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Energy Conservation Potentials in the Omar Effendi Department Store in Nasr City, Cairo, Egypt: An Energy Audit and Analysis of End-Use Data

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An Energy Audit and Analysis of End-Use Data

Final Report

April 1991

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Abstract

This report summarizes an effort to measure electricity consumption by end use in a government-owned Omar Effendi chain department store in Egypt. The monitored data are used to estimate electricity conservation potential in the building. The major end uses in this building are lighting, ventilation, and air conditioning. The building peak usage is about 60 W/m^2 of power for lighting and 63 W/m^2 for ventilation and air conditioning. It is possible to save 50% of electricity use through improvements in the efficiency of the lighting and air conditioning systems.

Energy Conservation Potentials in the Omar Effendi Department Store in Nasr City, Cairo, Egypt:

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This report has been developed in close collaboration with the engineering staff of the Egyptian Organization for Energy Planning (OEP). Moustafa Ahmed, Osama Nour-El-Din, Mohammed Emam, and Ahmed Abd-Rabou have participated in the process of data collection, initial data analysis, and report preparation. They have been instrumental in the successful completion of this project. This project has in turn provided a vehicle for technology transfer in terms of building energy auditing and advanced end-use monitoring.

Energy Conservation Potentials
in the Omar Effendi Department Store in Nasr City, Cairo, Egypt:
An Energy Audit and Analysis of End-Use Data

I. Introduction and Objectives

Meta Systems Inc. has contracted with the Lawrence Berkeley Laboratory (LBL) to assist them in analysis of energy conservation potentials in a department store in Egypt. This project is funded through a grant from the United States Agency for International Development (USAID) to Egypt and is coordinated by the Organization for Energy Planning (OEP) in Cairo, Egypt.

The objectives of the LBL project are four-fold:

1. Monitor the Omar Effendi department store to characterize the building's energy consumption by end use;
2. Based on engineering analysis and analysis of measured data, suggest conservation measures and monitor the performance of the measures once they are installed;
3. Demonstrate conservation potentials in a show-case study by developing software programs to show pre- and post-retrofit energy use of the building and thus energy savings of the selected measures; and
4. Transfer state-of-the-art monitoring technology, including equipment and techniques, to the Egyptian energy profession.

The LBL project was designed in two Phases. This report covers only the Phase I project consisting of the following 5 tasks: 1) specification and procurement of monitoring equipment; 2) a two-week visit to Cairo, including visiting, instrumenting, and evaluating the lighting and air-conditioning systems of the store; 3) installation of the monitoring equipment; 4) making recommendations on possible retrofit measures to be implemented; and 5) discussion of the elements of the proposal for the second phase with input from Meta Systems Inc. and OEP. Phase II was to cover the implementation of the lighting retrofit recommendations and to further analyze measured data in order to document savings as well as to better identify conservation retrofit opportunities for cooling.

Task 1 was completed at LBL; the equipment was shipped and delivered to OEP. It is the objective of this report to discuss the completion of the other tasks (Tasks 2-5). In this report, the elements of the second phase are mentioned but not discussed in detail, since that phase was eliminated from the project.

In Section II, the building and its systems are described, including the operation of the lighting and HVAC systems. Short-term measurements taken during the on-site audit are discussed in Section III. The details of the monitoring equipment, including installation and testing, are presented in Section IV. The first month's monitoring data, and the building's conservation potential based on those data, are analyzed in Section V. Conclusions and recommendations are contained in Section VI, and Section VII briefly discusses the tasks proposed for Phase II.

II. Building Description

1. General

This brand-new department store has 6,023 m^2 of floor area, of which about 5,135 m^2 is used for shopping, 216 m^2 for office uses, 211 m^2 for stairways, and 461 m^2 for other uses such as rest rooms and rooms for air-handling units. Table 1 shows the distribution of floor space by usage, both for each floor and for the entire building.

Table 1. Floor Area and Use By Floor (in m^2)

Floor	Shopping Area	Office Area	Stairway Area	Unconditioned Area	Total Area
Basement	1115	0	22	46	1183
Ground Floor	986	106	47	70	1210
1st Floor	986	55	47	122	1210
2nd Floor	986	55	47	122	1210
3rd Floor	1062	0	47	101	1210
Total	5135	217	211	461	6023

The main entrance to the store is on the west side of the building. The building has about 46% glazing area (as a percentage of wall area) on the west and north sides, of which about 19% are recessed windows and 27% are product display windows. The recessed windows are blocked from the inside by internal wood panelling. The shading coefficient of the rest of the glazing is about 0.7. Similarly, the east and west facades of the building have about 25% recessed glazing areas that are completely blocked from the inside.

The entrance door of the building is made of glass; there are two air curtains installed on the door. There are two doors on the rear of the building, one on the ground floor and one at the basement level. The basement door is used as a loading dock and is always open during the normal operation of the building.

2. Lighting

The general shopping areas and the display windows are both well-lit. Most window lights are incandescent; both incandescent and fluorescent lights are used in the shopping areas. The overall installed lighting intensity of the building is about 60 W/m^2. These high levels suggest that there are good conservation opportunities in the building. Table 2 gives a summary of the installed lighting intensities by type and floor.

Table 2. Installed Lighting Power By Floor

Floor	Lighting Power (kW) Fluorescent	Incandescent	Total kW	W/m^2
Basement	62	21	83	70
Ground	42	20	62	51
First	44	22	66	55
Second	43	18	61	50
Third	31	20	51	42
Total	222	101	323	54

About 90% of the installed fluorescent lights use T8 (26 mm diameter) lamps; the remaining 10% are T12 (38 mm); each lamp has its own ballast and starter. The T8 lamps are a mixture of 60 cm (18 watts) and 120 cm (36 watts), mostly the latter. Based on an earlier study of lighting technology in Egypt, the single-lamp, core-coil type ballast is assumed to consume 15 watts, yielding a total power for each lamp/ballast combination of 51 watts (Nadel 1990). All of the fluorescent lights are paired in common fixtures.

The incandescent lights are all 100-watt lamps except those (a few per cent) used in the stairways, which are 60 watts. The incandescent lamps are of the internal reflector flood-light type. The lamps are partially recessed into the ceiling fixtures.

3. HVAC

The Heating, Ventilating, and Air-Conditioning (HVAC) system of the building is used only for cooling applications. There are two cooling systems serving the building. The main cooling system serves the entire building except for the basement; it consists of three reciprocating chillers each with a nominal cooling capacity of 280 kW and a nominal (chiller only) COP of 2.5. Each chiller has two compressors that can be operated independently. The chiller condensers are cooled by water supplied by two cooling towers, each equipped with two fans powered by a single motor with a rated output of 7.5 kW. There are three condenser water pumps equipped with motors rated at 7.5 kW output; two of the three are used to circulate water through the towers and chiller condensers. Two of the four chilled water pumps (each powered by a motor with a 7.5 kW output rating) are used to circulate chilled water through the chiller evaporators and to the cooling coils located in the air-handling units on each floor. The chillers, pumps, and towers are all operated manually. During peak summer conditions only two of the chillers are operated; the third serves as a spare. The use of the three chillers is rotated (lead, lag, and spare) in order to equalize operating time and to ensure unit readiness. According to the operator of the HVAC system, during the winter the number of chillers in operation is reduced based on the operator's judgement.

The cooling for the basement is provided by two split systems, each with two thermostatically-controlled compressors and a rated cooling capacity of 24 kW. The fans of the split units can be operated independently of the cooling. The basement gets outside air through several openings to the outside, none of which are ducted to the AC units.

There are a total of 11 constant-volume Air-Handling Units (AHUs) for the ground, first, second, and third floors. The ground, first, and second floors each have two AHUs with 11 kW (output) motors and one AHU with a 4.1 kW output motor. The third floor has only two 11 kW AHUs.

Fresh air is supplied to the AHU rooms through three fans; two using motors of 3 kW output, the third powered by a 4 kW output motor. The fraction of outside air of the total supplied by the AHUs is unknown, since the AHU flows were too difficult to measure.

In addition to the two main air-conditioning systems, one of the ground-floor offices has window air-conditioning unit with an estimated capacity of 2 kW. Other miscellaneous loads in the building include several cash registers and a small number of personal computers. Table 3 summarizes the HVAC and other major equipment in the building.

4. Building Operation, Lighting, and HVAC Controls

The regular building operation is from 10 a.m. to 2 p.m. and from 5:30 to 9 p.m., Monday through Friday. Saturday operation is 10 a.m. to 3 p.m. and the store is closed on Sundays. The members of the building staff arrive at the building at about 15 minutes before the store opens and leave about 30 minutes after the store closes. This schedule results in approximately 2500 hours per year of store operation time. During the afternoon off hours, external shutters are pulled down on the ground floor.

The lighting is all controlled manually; it is turned on and off upon the store opening and closing. The air-conditioning systems are also controlled manually. On arrival to the building, the operator sequentially turns on the AHUs, fresh air fans, chilled water and condenser water pumps, cooling tower fans, and the chillers. The manual chiller control switch on each chiller allows the operator to choose between 4 compressor arrangements: one compressor only (either A or B) or both compressors, with A before B or B before A). The chillers are equipped with

Table 3. Inventory of Building Electrical Equipment

Equipment Name	Number of Units	Rated Input Power		Rated Input Current (amps per unit)
		kW/unit	Total kW	
Cooling System				
Chillers	3	110*	330	246
Cooling Tower Fans	2	9	17	16
Condenser Pumps	3	9	26	16
Chilled Water Pumps	4	9	34	16
Fans & Air-Handling Units				
Fresh Air Fans	2	4		7
	1	5	13	8
Ground-Floor AHUs	2	12		23
	1	5	29	8
First-Floor AHUs	2	12		23
	1	5	29	8
Second-Floor AHUs	2	12		23
	1	5	29	8
Third-Floor AHUs	2	12	24	23
Basement HVAC				
Air-Conditioning Unit	2	23	46	50
Air-Handling Unit	2	24	48	45
Other				
Elevator Motor	2	5	10	13
Main Water Feed Pumps	3	2	6	4
Total Power			641	

* each chiller has two compressors with rated input of 55 kW

automatic temperature controls (with sensors in the compressor suction lines) to prevent freezing; additional controls (with sensors in the chilled water discharge pipes) vary the compressor capacity in response to the cooling load. After turning on the main air-conditioning system, the operator turns on the basement A/C unit. As with the main system, he uses his judgement to decide how many of the compressors to operate. The cooling coils of the AHUs are controlled to maintain comfortable indoor conditions (approximately 21° C).

