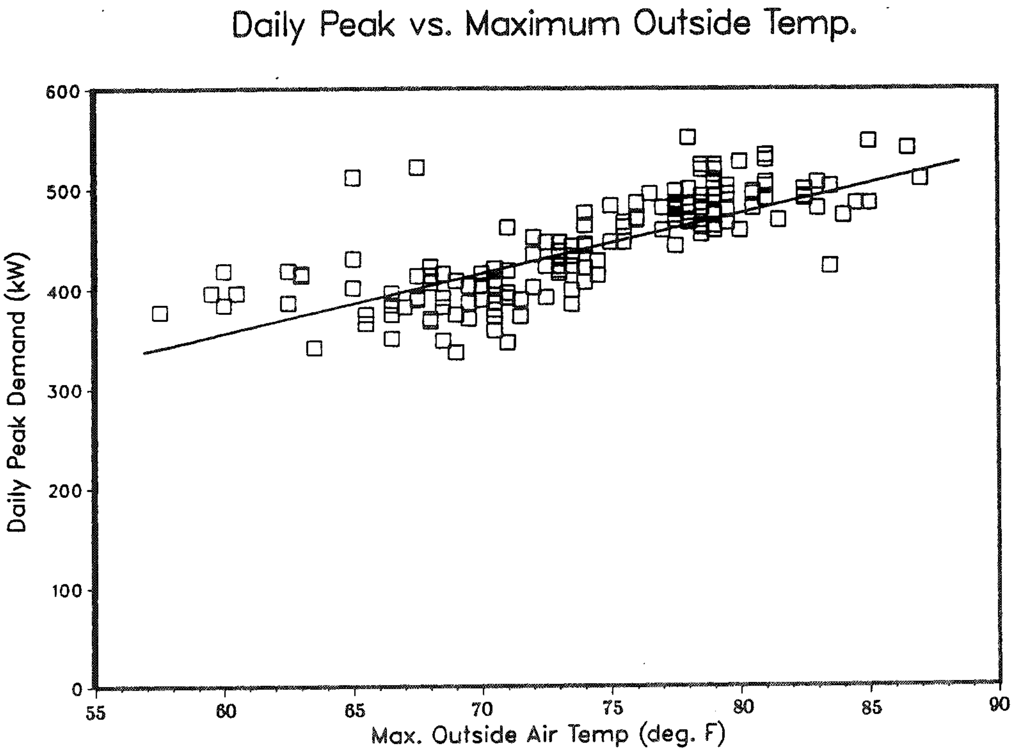

Figure 2. Daily peak versus maximum outside air temperature. Correlation coefficients : R = 0.75, slope = 5.54, intercept = 33.75, 167 plotted values.

HOUR	R	STEE	INTER(i)	Si	SLOPE(s)	Ss	PLOT.
1	0.0876	35.49	163.28		0.812		110
2	< 0.1	------	------	------	------	------	------
3	< 0.1	------	------	------	------	------	------
4	< 0.1	------	------	------	------	------	------
5	< 0.1	------	------	------	------	------	------
6	0.0472	41.94	136.03		0.503		111
7	0.458	29.54	99.74	34.21	3.272	0.612	110
8	0.675	21.24	138.52	23.46	3.759	0.396	110
9	0.659	25.51	160.02	24.96	3.540	0.392	108
10	0.742	23.22	157.05	22.4	3.586	0.332	97
11	0.762	24.08	152.41	23.25	3.703	0.332	92
12	0.780	25.10	128.57	24.8	4.143	0.343	95
13	0.797	25.27	114.74	25.08	4.366	0.345	94
14	0.843	23.76	99.61	22.58	4.704	0.311	95
15	0.855	23.71	88.07	22.42	4.947	0.313	94
16	0.892	21.77	61.11	20.05	5.410	0.285	95
17	0.920	17.98	86.57	12.5	5.026	0.223	94
18	0.918	19.12	46.42	15.96	5.487	0.245	96
19	0.895	21.19	-5.06	19.25	5.967	0.245	95
20	0.803	26.17	-72.59	28.87	6.310	0.483	96
21	0.546	39.18	-66.26		5.701		96
22	0.438	36.29	10.04		4.246		97
23	0.273	30.50	94.67		2.176		97
24	0.118	34.17	155.86		1.062		97

Table 1. Weather sensitivity. Statistics for each individual hour of a regular business day.
STEE = Standard Error of Estimate,
Si = Standard deviation for intercept,
Ss = Standard deviation for slope.
R = correl. coef., Pearson.

