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HEAT RECOVERY SUBSYSTEM AND OVERALL SYSTEM INTEGRATION OF FUEL CELL ON-SITE INTEGRATED ENERGY SYSTEMS

FINAL REPORT
TO
ENGELHARD CORPORATION

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LOUIS J. MOUGIN

THE TRANE COMPANY

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Author

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NOMENCLATURE

C_o	incremental first cost
CF_i	incremental cash flow in the i^{th} year
DHW	domestic hot water
E_c	conventional system first year utility cost
E_f	fuel cell/HVAC system first year utility cost
HVAC	heating, ventilating and air conditioning
IRR	after tax internal rate of return
NPV	net present value of incremental cash flows at 15% discount rate
SPB	simple payback period

ABS1	single stage absorption chiller
ABS2	two stage absorption chiller
CTV	Trane "Centravac" electric chiller
FC	fuel cell system
H	hot side thermal storage

BOS ED	Boston Edison (Boston)
CON ED	Consolidated Edison (New York)
COMM ED	Commonwealth Edison (Chicago)
GEO PWR	Georgia Power Co. (Atlanta)
NJPS	New Jersey Public Service Electric & Gas (Newark)
S CAL ED	Southern California Edison (Los Angeles)

EXECUTIVE SUMMARY

The overall objective of this project was to determine the best HVAC (heating, ventilating and air conditioning) subsystem to interface with the Engelhard fuel cell system for application in commercial buildings. To accomplish this objective, the effects of several system and site specific parameters on the economic feasibility of fuel cell/HVAC systems were investigated.

An energy flow diagram of a fuel cell/HVAC system is shown in Figure 1. The fuel cell system provides electricity for an electric water chiller and for domestic electric needs. Supplemental electricity is purchased from the utility if needed. An excess of electricity generated by the fuel cell system can be sold to the utility.

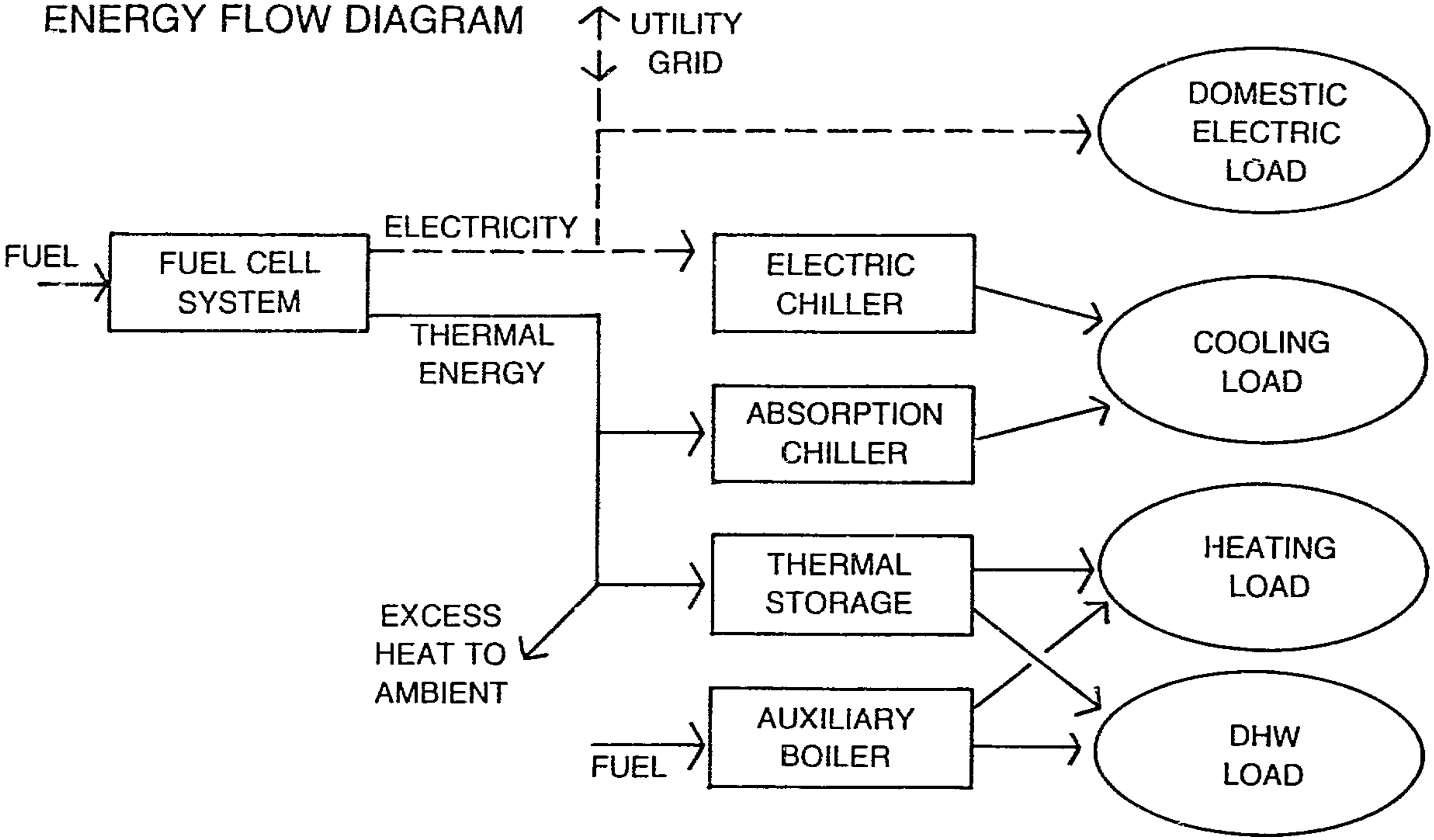
The fuel cell system also provides thermal energy which can be used for absorption cooling, space heating and domestic hot water. Thermal storage can be incorporated into the system. Thermal energy is also provided by an auxiliary boiler if needed to supplement the fuel cell system output.

Fuel cell/HVAC systems were analyzed with the TRACE computer program. TRACE is an energy and economic analysis program that has been developed by The Trane Company. Additions and modifications were made to TRACE in order to simulate fuel cell/HVAC systems.

Actual cogeneration electric rate structures for six different cities were used in the analysis. Future electricity prices were determined by applying escalation rates from Trane Company projections. Natural gas prices are also

FIG. 1

FUEL CELL/HVAC SYSTEM
ENERGY FLOW DIAGRAM



v1.

from Trane Company projections. All of the results in this report are for natural gas powered fuel cell systems.

The most important parameter affecting the economic feasibility of fuel cell/HVAC systems was found to be the installed cost of the fuel cell system. By varying the installed cost parametrically, a "break-even" cost was determined. The break-even cost was defined as that which yields a 15% internal rate of return to the building owner. The break-even cost was found to be a strong function of the electric rate structure. For the best building, the break-even cost was about \$650/KW with the lowest electricity prices, and about \$2000/KW with the highest electricity prices. The building owner can afford a higher priced fuel cell when more expensive electricity is displaced.

The current Engelhard estimate of installed fuel cell system cost, inflated for 1985 installation is \$980/KW. By comparing this value to the break-even costs, it is concluded that fuel cell/HVAC systems can be economic in regions with medium to high electric rates. For application throughout the U.S. however, the installed fuel cell system cost must be reduced below \$650/KW.

Three types of water chillers were investigated for application in fuel cell/HVAC systems: electric chillers, absorption chillers, and a combination of electric and absorption. Electric chillers are more efficient than absorption chillers and can be powered by the electric output of the fuel cell system. Absorption chillers are less efficient but can be powered by the thermal output of the fuel cell system.

The combination of electric and absorption chillers was found to be the best. The absorption chiller should be sized to match the thermal output of the fuel cell system. When the absorption chiller cannot meet the cooling load, the electric chiller is brought on-stream. Systems with only absorption chillers are less economical. When thermal energy from the fuel cell system is insufficient to power the absorption chiller at high cooling loads, natural gas must be burned in the auxiliary boiler to power the low efficiency absorption chiller. This results in a less economical system.

Applications of fuel cell/HVAC systems were investigated for four building types: a hospital, an apartment building, a retail store and an office building. These buildings represent a wide range of thermal to electric load ratios. The best buildings were found to be the hospital and the apartment building. These buildings have relatively high thermal loads. Applications in the retail store and office building were considerably less favorable. It was concluded that buildings with thermal to electric load ratios near unity are the best applications for fuel cell/HVAC systems. Buildings with load ratios much greater than unity require a larger investment for a larger fuel cell system and more electricity is sold back to the utility at unfavorable rates. In buildings with small load ratios, the thermal output of the fuel cell system is not effectively utilized.

The optimum fuel cell system capacity was found to be a function of the building's thermal to electric load ratio. For load ratios near unity (the best buildings) the optimum capacity is about 80% of the average electric load. At larger capacities, the fuel cell system thermal output is not effectively utilized, and a considerable amount of electric energy is sold back to the utility at unfavorable rates. A fuel cell system that provides all of a building's electric load was definitely not economic.

The effect of location on economic feasibility was determined by analyzing the best building in six different locations. The effect of location was found to be primarily due to changes in electric rate structures. Locations with high electric rates yield the highest internal rates of return because higher priced electricity is displaced by the fuel cell system. Weather has a secondary effect because the HVAC loads of commercial buildings are generally dominated by the internal loads.

The optimum operating mode for the fuel cell system was to operate continuously at rated capacity. Excess electricity can be sold back to the utility. If the fuel cell system electric output is varied in response to the electric load, the thermal output also varies. The fuel cell system then satisfies a smaller fraction of the daily thermal load and more natural gas is consumed for auxiliary heating.

The installed cost of the recommended HVAC subsystem for the hospital was estimated by Affiliated Engineers, Inc. The incremental installed cost over a conventional system was $358/KW to interface with a 460 KW fuel cell system. The total incremental installed cost, including $980/KW for the fuel cell system, is then $1338/KW. Using the highest electric rates, the calculated internal rate of return was 33%.

The results of this study show that fuel cell/HVAC systems can be economic in some building types in certain locations. The four most important requirements for economic feasibility are:

- applications in buildings with high thermal-to-electric load ratios,
- applications in localities with medium to high electric rates,
- achievement of fuel cell cost goals, and
- the continued existence of PURPA.

Deviations from these requirements can cause a considerable reduction in the internal rate of return. PURPA is necessary to guarantee that supplemental electricity can be purchased at a reasonable rate. The sell-back provisions of PURPA are not crucial since the optimally sized fuel cell will generate small quantities of excess electricity.

I. INTRODUCTION AND OBJECTIVES

The overall objective of this project was to determine the best HVAC subsystem design to interface with the Engelhard fuel cell system. The fuel cell system was defined, for the purpose of this project, as a system which includes the fuel cell stacks, reformer, inverter, and related controls.

The work was divided into three tasks.

TASK I - PRELIMINARY SYSTEM DESIGN

Objective: To complete a preliminary assessment of fuel cell/HVAC systems and to identify the most important design parameters.

Report: "Fuel Cell/HVAC Interface, Task I Report", presented to Engelhard on June 8, 1982.

TASK II - DESIGN STUDIES

Objective: To extend and refine the analyses of the important issues that were identified during Task I.

Report: "Heat Recovery Subsystem and Overall System Integration of Fuel Cell On-Site Integrated Energy Systems, Task II Report", presented to Engelhard on March 9, 1983.

Task II results are included in this Final Report.

TASK III - IMPROVED SYSTEM DESIGN

Objective: Using the results of Tasks I and II, to design the best HVAC subsystem and to determine its performance and installed cost.

Report: Task III results are included in this Final Report.

II. METHODS AND BASIS OF ANALYSIS

A. Systems Analyzed

A schematic diagram of a fuel cell/HVAC system is illustrated in Fig. 2. The fuel cell system provides electricity to the HVAC system and for domestic needs. Excess electricity is sold to the utility. Electricity is purchased from the utility if needed to augment the fuel cell system output. The fuel cell system also provides thermal energy for domestic hot water heating, space heating and absorption cooling. Thermal energy is provided by a conventional boiler if needed to augment the fuel cell system output. Three primary system variables were investigated: the type of chillers, either electric or absorption; the capacity of the fuel cell; and the capacity of the hot and/or cold thermal storage units.

Although Fig. 2 shows a combination of an electric chiller and absorption chiller, systems with only electric or only absorption chillers were analyzed. Both two-stage and single stage absorption chllers were considered. The thermal storage capacity was varied from zero up to the capacity at which no further benefit was realized. In most systems, the fuel cell system operates continuously at rated capacity. No allowance was made for down-time, either scheduled or unscheduled. All of the results in this report are for natural gas as the fuel for the fuel cell system.

B. Basis and Assumptions

Building descriptions. Four building types were analyzed: a hospital, an apartment building, a retail store and an office building. These are hypothetical buildings with characteristics

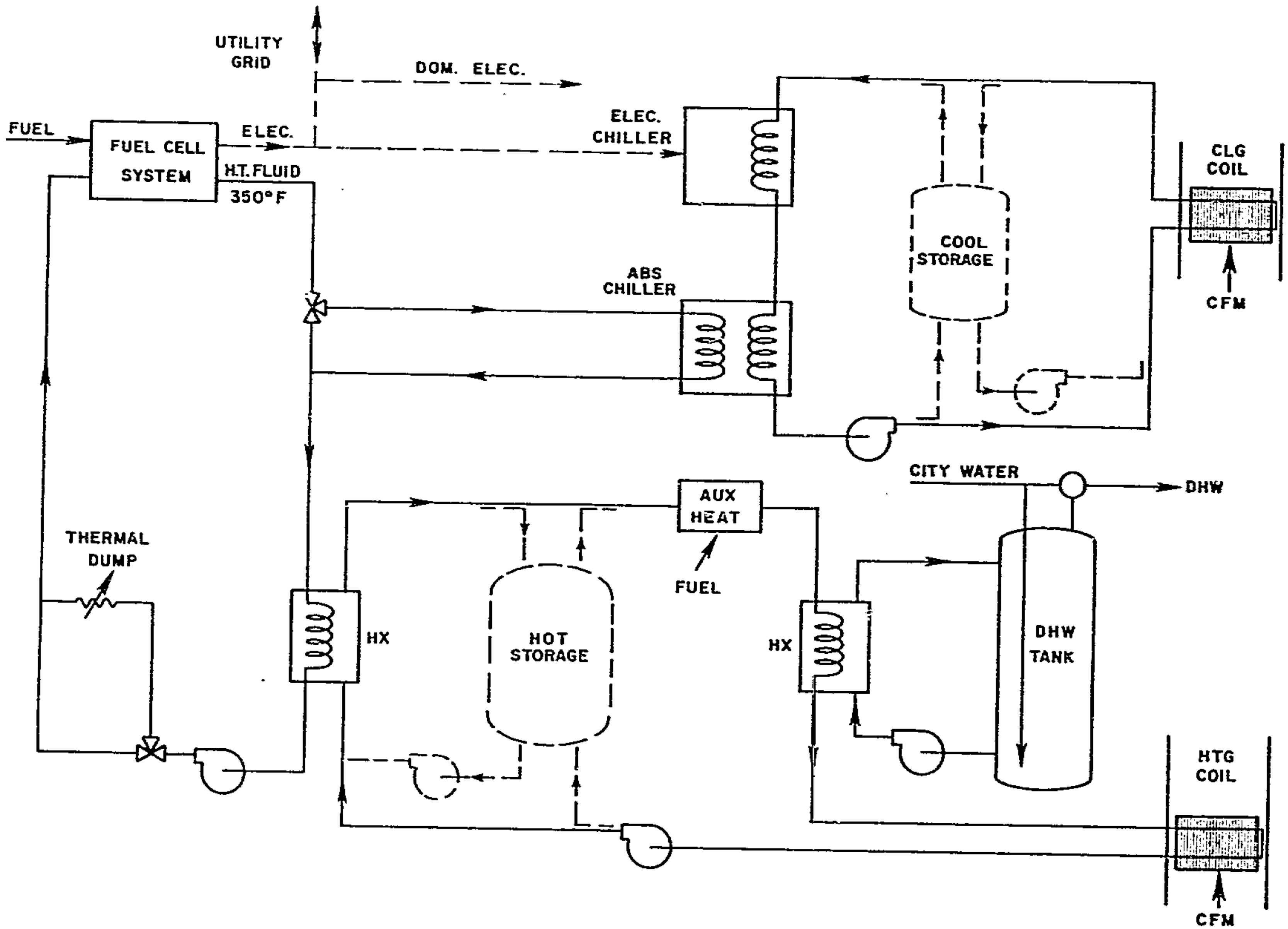


FIG. 2 SYSTEM SCHEMATIC ELECTRIC & ABSORPTION CHILLERS

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consistent with current building practice. The annual energy consumption of these buildings with conventional equipment (no fuel cell) is given in Table A for the Washington, D.C. climate. Note that the ratio of the electric to thermal loads varies considerably for the four buildings.

Table A
Building Descriptions

Building	Floor Area (m^2)	Annual Energy Usage Electric (10^6 KWH)	Annual Energy Usage Nat. Gas (10^6 KWH)
Hospital	18,300	4.93	5.80
Apartment	7,580	1.07	1.98
Office	6,210	1.40	0.11
Retail Store	10,420	1.79	0.52

Economic Parameters. The estimated costs and the economic parameters used in the analysis are given in Table B. The estimated costs are for 1985 installation. 1985 costs were obtained by inflating 1982 costs by 7% per year.

Table B
Economic Parameters

Installed Costs (1985)	
Fuel Cell System	\$980/KW fuel cell capacity
Piping, controls	\$110/KW fuel cell capacity
Boiler	\$33/KW boiler input
Storage-hot water	\$9.60/KWH
Storage-ice water	\$20.90/KWH

Table B (Cont'd)

Annual Costs

Property tax rate	1.0%
Insurance	0.5%
Maintenance	1.0%
Annual costs inflated at	7.0%
Platinum charge	$27/KW

Economic Variables

Income tax rate	48%
Investment tax credit	20%
Fuel cell weighted avg. life	10 years
Salvage value	12.5%
Discount rate	15%

Energy prices. Current electricity prices were based on the cogeneration rate schedules furnished by Engelhard and Arthur D. Little. These schedules are shown in the Appendix. Future electric prices were determined by applying the Trane electric price projections to these schedules.

Current and future natural gas prices were based on Trane Company projections. Table C summarizes the energy prices used in the TRACE analysis. The escalation rates include the effect of general inflation.

Table C
Energy Prices

	1985 Price	Escalation Rate 1985-1990	Escalation Rate Beyond 1990
Electricity	(See Appendix)	10%	7%
Nat. Gas	$\$8.20/10^6$ BTU	12%	9%

Fuel Cell System Efficiency. For all system simulations, the fuel cell system efficiency was assumed constant at the following values:

Electric	40%
Useful thermal	40%

C. Economic Criteria

Three economic criteria were used as a measure of the economic feasibility of fuel cell systems: the simple pay-back period (SPB), the after-tax internal rate of return (IRR), and the net present value of the incremental cash flows (NPV).

The SPB is based on the incremental first cost and the first year utility cost savings. No future costs or savings are considered. The SPB is defined as

$$SPB = C_o/(E_c - E_f)$$

where

C_o = the incremental first cost

E_c = the first year utility cost of the conventional system

E_f = the first year utility cost of the fuel cell system

The IRR is determined iteratively. The IRR is equal to x when the following equality holds.

$$\sum_{i=1}^{20} CF_i/(1+x)^i = C_0$$

where

$(1+x)^i$ = the discount factor

CF_i = the incremental cash flow for the i^{th} year

Included in CF_i are energy costs, taxes, insurance, maintenance, platinum charge, replacement costs, salvage value, depreciation effects and tax credits. A 20 year period of economic analysis has been assumed.

The NPV is based on a discount rate of 15%. The NPV is defined as

$$NPV = \sum_{i=1}^{20} CF_i/(1.15)^i - C_0$$

D. The TRACE Program

TRACE is an energy and economic analysis program that has been developed by The Trane Company. It is used extensively to compare various HVAC equipment and system alternatives in buildings. TRACE can be used to compute building loads, equipment loads, system capacities, energy usage, utility costs and various economic parameters.

Computer code was written to allow TRACE to analyze fuel cell cogeneration systems. The fuel cell system is treated as a "black box" with specified electric and thermal efficiencies. The fuel cell system's electric and thermal outputs are interfaced with the building's HVAC equipment.

TRACE computes building and equipment loads for four day types each month. The four day types are Sunday, Monday, a weekday and Saturday. The four day model is needed for buildings in which the occupancy is a function of the type of day, such as retail stores and office buildings. Monday is distinguished from other weekdays because of the unique start-up loads after a weekend shutdown or set-back. The four-day model also allows off-peak electric rates to be used throughout the weekend, typical of many electric rate structures.

TRACE adjusts the COP of the cooling equipment to reflect part load operation and changing ambient conditions. Also, the energy consumption is computed for all of the accessories for each piece of HVAC equipment. For example, if an electric chiller is specified, TRACE computes the energy consumption of the chilled water pumps, condenser water pumps, cooling tower fan, the controls and the chiller oil pump. The energy consumption of these items can be a significant fraction of the total energy usage.

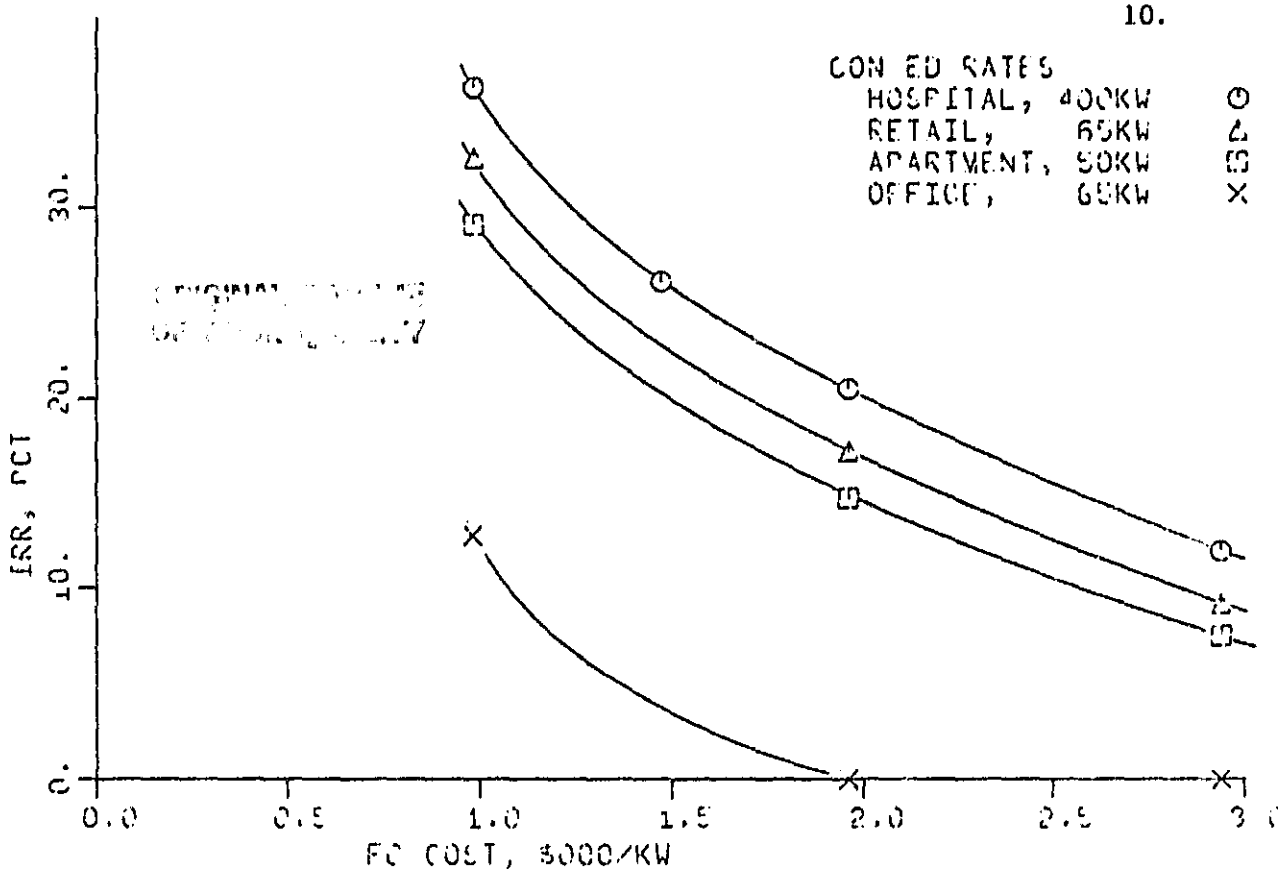
III. RESULTS AND DISCUSSION

A. Effect of Fuel Cell System Cost

One of the most critical parameters was found to be the installed cost of the fuel cell system. The Engelhard estimate is an installed cost of $800/KW in 1982, which was inflated to $980/KW for 1985 installation. The effect of fuel cell system cost was determined by simulating identical systems but with arbitrary increases in fuel cell system cost. The results are shown in Fig. 3 and in Table D. Results are shown for the four buildings and for two electric rate structures. Consolidated Edison has the highest electric prices used in this study, while Commonwealth Edison has the lowest. Incremental costs of the interface piping, heat exchangers, thermal storage and controls were also taken into account.