III. Audit Measurements

In addition to recording the name-plate information and counting the number and type of lighting fixtures, we performed some one-time measurements of the lighting intensity, lighting electricity use, AHU electricity use, and air flow rates of the fresh supply air. Measurements of energy use were performed during both normal operation and off hours of the store. Some measurements were repeated several times to determine the day-to-day variations of the loads.

The currents were measured with a hand-held current transducer (CT). Our hand-held wattmeter readings were questionable so we used the data loggers to measure the power consumption of the lighting and AHUs. The current measurements were used to check the accuracy of the data loggers.

Table 4 presents the current drawn by the lighting circuits and the air-handling units on each floor. This information was later used to check the data obtained by the data loggers. Note that the lighting circuits draw a major fraction of the total current on each floor. The emergency circuit is used at the same time as the main circuit; the two are supplied with power from different electrical services.

Table 4. Measured Current for Lighting and Air-Handling Units

LOCATION	LIGHTING Main Circuit (Amp.)	Emergency Circuit (Amp.)	Total (Amp.)	AHU (Amp.)
Basement	280	174	454	60
Ground Floor	392	27	419	32
First Floor	296	92	388	31
Second Floor	273	117	390	32
Third Floor	204	111	315	32
Outdoor	109	n/a	109	n/a

Table 5 summarizes the power consumption of the lighting systems for each floor. The lighting intensities vary from 50 to 80 watts per square meter. In general, the recommended lighting intensity for department stores in the U.S. is about 22 to 24 watts per square meter. As we discuss below, the excess lighting intensity shows a significant potential for energy conservation.

A comparison between Tables 2 and 5 shows that the measured lighting power is about 17% higher than the installed power according to fixture counts and assumed power per fixture. This difference is due to one or more of the following factors: inaccurate count, difference between assumed and actual power per fixture, and/or additional equipment being powered from the lighting circuits.

The lighting levels were measured in a few selected areas on each floor. These data are shown in Figures 1a-1e. The lighting levels vary significantly from point to point. However, the building is generally very well lit and in most areas there is excessive lighting.

The measurement of fresh air fans also revealed some interesting information. We measured the velocity of the supply air at each AHU with a hand-held hot-wire anemometer. The

Table 5. Measured Lighting Power by Floor

	Lighting Power (kW)		Total	
Floor	Fluorescent	Incandescent	kW	W/m^2
Basement	39	8	47	40
Ground	34	48	81	67
First	60	19	79	65
Second	57	24	8167	
Third	60	30	90	74
Total	249	129	378	63

measurements were performed at up to nine points in the exit ducts, then averaged to estimate the air flow rates. Table 6 summarizes the results of our fresh air flow measurement. Note that the basement air-conditioning unit does not have a supply-air fan; rather, fresh air is provided through an opening in the basement window. The control of the fresh air supply during hot summer conditions can lead to substantial energy savings.

IV. Monitoring Equipment, Installation, and Testing

1. Monitoring Equipment

Prior to leaving the U.S., an energy monitoring package was purchased from Synergistic Control Systems. The monitoring system was specified without a detailed knowledge of the building or its electrical system. The components of this package were selected to provide maximum flexibility depending on the actual layout of the building.

The equipment provided for collecting data consists of two Model C180 data loggers, each capable of recording 16 channels of power data, along with 15 analog and 16 digital inputs. Each power channel accepts the output of current transformers (CTs) which measure the amperage of the equipment of interest. (Only split-core CTs were used. Split-core CTs, though more expensive than standard CTs, can be installed without disconnecting the wire or bus-bar carrying current to the building loads.) Up to six CTs on any one phase can be paralleled into any one channel to give total amperage. This amperage reading is referenced to one of two available three-phase voltage inputs on each logger. Real power (kW), power factor, and apparent power (kVA) values are all available.

The analog inputs on the data loggers can be configured to accept any standard analog device. Connected to the analog inputs, two types of temperature sensors were purchased for measuring outside air, supply air and room air, as well as surface sensors for chilled water: RTD (Resistance-Temperature-Device) and solid-state devices which provide a linear output. Relative humidity sensors were also purchased for use in measuring outside air, supply air, and room

Table 6. Measurements of Fresh Air Flows

Fresh Air Fan and Area Served	Duct Area m^2	Average Speed m/sec	Air Flow Rate m^3/min
Fan Number 1.			
Ground Floor	0.25	0.8	12
First Floor	0.12	5	37
Second Floor	0.09	2	18
Third Floor	0.20	5	60
Subtotal			127
Fan Number 2.			
Ground Floor	0.05	6	18
First Floor	0.17	12	121
Second Floor	0.17	2	121
Subtotal			260
Fan Number 3.			
Ground Floor	0.16	1.7	16
First Floor	0.16	4	38
Second Floor	0.16	5	48
Third Floor	0.04	4	10
Subtotal			112
Total			499

air conditions.

The data loggers also have the capability to record digital inputs, including the output of pulse-initiating utility meters or pulse-output watt transducers. While neither of these options was used at the building, they could be added as an enhancement to future data collection installations.

The complete procedure for programming the data loggers is documented in the operation manual. Briefly, a parameter file must be written in the data logger software package. This software is loaded on an IBM-PC compatible machine. A connection is made between the PC and the logger via either modem or RS-232 interface. Data on the CTs and sensors are loaded into the proper fields provided by the application software and flags are used to select which channels will be written to the data files. For example, ten temperatures are currently being measured in the building, but only two are being saved to the data files. Because the logger has a limited memory of 32 kbytes, this allows the programmer to select which channels will be collected, thereby determining the time between downloadings. Storing data on all of the channels installed would require more frequent down-loading of data.

For measuring electricity use, we purchased 36 CTs of the combination shown in Table 7.

Table 7. Current Transformers Purchased

CT Size	Quantity
1500 amp	3
400 amp	6
200 amp	6
100 amp	6
50 amp	12
5 amp	3

2. Installing Equipment

The first step in the installation of equipment was a walk-through survey of the building and a review of the electrical plans. Based on the information gathered through these exercises, a measurement plan was developed which sought to maximize the usefulness of the 32 channels of power data available. In addition, changes were made to accommodate the limited number of current transformers. The result was a measurement plan which captures all relevant end-use data, as well as the building total. The final measurement arrangement is shown in Figure 2, which shows the basic connections of the data loggers and their sensors. Figure 3 lists the CTs as they were installed, and shows their placement on a one-line diagram.

The department store is served by two transformers, each of which carries a portion of the building lighting and HVAC loads. (See Figure 3.) The main distribution panel for the building is in the transformer vault outside the rear of the building. Secondary distribution is provided by panels on the ground floor and on the roof. There are lighting panels on each of the five floors in the building. In order to minimize the length of wire runs from the sensors to the logger, one data logger (which we called Logger A-1281) was placed in the ground floor panel room, the other (Logger B-1282) was placed in the elevator room on the roof.

To optimize the number of channels for measuring power, some combination of available CTs had to be fit into 32 total power channels in the two data loggers. After the initial walk-through, a rough measurement plan was developed which attempted to measure directly the most important loads in the building. In the course of installing the measurement equipment in accordance with the original measurement plan, it was decided that a more general approach to monitoring could be adopted which would free up our limited number of CTs, without significantly affecting the accuracy of the data collected. Whereas originally we had intended to measure all three phases of several representative pieces of equipment, such as air handlers and chillers, we instead opted to measure only one phase of these balanced loads, thereby freeing up CTs for other measurements.

While assuming balanced loads in the cases of three phase equipment introduces some measurement error, a "sum check" test of the measured building total vs. the calculated building total showed acceptable agreement for this type of survey. (The calculated total was based on the measured submetering points, extrapolated to include points not measured by the data logger but assumed identical to logged points based on one-time measurements.) The overall agreement (for all hours) is 7.8 percent; agreement for hours of normal building operation is 3.2 percent. Figure 4 shows a typical day's profile, showing the measured and calculated values. Other days have errors which partially cancel those shown.

Several iterations were made before a final measurement configuration was arrived at. In the final layout, we measure one phase on each of the three chillers, one phase of the supply fans, and one phase of one of two chilled water pumps which are operated in tandem. For example, the readings of Channel 6 on logger B-1282 should be multiplied by three to get the total power for Chiller #1. The readings of channels 4 and 5 should be multipied by 6 to arrive at the power for the pumps they are measuring. In the case of Channels 6, 7, and 8 on Logger A-1281, there are two CTs in parallel for each channel and the reading needs no adjustment (all of the phases are directly measured).

The data loggers were mounted as close as possible to the points being measured. Each logger was supplied with 24-volt AC power for logger power and three phases of reference voltages from each of the transformers. Split core current transformers were mounted on the appropriate wires in the distribution panels and the CT leads were connected to the logger using shielded, multi-pair cable.

As we mentioned earlier, each data logger can accommodate 15 analog inputs. However, because of an equipment failure on the analog board of Logger A, all of the analog channels were connected to Logger B. The analog channels measured are summarized in Table 8.

Table 8: Logger B Analog Channels

Channel	Measurement
0	Roof Air Temperature
1	Second Floor Air Temperature
2	Third Floor Air Temperature
3	Second Floor Supply Duct Temperature
4	Third Floor Supply Duct Temperature
5	Ground Floor Temperature
6	Ground Floor Supply Duct Temperature
7	Ground Floor Supply Duct Relative Humidity
8	Chilled Water Supply
9	Chilled Water Return
10	Outdoor Relative Humidity
11	Outdoor Temperature

The analog channels were distributed to provide data on the operation of the HVAC system, and indoor and ambient temperatures. Three floors had temperature sensors installed which measure the return air temperature and the supply temperature from the air handler.