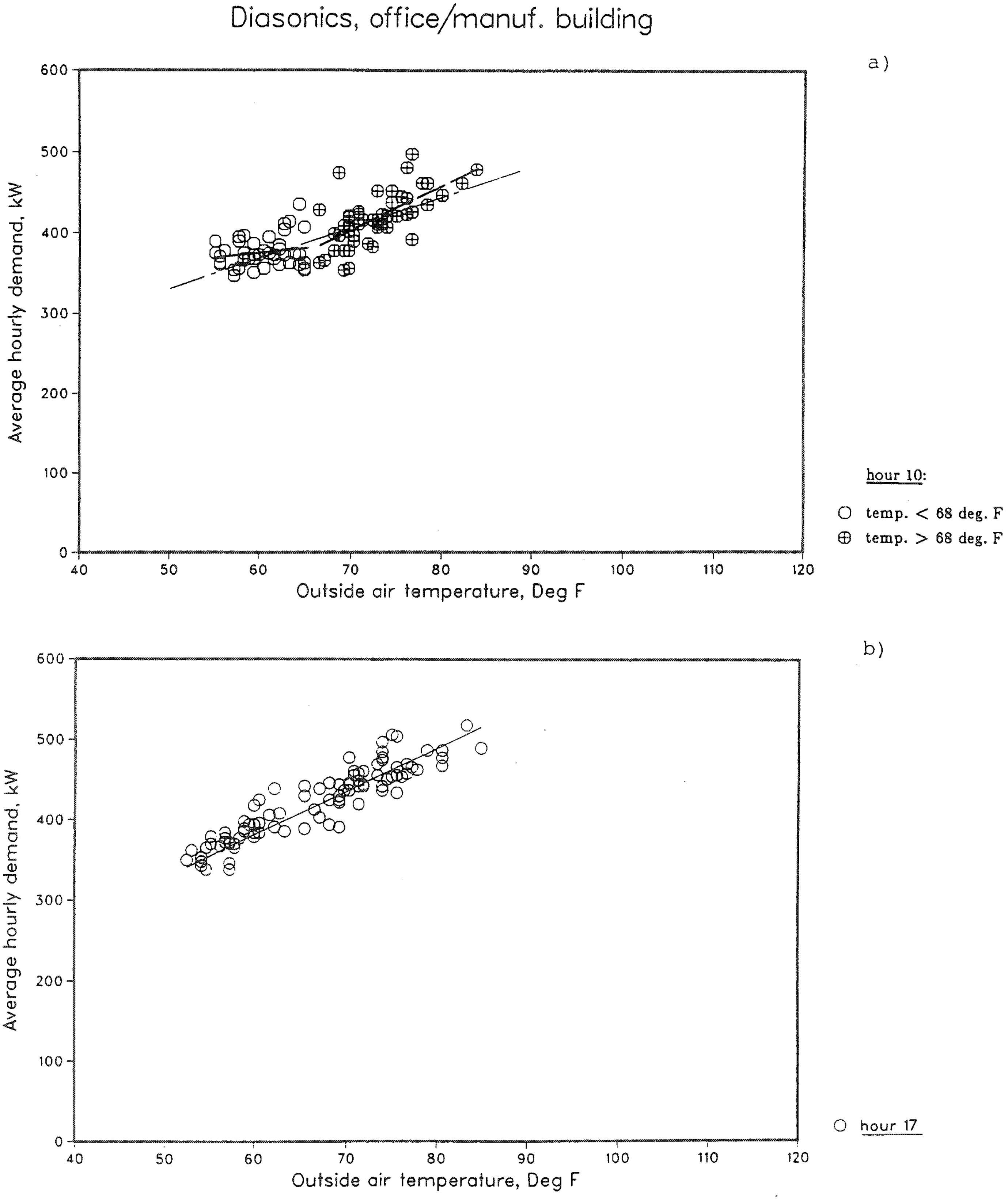

Figure 3. Weather sensitivity.
a) Plot for hour 10, the correlation coefficients for the global trend are : R = 0.74, slope = 3.586 ± 0.33, intercept = 157.1 ± 22.4, 97 plotted values.
b) Plot for hour 17, R = 0.92, slope = 5.03 ± 0.22, intercept = 86.57 ± 12.5, 94 plotted values.