The results of Fig. 3 and Table D show that the NPV and IRR both decrease substantially as the fuel cell system cost increases. It is also seen that the electric rate structure has a strong effect on the economics of fuel cell systems. This subject is treated in more detail in a subsequent section of this report.

The results of Fig. 3 can be used to determine a "break-even" fuel cell system cost. The break-even cost is defined as the fuel cell system cost that yields a 15% IRR, or a NPV of zero. An IRR of 15% represents an approximate break-even cost to the building owner relative to alternative investments or to the cost of capital. Of course, the building owner will need an IRR greater than 15% in order to justify the purchase of a fuel cell system.



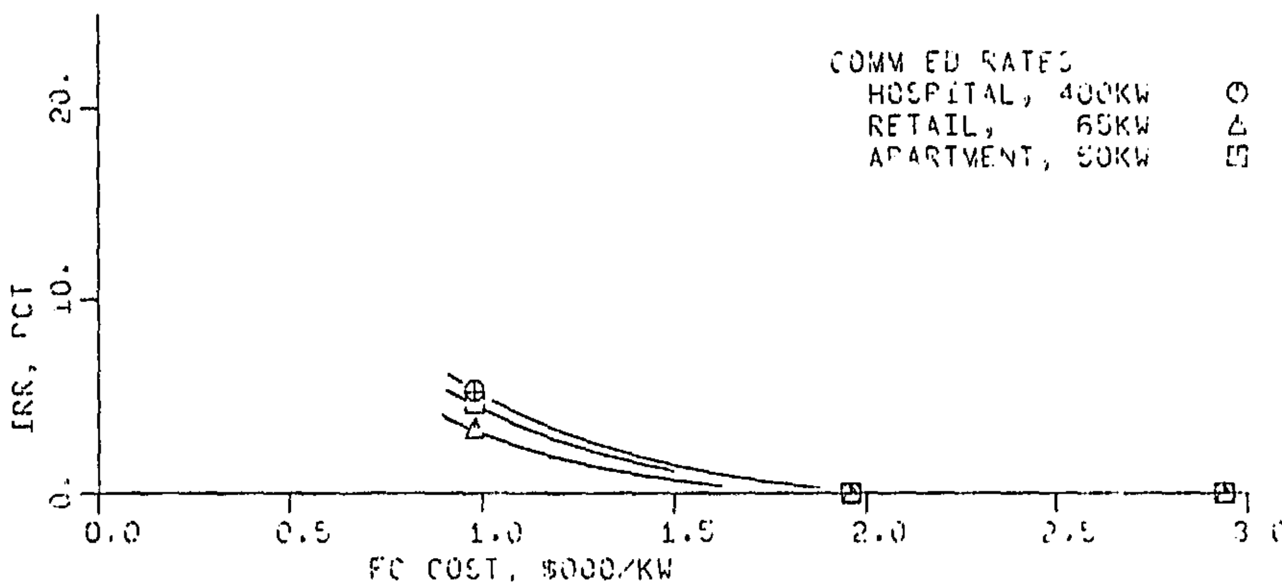


FIG. 3. EFFECT OF FUEL CELL COST
WASHINGTON, D.C. WEATHER
FC/CTV/H SYSTEM
BASE SIZE FUEL CELL

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TABLE D
EFFECT OF FUEL CELL COST
1985 INSTALLATION

RUN	SYSTEM	FUEL CELL COST ($/KW)	INCR. INST'D. COST ($)	1985 UTIL. COST ($)	SPB (YRS)	NPV ($)	IRR (PCT)
HOSPITAL (400 KW)							
CON. ED. RATES							
7	CTV	-	-	741,500	-	-	-
7	FC/CTV/H	980	454,330	532,400	2.2	559,500	36.4
7	FC/CTV/H	1470	650,300	532,400	3.1	380,200	26.2
7	FC/CTV/H	1960	846,300	532,400	4.0	220,400	20.6
40	FC/CTV/H	2940	1,238,300	532,400		-157,400	12.0
COM. ED. RATES							
10	CTV	-	-	528,700	-	-	-
10	FC/CTV/H	980	454,300	444,700	5.4	-130,000	5.3
41	FC/CTV/H	1960	846,300	444,700		-488,600	0.0
41	FC/CTV/H	2940	1,238,300	444,700		-847,000	0.0
APARTMENT (50 KW)							
CON. ED. RATES							
20	CTV	-	-	192,800	-	-	-
20	FC/CTV/H	980	58,450	171,500	2.7	44,700	29.2
42	FC/CTV/H	1960	107,500	171,500	5.0	-735	14.8
42	FC/CTV/H	2940	156,500	171,500	7.3	-45,140	7.5
COM. ED. RATES							
43	CTV	-	-	149,300	-	-	-
43	FC/CTV/H	980	58,450	138,700	5.5	-14,200	4.7
43	FC/CTV/H	1960	107,500	138,700	10.1	-59,700	0.0
RETAIL STORE (65 KW)							
CON. ED. RATES							
28	CTV	-	-	253,600	-	-	-
28	FC/CTV/H	980	76,500	222,300	2.4	73,900	32.7
44	FC/CTV/H	1960	140,200	222,300	4.5	14,300	17.3
44	FC/CTV/H	2940	203,800	222,300	6.5	-47,200	9.2
COM. ED. RATES							
45	CTV	-	-	172,200	-	-	-
45	FC/CTV/H	980	76,500	158,500	5.6	-23,400	3.4
45	FC/CTV/H	1960	140,200	158,500	10.3	-83,100	0.0
45	FC/CTV/H	2940	203,800	158,500	14.9	-144,600	0.0
OFFICE BUILDING (85 KW)							
CON. ED. RATES							
24	CTV	-	-	193,200	-	-	-
24	FC/CTV/H	980	95,500	168,900	3.9	-6,263	12.8
46	FC/CTV/H	1960	178,800	168,900	7.3	-85,300	0.0
46	FC/CTV/H	2940	262,100	168,900	10.8	-159,100	0.0

Table E shows the estimated break-even fuel cell system costs. Again, the strong effect of electric rate structure is apparent. Comparison of the breakeven costs to the Engelhard estimate of $980/KW leads to the conclusion that fuel cell systems will be too expensive in regions with low electric rates. However, fuel cell systems can be economically attractive in regions with high electric rates. In order for fuel cell systems to be attractive throughout the U.S., the fuel cell system installed cost would have to be less than $600/KW.

Table E
Break-Even Installed Fuel Cell System Cost
($/KW) in 1985 (15% IRR)

Building	Comm. Ed.	Con. Ed.
Hospital	630	2550
Apartment	680	1810
Retail Store	600	1780
Office		910

B. Effect of Chiller Type

Three alternatives were investigated: electric chillers, absorption chillers, and a combination of electric and absorption chillers. The results for the hospital are shown in Fig. 4. Also shown on Fig. 4 are the effects of fuel cell capacity and thermal storage, which are discussed in the next two sections of this report.

Fig. 4 shows that the systems that contain both electric and two-stage absorption chillers yield the highest NPV. The NPV is only

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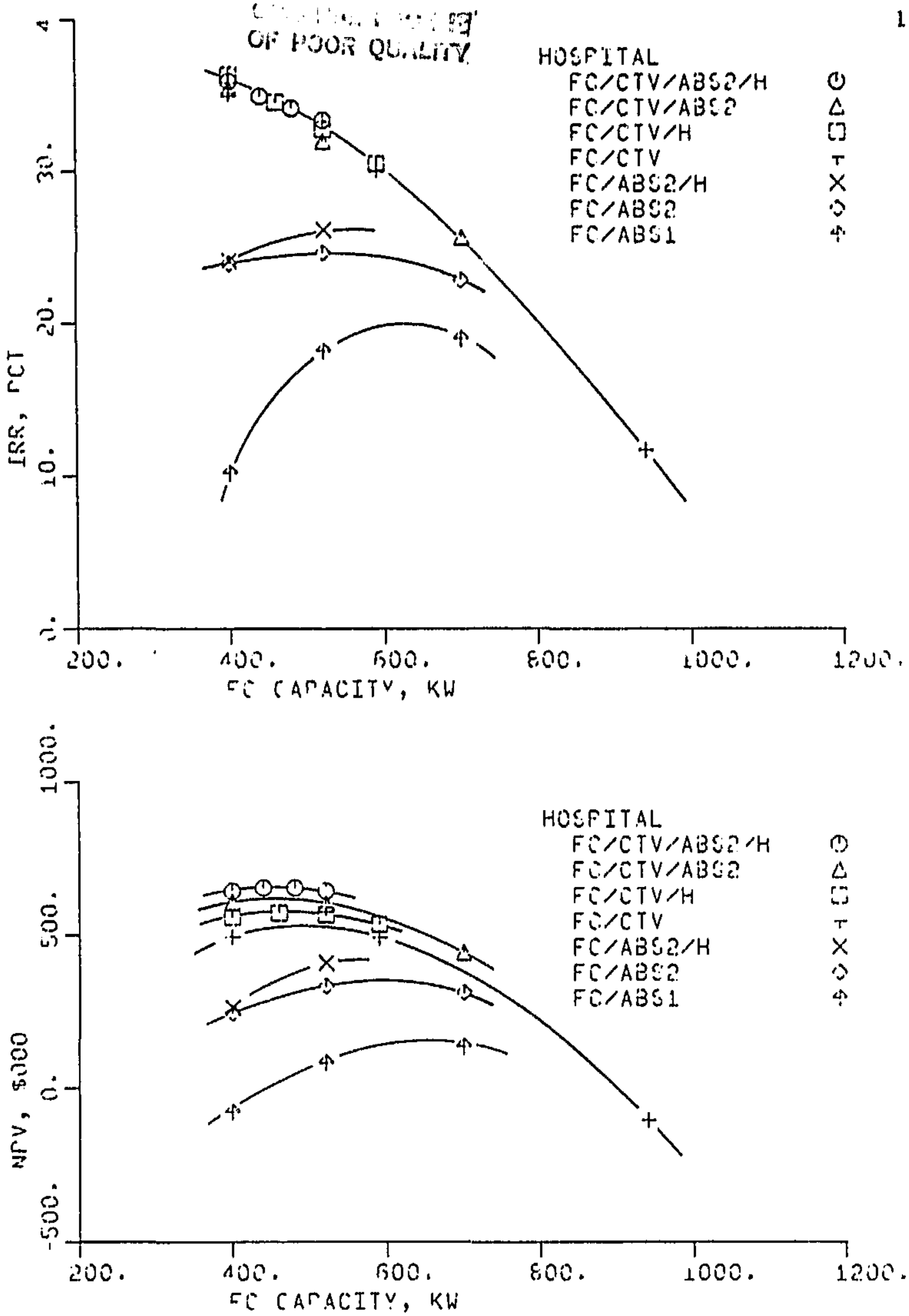

FIG. 4, EFFECT OF FUEL CELL CAPACITY,
CHILLER TYPE AND THERMAL STORAGE.
HOSPITAL, WASHINGTON, D.C. WEATHER
CON ED RATES, $960/KW FUEL CELL

slightly lower for the systems containing only electric chillers. But systems containing only absorption chillers are clearly less economic than the other systems.

There are two reasons why "absorption only" systems are less economic. The first is that absorption chillers are more expensive than electric chillers. The second reason is that absorption chillers are much less efficient than electric chillers. The consequence of the low efficiency can be seen by first considering a small capacity fuel cell. Since the absorption unit increases the thermal load beyond the fuel cell thermal capacity, the gas-fired boiler must supply heat to the absorption unit for a considerable number of cooling hours. The low efficiency causes large quantities of gas to be consumed, which increases the utility costs. To minimize the usage of the auxiliary boiler, the fuel cell capacity can be increased. This improves the economics slightly, as shown on Fig. 4. However, the large fuel cell capacity, coupled with the lower electric load with absorption cooling, causes more electricity to be sold back to the utility at unfavorable rates. The additional first cost of the fuel cell cannot be justified on the basis of sell-back electricity. All of these factors taken together result in "absorption only" systems being less economic than the other systems.

Figures 5-7 are similar to Fig. 4, but show results for the other three buildings. The combination absorption and electric chiller is not shown for these three buildings because performance and cost data

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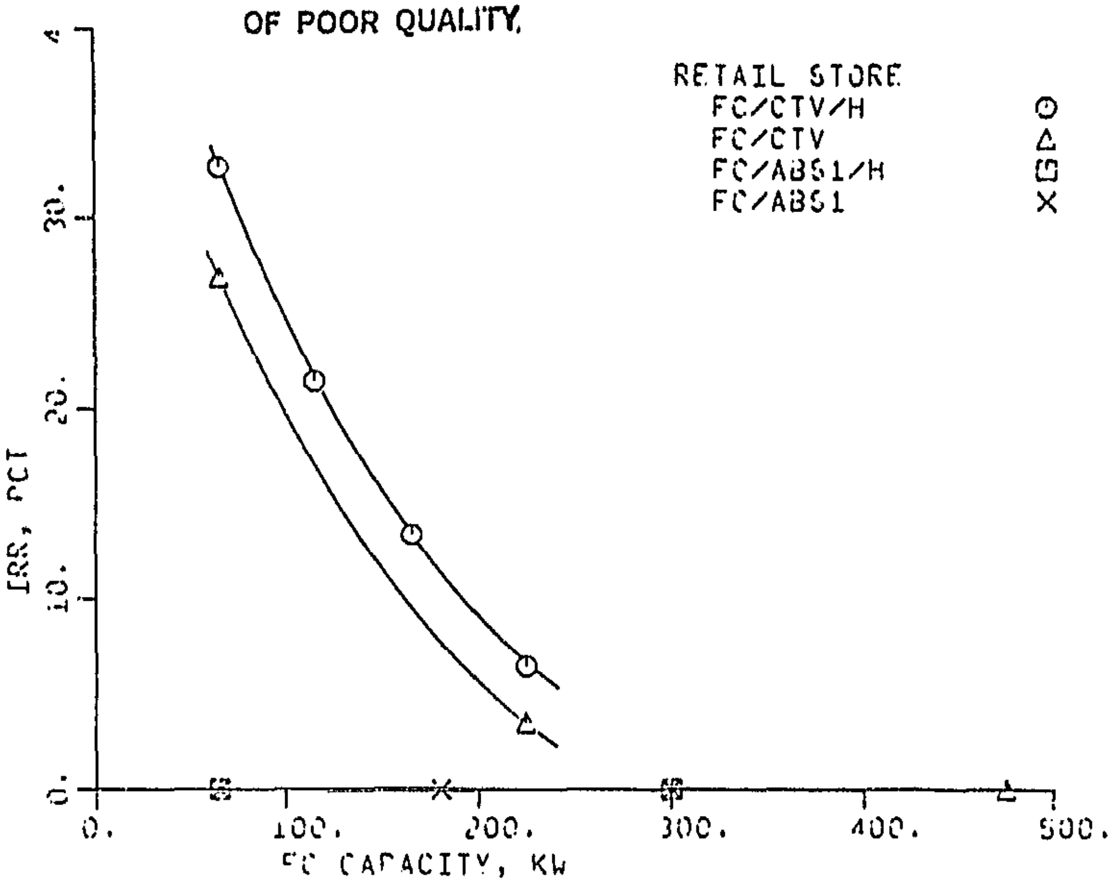

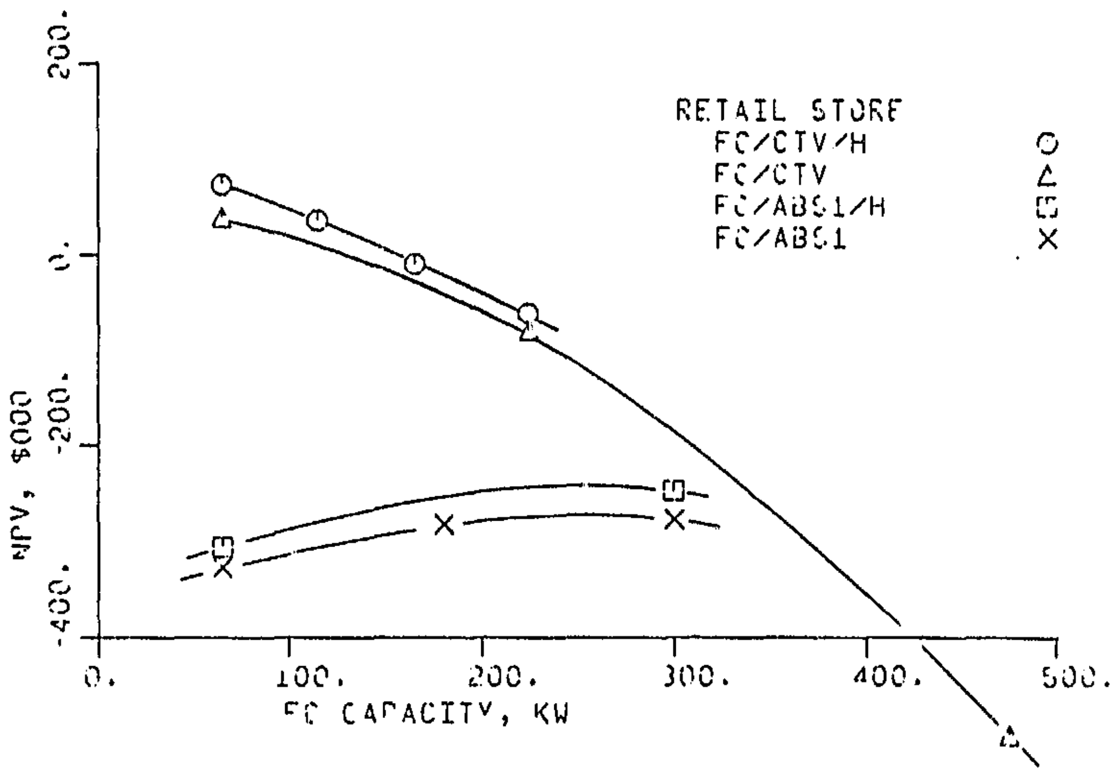

FIG. 5, EFFECT OF FUEL CELL CAPACITY,
CHILLER TYPE AND THERMAL STORAGE.
RETAIL STORE, WASHINGTON, D.C. WEATHER.
CON ED RATES, $960/KW.

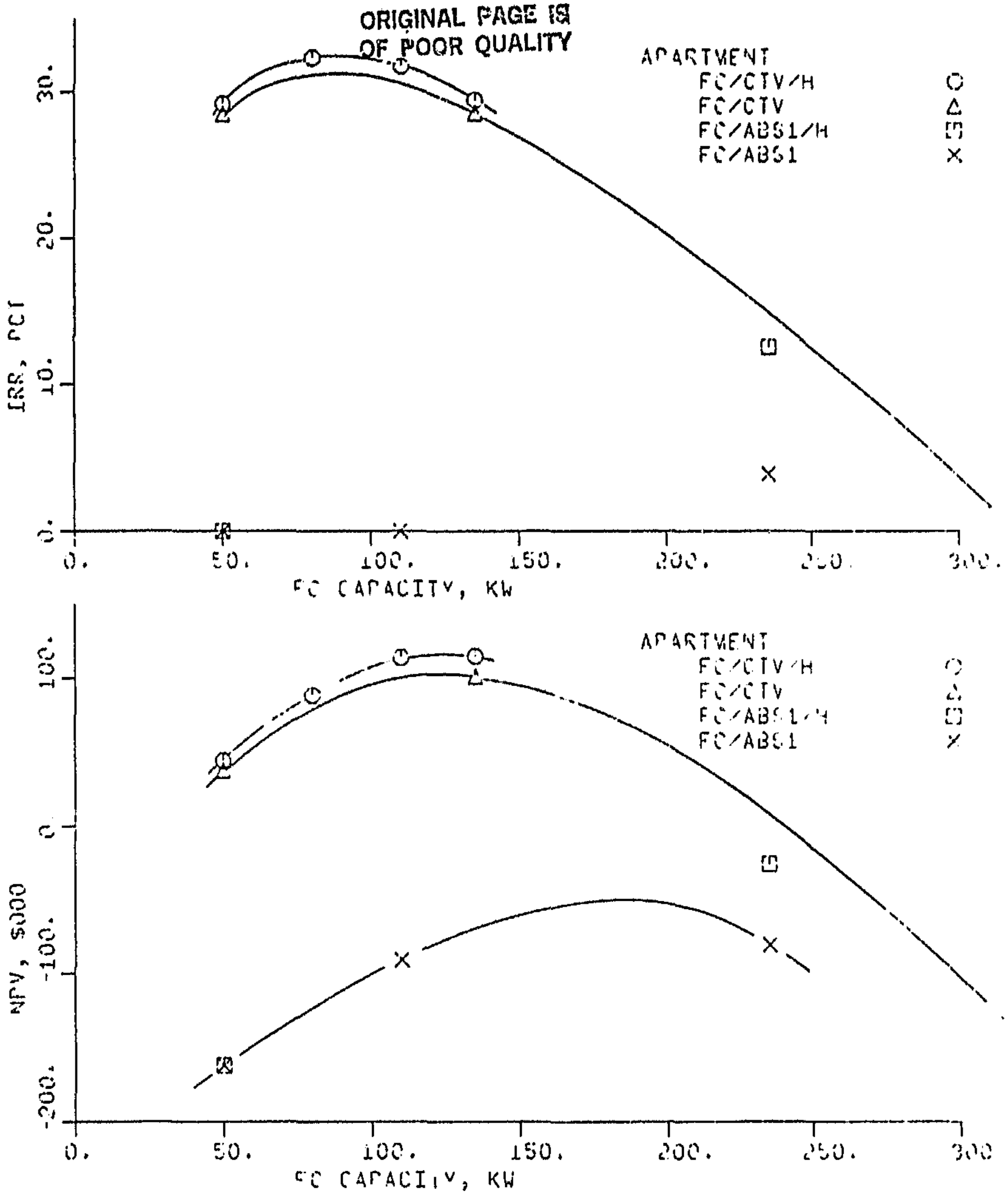

FIG. 6, EFFECT OF FUEL CELL CAPACITY,
CHILLER TYPE AND THERMAL STORAGE.
APARTMENT, WASHINGTON, D.C. WEATHER.
CON ED RATES, $060/KW

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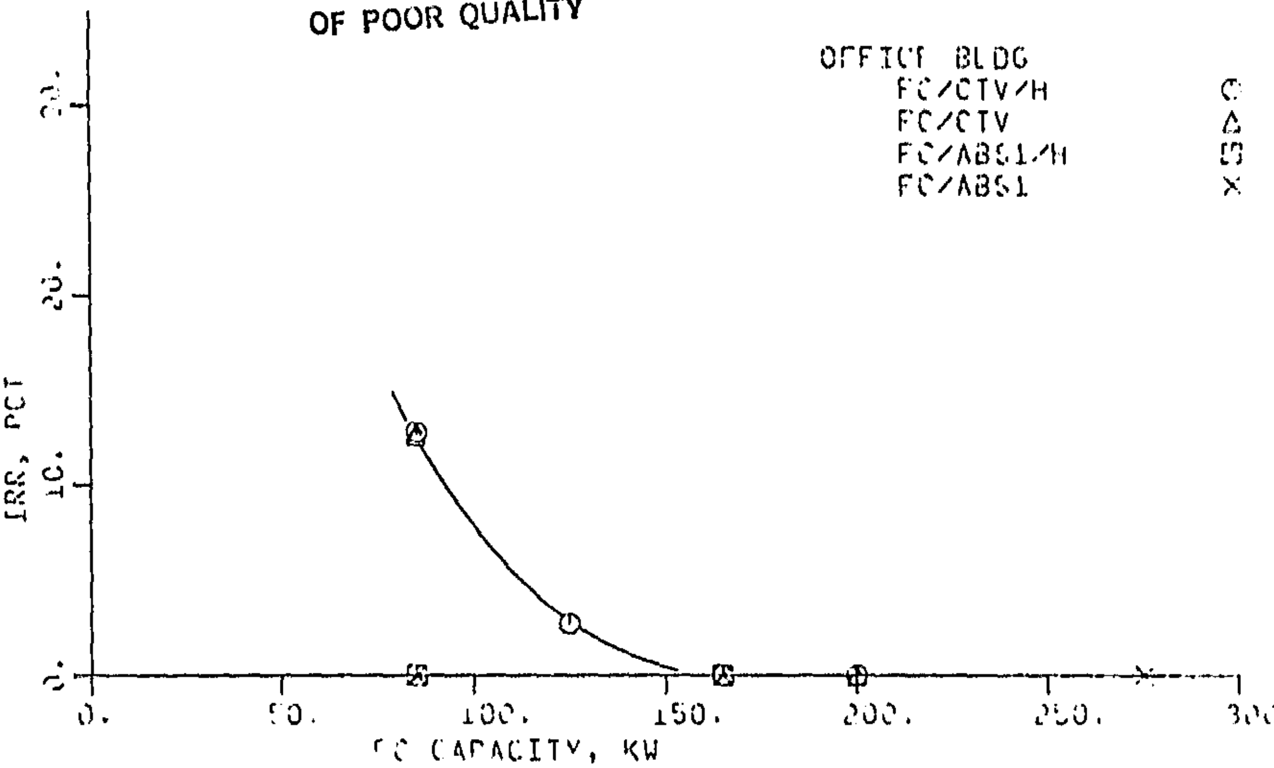