3. Lessons Learned

The short lead time for selecting and purchasing a monitoring system, combined with the lack of information on the building to be monitored, created a less-than-optimal situation in which to set up a building monitoring project. A more appropriate approach would require a finalized measurement plan prior to the selection of the measurement hardware. However, in this project, necessity forced us to be creative and efficient with the use of hardware, leading to techniques which could be used in the future. For example, by measuring only one phase of several balanced three phase loads, we were able to use our limited CTs to measure more loads.

Aside from the challenges described above, the application of this equipment to an Egyptian electrical system proved surprisingly easy, and no significant operational barriers were confronted.

In this project, we followed a protocol consisting of six steps:

i. Develop a measurement plan (what should be monitored and what exactly will be done with the data).
ii. Install monitoring equipment per the measurement plan.
iii. Program the data logger.
iv. Debug the system and verify the correct operation of the measurement devices.
v. Provide a method for efficient downloading of the data.
vi. Develop concise analysis goals to test the validity of the data.

Future projects would benefit from the development of a complete measurement plan based on a set of analysis goals, prior to the specification of the monitoring hardware package. At a minimum, a complete plan would minimize the amount of reconfiguring needed to finalize the measurement setup.

V. Analysis of Energy Data and Conservation Potential

1. Analysis of Measured Data

The analysis of the measured data appears in part in Section III above (though the emphasis there is on the short-term or one-time measurements made with the portable equipment). In this section we emphasize the results of the data from the data loggers. The analysis is based on one month of data, gathered during September and October 1990.

Figure 5 shows the overall end-use breakdown of energy use: approximately 54% to lighting and 46% to HVAC. This compares to 55% lighting and 45% HVAC for similar large retail buildings in a similar climate in the U.S. (Akbari, Rainer, and Eto 1991). Figure 5 also shows the breakdown within the HVAC end use, with percentages (of the building total electricity for the test period) for the basement A/C units, the chillers, the HVAC auxiliary (pumps for condenser water and chilled water and the cooling tower fans), and the fans for the AHUs and the supply air. The chillers use nearly half of the total HVAC energy. The absolute annual intensities extrapolated from the one-month period of monitored data were 150 kWh/m^2 for lighting and 120 kWh/m^2 for HVAC, about 50% and 25% higher, respectively, than their corresponding intensities (of 100 and 95) for comparable existing buildings in the U.S. Note that the building's annual lighting intensity is well established, since the operation of the lights is consistent throughout the year. The HVAC annual numbers are not well known, since the data available are for one month only, and the correlation between cooling energy use and weather is uncertain (see Figure 8). The month of data is for a shoulder month, which is assumed to represent roughly the average HVAC consumption. The fluctuation over the year is limited by the fact that much of the cooling load is internal, and that the consumption of the AHUs and chiller auxiliaries is constant. Figure 6 shows the profiles of HVAC (including the several sub-categories), Lights, and Building Total over a typical week during September and October, 1990. This figure shows the excellent manual control of the building equipment during unoccupied hours: the building uses virtually no energy when it is closed. Figure 7 contains the same categories as Figures 6c, 6e, and 6f, but for the average of five typical weekdays (when the store is open in both the morning and afternoon). The intermediate values are mostly due to the fact that the data is reduced to hourly averages, so that unless the equipment is turned on close to the hour, the average will be significantly reduced for that hour.

Figure 8 shows the chiller power as a function of Outside Air Temperature. Hours when the chillers were all off (or partially off) are omitted. The correlation between chiller usage and temperature is only fair.

Figure 9 is a profile of the lighting input power averaged over the same 15-minute intervals for the five days per week of normal building operation. As with the HVAC equipment, the manual control is very good, with negligible energy use during afternoon and night periods when the store is closed.

2. Conservation Potentials

    a. Lighting

- **incandescent to compact fluorescent**

The 100-watt incandescents total 115 kW, corresponding to 1150 lamps. By replacing these with compact fluorescent flood lights of 18 watts each, a savings of 72% can be achieved. The light levels will be reduced somewhat, but the levels will still be adequate. The cost of these lights is about US$35 each for a total of $40,000. The energy saving is 329,000 kWh/year (235,000 directly from a reduction of 94 kW, plus 94,000 indirect from the chillers (due to reduced cooling load), using the compressor Coefficient of Performance (COP) rating of 2.5), corresponding to a dollar saving of $13,000/year (at a subsidized price of

$0.04/kWh) or $26,000/year (at a market price for oil-fired electricity of about $0.08/kWh). The simple payback period for this retrofit is thus 3.1 years or 1.5 years, respectively.

- **fluorescent (delamping, reflectors, T-8 lamps, electronic ballasts)**

The store's fluorescent lighting is made up predominantly of 120cm length, 26mm diameter (T-8) lamps each driven by a standard single-lamp core-coil type ballast for a per-lamp input power of about 51 watts (Nadel 1990). The total fluorescent lighting power is 235 kW, corresponding to the equivalent of 4,610 lamps.

Four measures can be applied to improve the efficiency of the lighting system. Replacing the existing standard T-8 lamps with tri-phosphor lamps will improve the lamp efficiency and the color rendering. Replacing the standard ballasts with high-frequency electronic ballasts operating two lamps each would reduce the per-lamp power to 30 watts. In most cases, specular reflectors could be used to eliminate one of every two lamps; the somewhat-reduced light levels from this delamping should still be adequate. The cost of each of the 2,305 lamps is about US$3; the reflectors, $25 per lamp; the ballasts, $12 per lamp; installation of these measures would add about $13 per lamp, for a total cost of $53 per lamp. The total cost of the fluorescent retrofit is thus a total of $6,900, $57,600, $27,700, and $30,000 respectively, or about $120,000. The energy saving from this 166 kW reduction for 2,500 hours per year is 415,000 kWh/year direct, plus 170,000 kWh/yr indirect from the chillers. The dollar savings are $23,000/year at $0.04/kWh, and $47,000/year at $0.08, with corresponding simple payback periods of 5.2 years and 2.6 years, respectively.

As noted, the above calculations include reductions in cooling load through reduced lighting power. The compressor design COP of 2.5 is used, not counting the auxiliaries, which drop the COP to about 2.1. The marginal COP is 2.5, since the auxiliaries would continue to operate regardless of the lighting retrofit. Also, it would be possible to retain the existing lighting levels, but the savings would be significantly reduced, and the costs would increase (since a greater number of lamps and ballasts would be involved).

The above retrofit recommendations are summarized in Table 9.

Table 9. Recommended Lighting Retrofits for Omar Effendi

Retrofit	Energy Savings (kWh/yr)	Dollar Savings @4¢/kWh	Dollar Savings @8¢/kWh	Estimated Cost (U.S. Dollars)	Simple Payback Period (Years) @4¢/kWh	Simple Payback Period (Years) @8¢/kWh
A. Fluorescent Lights, including: 1. reflectors 2. delamping 3. T-8 tri-phosphor lamps 4. electronic ballasts	585,000	23,000	47,000	120,000	5.2	2.6
B. Incandescent Lights: Replace with compact fluorescents	329,000	13,000	26,000	40,000	3.1	1.5

Notes:

1. All information is based on U.S. experience on purchase and installation cost. The actual costs may vary significantly for Egypt.
2. Estimates for lead times depend on timely information about the existing incandescent and fluorescent fixtures.
3. Payback times based on energy cost data from Mr. Mohammed Emam (equivalent to $0.04/kWh), from estimate of market price of electricity generated from oil ($0.08/kWh), and a currency conversion of $1.00 US = 2.75 Pound Egypt (LE). (100¢ = $1.00).
4. If existing fluorescent lamp life is shorter than 20,000 hours, the fluorescent retrofit will be more cost-effective (and less so if the existing lamp life is longer). The incandescent cost-effectiveness will be better than shown because the savings in incandescent replacement lamp and labor costs is not included in the analysis (the compact fluorescents typically last 10 times as long as incandescents).
5. The energy savings shown include chiller energy savings at at COP of 2.5. The lighting-only savings are thus 71% of the numbers shown.

b. HVAC

Several options exist for reducing HVAC energy use. Thorough analysis of these requires further data from the data loggers and the HVAC (fan, pump, cooling tower, and chiller) equipment manufacturers, and in most cases would benefit greatly from running a simulation model on the building in order to more accurately determine the building, weather, and system dynamics so as to better predict the savings. However, the following paragraphs discuss approximate cooling load and energy savings based on crude analysis of several of the measures. It should be noted that comfortable indoor air conditions are currently provided by the system, and that the savings discussed here would not compromise these conditions. Also, the uncertainties in savings and costs are so great for the HVAC measures that reasonable economic analysis is not possible, and has not been attempted at this time.

As mentioned in the lighting section, the lighting retrofits will significantly reduce the cooling load. If the proposed lighting retrofits are performed, a 260 kW reduction will occur (230 kW on the floors served by the central chillers).

The flow of fresh air (Table 6) into the building is about 500 m^3 per minute. The recommended flows from ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers), are 0.09 m^3/minute per square meter for the basement and ground floors of retail stores; 0.06 for upper floors, with maximum occupancy of 30 persons per 100 m^2 in the basement and ground floors and 20 in the upper floors (ASHRAE 1989). Using these directly, the recommended flow would be 430 m^3/minute. However, the actual occupancy at the building is far less than the ASHRAE maximum (typically below 2 persons per 100 m^2, with a maximum of 7, based on observation and discussions with the building management). Converting the ASHRAE numbers to the per-person flow of 0.30 m^3/minute, the recommended flow becomes 120 m^3/minute. Erring on the side of fresher air, the flow used in this preliminary analysis is 350 m^3/minute, or 70% of the existing flow. Reducing this flow, and that of the air-handling units (through the use of different pulleys on the belt drives of the fans) saves cooling load in two ways: by reducing the amount of fan power (which heats the air) and by reducing the amount of fresh air that needs to be cooled. The first saving is about 57 kW; the second, about 66 kW. Table 10 shows the reduction in peak cooling load due to these three measures. The result of the lighting and fresh air reductions is that about 350 kW could be removed from the peak cooling load. When compared with the 280 kW capacity of each chiller, this reduction means that the entire load could be met by one chiller, and one of the existing chillers could be made available for use in another store or sold on the market.