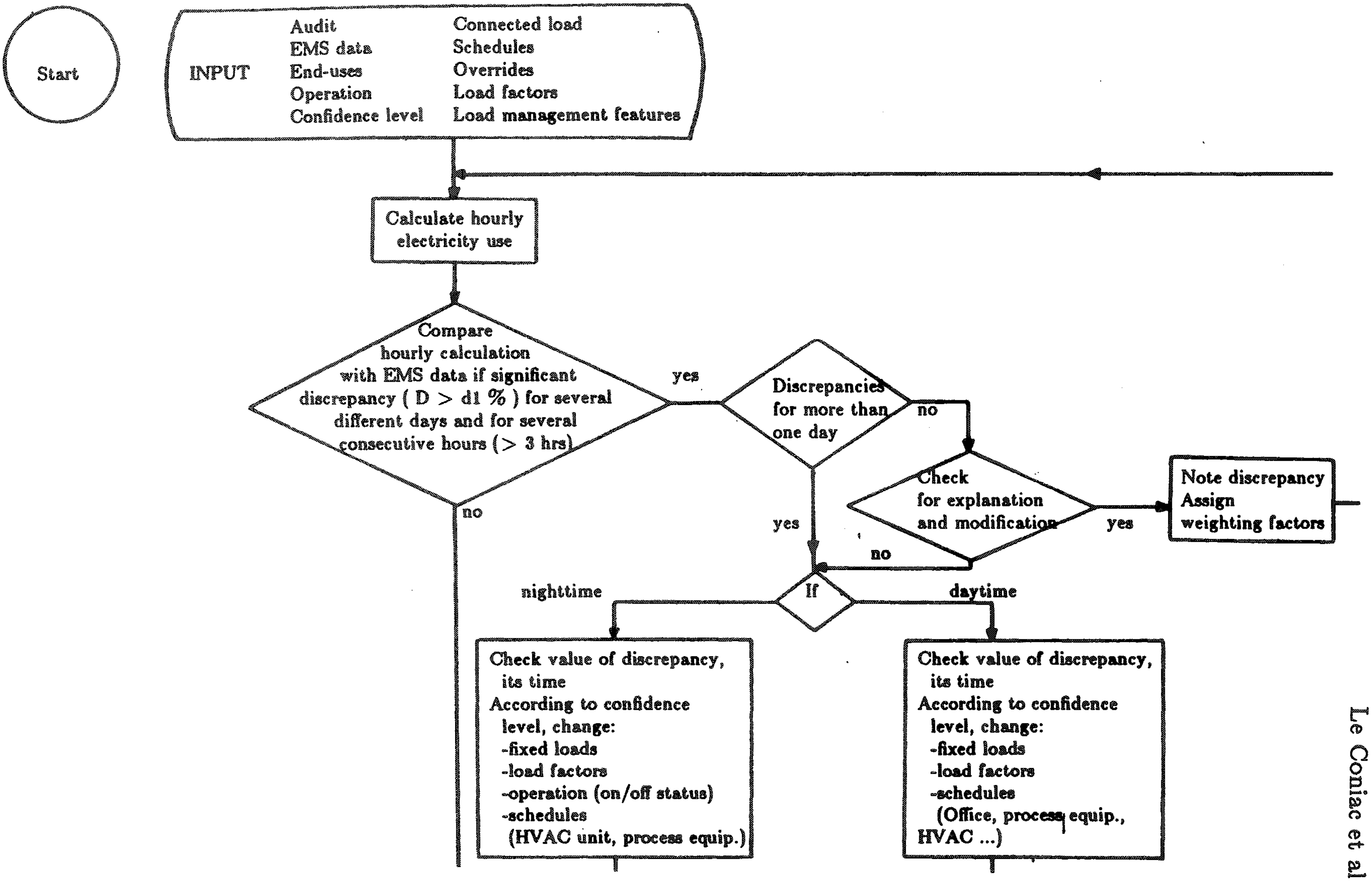

Figure 4. Flowchart of hourly reconciliation methodology. This methodology is used to adjust assumptions in an engineering load calculation to reconcile predicted and measured hourly electricity use and to disaggregate the hourly total to end-use breakdown.