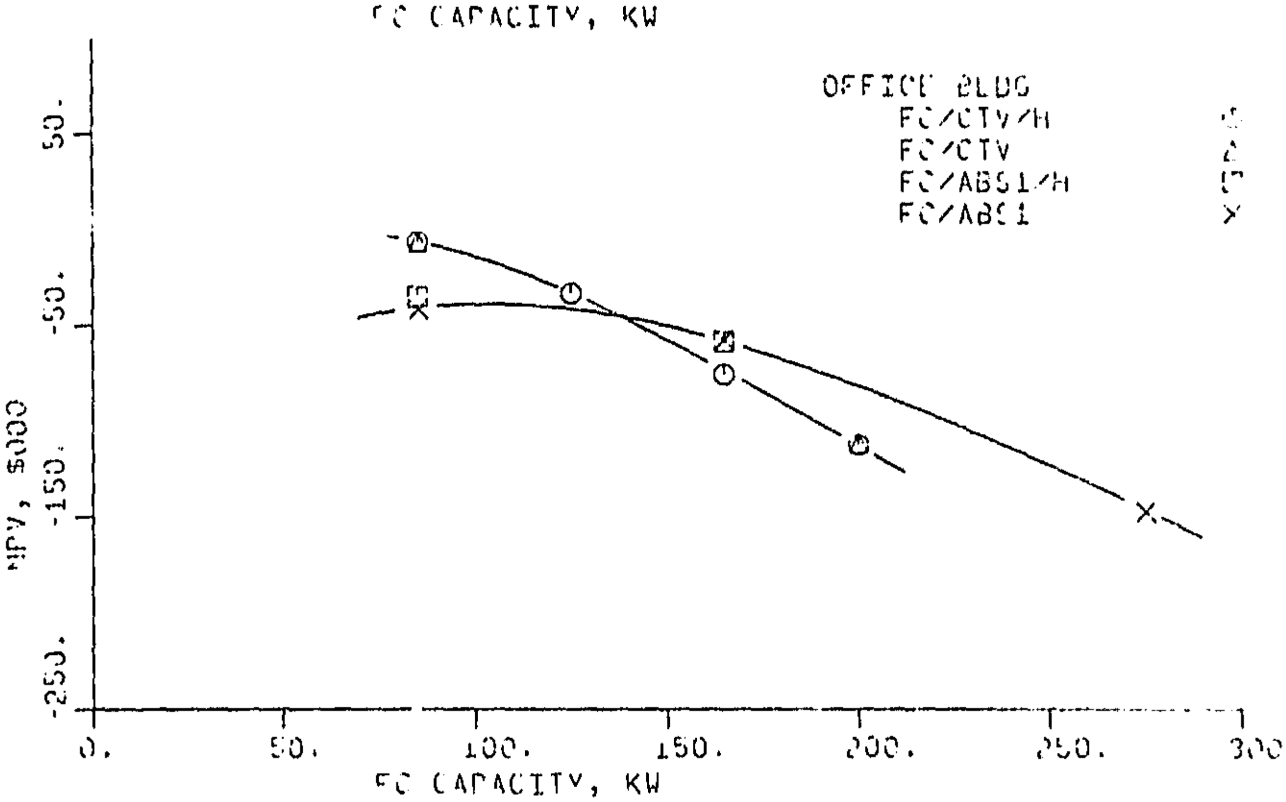


FIG. 7. EFFECT OF FUEL CELL CAPACITY, CHILLER TYPE AND THERMAL STORAGE. OFFICE, WASHINGTON D.C. WEATHER. CON ED RATES, $900/KW

were not available for low capacity absorption units. Figures 5-7 show again that systems containing only absorption units are less economic than systems containing electric chillers. The other features of Figs. 5-7 are discussed in the next two sections.

C. Effect of Hot-Side Thermal Storage

Figures 4-7 show the effect of thermal storage on the economics of fuel cell systems in the four buildings. Systems with thermal storage are identified by the letter "H". Thermal storage by hot water at a temperature below 212°F was considered. Storage at a temperature high enough for two-stage absorption (350-400°F) was judged to be uneconomic. Hot water at 160-210°F is adequate for space and domestic hot water heating.

Thermal storage was found to improve the economics of fuel cell systems in all four buildings. The largest effect was found for the retail store where most of the thermal load is for daytime domestic hot water. The smallest effect was for the office building where thermal loads are relatively small.

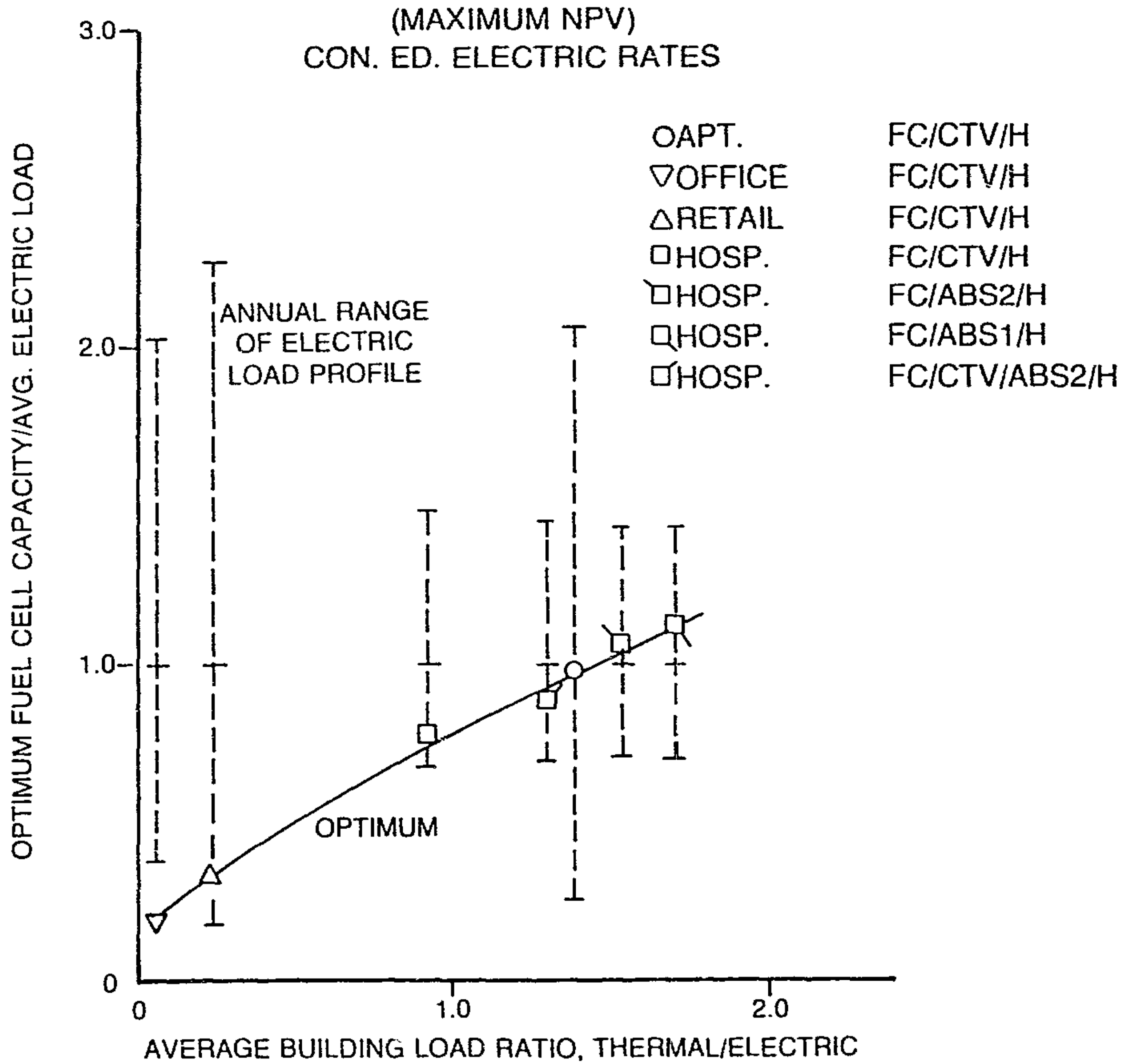
D. Effect of Fuel Cell System Capacity

Referring again to Figs. 4-7, it is seen that the optimum fuel cell system capacity depends on the type of HVAC system as well as the building type. Systems that include only absorption chillers optimize at larger fuel cell system capacities than systems with electric chillers. Buildings with higher thermal loads relative to electric loads optimize at relatively larger fuel cell system capacities.

An attempt was made to generalize the optimum fuel cell system capacity data from Figs. 4-7. It was found that the most significant factor affecting the optimum fuel cell capacity was the building load ratio -- the ratio of the average thermal load to the average electric load. Fig. 8 shows the optimum fuel cell capacity plotted vs. the building load ratio. Optimum fuel cell capacity is defined as the fuel cell capacity that maximizes the NPV. Fig. 8 includes data for four system types in the hospital from Fig. 4, and data for one system type in four different buildings from Figs. 4-7. All of the data can be fairly well represented by a single curve.

At high building load ratios, larger fuel cell systems can be installed because the fuel cell thermal output can be effectively utilized. Systems with absorption chillers increase the building load ratio, so that the optimum fuel cell system capacity is larger than for systems with electric chillers. For a given system type, buildings with large load ratios optimize at larger fuel cell system capacities (relative to the average electric load) than buildings with smaller load ratios. The significance of Fig. 8 is that one can predict the optimum fuel cell system capacity of any building if the building load ratio can be predicted. However, Fig. 8 only applies to regions with electric rates comparable to those of Consolidated Edison. Lower electric rates will cause the curve to shift downward.

FIG. 8
OPTIMUM FUEL CELL CAPACITY



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E. <u>Effect of Building Type</u>

Table F is a comparison of the four building types. The comparison is based on the same system, electric rate structure and weather for each building.

The second column shows that the building load ratio varies considerably for the four buildings. The tabulated values of IRR and NPV correspond to the optimum fuel cell system capacity for each building.

Table F
Effect of Building Type

FC/CTV/H System
Wash, D.C.; Con. Ed. Rates
$980/KW Fuel Cell Installed Cost

Building	Load Ratio (therm./elec.)	Max IRR (pct)	Max NPV ($)	Ratio NPV to Avg. Elec. Load ($/KW)
Hospital	.92	36.2	578,000	1000
Apartment	1.38	32.5	118,000	900
Retail	.23	32.7	81,000	390
Office	.06	12.8	10,000	60

Based on IRR, the hospital ranks highest, with the apartment building and retail store close behind. The office building is clearly the worst application of the four buildings.

A direct comparison of the NPV of the four buildings is not meaningful because the buildings vary considerably in size. In order to make a meaningful comparison, the NPV numbers were normalized by dividing by the optimum fuel cell capacities for each building.

The NPV ratio in the last column shows more variation between buildings than the IRR. Although the retail store yields a value of IRR nearly as high as the hospital, the NPV ratio is considerably lower. The reason is that the optimum fuel cell system capacity for the store is much smaller, relative to the average electric load, than it is for the hospital. The fuel cell system then has a much smaller impact on the building owner's owning and operating expense.

The NPV ratios can be interpreted as a measure of the impact on the building owner's owning and operating cost. For both maximum impact and maximum IRR, it is concluded that the building load ratio should be near unity.

The above information, along with the optimum fuel cell system capacity data given previously, could be used as input to a market study. Knowledge of the number of buildings and the building loads would allow a market study to be made. However, a market study is beyond the scope of this project.

F. Effect of Location

Table G compares the same fuel cell system in the same building in six different locations. The second and third columns show the results using the actual electric rate structure and weather for each city. These results show a strong effect of location.

The fourth and fifth columns show the results when the same weather data is used for all cities. Only the electric rate structure changes. This data shows that the primary factor is the electric rate structure rather than the weather.

Some effect due to weather can be seen by comparing the results in the second and third columns to those in the fourth and fifth columns. The northern cities (New York, Boston, Newark, Chicago) show less favorable economics when Washington, D.C. weather is used due to the lower thermal loads. The southern cities (Atlanta, Los Angeles) show more favorable economics with Washington D.C. weather. However, these effects are small when compared to the effects due to electric rate structure. It is concluded that the effect of location on fuel cell system econmics is primarily due to the electric rate structure.

G. Effect of Taxes

Hospital income can be either taxable or non-taxable. Table H shows that the effect of taxes is to lower the IRR. The primary reason is that utility costs are tax deductible expenses for the privately

Table G
Effect of Location

Elec. Rate Structure	Actual City Weather		Washington D.C. Weather	
	NPV ($000)	IRR (%)	NPV ($000)	IRR (%)
CON. ED. (NYC)	609	37.6	560	36.4
GEO. PWR (ATL)	521	35.3	612	37.8
BOS. ED. (BOS)	516	34.8	431	32.3
N.J.P.S. (NEWK)	330	28.8	278	27.1
COM. ED. (CHIC)	-32	13.1	-130	5.3
S. CAL. ED. (L.A.)	-120	4.9	109	20.4

Hospital, 400 KW Fuel Cell System

$980/KW installed cost in 1985

owned hospital. The utility cost savings achieved by the fuel cell system are, in effect, reduced by the tax rate. For typical tax rates, the savings are reduced by nearly one-half.

Some tax effects favor the fuel cell system: a 20% investment tax credit depreciation; and tax deductible expenses such as insurance, maintenance and mortgage interest. However, tax deductible utility costs remain the dominant factor. The net effect is a reduction in IRR due to tax effects.

All economic comparisons in this report, other than Table H, assume that the building owner's income is taxable. In this way, all comparisons are made on an equal basis.

Table H
Effect of Taxes

Building	Ownership	Tax Rate	NPV	IRR
Hospital	Tax-exempt	0	$1,076,000	47.7%
Hospital	Private	48%	$ 495,900	35.2%

Washington, D.C., weather, Con. Ed. electric rates.

400 KW Fuel Cell, $980/KW in 1985.

H. Effect of Fuel Cell System Operating Mode

In all of the cases discussed in prior sections of this report, the fuel cell system operates continuously at rated capacity. When the fuel cell electric output exceeds the electric load, electricity is sold back to the utility. Since sell-back rates are considerably lower than purchase rates, the effect of allowing the fuel cell to track the electric load was investigated. No savings due to electric sell-back would be realized, but less natural gas would be needed to operate the fuel cell.

The effect of a load-tracking fuel cell was determined for the hospital and the apartment building. It was assumed that the fuel cell ratio of electric to thermal output remained constant as the fuel cell electric output varied, and that the fuel cell efficiency remained constant. The results are shown in Table I. The economics of the load tracking fuel cell are compared to those for the fuel cell operating continuously at rated capacity. For both buildings, the load tracking fuel cell caused a decrease in the IRR. The reason is that the load tracking fuel cell satisfies a smaller fraction of the thermal load. More natural gas is required for auxiliary space heating and domestic hot water. The additional gas cost and the loss of the sell-back electricity exceeded the gas cost savings from reducing the fuel cell output.

It is seen from Table I that the load tracking fuel cell causes a greater reduction in IRR for the apartment building than for the

Table I
Effect of Electric Load Tracking Fuel Cell System

Building	Mode	F.C. Rated Capacity (KW)	IRR (%)	NPV ($000)
Hospital	Continuous at rated	440	35.0	655
	Continuous at rated	520	33.4	645
	Load tracking	520	31.6	552
Apartment	Continuous at rated	110	31.8	114
	Continuous at rated	135	29.5	114
	Load tracking	135	18.7	16

FC/CTV/ABS2/H System

Washington, D.C. Weather; Con. Ed. rates

$980/KW Fuel Cell installed in 1985

hospital. The reason is that the apartment building has a higher thermal-to-electric load ratio than the hospital, (1.38 vs. 0.92). Therefore, the reduced thermal output, as the fuel cell tracks the electric load, has a larger detrimental effect on the apartment building.

I. Fuel Cell Heat Output Temperature

All of the previous analyses assumed that all of the fuel cell thermal output was at a high temperature - approximately 350F. Subsequent information from Engelhard indicated that 89% of the thermal output would be at 350F and the remainder at about 200F. An analysis was then made of the effect of temperature level on the economics of fuel cell/HVAC systems.

The high temperature thermal output is only needed for input to absorption chillers. The space heating and DHW loads can be satisfied by 200°F thermal energy. The effect of temperature level could then be analyzed by varying the installed capacity of the absorption chillers.

The results of the analysis are shown on Table J. The four entries correspond to varying percentages of heat at 350F:

a) The most optimistic;

b) the current best estimate;

c) the worst case, and

d) a previous run without absorption chillers

It was found that the percentage of thermal energy at 350F had a relatively small effect on the economics. As the percentage is decreased, less cooling is provided by absorption. However, a larger fraction of the space heating and DHW loads are then satisfied by the fuel cell. In fact, if all of the thermal energy from the fuel cell system were at 200F, the economics are still favorable as shown by the last entry in Table J. This entry corresponds to a fuel cell system with only electric chillers. The economics of this system are nearly as favorable as the system with a combination of absorption and electric chillers, as was shown in an earlier section of this report.

It is concluded that the economics of a fuel cell system with 89% of its thermal output at 350F will be negligibly different from the fuel cell with 100% at 350F.

Table J
Effect of Fuel Cell Thermal Output Temperature

Fuel Cell Capacity (KW)	Thermal Output @ 350F (%)	@ 200F (%)	CTV Capac. (10^6 Btuh)	ABS2 Capac. (10^6 Btuh)	NPV ($000)	IRR (%)
460	96	4	4.6	1.5	655	35.0
460	89	11	4.7	1.4	649	34.9
460	48	52	5.4	0.7	615	34.7
440	0	100	6.1	0	573	34.6

J. Effect of Cold Side Thermal Storage

The use of cold side thermal storage reduces the electric demand charges during peak periods. However, cold storage can also be applied in a conventional system as well as in a fuel cell/HVAC system. Since the optimum fuel cell capacity is generally less than the average electric load, the application of cold storage provides about the same benefit to the conventional system as to the fuel cell system. The following results therefore apply to both systems.

The economics of cold storage were analyzed for the four buildings. The analysis is given in the Appendix. Costs of cold storage were determined by Affiliated Engineers. The analysis given in the Appendix was modified, taking into account the cost estimate by Affiliated Engineers, to yield the results shown in Figure 9 and Table K.

Figure 9 shows two cost curves. One is for the cost of cold storage. The other includes a cost savings due to a reduced chiller size. With cold storage, a smaller chiller can be installed that operates for more hours to produce the same total amount of cooling. Fig. 9 shows that the optimum storage capacity for the hospital is about 4200 KWH (1200 tons-hrs), with a simple payback period of 4.3 years. A similar analysis for the other three buildings is shown on Table K.

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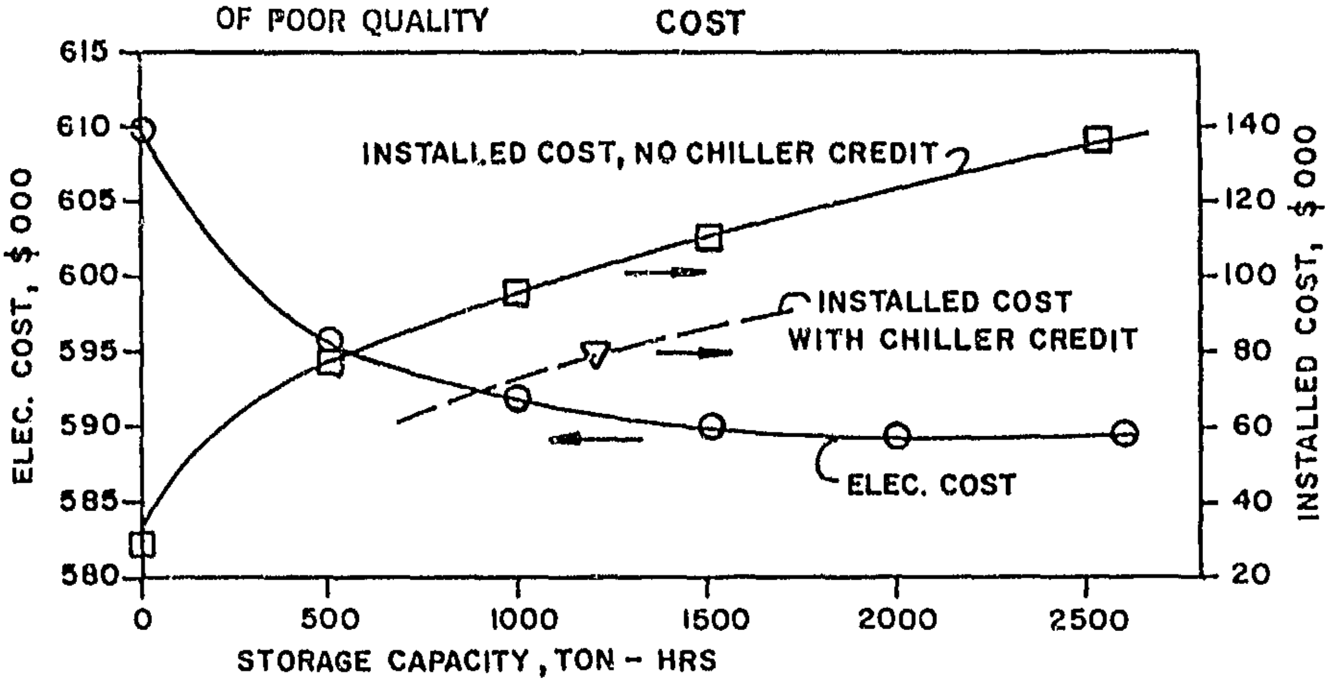


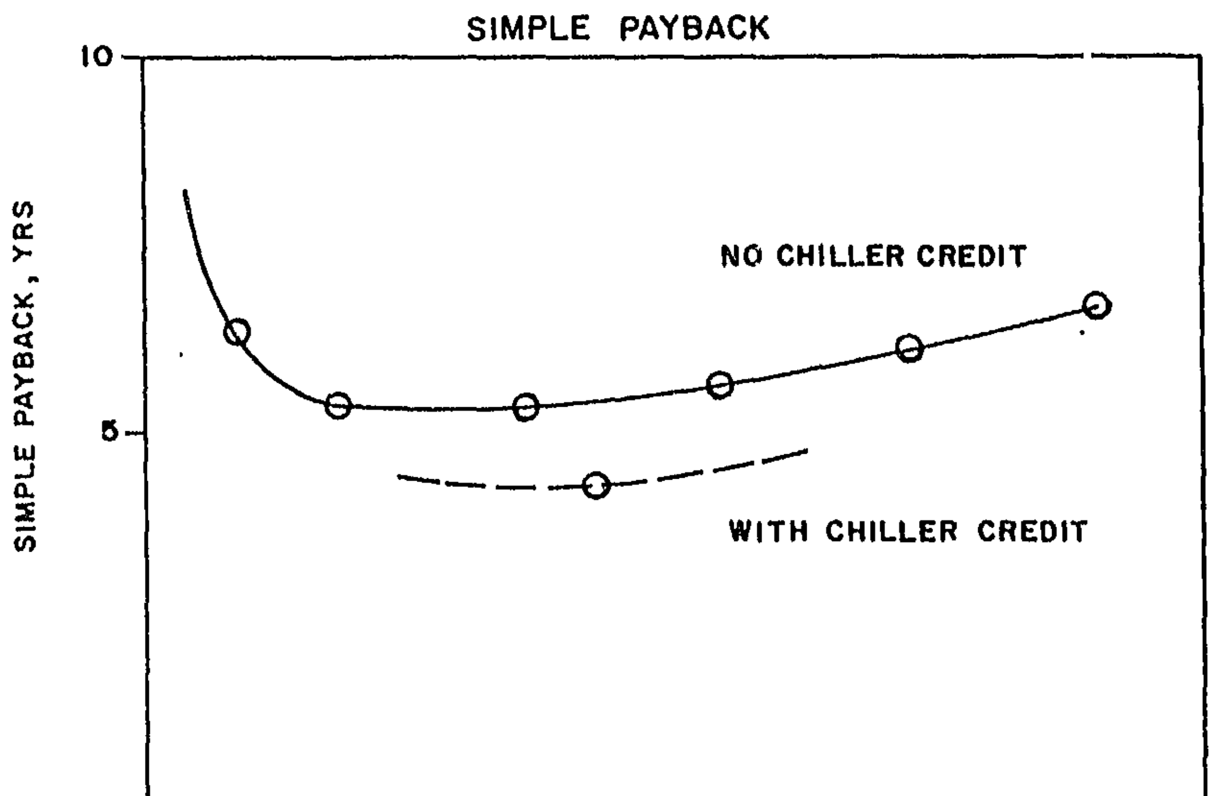


FIG. 9 COLD SIDE THERMAL STORAGE, HOSPITAL, WASH. D.C.
(Multiply Ton-hrs by 3.52 to get KWH)