Energy savings from the following measures should be further analyzed, beyond the estimates contained in Table 11.

- Ventilation reduction

  As discussed above, the fresh air and general ventilation rates in the building are excessive. Our rough analysis suggests that the air flow of all fans can be

Table 10. Cooling Load Reductions

Measure	Reduction in Peak Cooling Load (kW)
Lighting	230
Ventilation Fans	57
Outside Air Flow	66
Total	353

Table 11. Estimated Energy Savings from Selected HVAC Measures

Measure	Estimated Annual kWh Reduction Minimum	Maximum
1. Ventilation reduction		
fans	110,000	160,000
chillers	48,000	106,000
2. Reduced use of cooling towers and pumps	43,000	63,000
3. Economizer control	8,000	23,000

reduced by about 30%, saving fan energy on the order of 140,000 kWh/yr, as well as chiller energy of about 78,000 kWh/yr. (Key assumptions are that the 97 kW of the existing fans will scale with the 2.5 power of the flow (discounting the cube law fan savings to account for efficiency losses), and that the average Outside Air (OSA) cooling load is one-third of the peak.

- Outside Air control (economizer or equivalent)

The existing outside (supply) air is delivered to the building at constant volume regardless of indoor and outdoor conditions. Installing dampers and controls in order to control the amount of fresh air to a level appropriate for the actual conditions would save cooling energy. In Table 10, savings are from reduced air during hot periods (assumes 140 m^3 reduction in air flow for half of 2500 hour per year operation, under average conditions of 32° C air cooled to 21° C). The big savings from OSA economizers come from increased fresh air flow when cool outside air can be used to remove internal loads. Since the OSA ducts are probably too small to make use of 100% OSA practical, the use of a water-side economizer should be investigated.

- Water-side economizer

Since the OSA ducts would not easily permit the use of increased outside air for cooling under favorable conditions, the possibility of using water cooled by the cooling tower(s) in the cooling coils (and thus bypassing the chillers) should be further investigated. The tower water can be used directly in the chilled water loop, or indirectly through a heat exchanger (usually of the plate-and-frame type for high performance) to help prevent contamination of the chilled water from the open tower(s).

- Chiller control-staging within and between chillers

This is one of the few areas where automatic control is likely to save energy relative to the existing manual control. (The building operation is relatively simple, and the building operators do an excellent job of manual control, so a sophisticated EMCS would be cost-effective.) The decision of how many compressors to operate, and at what level of load, is one that often needs to be made dozens of times a day. A controller with the correct control algorithm for the chiller plant at Omar Effendi could result in savings of about 5 to 10%.

- Use chilled water to cool the basement

It might be possible to significantly improve the efficiency of cooling the basement by converting the existing A/C units to act as air-handling units served with chilled water from the main building supply. The cost of extending the chilled water pipes and converting the A/C units would have to be weighed against the energy savings. Since the chillers are not highly efficient, and the COP of the basement A/C units is not known, this measure cannot be quantified at this stage.

- Repipe condenser water loop (reduce pumping requirements)

The present piping scheme for the condenser water is much longer than necessary to transport the water between the chillers and towers. The possibility of re-piping the loop in order to reduce pipe friction losses should be further investigated.

- High-efficiency motors

Replacing the standard motors in the pump and fan applications with high-efficiency motors would save about 5 to 8% of the motor inputs. This option should be further studied.

c. Operation

- Pump and tower control (stage with chillers)

At present, four pumps and both towers are operated regardless of the number of chillers operating. This control scheme should be re-evaluated to see if half of the auxiliary equipment could be shut down when only one chiller is operating. The savings are about 55,000 kWh per year, assuming three motors running at a total of 22 kW could be left off for 2500 hours per year.

VI. Conclusions and Recommendations

The Omar Effendi department store is a modern, air-conditioned building that uses far more electricity for lighting and cooling than necessary.

The replacement of incandescent lamps with compact fluorescents, as well as upgrading the fluorescent lighting with tri-phosphor lamps, electronic ballasts, and reflectors (with delamping) is cost-effective if the market electricity price is used.

Savings from lighting and HVAC measures can most probably eliminate the need for one of the three chillers, making it available for use in another building.

There are several HVAC retrofit options that appear to be promising. The complexity of adequately analyzing these HVAC options makes that analysis appropriate for Phase II of the project.

Given the simplicity of the building and the excellent manual control already being practiced, a sophisticated EMCS is unlikely to be a worthwhile retrofit. A dedicated chiller optimizer for staging control is worthy of further study for the store.

VII. Proposed Phase II Tasks

Phase II of the project (now cancelled) was to focus on implementation of conservation measures related to lighting with further analysis of measured data to document savings as well as identify conservation opportunities in cooling. The analysis would have included simulation of the cooling energy needs of the building, using the DOE-2 building energy simulation program.

The cooling conservation options to be analyzed include outside-air or water-side economizer control, chiller optimization control, high-efficiency chillers, use of chilled water to cool the basement, reconfiguration of the condenser water loop, high-efficiency motors, and external shading of windows.

References

Akbari, H., Rainer, L., and Eto, J., 1991. "Integrated Estimation of Commercial-Sector End-Use Load Shapes and Energy-Use Intensities, Phase II. Lawrence Berkeley Laboratory Report LBL-30401. January 1991. Berkeley, CA: Lawrence Berkeley Laboratory.

ASHRAE, 1989. "Ventilation for Acceptable Indoor Air Quality". Standard 62-1989. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Nadel, 1990. "Lighting Energy Use and Conservation Opportunities in Egypt". Memorandum from Steve Nadel (American Council for an Energy-Efficient Economy) to Isaac Turiel (Lawrence Berkeley Lab). April 17, 1990. Washington D.C.: ACEEE.

Figure 1. Measured Light Levels (Lux) All floors are open plan (no partitions except for the merchandise display cases). Note that the lighting levels vary significantly from point to point. The building is generally very well lit and in most areas there is excessive lighting.

Figure 1a. Measured Basement Light Levels (Lux)

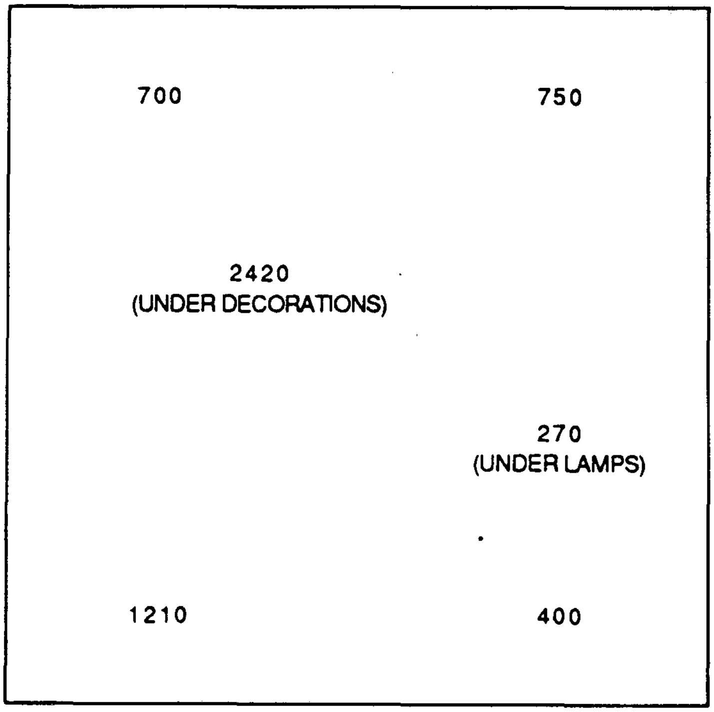


Figure 1b. Measured Ground-Floor Light Levels (Lux)

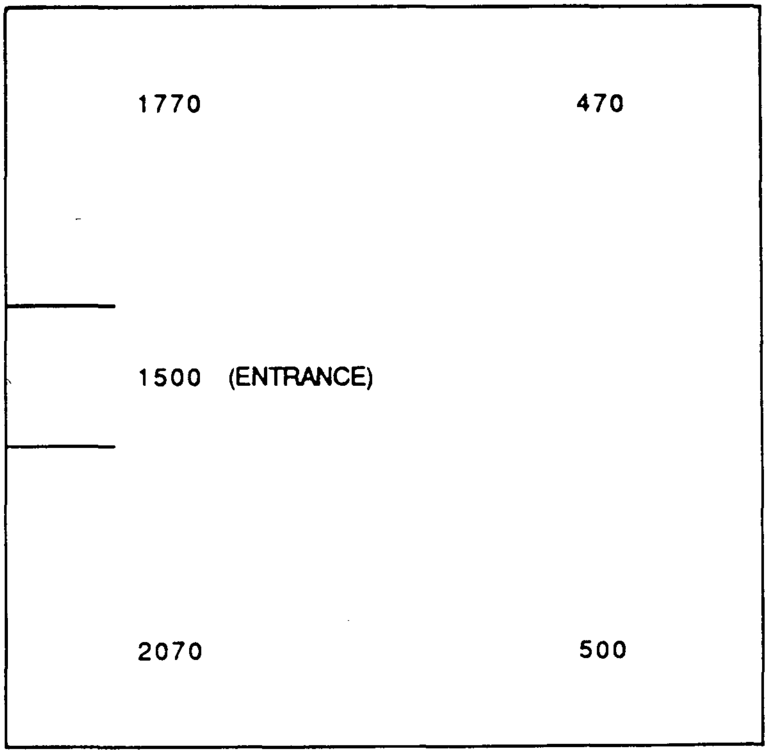


Figure 1c. Measured First-Floor Light Levels (Lux)