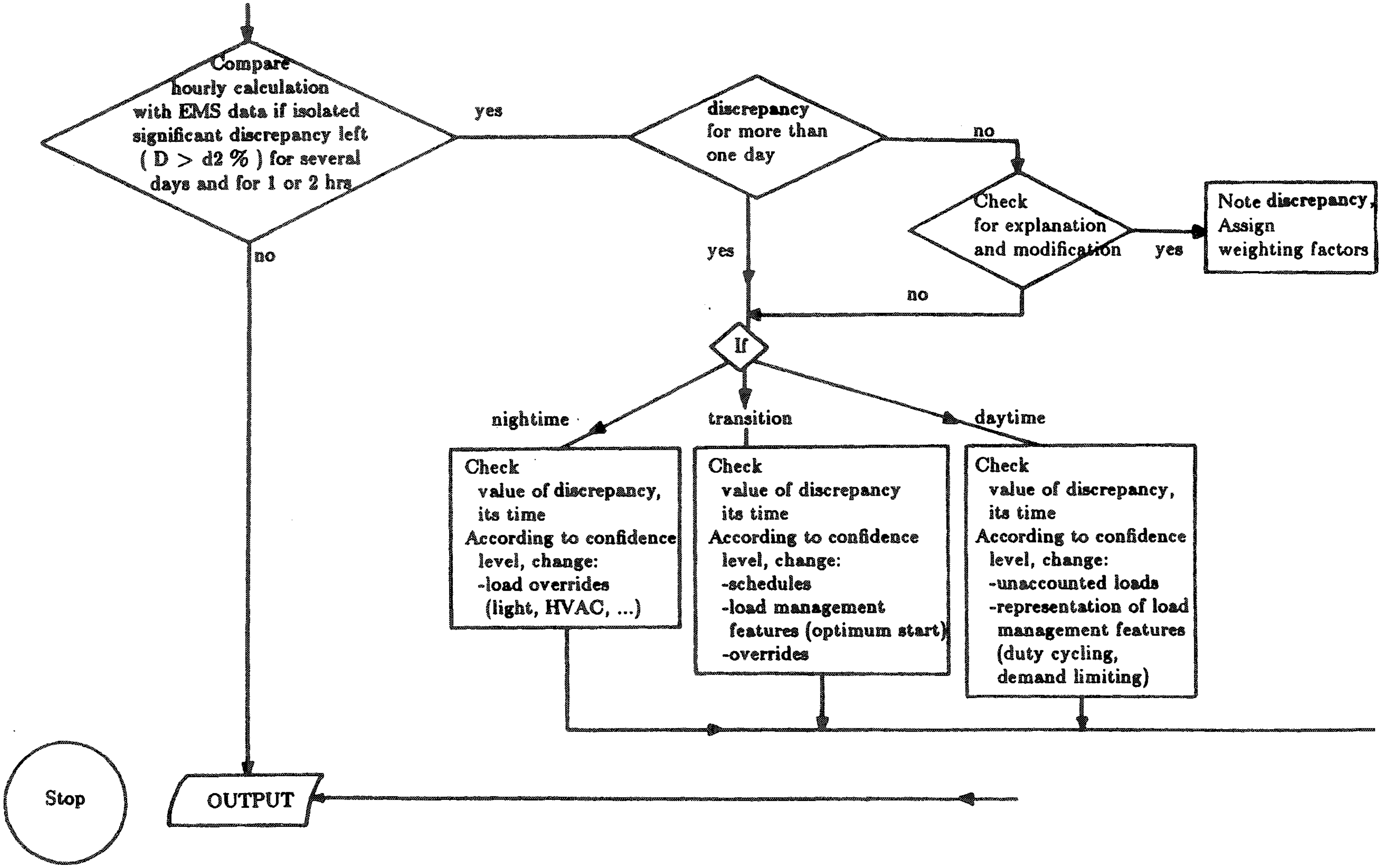

Figure 4. Continued.