Table K.
Effect of Cold Side Thermal Storage

Building	Storage Capacity (KWH)	(Ton-Hrs)	Simple Payback (yrs)
Hospital	4200	1200	4.3
Apartment	1800	500	3.4
Office	2500	700	3.5
Retail	3500	1000	4.0

K. Recommended HVAC Subsystem Design

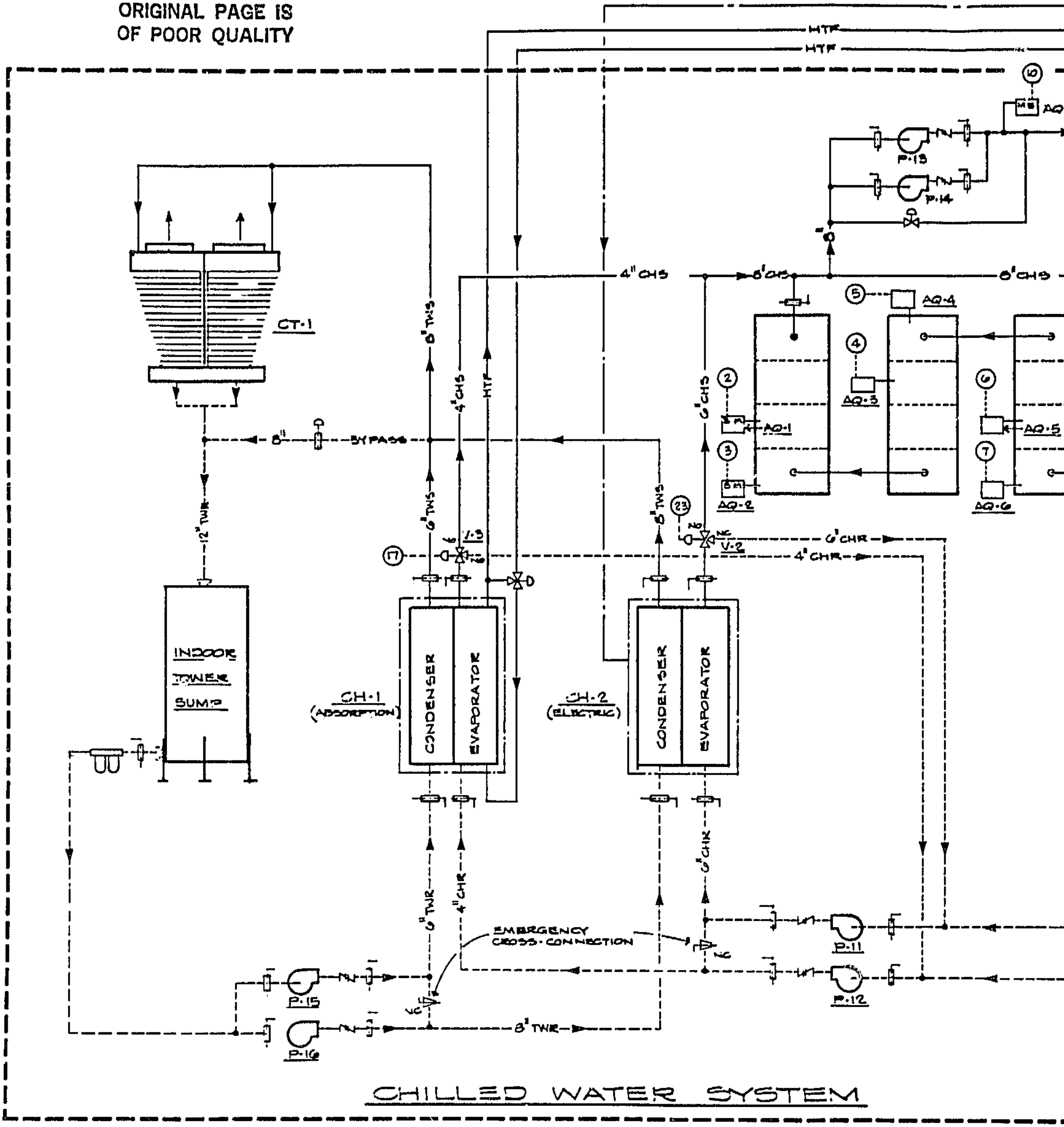
The recommended HVAC subsystem design is shown on Fig. 10. The design incorporates a combination of electric and absorption chillers and thermal storage as recommended in the previous sections of this report. All of the necessary components, including heat exchangers, pumps, interconnecting piping and controls, are shown on Fig. 10. For comparison, a conventional HVAC system is shown on Fig. 11. The systems were designed and specified for a 460 KW fuel cell in the hospital. This work was performed by Affiliated Engineers, Inc.

Fig. 12 shows how the components would fit into a mechanical room. A large part of the floor area is occupied by the chilled water storage tanks. If ice were used for cold storage, the floor area for storage would only be about one-fourth of that shown.

Supporting information on system components, controls, and system operation are given in the Appendix.

L. HVAC Subsystem Installed Cost

Affiliated Engineers estimated the installed cost of the HVAC subsystem shown on Fig. 10. These costs are given in Table N for the hospital. The costs are incremental costs over a conventional system. The total incremental costs for the HVAC subsystem with the 460 KW fuel cell reduce to a cost of $358/KW.



CHILLED WATER SYSTEM

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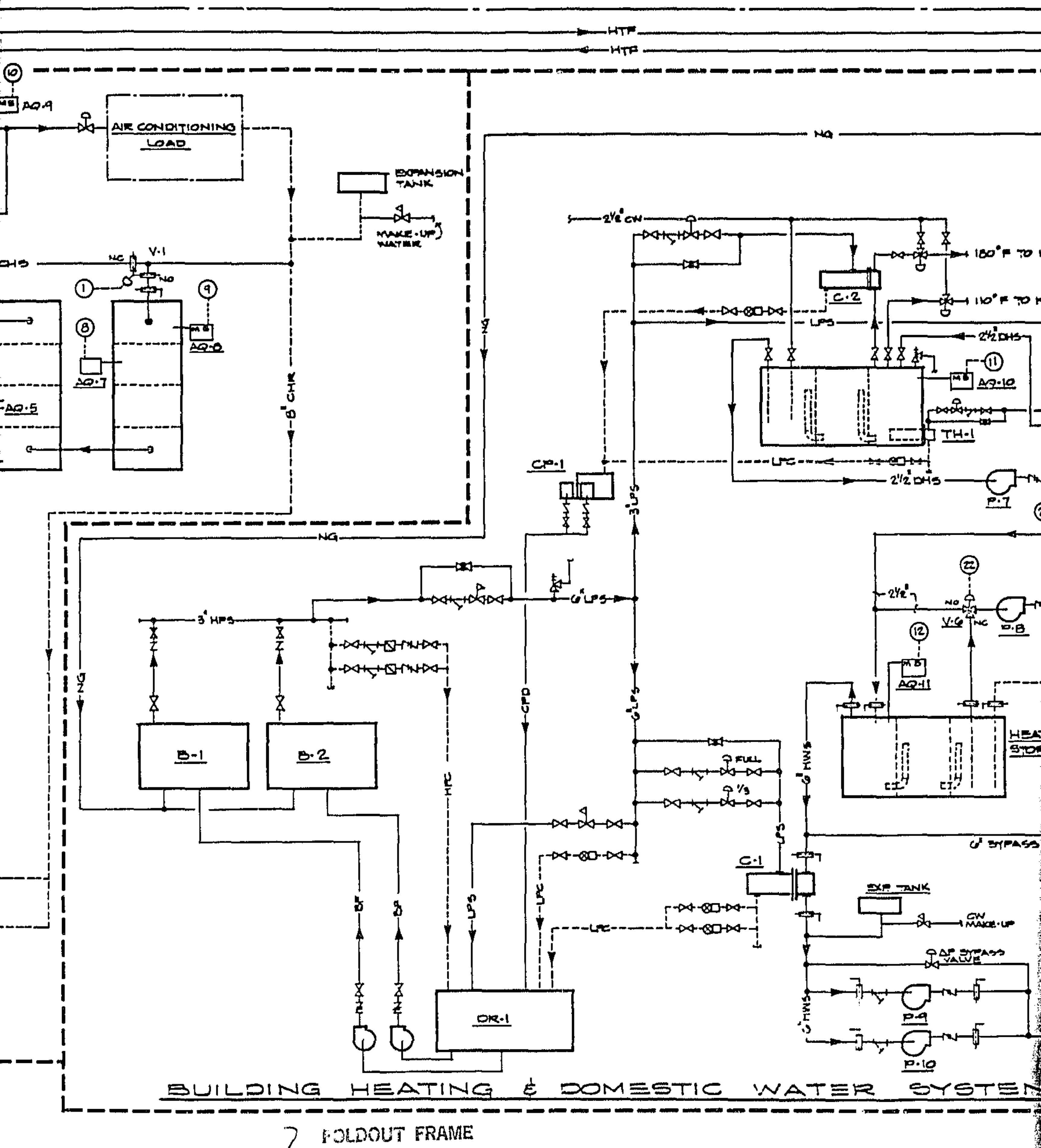

BUILDING HEATING & DOMESTIC WATER SYSTEM

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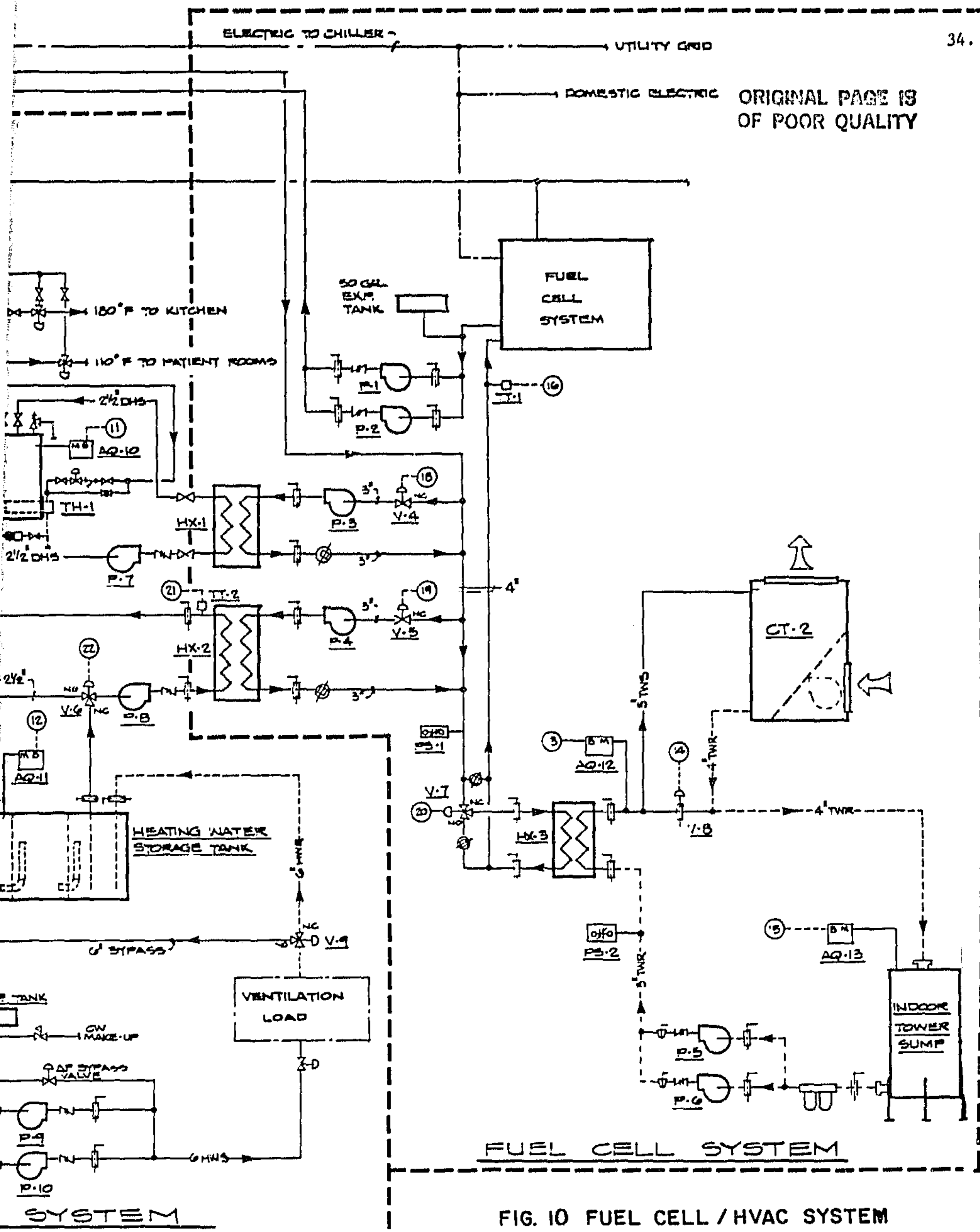

FIG. 10 FUEL CELL / HVAC SYSTEM

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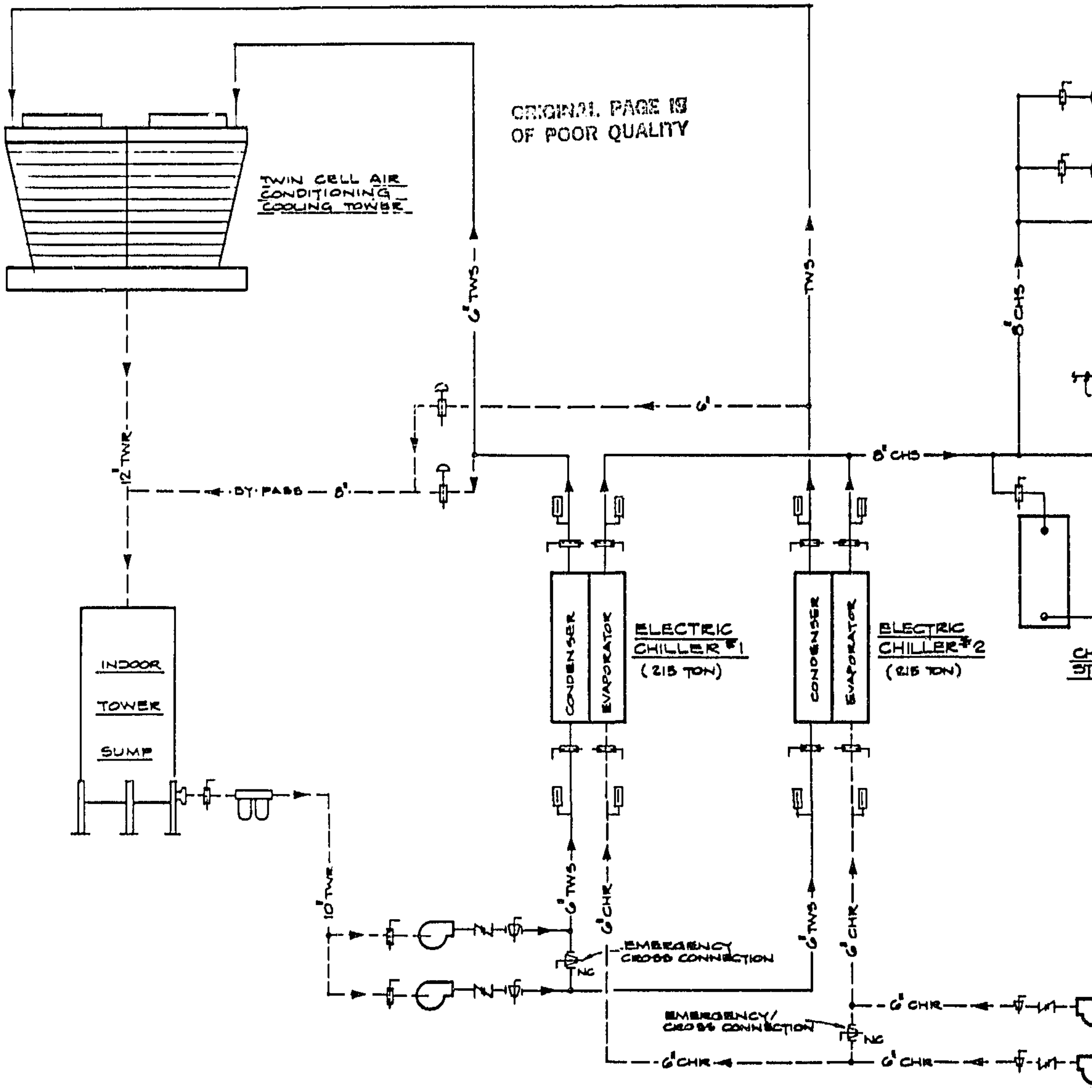

CHILLED WATER SYSTEM

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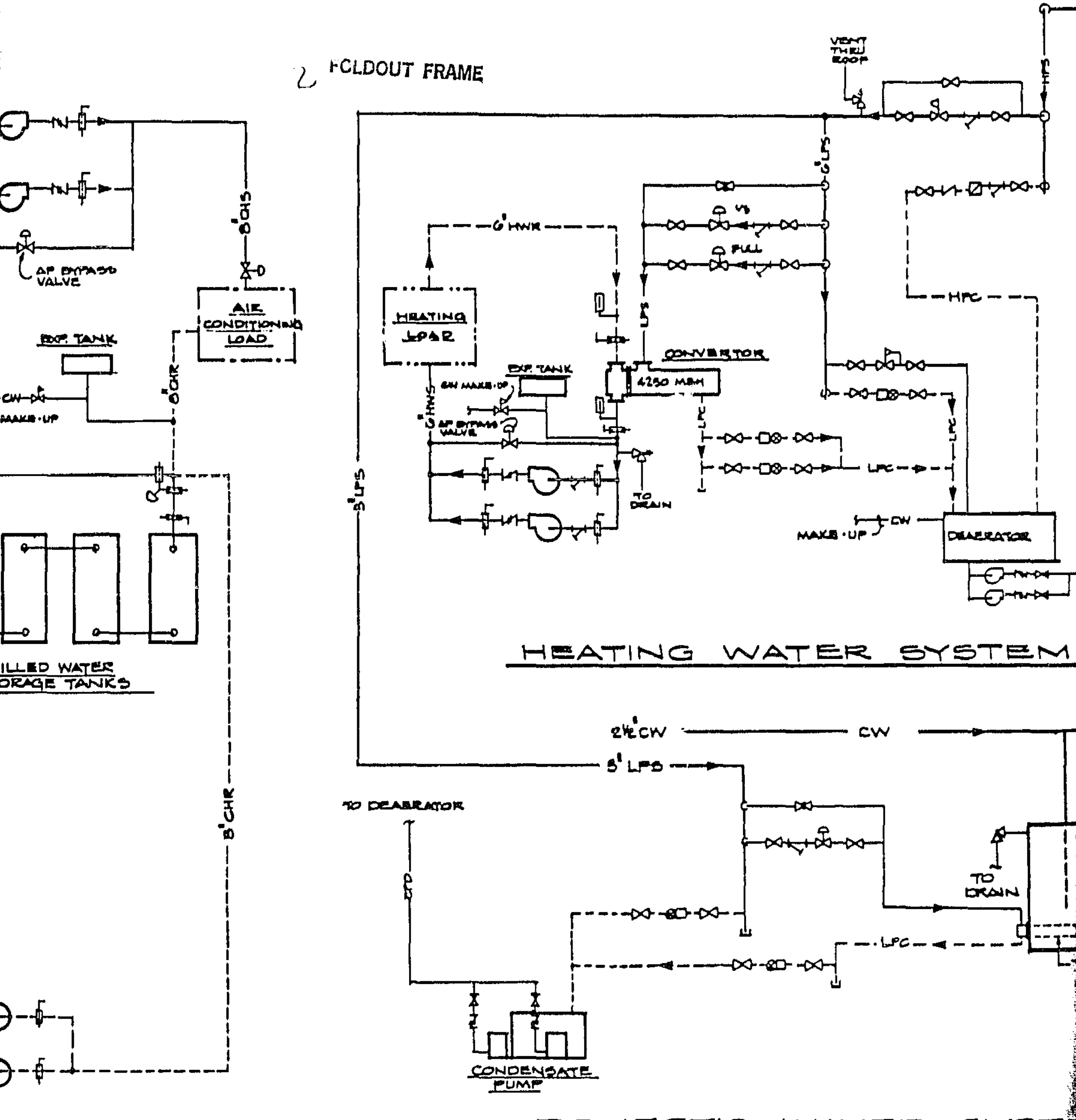
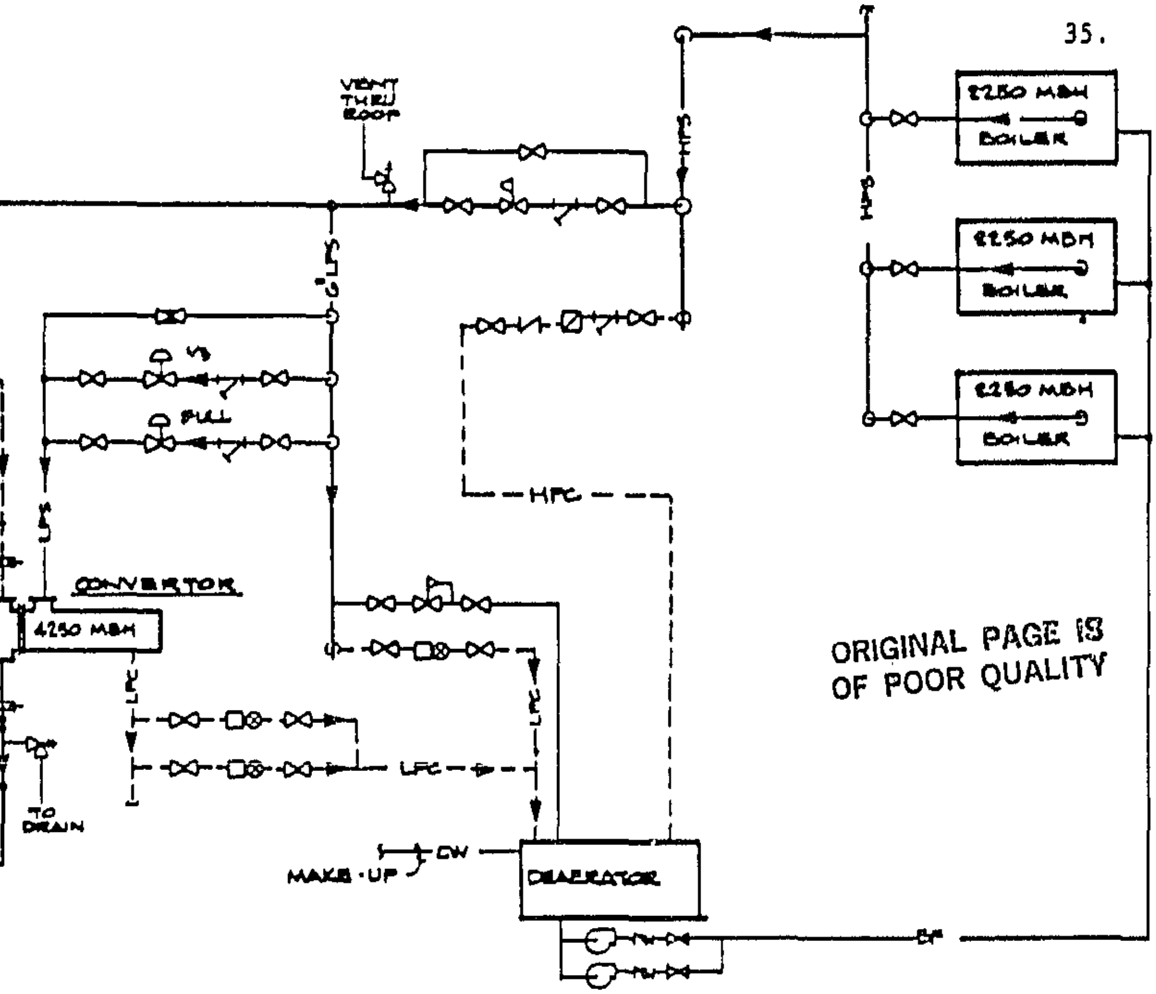
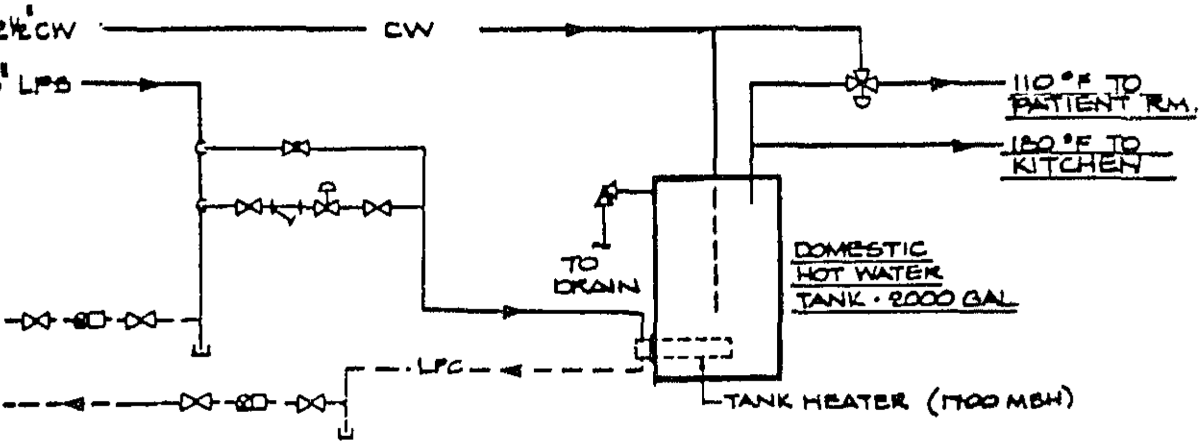