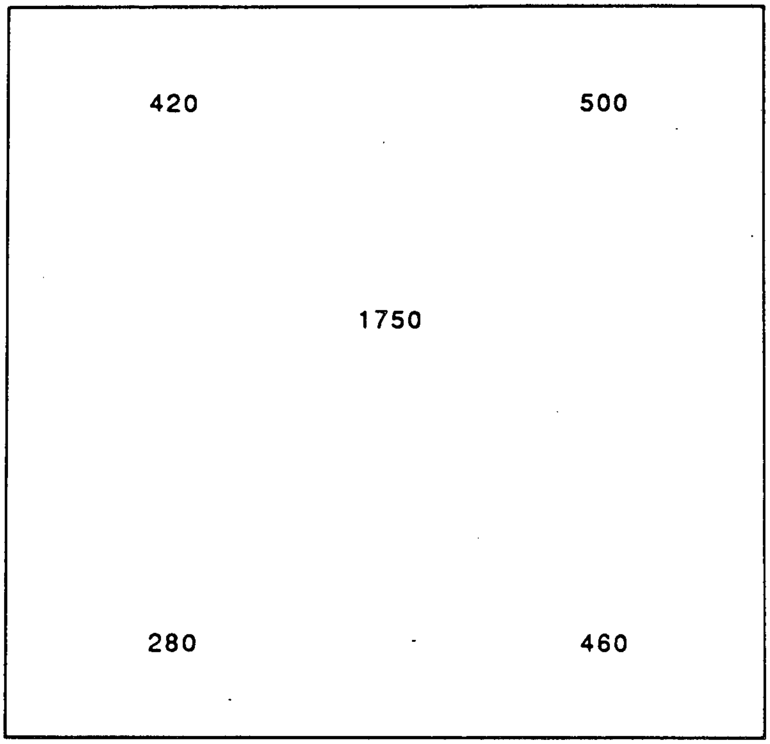


Figure 1d. Measured Second-Floor Light Levels (Lux)

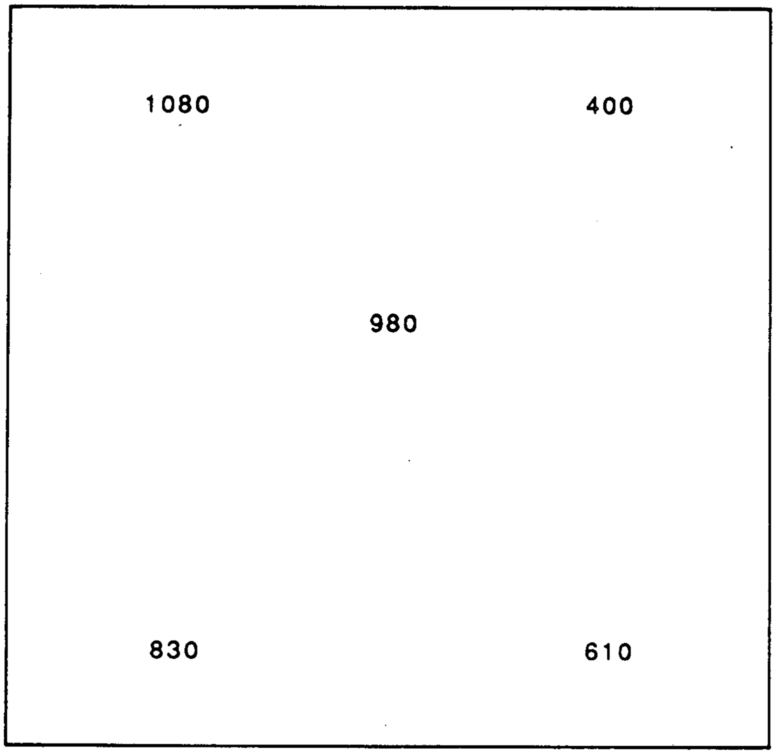


Figure 1e. Measured Third-Floor Light Levels (Lux)

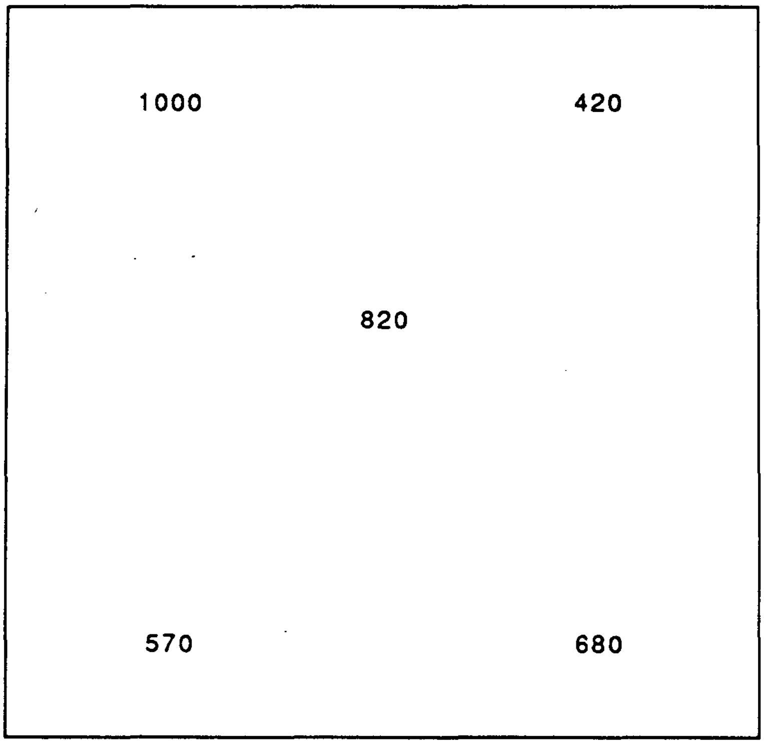


FIGURE 2. DATA LOGGER WIRING

The basic connections of the data loggers and their sensors are shown in their final measurement arrangement.

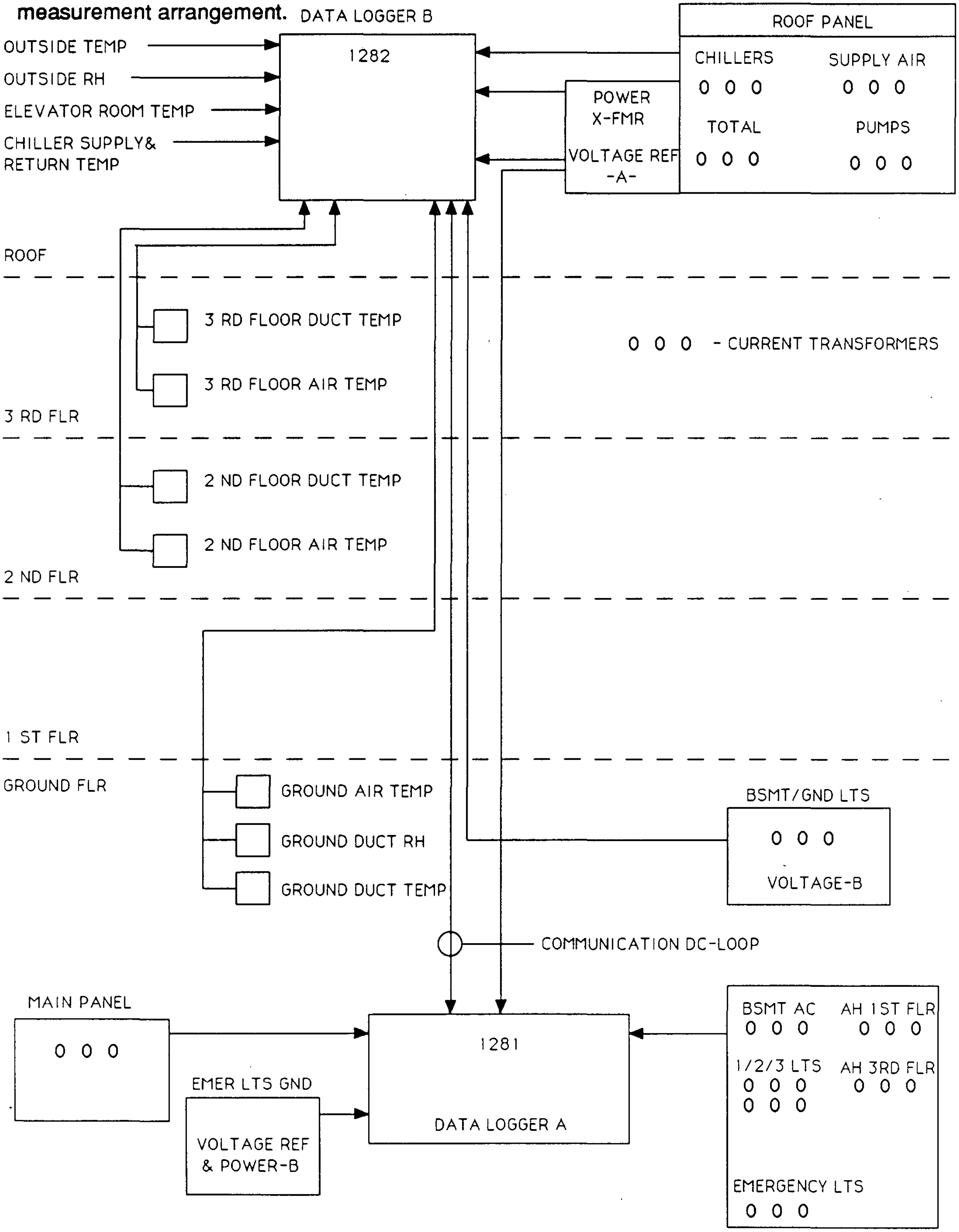
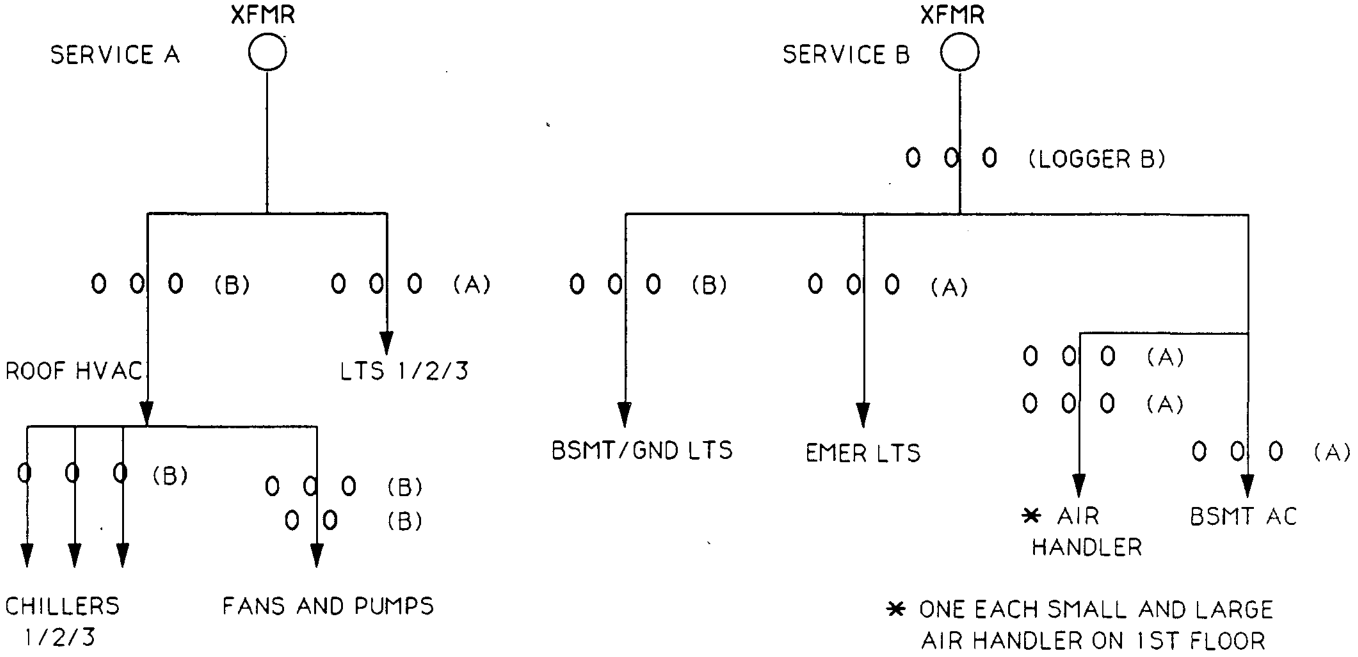