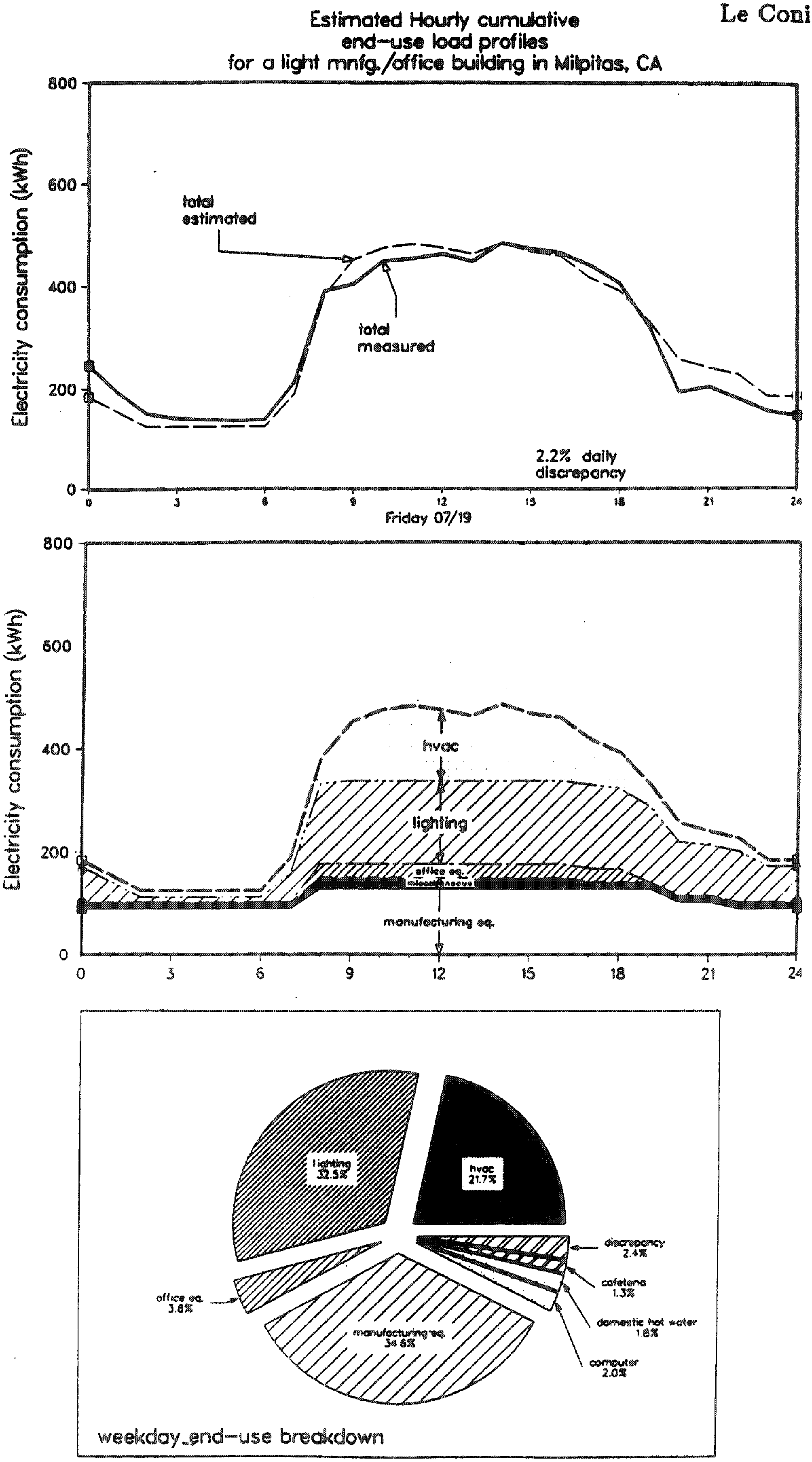

Figure 5. Hourly end-use load for pilot study building. Data for Friday July the 19th, 1985.
a) Profile comparison between measured and estimated total building load and its major constituent end-uses.
b) Daily end-use breakdown. The total electricity use for the day is 7425 kWh.