FIG. 11 CONVENTIONAL SYSTEM



TING WATER SYSTEM



MESTIC WATER SYSTEM

IG. 11 CONVENTIONAL SYSTEM

3

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SYMBOLS

---CHR---	CHILLED WTR. RETURN	—LPS—	LOW PRESSURE STEAM
—CHS—	CHILLED WTR. SUPPLY	---LPC---	LOW PRESSURE COND.
---TWR---	TOWER WTR. RETURN	—HPS—	HIGH PRESSURE STEAM
—TWS—	TOWER WTR. SUPPLY	---HPC---	HIGH PRESSURE COND.
—DHS-110°—	DOMESTIC HOT WTR. 110°F	—CPD—	COND. PUMP DISCHARGE
—DHS-180°—	DOMESTIC HOT WTR. 180°F	—CW—	CITY WATER
—HWS—	HEATING WTR. SUPPLY	—HTF—	HEAT TRANSFER FLUID
---HWR---	HEATING WTR. RETURN	—BF—	BOILER FEED
	PRESS. REG. VALVE		GLOBE VALVE
	3 WAY MOD. CONTROL VALVE		SPRING LOADED CHECK VALVE
	2 POSITION CONTROL VALVE		BALANCING VALVE
	2 POS. 3W. CONTROL VALVE		DUPLEX BASKET STRAINER
	2 WAY MOD. CONTROL VALVE		INVERTED BUCKET TRAP
	ECCENTRIC PLUG VALVE		F & T TRAP
	GATE VALVE		PRESS. RELIEF VALVE
(IR)	ELECTRIC RELAY COIL		PNEUMATIC/ELECT. SWITCH (PE)
	RELAY CONTACT		BUTTERFLY VALVE
	PIPELINE STRAINER	—NG—	NATURAL GAS

ABBREVIATIONS

TC - PNEUMATIC TEMP. CONTROLLER	RA - REVERSE ACTING
AQ - PNEUMATIC AQUASTAT (THERMOSTAT)	CH - CHILLER
RR - PNEUMATIC RATIO RELAY	CT - COOLING TOWER
RV - PNEUMATIC REVERSING RELAY	HX - HEAT EXCHANGER
PR - PNEUMATIC SWITCHING RELAY	C - CONVECTOR
V - PNEUMATIC CONTROL VALVE	P - PUMP
PS - PRESSURE SWITCH	CP - CONDENSATE PUMP
NC - NORMALLY CLOSED	DR - DEAERATOR
NO - NORMALLY OPEN	TH - TANK HEATER
DA - DIRECT ACTING	B - BOILER
TT - PNEUMATIC TEMP. TRANSMITTER	CS - CHILLER STARTER
MCC - MOTOR CONTROL CENTER	

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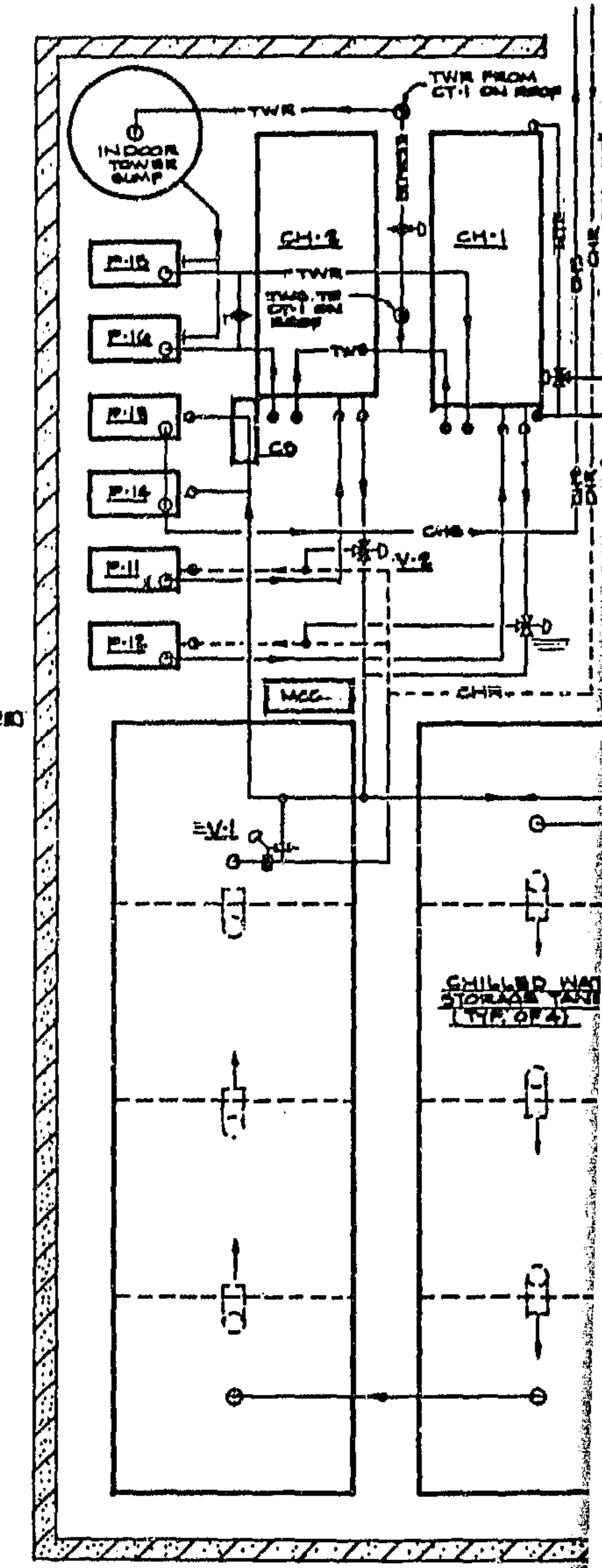

MECHANICAL ROOM

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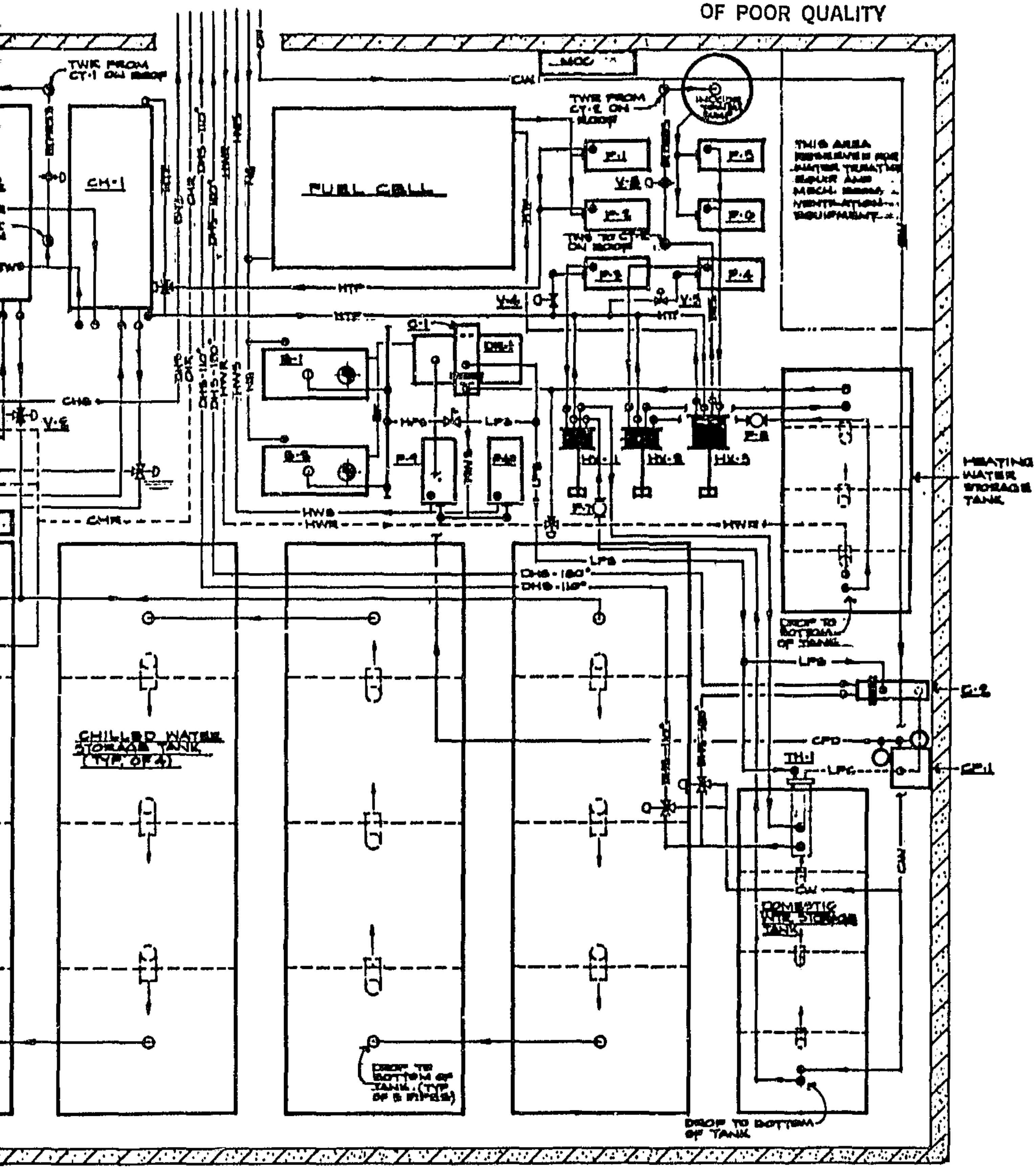

AL ROOM PLAN

10 FT.

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FIG. 12 MECHANICAL ROOM PLAN

TABLE L.

ADDITIONAL FUEL CELL MECHANICAL SYSTEM COST ABOVE CONVENTIONAL SYSTEM COST

CHILLED WATER SYSTEM COST		$ 6,200
a. Chiller Cost Difference	$ 5,000	
b. Chiller Bypass (one chiller)	$ 700	
c. Controls	$ 500	
BUILDING HEATING SYSTEM		$(12,100)
a. Boiler Cost Difference	$(21,000)	
b. Water Storage Tank	$ 3,600	
c. Tank Bypass & 3-Way Valve	$ 700	
d. Recovery Loop (includes pump, valves, piping)	$ 3,400	
e. Controls	$ 1,200	
DOMESTIC WATER HEATING SYSTEM		$ 6,400
a. Storage Tank	$ 2,400	
b. Steam/Water HX	$ 1,300	
c. Tank Heater	$ (1,400)	
d. Recovery Loop (includes pump, valves, piping)	$ 3,400	
e. Controls	$ 700	
HEAT TRANSFER FLUID SYSTEM		$ 62,000
a. Heat Exchangers HX-1,2,3	$ 8,000	
b. Pumps P-1 through P-6	$ 25,000	
c. Cooling Tower CT-2 and Sump	$ 5,200	
d. Piping, Valves, Expansion Tanks	$ 18,500	
e. Controls	$ 5,900	
ELECTRIC COSTS		$ 70,700
a. Motor Connections	$ 7,700	
b. Paralleling Gear	$ 98,000	
c. No Emergency Generator	$(35,000)	
MISCELLANEOUS COSTS		$ 31,500
a. Additional Mechanical Space ($30/sq.ft.)	$ 30,000	
b. Exhaust Stack, Inlet Duct, Natural Gas Pipe for Fuel Cell	$ 1,500	
TOTAL ADDITIONAL COST		$164,700

(   ) Denotes a credit

The cost estimate of Table L was done in more detail, and is more accurate, than the cost estimates used in the economic analyses (Task II). The estimate of Table L is somewhat higher as shown on Table M. However, when the fuel cell system cost is included, the total system cost is only 5% larger than the Task II estimate. There is only a small effect on the economics, as is also shown on Table M. Therefore, all of the previous economic results are slightly optimistic, but the conclusions do not change.

Table M.
Effect of Refined Cost Estimate

	Task II	Refined (Table N)
1. Installed Cost		
HVAC over conventional	$133,600	$164,700
Fuel cell system @ $980/KW	450,800	450,800
Total	$584,400	$615,500
2. Economics		
Net present value	$655,000	$615,000
Internal rate of return	34.6%	33.0%

FC/CTV/ABS2/H System

Hospital, Wash., D.C.

460 KW Fuel Cell, Con. Ed. rates

IV. CONCLUSIONS

Type of Chiller. The most economical system contains both an absorption chiller and an electric chiller. A system with only electric chillers is nearly as good. Systems with only absorption chillers are clearly less economic than the other two system types.

Fuel Cell System Capacity. The optimum fuel cell system capacity was found to be primarily a function of the building load ratio -- the ratio of the average thermal load to the average electric load. For buildings with a load ratio near unity, the fuel cell system capacity should be approximately 80% of the average electric load.

Type of Building. The hospital represents the best application for fuel cell systems of the four buildings studied. The apartment building was the next best of the four. The retail store can yield an internal rate of return nearly as high as the hospital and apartment. However, the impact on the building owner's owning and operating cost is less because the optimum fuel cell capacity is relatively much smaller. Fuel cell system applications in office buildings are not economically competitive at current estimates of installed fuel cell system cost.

Location. The primary variable is the electric rate structure. Weather has a secondary effect because the cooling loads of commercial buildings are dominated by internal loads.

Thermal Storage. The use of thermal storage for domestic hot water and space heating improves the economics for most systems and buildings. The largest improvement was for the retail store, where most of the thermal load is for daytime domestic hot water.

Taxes. A tax exempt hospital will yield a higher internal rate of return than a privately owned hospital. The main reason is that utility costs are tax deductible expenses for the privately owned hospital, which in effect reduces the utility cost savings by about one-half.

Fuel Cell System Cost. A comparison was made between the maximum allowable cost to yield a "break-even" internal rate of return of 15% and the current Engelhard cost estimate. In regions with low electric prices, such as Commonwealth Edison, the Engelhard estimate exceeded the break-even cost. This conclusion holds for all building types. However, in regions with high electricity prices, such as Consolidated Edison, the Engelhard estimate was about one-half the break-even cost for the hospital, apartment and retail store. For the office building, the Engelhard estimate exceeded the break-even cost for all electric rate structures. These results show that the allowable fuel cell cost depends strongly on the electric rate structure and the type of building.

Fuel Cell Operating Mode. The most economical operating mode for the fuel cell system is to operate continuously at rated capacity.

Fuel Cell System Thermal Output Temperature. A fuel cell system with 89% of the thermal output at 350F and 11% at 200°F yields values of IRR and NPV very close to those for a fuel cell system with 100% output at 350F.

Cold Side Thermal Storage. The application of cold side thermal storage to fuel cell/HVAC systems yields about the same benefit as for application in conventional HVAC systems. Cold side thermal storage can yield a simple payback period of 3-4 years in localities with Consolidated Edison electric rates.

Fuel Cell Condenser Heat Utilization. Systems that utilize fuel cell condenser heat to heat domestic hot water can yield short payback periods and are recommended for a fuel cell/HVAC system.

General Economic Feasibility. The four most important requirements for the economic feasibility of fuel cell/HVAC systems are:

- applications in buildings with high thermal to electric load ratios;
- applications in localities with medium to high electric rates;
- achievement of fuel cell cost goals; and
- the continued existence of PURPA.

PURPA is necessary to guarantee that supplemental electricity can be purchased from the utility at a reasonable rate. The sell-back provisions of PURPA are not crucial since the optimally sized fuel cell will generate small quantities of excess electricity.

Figure 16 illustrates qualitatively the effect of the above factors on the market in commercial buildings. The largest market penetration will occur at high electric prices, at medium to high load ratios, and at the fuel cell system cost goals. Deviations from these three requirements will decrease the market penetration. The total fuel cell system market would be represented by the volume under the surface.

V. PROJECT FINANCIAL SUMMARY & SCHEDULE

	Estimated	Actual
Project Costs		
(to 4/30/83		175,932
Final Report		706
Total	178,133	176,638
Project Schedule		
Task I	6/7/82	6/8/82
Task II	2/7/83	3/9/83
Task III	4/4/83	4/30/83
Final Report		7/15/83

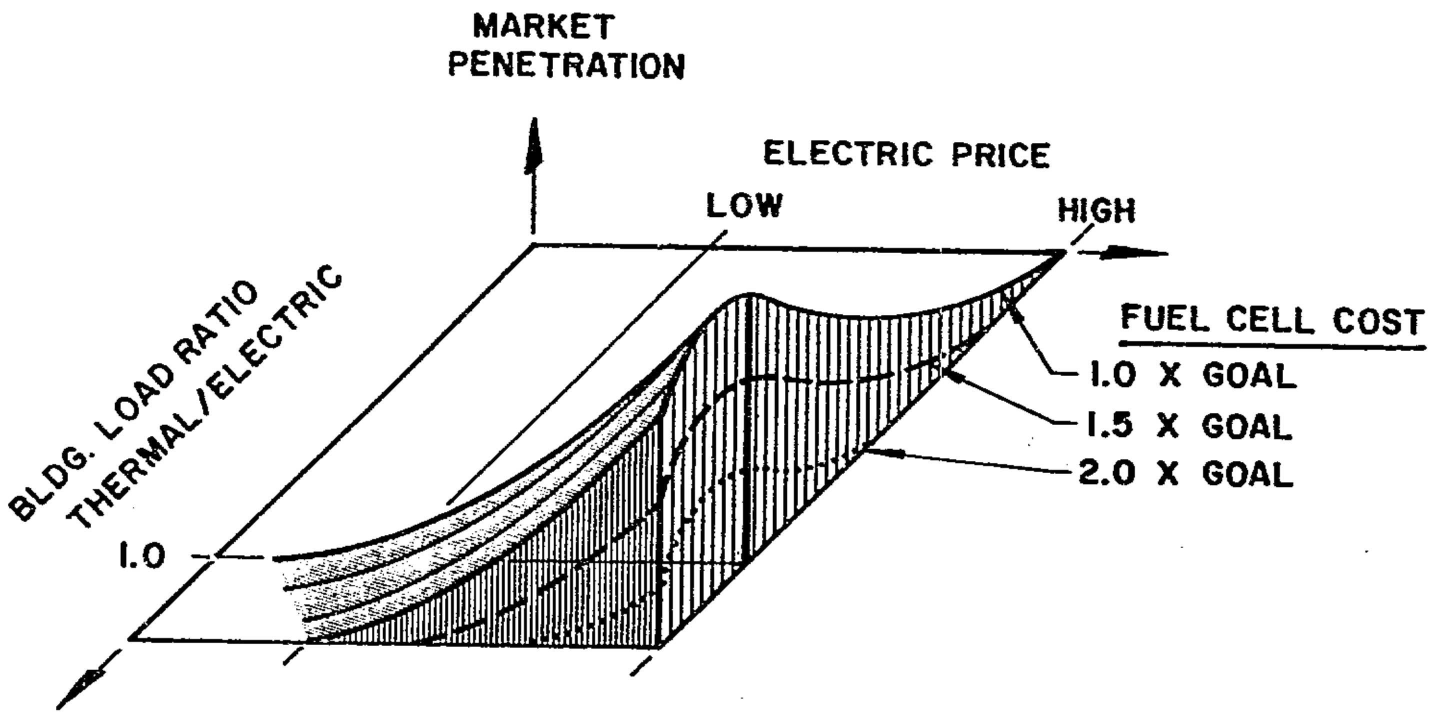


FIG. 13 FUEL CELL / HVAC MARKET

ACKNOWLEDGEMENTS

The following Trane Company personnel made valuable contributions to the success of this project.

Floyd C. Hayes, Manager, Thermal Systems Research; Project Manager

James A. Bierkamp, Senior Engineer, Building Energy Systems Engineering; computer code for incorporating fuel cell systems into the TRACE program.

Paul R. Glamm, Sr. Principal Engineer, Thermal Systems Research; Task I computer coding.

James C. Wendschlag, Senior Engineer, Thermal Systems Research; analysis of cold-side thermal energy storage.

Valuable assistance in the design and costing of the HVAC subsystem was provided by Affiliated Engineers, Inc. under the direction of Timothy J. Peckham, Project Manager.

The guidance and support provided by Engelhard Industries Division personnel is gratefully acknowledged, in particular for the assistance provided by John Werth, Research Section Head, Research & Development Department.

APPENDICES

A. Electric Rate Structures

B. Cold Storage Analysis

C. HVAC Subsystem Design Information

D. TRACE Run Summaries

E. Sample TRACE Output Summary (Selected Pages)

F. Sample Load Profiles

A. ELECTRIC RATE STRUCTURES

CON ED COGENERATION RATES

(From Engelhard)

		1982	1985
Energy Charge			
8 a.m. - 10 p.m., weekdays		6.7¢/KWH	9.1
All other hours		5.7¢/KWH	7.8
Demand Charge			
Oct. 15 - May 15		$ 9.68/KW	13.16
May 15 - Oct. 15		$24.28/KW	33.02
Back-up and Reverse Distribution Charge			
(Installed fuel cell KW)	X	$1.77/Mo.	2.41
+ (Peak sell-back KW)	X	1.77/Mo.	2.41
Sell-back Rates			
May 15 - Oct. 15,	noon - 6 p.m.	11.0¢/KWH	15.0
	8 a.m. - noon & 6 p.m. - 10 p.m.	5.3¢/KWH	7.21
	Off-Peak	3.5¢/KWH	4.76
Oct. 15 - May 15,	8 a.m. - 10 p.m.	4.1¢/KWH	5.58
	Off-Peak	3.3¢/KWH	4.49

BOSTON EDISON COGENERATION RATES

(from Engelhard)

	1982	1985
Energy Charge		
July 1 - Oct. 31	7.1¢/KWH	9.66
Nov. 1 - June 30	6.8¢/KWH	9.25
Demand Charge		
July 1 - Oct. 31	$4.93/KW	6.70
Nov. 1 - June 30	$3.91/KW	5.32
Back-up Charge (applies up to fuel cell capacity)		
(Installed fuel cell KW) x	$2.40/Mo.	3.26
Sell-back Rates		
July 1 - Oct. 31, 11 a.m. - 5 p.m. weekdays	6.82¢/KWH	9.28
Other times	3.97¢/KWH	5.40

SO. CAL. EDISON COGENERATION RATES

(from ADL)

	1982	1985
Energy Charge		
On-Peak	5.72¢/KWH	7.78
Mid-Peak	5.39¢/KWH	7.32
Off-Peak	5.04¢/KWH	6.85
Demand Charge		
On-Peak	\$5.05/KW	6.87
Mid-Peak	\$ .65/KW	.88
Off-Peak	0	0
Back-Up Charge		
(Installed fuel cell KW) x \$1.00/Mo.		1.36

Minimum Demand Charge

25% of maximum on-peak demand charge during previous 11 months

Sell-back Rates

Same as "buy" rates except the net energy demand cannot be less than zero.

Definitions:

On-Peak: May 1 - Oct. 31, 1 p.m. - 7 p.m. weekdays

Nov. 1 - Apr. 30, 5 p.m. - 10 p.m., weekdays

Mid-Peak: May 1 - Oct. 31, 9 a.m. - 1 p.m. & 7 p.m. - 11 p.m. weekdays

Nov. 1 - Apr. 30, 8 a.m. - 5 p.m. weekdays

Off-Peak: All other times

COMMONWEALTH EDISON COGENERATION RATES

(from ADL)

	1982 On-Peak	1982 Off-Peak	1985 On-Peak	1985 Off-Peak
Energy Charge - First 6000 KWH	$6.50¢/KWH	5.36¢/KWH	8.84	7.29
Next 24,000 KWH	5.57	4.43	7.58	6.02
Next 70,000 KWH	4.97	3.83	6.76	5.21
Next 400,000KWH	4.68	3.53	6.36	4.80
Remainder	4.24	3.10	5.77	4.22

On-Peak: 9 a.m. - 10 p.m. weekdays

Off-Peak: All other hours

Demand Charge

	1985
June 1 - Sept. 30, First 1000 KW, $7.54/KW	10.25
Next 9000 KW, $6.77/KW	9.21
Oct. 1 - May 31, First 1000 KW, $5.88/KW	8.00
Next 9000 KW, $5.26/KW	7.15

Minimum Demand Charge

Oct. 1 - May 31: 75% of highest summer demand charge during previous 23 months.