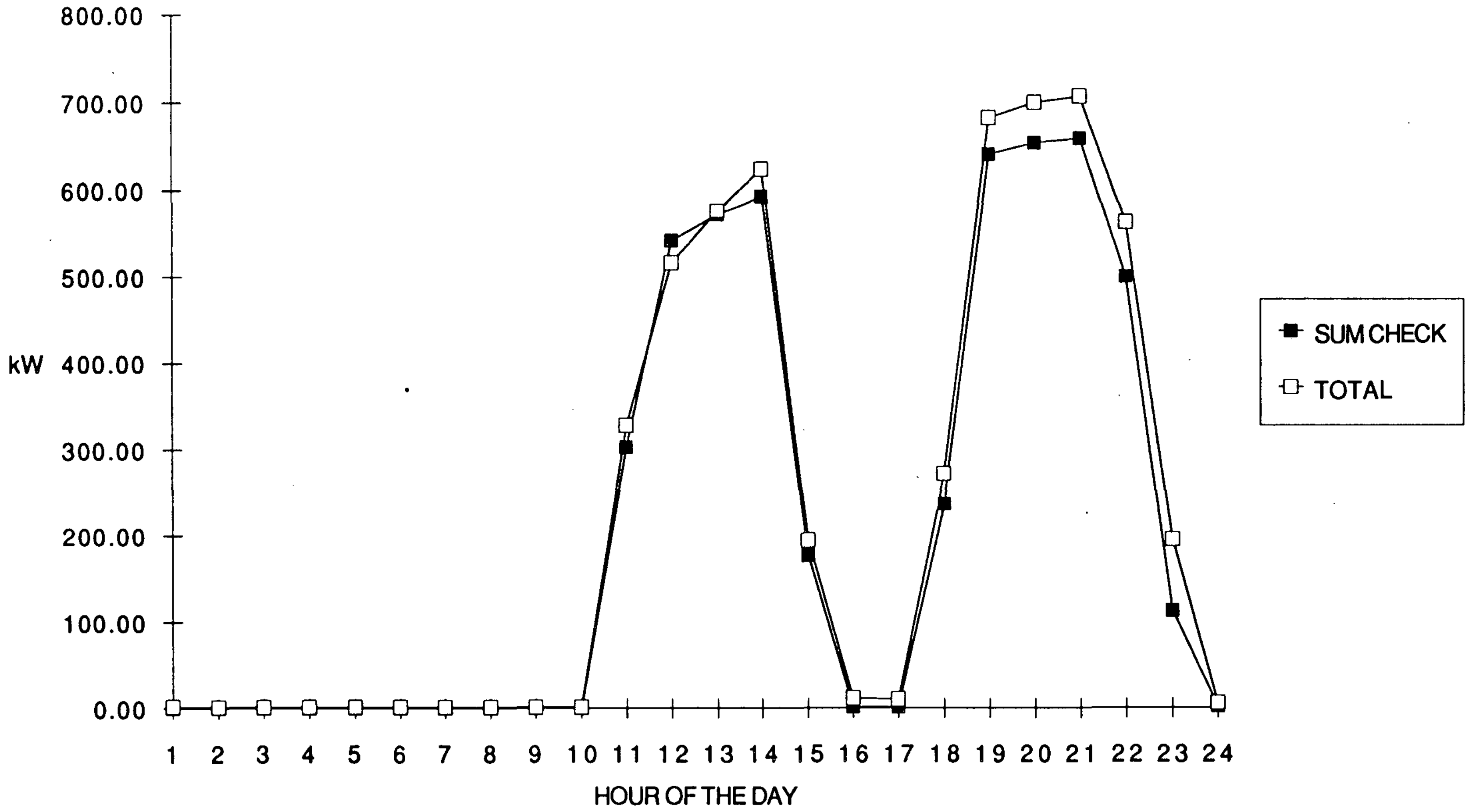
FIGURE 3. ONE-LINE DIAGRAM
OF BUILDING ELECTRICAL WIRING



	LOGGER A-1281		LOGGER B-1282
0	GROUND FLOOR AIR HANDLER	0	TRANSFORMER II TOTAL
1	GROUND FLOOR AIR HANDLER	1	TRANSFORMER II TOTAL
2	GROUND FLOOR AIR HANDLER	2	TRANSFORMER II TOTAL
3	THIRD FLOOR AIR HANDLER	3	SUPPLY AIR FANS
4	THIRD FLOOR AIR HANDLER	4	CHILLED WATER PUMPS 1&2
5	THIRD FLOOR AIR HANDLER	5	CHILLED WATER PUMPS 3&4
6	BASEMENT HVAC	6	CHILLER #1 "R" PHASE
7	BASEMENT HVAC	7	CHILLER #2 "S" PHASE
8	BASEMENT HVAC	8	CHILLER #3 "T" PHASE
9	1/2/3 FLOOR LIGHTS	9	ROOF HVAC TOTAL
10	1/2/3 FLOOR LIGHTS	10	ROOF HVAC TOTAL
11	1/2/3 FLOOR LIGHTS	11	ROOF HVAC TOTAL
12	EMERGENCY LIGHTS	12	BSMT/GROUND FLOOR LIGHTS
13	EMERGENCY LIGHTS	13	BSMT/GROUND FLOOR LIGHTS
14	EMERGENCY LIGHTS	14	BSMT/GROUND FLOOR LIGHTS
15	NOT USED	15	NOT USED

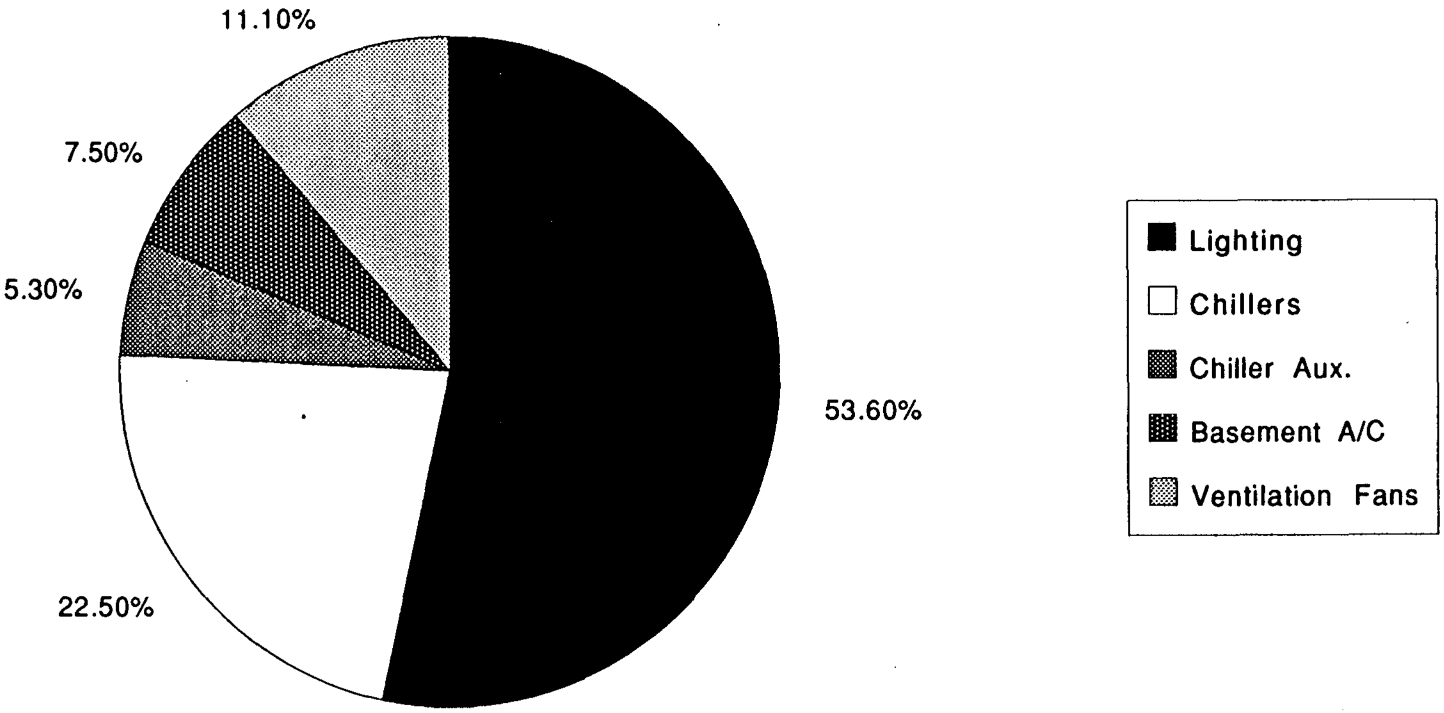
The upper section of the figure shows the placement of the current transducers (each one symbolized by an "O") on a one-line diagram of the building wiring. The lower section lists the CTs as they were installed.

FIGURE 4. BUILDING TOTAL VS. SUM CHECK (AVERAGE DAY)



The "sum check" compares the measured building total to the calculated building total. The calculated total was based on the measured submetering points, extrapolated to include points not measured by the data logger but assumed identical to logged points based on one-time measurements. The overall agreement (for all hours) is 7.8 percent; agreement for hours of normal building operation is 3.2 percent. A typical day's profile is shown, showing the measured and calculated values.

FIGURE 5. END-USE BREAKDOWN OF TOTAL ELECTRICITY CONSUMPTION



The overall end-use breakdown of energy use (about 54% to lighting and 46% to HVAC) compares to 55% lighting and 45% HVAC for similar large retail buildings in a similar climate in the U.S. (Akbari, Rainer, and Eto 1991). The one-month monitoring period was during September and October 1990. The absolute intensities for the monitoring period were 150 kWh/m^2 for lighting and 120 kWh/m^2 for HVAC, about 50% and 25% higher, respectively, than their corresponding intensities (of 100 and 95) for comparable existing buildings in the U.S. Also shown is the breakdown within the HVAC end use, with percentages (of the building total electricity for the test period) for the basement A/C units, the chillers, the HVAC auxiliary (pumps for condenser water and chilled water and the cooling tower fans), and the fans for the AHUs and the supply air. The chillers use nearly half of the total HVAC energy. See text for further discussion.

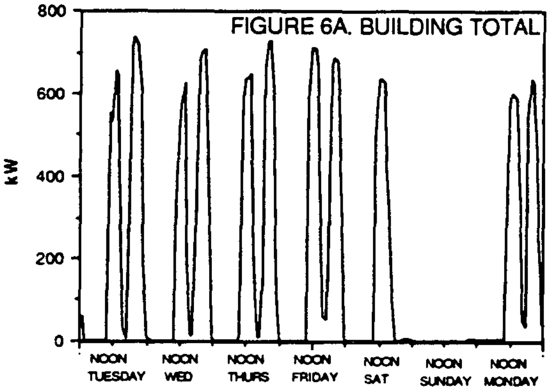


FIGURE 6A. BUILDING TOTAL

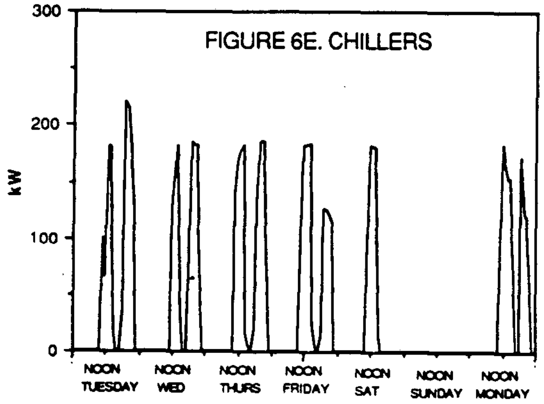


FIGURE 6E. CHILLERS

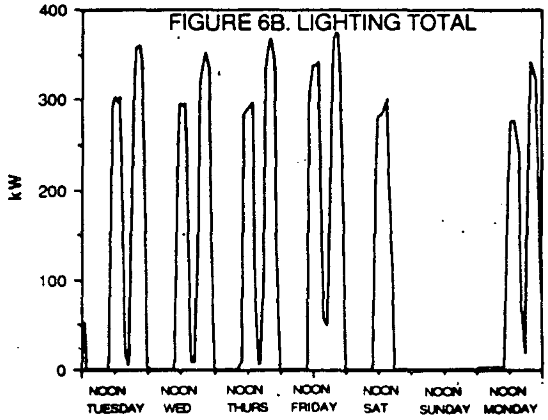


FIGURE 6B. LIGHTING TOTAL

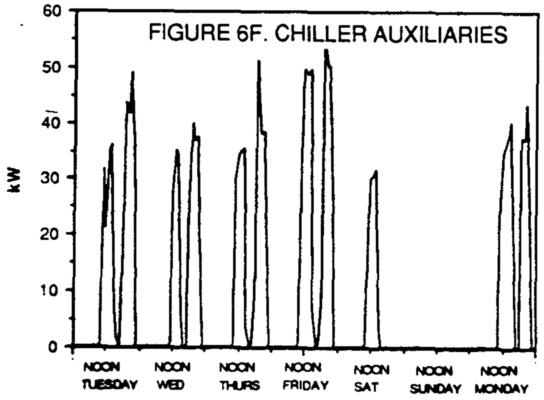
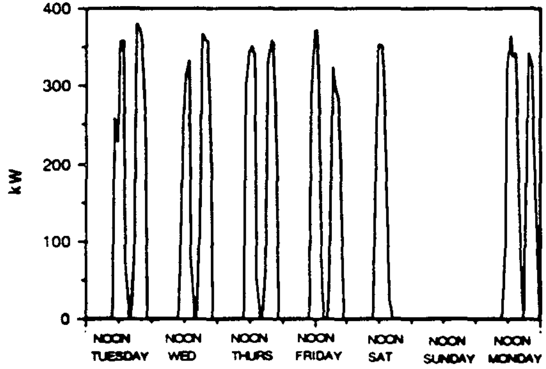


FIGURE 6F. CHILLER AUXILIARIES

FIGURE 6C. HVAC TOTAL



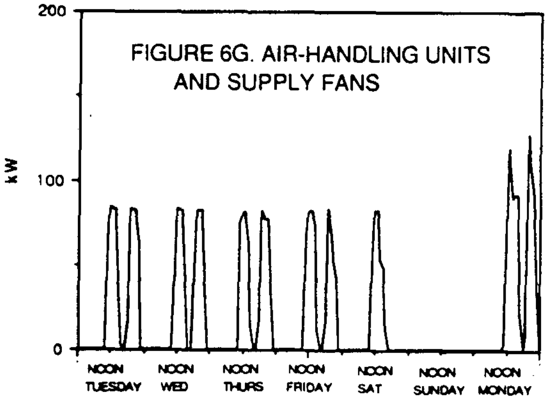


FIGURE 6G. AIR-HANDLING UNITS AND SUPPLY FANS

FIGURE 6D. BASEMENT AIR CONDITIONING

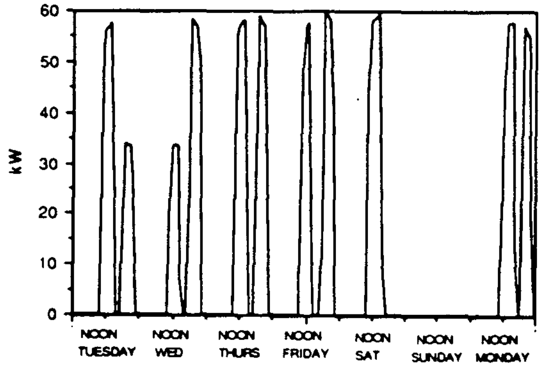
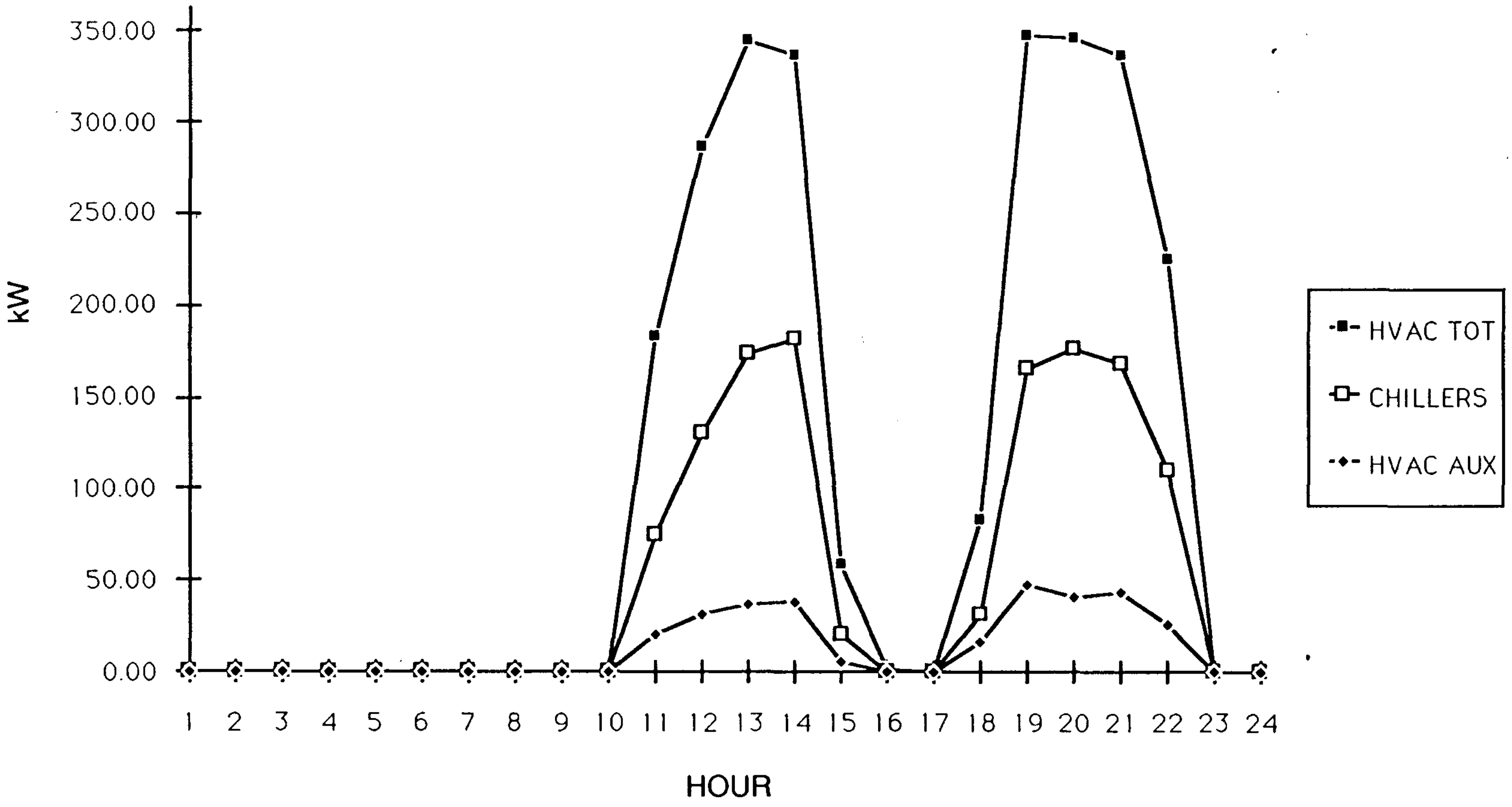