Sell-back Rates

June 1 - Sept. 30, 9 a.m. - 10 p.m. weekdays	5.69¢/KWH	7.74
All other hours	3.11¢/KWH	4.23
Oct. 1 - May 31, 9 a.m. - 10 p.m. weekdays	5.54¢/KWH	7.53
All other hours	3.61¢/KWH	4.91

GEORGIA POWER COGENERATION RATES

(from ADL)

	1982	1985
Energy (and demand) Charge		
For KWH consumption less than 300 X demand:		
First 3000 KWH	11.36¢/KWH	15.45
Next 7000 KWH	10.26¢/KWH	13.95
Next 190,000 KWH	8.20¢/KWH	11.15
Over 200,000 KWH	6.73¢/KWH	9.15
For KWH consumption over ~~400~~ 300 X demand:		
First 3000 KWH	11.00¢/KWH	14.96
Next 7000 KWH	9.90¢/KWH	13.46
Next 190,000 KWH	7.84¢/KWH	10.66
Over 200,000 KWH	6.37¢/KWH	8.66
Sell-back Rates (estimate)		
6.37¢/KWH		8.66

NEW JERSEY

PUBLIC SERVICE ELECTRIC & GAS

(from Engelhard)

	1982	1985
Energy		
7 a.m. - 9 p.m., weekdays	6.67¢/KWH	9.19
7 a.m. - 9 p.m., Saturdays	6.46¢/KWH	8.79
Other times	4.5¢/KWH	6.12
Demand		
June - Oct	$7.59/KW/Mo.	10.20
Nov - May	6.60/KW/Mo.	8.98
Sell-Back		
June - Oct		
7 a.m. - 9 p.m., weekdays	8.00¢/KWH	10.88
7 a.m. - 9 p.m., Saturdays	3.67¢/KWH	7.71
Other times	3.69¢/KWH	5.02
Nov - May		
7 a.m. - 9 p.m., weekdays	8.14¢/KWH	11.07
7 a.m. - 9 p.m., Saturdays	6.01¢/KWH	8.17
Other times	4.86¢/KWH	6.61

B. COLD STORAGE ANALYSIS

TRANE
AIR CONDITIONING

LA CROSSE

TO: L. MOUGIN - 12G

cc: P. JOYNER - 11R
F. HAYES - 12G

FROM: J. WENDSCHLAG - 12G

DATE: FEBRUARY 28, 1983

SUBJECT: CHILL STORAGE

Chill storage systems for commercial buildings are increasingly being investigated as viable means of reducing peak electrical demands. This results in cost savings both to the utilities, by deferring the capital costs of increasing capacity, and to the customer, by favorable utility imposed rate structures. As part of our contract with Engelhard on Fuel Cells, the economics of chill storage was investigated using TRACE.

The strategy used in TRACE for simulating chill storage simply attempts to take advantage of the on-peak to off-peak energy charge differentials. No attempt is made to reduce peak demand charges and, in fact, these charges may actually increase when the system is controlled in this manner. Another problem with the TRACE method of simulating chill storage is the lack of any means to include tank loss terms. Actual chill storage systems will require increased energy utilization due to heat gains into the tank as a result of the temperature difference between the tank contents and its environment. Furthermore, all of the chill which is stored in a tank is not useable because mixing inherently takes place, resulting in a portion of the storage attaining unsuitable temperatures.

In an effort to more thoroughly evaluate the potential of chill storage in the buildings analyzed in this project, two new computer programs have been written. These programs assess the performance of chill storage with more optimum control strategies. Two programs were written to allow comparisons for two different types of utility rate structures. The programs use, as input, the air conditioning and electrical loads which are computed and output from TRACE. Provision is also made to allow input of user specified tank loss terms which result from mixing and heat gain.

GROSS PROGRAM DESCRIPTIONS

The first program was written to optimize control for Consolidated Edison's electrical rate structure as summarized in Table I. This rate structure has very high demand charges, especially during the summer months when the bulk of air conditioning is required. The difference between on-peak and off-peak energy charges is only 14%. The greatest amount of savings through the utilization of chill storage thus comes about through minimization of the peak demand for a given storage capacity.

Figure 1 shows the electrical demand vs. time of day for a hospital in Washington, DC on a weekday during August. The shaded areas show the times when 1500 ton-hours of chill storage are being charged and utilized. Besides reducing the peak demand by 134 KW, a portion of the energy utilization is shifted from on-peak to off-peak. The shaded area under the charging portion of the curve is greater than the shaded area under the utilization portion due to losses associated with the storage system. In this case a 10% loss was assumed due to heat gain as a result of temperature differences across the tank and associated plumbing during charging of the tank. Thus 1650 ton-hrs of cooling must be generated to fully charge the tank to 1500 ton-hrs. An additional 10% loss was assumed associated with mixing during utilization of the tank storage. This results in only 1350 ton-hrs of the stored chill being usable for air conditioning. The total increase in energy utilization associated with the storage system is thus (1650/1350-1) or 22% of the storage capacity.

The second computer program was written to optimize control for Southern California Edison's Electrical Rate Structure as summarized in Table II. This rate structure has a high peak demand charge during on-peak periods, a very low peak demand charge during shoulder periods, and no peak demand charge off-peak. The difference between on-peak and off-peak energy charges is 12%. The greatest savings in the utilization of chill storage comes about by minimizing the peak demand during on-peak times. This also shifts the stored energy charges from on-peak to off-peak rates.

Figure 2 shows control of the storage system for the same loads used in Figure 1, but under the Southern California Edison rate structure. The 1000 ton-hours of storage in this case reduces the peak demand during the on-peak period by 160 KW. In addition this load is shifted to the off-peak energy charge. Again 10% losses are assumed both for the heat gains due to temperature differences and for mixing in the tank.

PARAMETRIC ANALYSIS

The economics of chill storage have been examined for four commercial building types using both the Con. Ed. and So. Cal. Ed. rate structures. Table III summarizes the building types examined, showing their relative sizes and the magnitudes of their electrical loads and air conditioning costs. Each of these buildings were in turn simulated over a range of chill storage capacities for both utility rate structures.

Tables IV and V show the results of this analysis for the Con. Ed. and So. Cal. Ed. rate structures, respectively.

The increases in annual electrical energy requirements with increasing storage capacity reflect the losses associated with chill storage. The annual peak electrical demand typically occurs during an August weekday, so the effect of chill storage capacity on this peak is highlighted. The electrical costs include demand and energy charges and are calculated using the 1985 projected rate structures.

Figures 3 and 4 show the relative savings on air conditioning costs for each building as a function of the storage capacity. Cost savings of over 50% are achievable under some circumstances.

The installed cost of chill storage may vary over a considerable range. The actual cost will depend on such things as the type of storage used, such as water vs. ice, the type of tank construction, local construction costs, and an assessment of the value of the space taken up by the tank and additional associated equipment. In an effort to provide general data for easily computing economical chill storage capacities, Figures 5 and 6 have been prepared for the two utility rate structures. These curves plot the annual savings per ton-hour of storage capacity as a function of the storage capacity. For example, if the cost of chill storage in a hospital is $80 per ton-hour, and a five-year payback is acceptable, the annual savings per ton-hour of capacity must be $16. Figure 5 shows that this savings can be achieved with an installed capacity of 1100 ton-hours, under Con. Ed. electrical rates.

A factor which can significantly reduce the installed cost of chill storage is credit for reduced chiller size. Depending on the amount of storage installed and the building air conditioning load profile, chiller capacity may be reduced as much as 50%. This can offset a substantial part of the added costs of chill storage. Figure 7 shows the estimated installed chiller costs as a function of the chiller size in 1985 dollars. The actual chiller size reduction in a chill storage application will be a function of the HVAC designer and the assessment of storage system reliability. All computations presented were made with full size chillers.

CALMAC Manufacturing Corporation is a manufacturer of ice storage modules for chill storage applications. They estimate the installed cost of their storage system at $60 per ton-hour. Based on this cost number, simple paybacks were calculated for the four buildings examined over a range of storage capacities. The results of these calculations are presented in Tables VI and VII for the two utility rate structures.

Besides the computations which include estimated system losses, the payback was projected assuming an ideal system with no increase in energy usage. This serves to emphasize the affects that loss estimates can have on chill storage economic analysis.

CONCLUSIONS

Chill storage, when properly controlled, has the capability to significantly reduce the peak electrical demands for commercial buildings. For utility rate structures which have high demand charges, this translates into substantial annual operating cost savings. Simple payback analysis have shown that paybacks of less than 2 years are attainable for small amounts of chill storage under Consolidated Edison's rate structure, if the incremental cost of the storage is assumed to be $60 per ton-hour. Chill storage thus appears to be economical in some parts of the country.

TABLE I. CONSOLIDATED EDISON ELECTRICAL RATE STRUCTURE

<u>ENERGY CHARGE</u>

	1982	1985
8 a.m. - 10 p.m., weekdays	6.7¢/KWH	9.1¢/KWH
All other hours	5.7¢/KWH	7.8¢/KWH

<u>DEMAND CHARGE</u>

Oct. 15 - May 15	\$9.68/KW	\$13.16/KW
May 15 - Oct. 15	\$24.28/KW	\$33.02/KW

TABLE II. SOUTHERN CALIFORNIA EDISON ELECTRICAL RATE STRUCTURE

ENERGY CHARGE

	1982	1985
On-Peak	5.72¢/KWH	7.78¢/KWH
Mid-Peak	5.39¢/KWH	7.32¢/KWH
Off-Peak	5.04¢/KWH	6.85¢/KWH

DEMAND CHARGE

On-Peak	\$5.05/KW	\$6.87/KW
Mid-Peak	\$0.65/kw	\$0.88/KW
Off-Peak	0	0

MINIMUM DEMAND CHARGE

25% of maximum on-peak demand charge during previous 11 months.

DEFINITIONS

ON-PEAK: May 1 - Oct. 31, 1 p.m. - 7 p.m., weekdays
Nov. 1 - Apr. 30, 5 p.m. - 10 p.m., weekdays

MID-PEAK: May 1 - Oct. 31, 9 a.m. - 1 p.m. & 7 p.m. - 11 p.m. weekdays
Nov. 1 - Apr. 30, 8 a.m. - 5 p.m., weekdays

OFF-PEAK: All other times

TABLE III. DESCRIPTION OF BUILDINGS USED FOR CHILL STORAGE PARAMETRIC ANALYSIS

Building	Size (ft_2)	Annual Electricity Req. (KWH)	Annual Air Conditioning Costs Con. Ed. $	So. Cal. Ed $
Hospital	197,000	4.9×10^6	84,513	62,152
Apartment	81,600	1.1×10^6	23,941	15,591
Office Bldg.	66,800	1.4×10^6	23,633	12,701
Retail Store	112,000	1.8×10^6	57,897	34,921

TABLE IV. ANALYSIS OF CHILL STORAGE FOR FOUR TYPES OF COMMERCIAL BUILDINGS OPERATING ON CONSOLIDATED EDISON'S UTILITY RATE STRUCTURE

Building	Storage Ton-Hrs	Annual Energy (KWH)	Avg. Peak (KWH)	Elec. Cost ($)
Hospital	0	4,915,219	838	609,778
	500	4,944,623	767	595,627
	1000	4,965,401	733	592,130
	1500	4,981,009	704	590,134
	2000	4,989,541	701	589,640
	2500	4,990,362	701	589,687
Office	0	1,420,971	329	199,199
	150	1,427,518	304	194,085
	300	1,433,146	291	191,292
	500	1,439,050	277	188,706
	700	1,442,884	263	187,042
	850	1,444,870	257	186,812
	950	1,445,246	257	186,846
Apartment	0	1,064,513	259	146,801
	250	1,075,132	208	138,713
	500	1,081,648	194	137,962
	750	1,086,577	194	138,141
	1000	1,089,717	194	138,257
	1200	1,089,717	194	138,257
	1400	1,089,717	194	138,257
Retail Store	0	1,810,016	451	255,232
	500	1,837,644	400	245,677
	1000	1,856,426	366	240,271
	1500	1,871,175	333	235,911
	2000	1,880,940	299	232,732
	2450	1,881,645	291	232,362
	2700	1,881,645	291	232,362

TABLE V. ANALYSIS OF CHILL STORAGE FOR FOUR TYPES OF COMMERCIAL BUILDINGS OPERATING ON SOUTHERN CALIFORNIA EDISON'S UTILITY RATE STRUCTURE

Building	Storage Ton-Hrs	Annual Energy (KWH)	Avg. Peak (KWH)	Elec. Cost ($)
Hospital	0	4,915,219	838	424,215
	500	4,944,714	738	419,276
	1000	4,972,230	678	418,159
	1500	4,990,872	617	417,293
	2000	5,007,338	555	417,088
	2500	5,018,884	553	417,503
	3000	5,022,304	553	417,654
	3300	5,021,809	553	417,617
Office	0	1,420,971	329	134,840
	150	1,429,043	298	132,959
	300	1,436,342	274	132,771
	500	1,445,196	257	132,207
	700	1,451,720	257	132,451
	850	1,455,044	257	132,639
	950	1,457,177	257	132,788
Apartment	0	1,064,513	259	102,213
	250	1,079,254	183	100,112
	500	1,092,148	166	100,444
	750	1,099,619	166	100,751
	1000	1,105,768	166	101,032
	1200	1,109,711	166	101,224
	1400	1,111,265	166	101,313
Retail Store	0	1,810,016	445	172,419
	500	1,839,511	377	169,145
	1000	1,868,605	317	168,422
	1500	1,889,730	269	168,518
	2000	1,903,644	269	169,067
	2450	1,909,315	269	169,335

TABLE VI. SIMPLE PAYBACK ANALYSIS FOR CHILL STORAGE USING CONSOLIDATED EDISON RATE STRUCTURE

Building	Storage (Ton-Hrs)	Savings * ($)	Payback ** (Yrs)
Hospital	500	14,151	2.1 (1.7)***
	1000	17,648	3.4 (2.7)
	1500	19,644	4.6 (3.5)
	2000	20,138	6.0 (4.4)
Office	150	5,114	1.8 (1.5)
	300	7,907	2.3 (1.9)
	500	10,493	2.9 (2.4)
	700	12,157	3.5 (3.0)
Apartment	250	8,088	1.9 (1.6)
	500	8,839	3.4 (2.9)
	750	8,660	5.2 (4.3)
Retail Store	500	9,555	3.1 (2.4)
	1000	14,961	4.0 (3.0)
	1500	19,321	4.7 (3.5)
	2000	22,500	5.3 (4.2)

*Assumes 10% Mixing Losses, 10% OT Losses
**Assumes $60/Ton-Hr
***Payback with no losses

TABLE VII. SIMPLE PAYBACK ANALYSIS FOR CHILL STORAGE USING SOUTHERN CALIFORNIA EDISON RATE STRUCTURE.

Building	Storage (Ton-Hrs)	Savings * ($)	Payback ** Yrs
Hospital	500	4,939	6.1 (4.1)***
	1000	6,056	9.9 (5.8)
	1500	6,922	13.0 (7.1)
	2000	7,127	16.8 (8.8)
Office	150	1,881	4.8 (3.5)
	300	2,569	7.0 (4.8)
	500	2,633	11.4 (6.9)
Apartment	250	2,101	7.1 (4.7)
	500	1,769	17.0 (8.1)
	750	1,462	30.8 (11.5)
Retail Store	500	3,274	9.2 (5.3)
	1000	3,997	15.0 (7.1)
	1500	3,901	23.1 (9.5)

*Assumes 10% Mixing Losses & 10% OT Losses.
**Assumes $60/Ton-Hr.
***Payback with no losses.

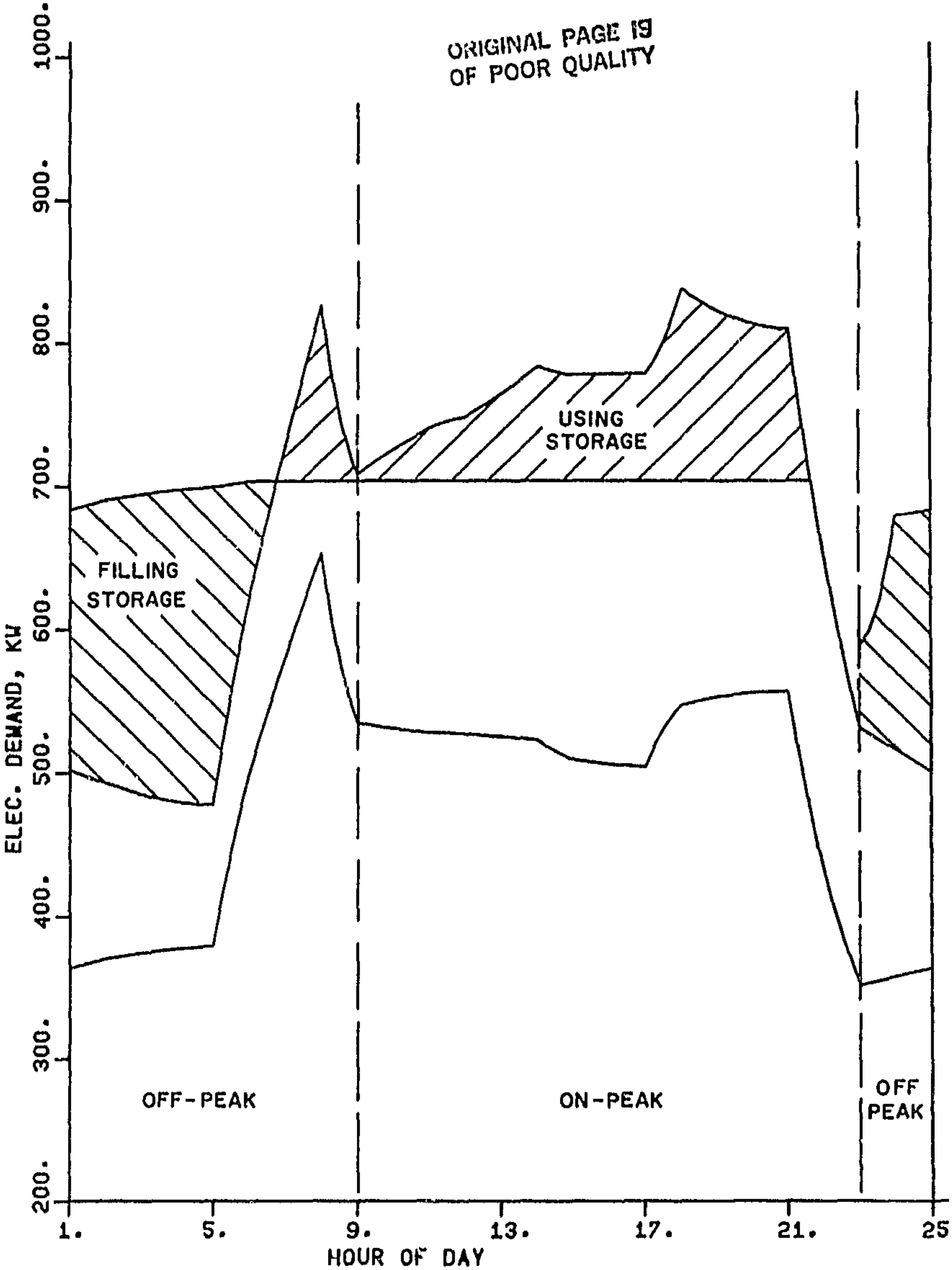


FIGURE 1. EFFECTS OF CHILL STORAGE ON
ELECTRICAL REQUIREMENTS FOR A HOSPITAL

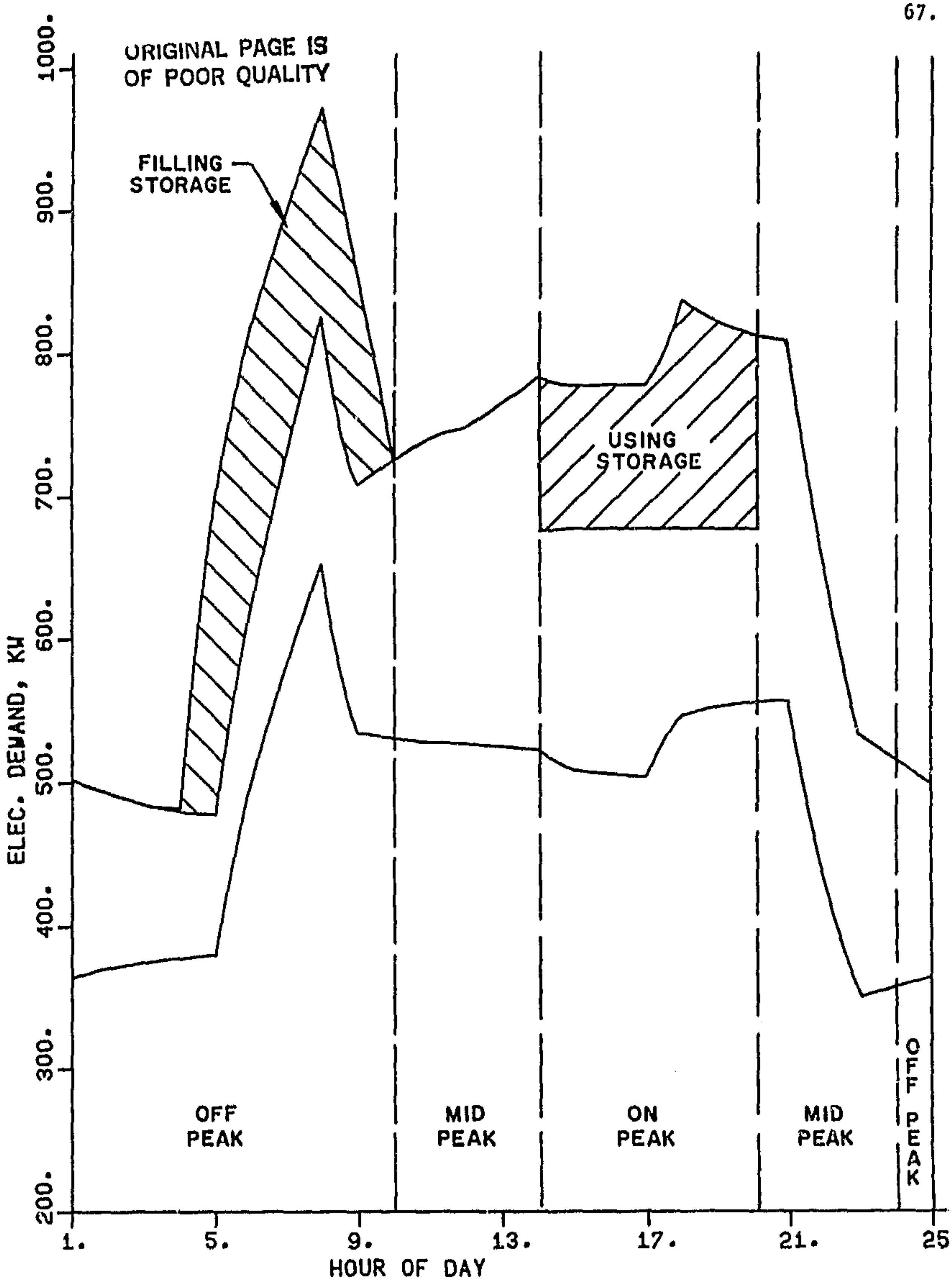


FIGURE 2. EFFECTS OF CHILL STORAGE ON ELECTRICAL REQUIREMENTS FOR A HOSPITAL IN LOS ANGELES, CAL.