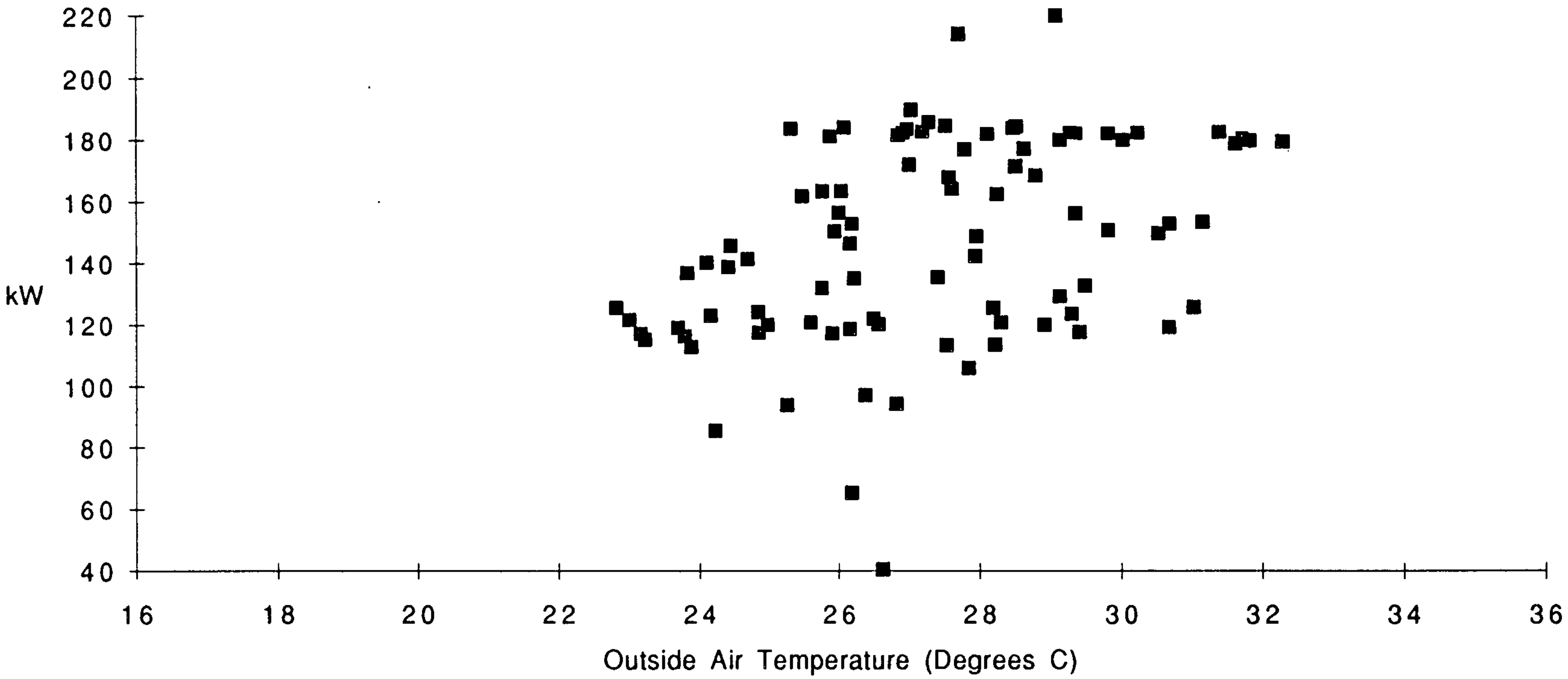
FIGURE 6. This figure shows the profiles of the total building electricity, lighting, and HVAC (including the several sub-categories) over a typical week during September and October, 1990. Note the excellent manual control of the building equipment during unoccupied hours: the building uses virtually no energy when it is closed. There is very little usage in the building that is not lighting or HVAC.

FIGURE 7. HVAC LOADS (AVERAGE DAY)



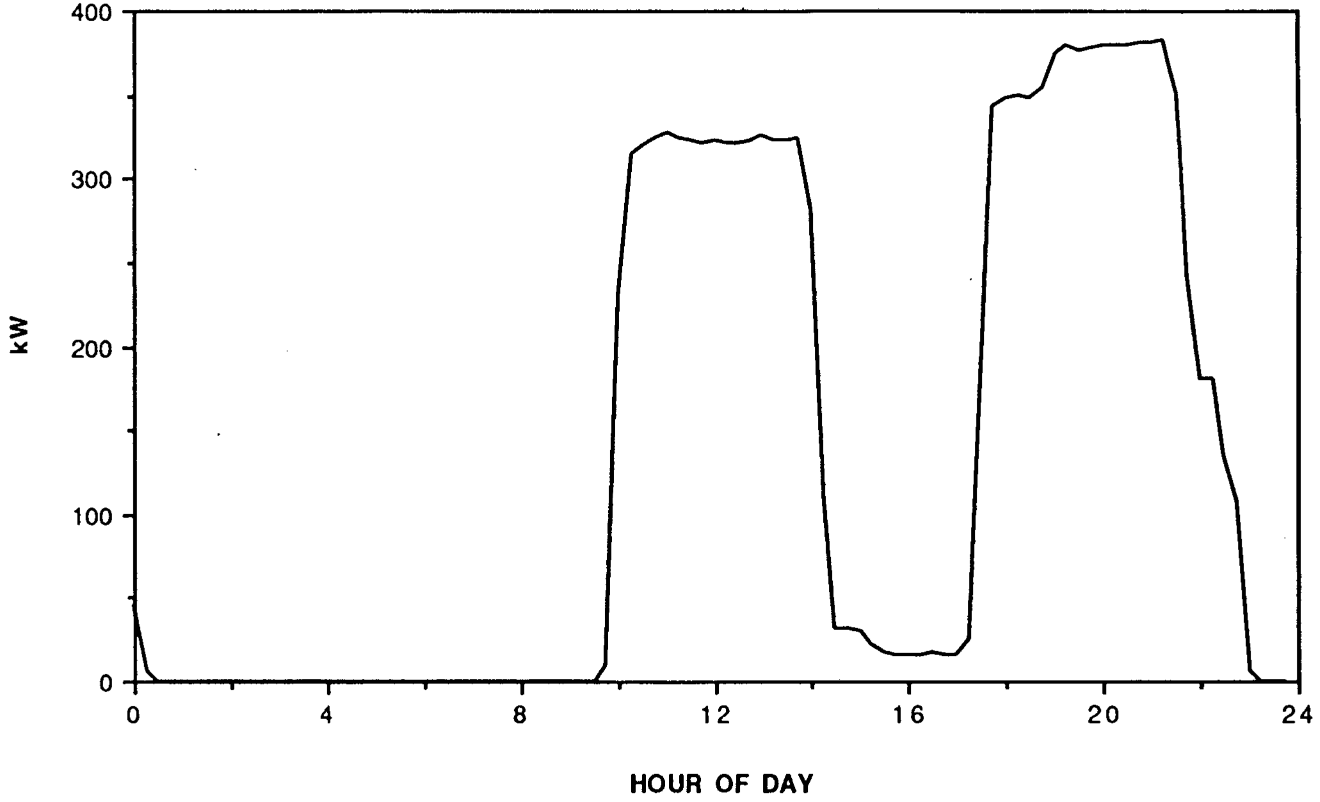
This figure contains the same categories as Figures 6c, 6e, and 6f, but for the average of five weekdays (when the store is open in both the morning and afternoon). The intermediate values are mostly due to the fact that the data is reduced to hourly averages, so that unless the equipment is turned on close to the hour, the average will be significantly reduced for that hour.

FIGURE 8. TOTAL CHILLER USAGE vs. OUTSIDE AIR TEMPERATURE



Scatter-plot of the chiller input power as a function of Outside Air Temperature. Hours when the chillers were all off (or partially off) are omitted, in order to eliminate the appearance of partial loading that in fact was due to the unit being started or stopped during the hour. The correlation between chiller usage and temperature is only fair. Possible reasons for the lack of correlation include the inability of manual control to closely follow the load, and that the load itself is not highly dependent on the outside air temperature (instead, much of it is due to high internal gains).

FIGURE 9. LIGHTING (AVERAGE DAY)



This figure shows the lighting input power averaged over the same 15-minute intervals for the five days per week of normal building operation. As with the HVAC equipment, the manual control is very good, with negligible energy use during afternoon and night periods when the store is closed.