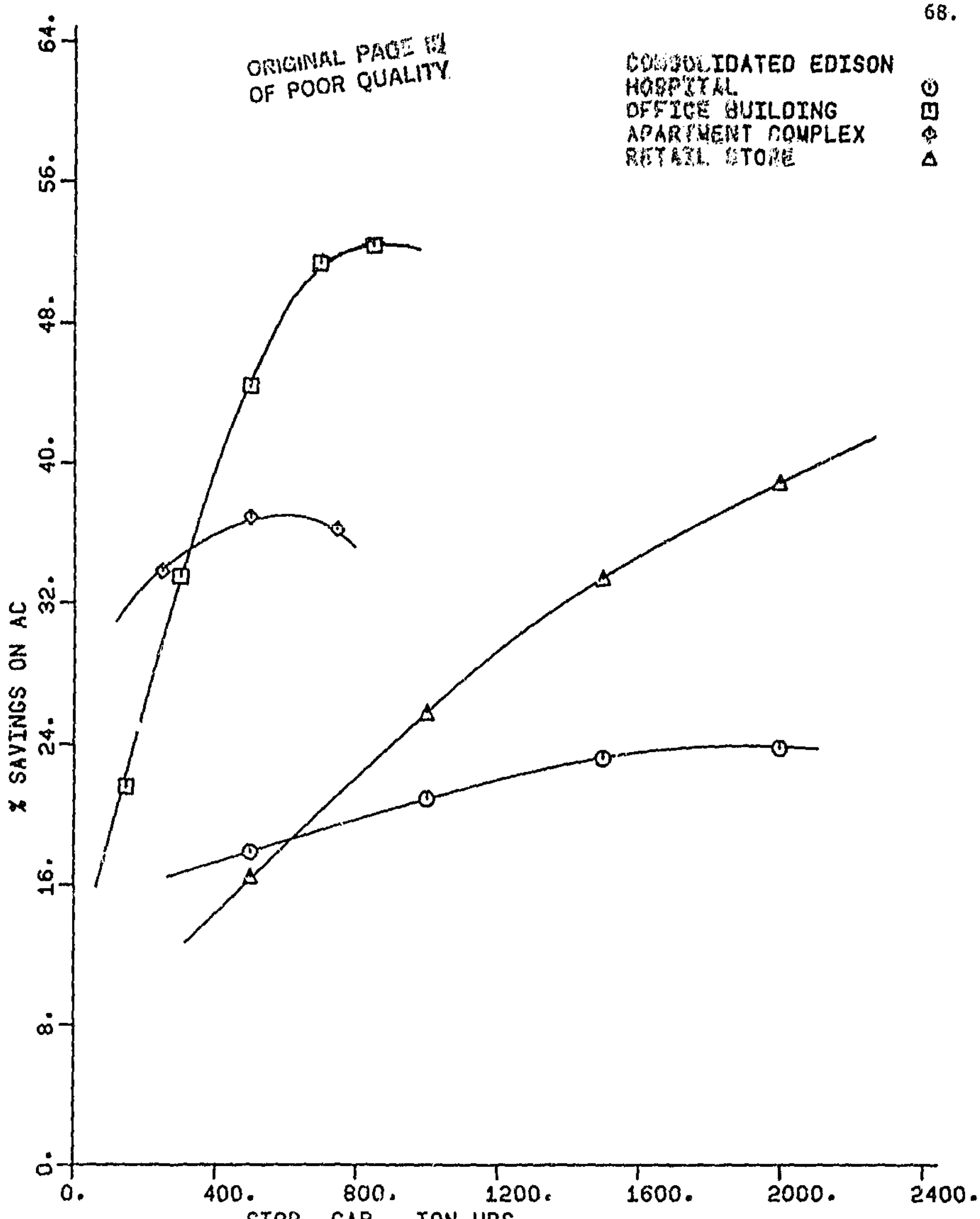


FIGURE 3. RELATIVE AIR CONDITIONING COST SAVINGS AS A FUNCTION OF CHILL STORAGE CAPACITY.

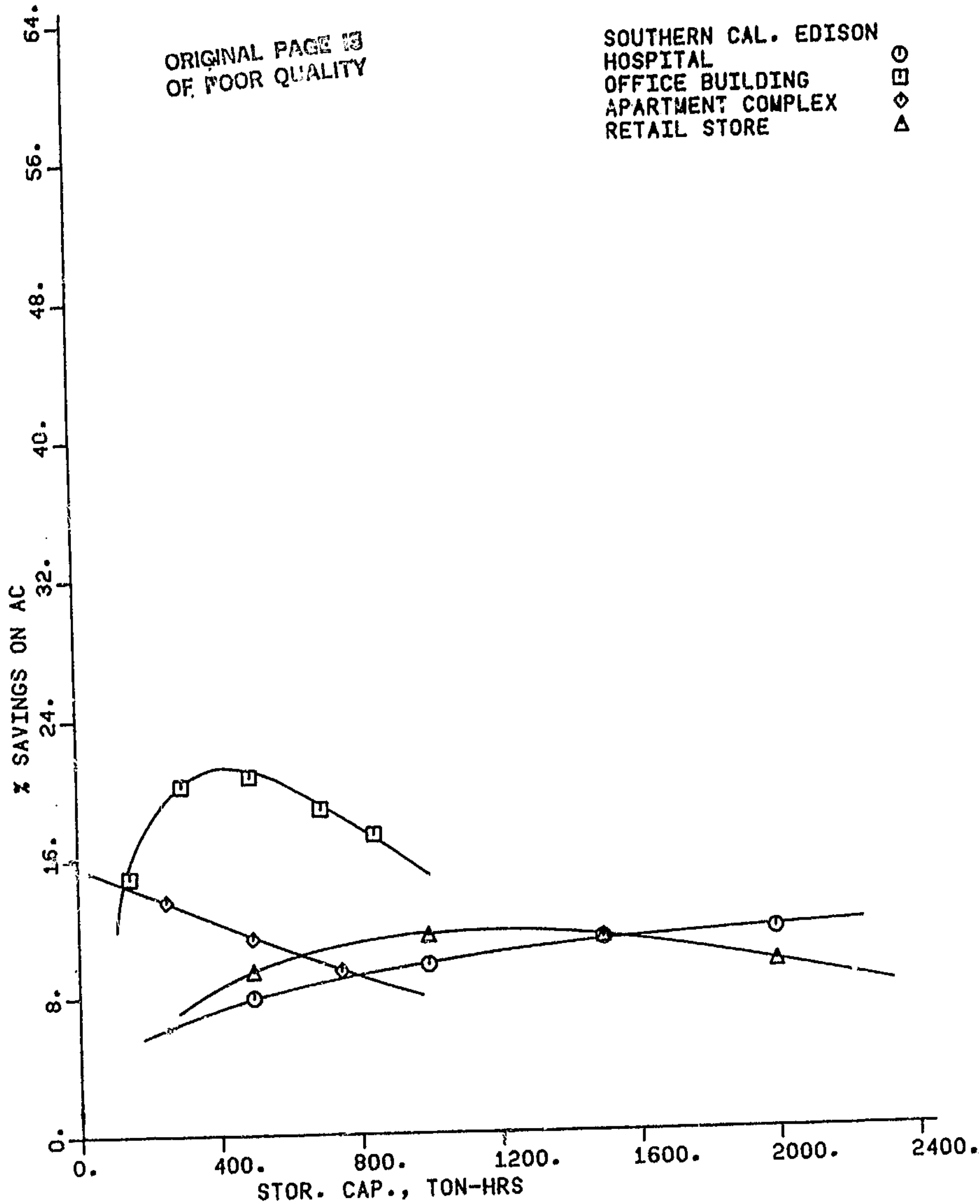
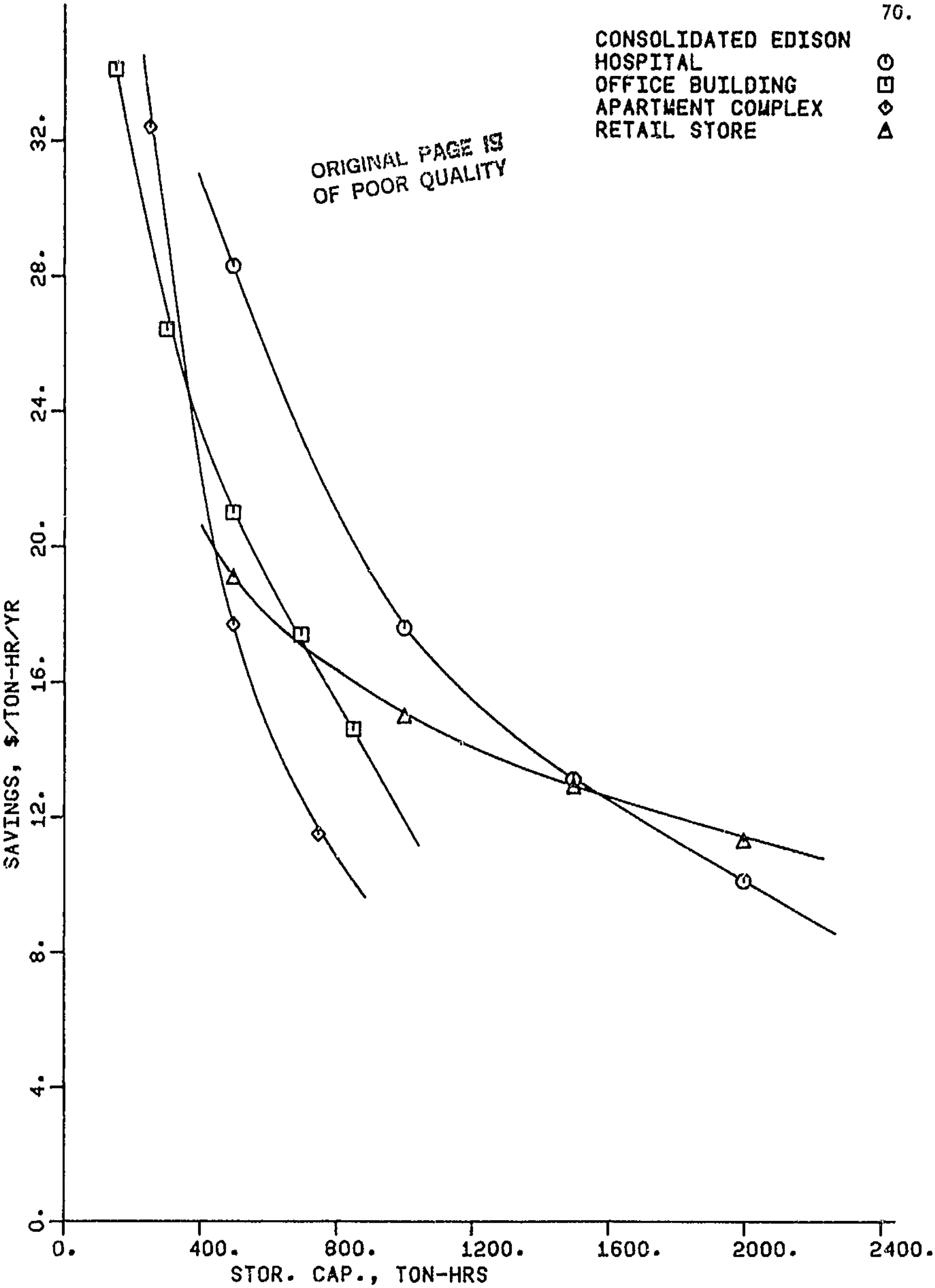


FIGURE 4. RELATIVE AIR CONDITIONING COST SAVINGS AS A FUNCTION OF CHILL STORAGE CAPACITY.


CONSOLIDATED EDISON
HOSPITAL
OFFICE BUILDING
APARTMENT COMPLEX
RETAIL STORE
ORIGINAL PAGE IS
OF POOR QUALITY
SAVINGS, $/TON-HR/YR
STOR. CAP., TON-HRS
0.
4.
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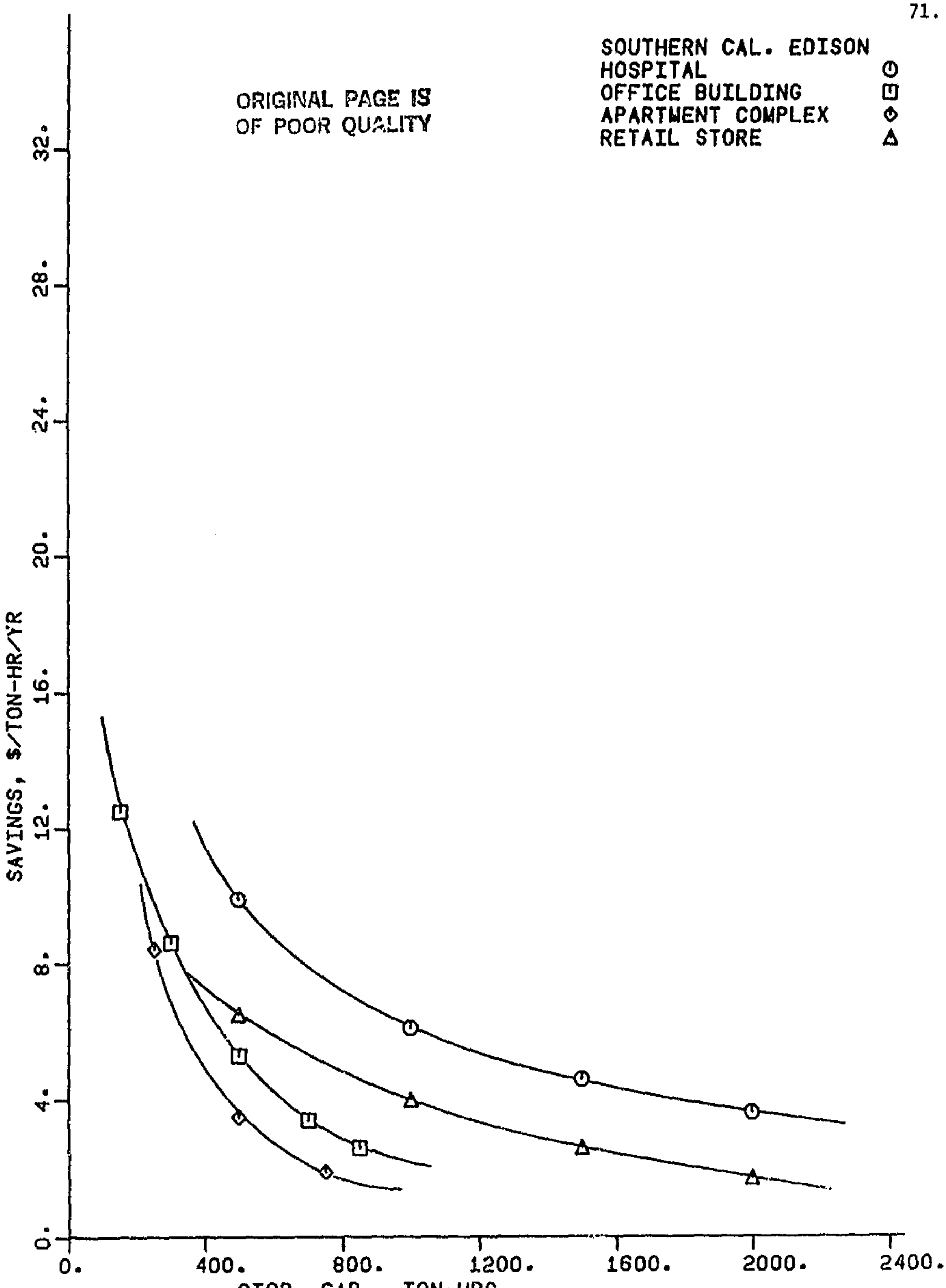
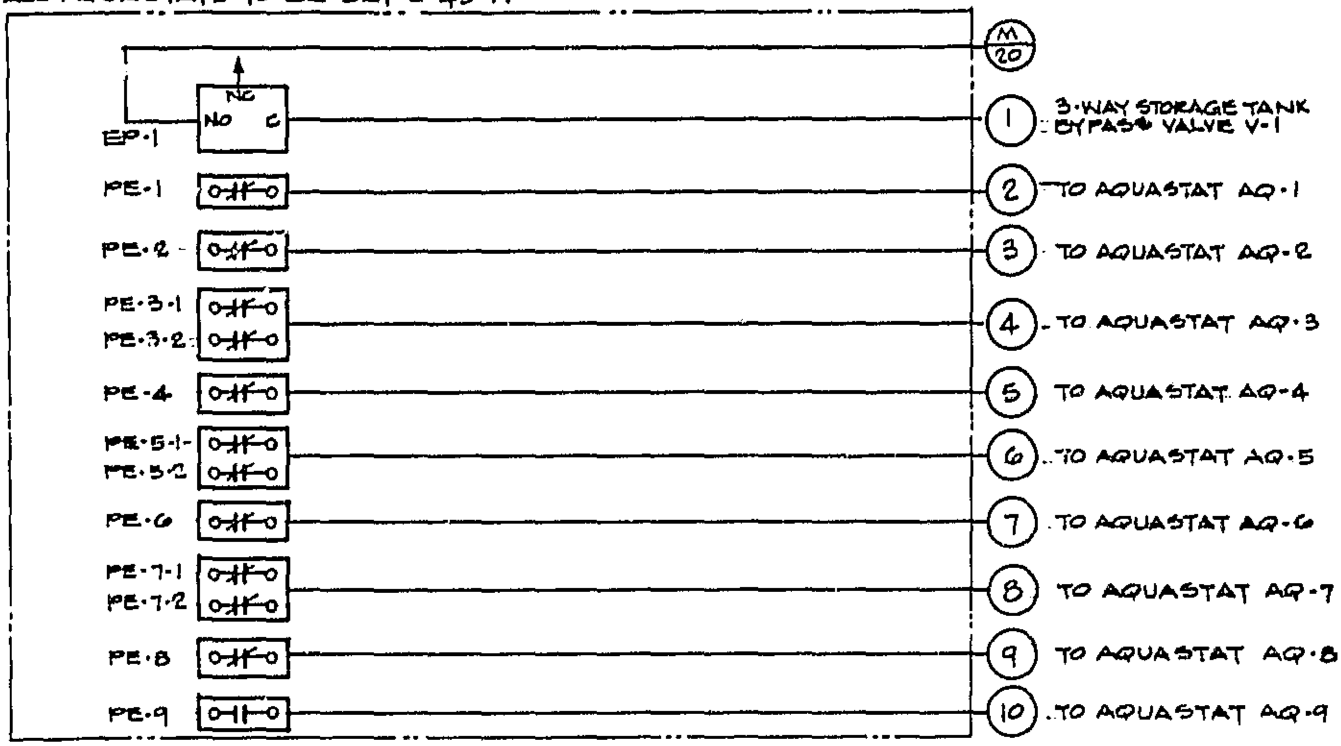


FIGURE 6. ECONOMICS OF CHILL STORAGE.

C HVAC SUBSYSTEM DESIGN

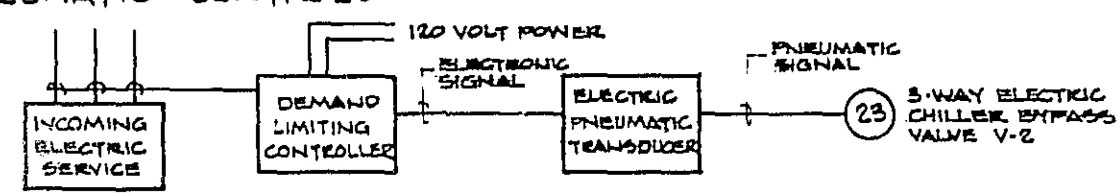
ORIGINAL PAGE IS
OF POOR QUALITY

REFER TO SCHEMATIC FOR AQUASTAT AND VALVE LOCATIONS.
ALL AQUASTATS TO BE SET @ 45°F.



PANEL ON-OF SWITCH

2 CHILLED WATER SYSTEM
PNEUMATIC CONTROLS



3 CHILLED WATER SYSTEM
ELECTRIC CHILLER DEMAND CONTROL

ABSORPTION CHILLER

The absorption chiller shall be interlocked with pumps P-12 & P-15. The absorption chiller shall operate continuously during the cooling season (April thru November). During the storage charging cycle, the absorption chiller will operate at full capacity. Once the charging cycle is complete, the absorption chiller will operate at the level required to meet the current cooling load maintaining full storage capacity. The chiller shall maintain 45 F leaving chilled water temperature thru its own controls.

ELECTRIC CHILLER

The electric chiller shall be interlocked with pumps P-11 & P-16. The electric chiller shall not operate unless the selector switch is placed in the summer position. The selector switch will be placed in the summer position whenever the absorption chiller can no longer charge the specified number of tanks during "off peak" hours (probably June - September). The electric chiller shall only operate during "off peak" hours to help charge the storage system, unless the water storage is insufficient to handle the cooling load during "on-peak" hours. At this time, the 0-12 hour override timer will be set. Manual setting of this timer will be based on the previous day's load and outdoor air temperature. The chiller shall maintain 45 F leaving water temperature thru its own controls. The electric chiller demand shall be limited to the existing daily base electric demand peak, as determined by the demand limiting controller. To reduce electrical consumption, a 3-way control valve V-2, shall bypass chiller water from the evaporator outlet to the return water entering the evaporator. This will reduce the evaporator inlet temperature, thus reducing the electric load at the chiller.

STORAGE CHARGING SYSTEM

A five position selector switch shall be manually set to determine the number of tanks to be charged. A timeclock, set to close its contacts during "off-peak" electrical rates, or a heat rejection signal from the fuel cell (refer to heat recovery system description) thru PE-12 and relay 8R shall initiate the charging cycle. Depending on the position of the selector switch, either relay 2R, 4R, 6R or 7R shall close their respective contacts if the temperature in the tank is above 45 F as determined by aquastats AQ-1 thru AQ-8 and PE-1 thru PE-8. Once these contacts close, EP-1 is energized and valve V-1 returns to its normal position which allows water flow thru the storage tank. The absorption chiller and possibly the electric chiller, if it is switched to the summer position, will operate until the selected storage capacity has been cooled to 45 F. The electric chiller shall then shut off, the storage tank bypass valve V-1 shall open and the absorption chiller shall try to meet the current cooling load. If the current cooling load exceeds the absorption chiller capacity, and the CHS temperature rises above 45 F, EP-1 shall be energized thru PE-9 and AQ-9. This will open the storage tank valve V-1 and use stored energy to meet the remainder of the cooling load. When one full compartment of the last storage tank charged has been used, the electric chiller shall come back on line to recharge the tank, provided it is still during "off-peak" hours.

In the event that more of the storage tank has been cooled to 45 F than is required by the 5 position selector switch, the absorption chiller shall be turned off thru PE-3-2 and relay 9R, PE 5-2 and relay 10R or PE 7-2 and relay 11R. The absorption chiller will be turned on when the amount of storage drops to the selected quantity.

In the event the fuel cell is operating, the required amount of chilled water storage has been met, and the domestic water and heating water storage tanks are fully charged, the absorption chiller will charge all four tanks before rejecting the fuel cell heat directly outside.

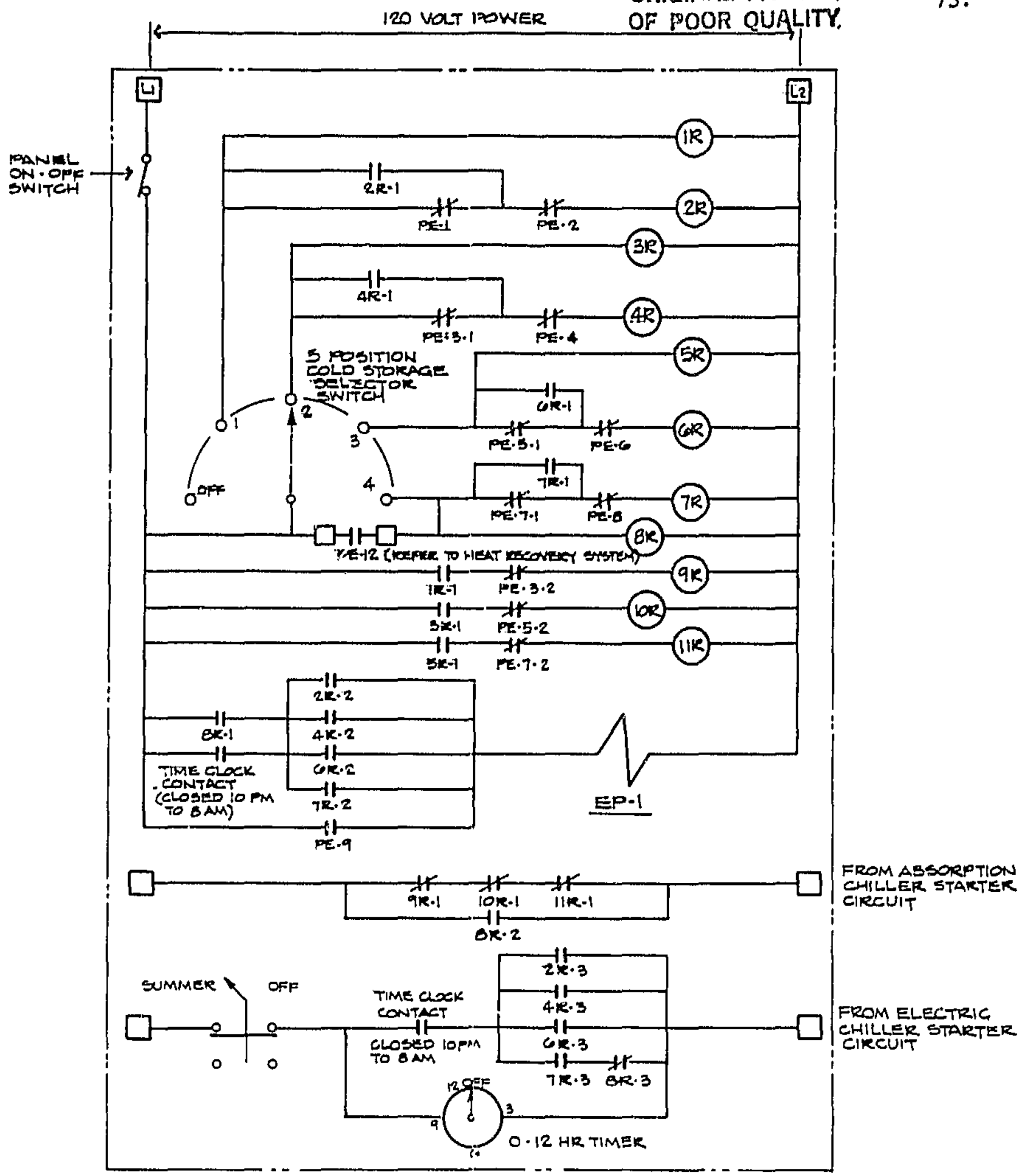
CHILLED WATER SECONDARY SYSTEM

This system will operate identical to a conventional system, with the lead pump being started when the O.A. temperature is above 50 F and the lag pump being started by a differential pressure sensor across the secondary circuit. This will also modulate the two-way bypass valve.

TOWER WATER SYSTEM

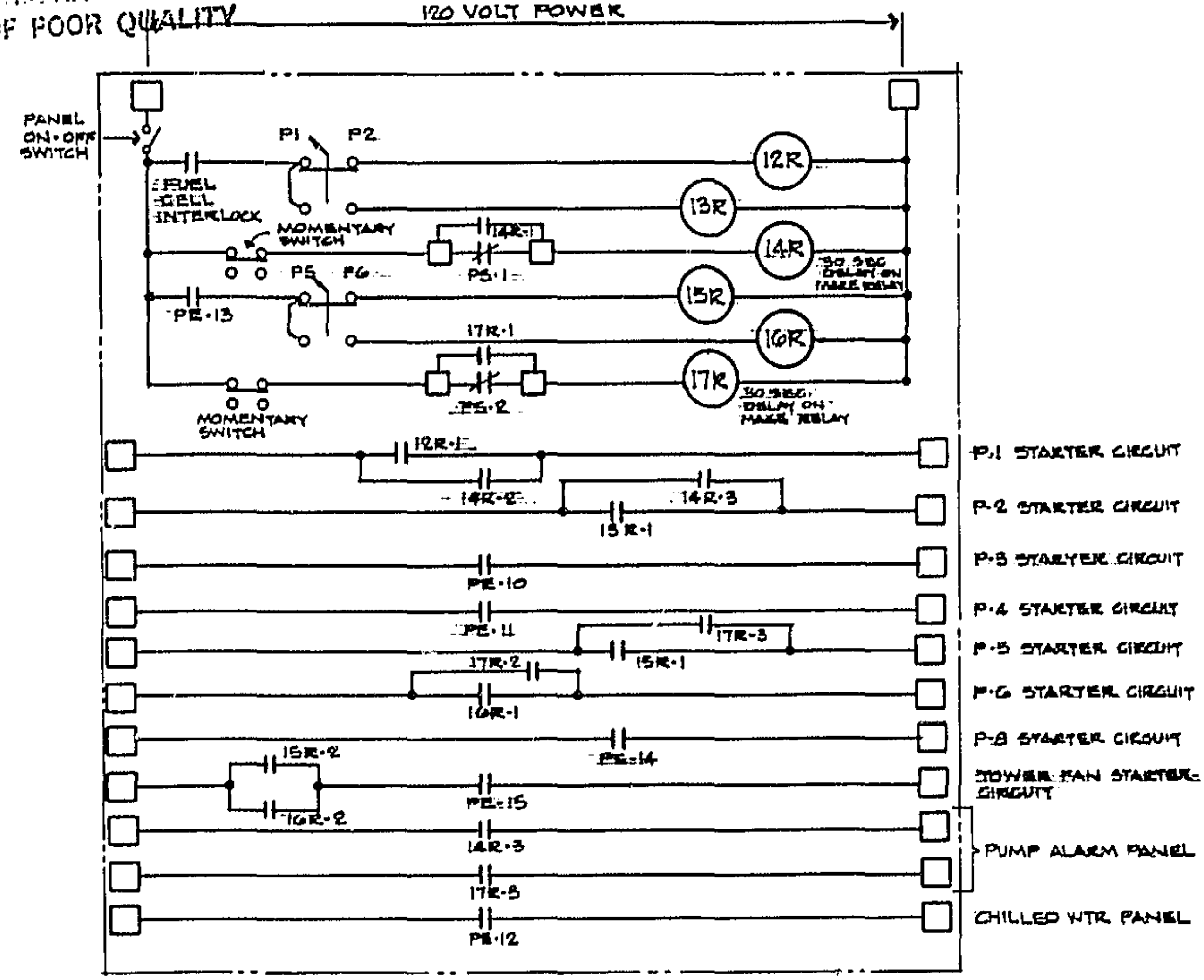
This system will operate identical to a conventional system, with each pump being started with its respective chiller. The two-way bypass valve shall be opened whenever the temperature of the water going to the cooling tower is below 60 F. The tower fans shall be cycled to maintain a 75 F indoor sump temperature and shall be interlocked with the tower water pumps.

4 CHILLED WATER SYSTEM
CONTROL SEQUENCE

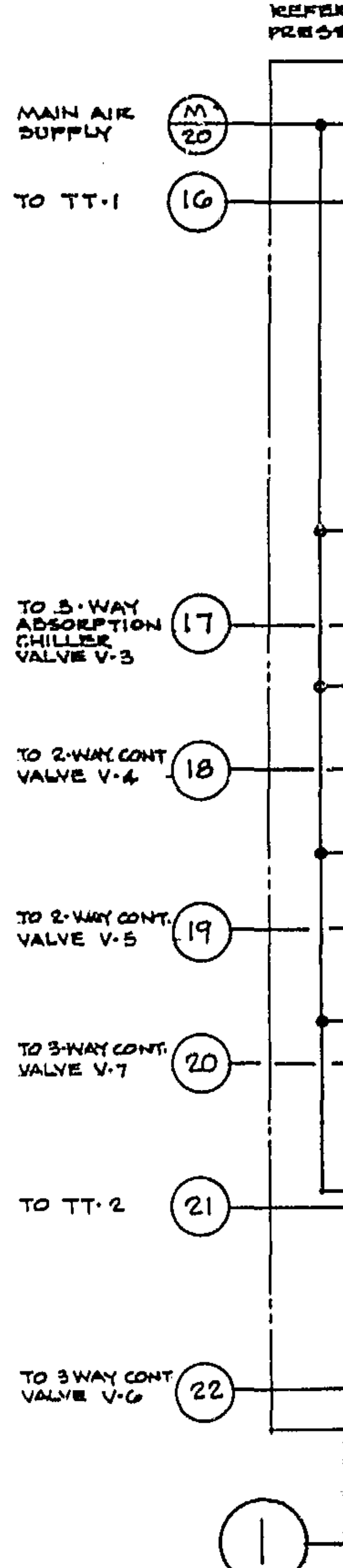


1 CHILLED WATER SYSTEM
ELECTRIC CONTROLS

2 FOLDOUT FRAME



(2) HEAT RECOVERY SYSTEM
ELECTRIC CONTROLS



HEAT TRANSFER FLUID TEMPERATURE CONTROL

The heat transfer fluid pumps P-1 and P-2 shall be interlocked with the fuel cell. A selector switch shall determine which pump will operate. Should the selected pump fail, the other pump shall be started thru pressure switch PS-1 and 30 second delay on make relay 14R. A signal shall be sent to an alarm panel to indicate the pump failure.

Temperature transmitter TT-1 shall transmit the heat transfer fluid temperature entering the fuel cell to temperature controller TC-1, which shall do the following to maintain 330 F return fluid temperature:

1. Modulate the absorption chiller three-way bypass valve V-3 from full bypass to no bypass as the heat transfer fluid temperature rises from 324 F to 327 F. Ratio relay RR-1 will change a 3-6 psi signal to a 3-13 psi signal. Reversing relay RV-1 reverses the 3-13 psi signal to a 13-3 psi signal.
2. Start injection pump P-3 thru PE-10 when the fluid temperature reaches 328 F and modulate two-way control valve V-4 from fully closed at 327 F to fully open at 330 F. Ratio relay RR-2 will change a 6-9 psi signal to a 3-13 psi signal. Pneumatic switching relay PR-1 will close valve V-4 and turn off pump P-3 when the temperature in the domestic water storage tank rises to 200 F, as sensed by aquastat AQ-10.
3. Start injection pump P-4 thru PE-11 when the fluid temperature rises to 331 F and modulate two-way control valve V-5 from fully closed at 330 F to fully open at 333 F. Ratio relay RR-3 will change a 9-12 psi signal to a 3-13 psi signal. Pneumatic switching relay PR-2 will close valve V-5 and stop pump P-4 when the temperature in the heating water storage tank rises to 200 F, as sensed by aquastat AQ-11.
4. Send a rejection signal, thru PE-12, to allow the absorption chiller to cool the entire chilled water storage tank to 45 F when the fluid temperature rises to 334 F.
5. Start the tower water pump thru PE-13 when the fluid temperature rises to 335 F and modulate 3-way control valve V-7 from fully closed at 335 F to fully open at 336 F. Ratio relay RR-4 will change a 12-15 psi signal to a 3-13 psi signal.

TOWER WATER SYSTEM

The tower water pump shall be started thru PE-13 when the heat transfer fluid temperature rises to 335 F. A selector switch shall determine whether P-5 or P-6 will operate. Should the selected pump fail, the other pump shall start and an alarm will be sounded in the same manner as the P-1, P-2 control. The two position tower bypass valve V-8 shall be held open thru pneumatic switching relay PR-3 whenever the water temperature leaving HX-3 is below 70 F as sensed by aquastat AQ-12. When the temperature rises above 70 F, PR-3 shall switch and V-8 shall close. The cooling tower fan shall be interlocked with P-5 and P-6 and shall be started thru PE-15 whenever the temperature in the tower sump reaches 85 F as sensed by aquastat AQ-13.

DOMESTIC WATER HEATING SYSTEM

Circulating pump P-7 shall operate continuously and reclaim heat thru HX-1 whenever it is available. The domestic water tank will be heated to 110 F by tank heater TH-1. Steam/water convertor C-2 shall maintain a 180 F water temperature for the kitchen hot water supply.

BUILDING HEATING SYSTEM

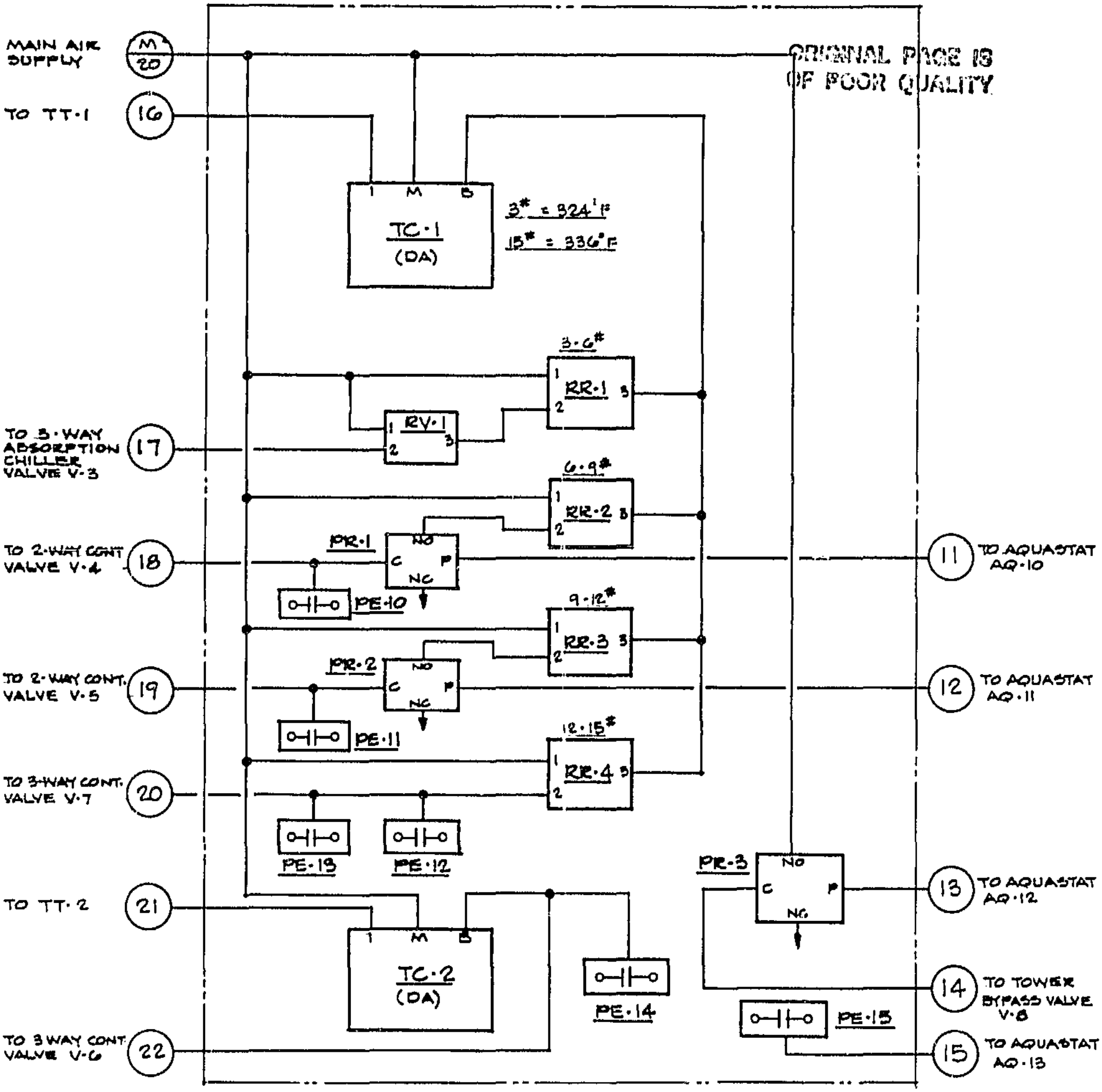
Circulating pump P-8 shall be started thru PE-14 whenever the water temperature on the outlet of HX-2 is above 150 F, as determined by TT-1 and TC-2. 3-way control valve V-6 shall be modulated to maintain 200 F leaving HX-2, as determined by TT-1 and TC-1.

The remainder of the heating system shall operate identical to a conventional system. P-9 or P-10 shall operate continuously, as determined by a selector switch. The temperature leaving converter C-1 shall be reset based on O.A. and shall control 3-way tank bypass valve V-9 and the two-way steam control valves in sequence to maintain set temperature. Reset schedule shall be as follows: 140 F hot water temperature at 25 F outside temperature and below, 100 F hot water temperature at 70 F outside temperature and above.

(3) HEAT RECOVERY SYSTEM
CONTROL SEQUENCE

FOLDOUT FRAME

REFER TO SCHEMATIC FOR AQUASTAT, TRANSMITTER, VALVE & PRESSURE SWITCH LOCATIONS



1 HEAT RECOVERY SYSTEM
PNEUMATIC CONTROLS

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EQUIPMENT SCH

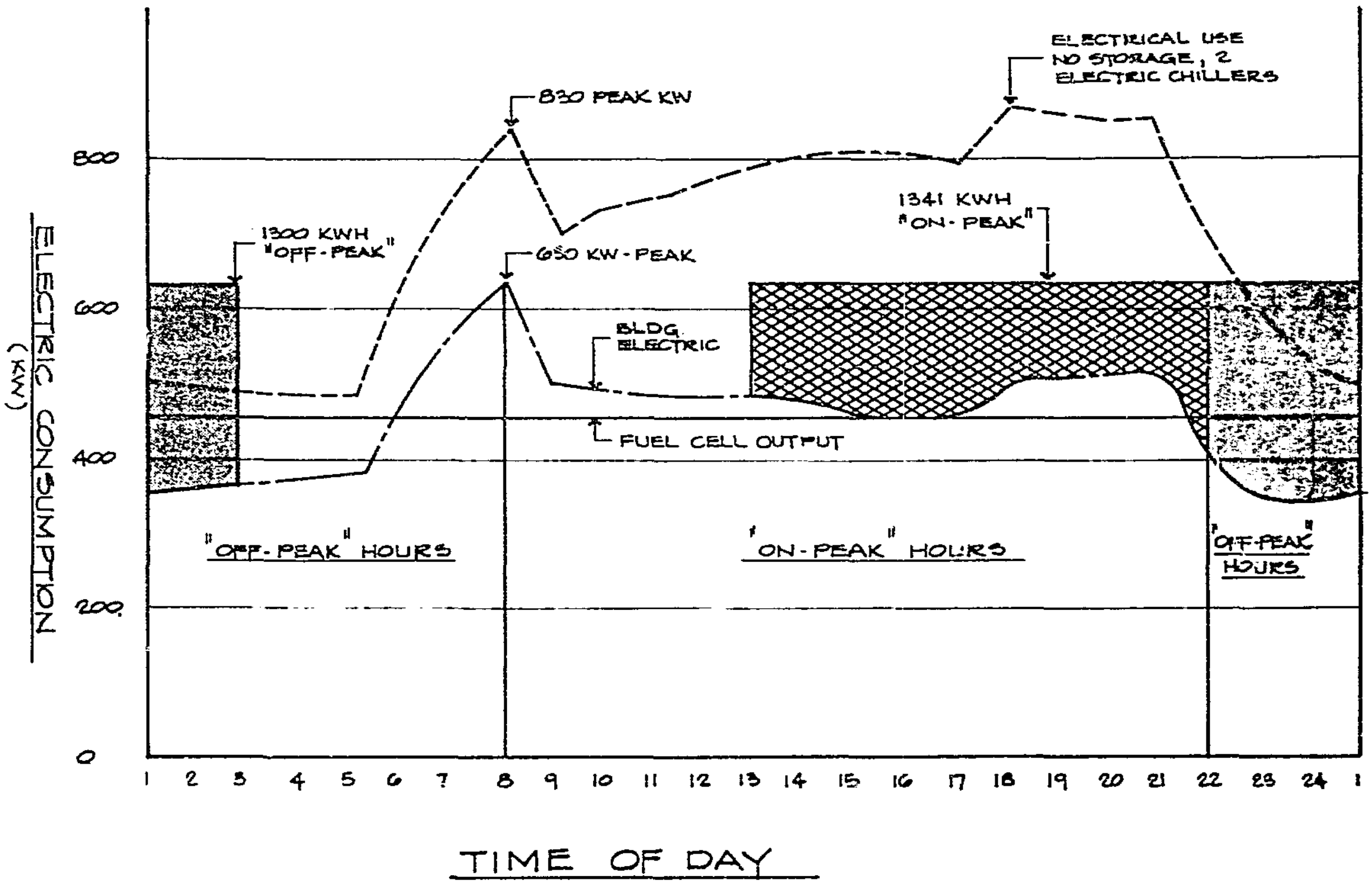
MARK	DESCRIPTION
P-1, P-2	Heat transfer fluid pumps, 320 GPM @ 25 psi and 38 SSU, suitable for 350°F, 20 hp m
P-3, P-4	HX-1, HX-2 injection pumps, 50 GPM @ 25 psi and 38 SSU, suitable for 350°F, 5 hp mo
P-5, P-6	Tower water pumps - CT-2, 107 GFM @ 75' head, 61% efficiency, 3.1 BHP, 5 hp motor,
P-7	Domestic water circulating pump, 50 GPM @ 25' head, 45% efficiency, 0.5 BHP, 3/4 hp
P-8	Heating water reclaim pump, 50 GPM @ 40' head, 50% efficiency, 1.0 BHP, 1-1/2" hp m
P-9, P-10	Heating water pumps, 425 GPM @ 50' head, 70% efficiency, 7.5 BHP, 10 hp motor, 8-1/
P-11	CH-2 evaporator pump, 600 GPM @ 40' head, 81% efficiency, 7.5 BHP, 10 hp motor, 7-1
P-12	CH-1 evaporator pump, 250 GPM @ 40' head, 72% efficiency, 4.0 BHP, 5 hp motor, 7-1/
P-13, P-14	Chilled water secondary pumps, 425 GPM @ 50' head, 70% efficiency, 7.5 BHP, 10 hp m
P-15	CH-1 tower water pump, 450 GPM @ 45' head, 68% efficiency, 7.0 BHP, 10 hp motor, 8-
P-16	CH-2 tower water pump, 900 GPM @ 45' head, 81% efficiency, 12.5 BHP, 15 hp motor, 8
CP-1	Duplex condensate pump, 6000 ф EDR, 9 GPM @ 20 psi, 3500 rpm, 14 gallon receiver,
CH-1	Two stage absorption chiller, 125 tons, cool 250 GPM from 57-45 with 450 GPM of tow
CH-2	Electric centrifugal chiller, 300 tons, cool 600 GPM from 57-45 with 872 GPM of tow
CT-1	Air conditioning cooling tower, cool 1350 GPM from 96°F - 85°F @ 78°F W.B., twin ce
CT-2	Process cooling tower, cool 107 GPM from 120°F - 90°F @ 78°F W.B., counterflow type
HX-1,2	Domestic/heating water reclaim, heat 50 GPM of water from 140-200 F with 95 GPM of
HX-3	Fuel cell thermal dump, cool 80' GPM of multitherm PG-1 from 350-265°F with 107 GP
DR-1	Packaged deaerator, 36" x 72" receiver, duplex pumps - 20 GPM @ 125 psi, 7-1/2 hp
B-1, B-2	150 psi steam boiler, 3000 MBH input, 2250 MBH output, natural gas firing rate 300
C-1	Heating water convertor, heat 425 GPM from 120-140°F with 2 psi steam, 4250 MBH, 4
C-2	Domestic water convertor, heat 22 GPM from 110-180°F with 2 psi steam, 770 MBH, 79
TH-1	Domestic water tank heater, heat 1000 GPH from 50-110°F with 2 psi steam, 500 MBH,
CHS Storage Tanks	ASME steel tank, nominal 25,000 gallons each, (4) required, stamped and tested for
DHS Storage Tank	ASME steel tank, nominal 7500 gallons, stamped and tested for 125 psi, provide w/4
HWS Storage Tank	ASME steel tank, nominal 5500 gallons, stamped and tested for 125 psi, provide w/8
CT-1 Indoor Sump	Steel tank, nominal 2500 gallons, vertical style
CT-2 Indoor Sump	Steel tank, nominal 500 gallons, vertical style

FOLDOUT FRAME

MENT SCHEDULE

	REMARKS
ble for 350°F, 20 hp motor, 47% efficiency	Viking, MR4124V
ble for 350°F, 5 hp motor, 58% efficiency	Viking, K4124V
3.1 BHP, 5 hp motor, 8-5/8" impeller, stuffing box seal, 1750 rpm	Bell & Gossett Series 1510-1-1/2"BB
iency, 0.5 BHP, 3/4 hp motor, 5-1/2" impeller, mechanical seal, 1750 rpm	Bell & Gossett Series 80-1½x1½x7
, 1.0 BHP, 1-1/2" hp motor, 6-1/2" impeller, mechanical seal, 1750 rpm	Bell & Gossett Series 80-1½x1½x7
BHP, 10 hp motor, 8-1/2" impeller, mechanical seal, 1750 rpm	Bell & Gossett Series 1510-3"BB
BHP, 10 hp motor, 7-1/2" impeller, mechanical seal, 1750 rpm	Bell & Gossett Series 1510-4BC
BHP, 5 hp motor, 7-1/4" impeller, mechanical seal, 1750 rpm	Bell & Gossett Series 1510-2-1/2BB
ency, 7.5 BHP, 10 hp motor, 8-1/2" impeller, mechanical seal, 1750 rpm	Bell & Gossett Series 1510-3"BB
0 BHP, 10 hp motor, 8-1/4" impeller, stuffing box seal, 1750 rpm	Bell & Gossett Series 1510-3"BB
.5 BHP, 15 hp motor, 8" impeller, stuffing box seal, 1750 rpm	Bell & Gossett Series 1510-5"BC
, 14 gallon receiver, 1/3 hp pump motors	Domestic 62CC
45 with 450 GPM of tower water @ 85-98.3°F, 350°F concentrator temp	
45 with 872 GPM of tower water @ 85-95°F, 0.707 kw/ton	Trane CVHE-25F-AA-2K-2604DA 12DA-7
F @ 78°F W.B., twin cell, crossflow type, 2 fans @ 10 hp each	B.A.C. CFT (2) 2416
W.B., counterflow type, 5 hp fan motor	B.A.C. VX-45
-200 F with 95 GPM of multitherm PG-1 @ 350-281 F	Tranter UX-016-UJ-26
350-265°F with 107 GPM of tower water @ 90-118.1°F	Tranter UX-016-UJ-26
@ 125 psi, 7-1/2 hp each, two compartment design	Domestic .005cc/liter package
l gas firing rate 3000 ft^3/hr, forced draft fan - 2 hp	Cleaver Brooks M4HP-3000
si steam, 4250 MBH, 4381 #/hr, 125 psi design pressure	Bell & Gossett SU-144-2
si steam, 770 MBH, 794 #/hr, 125 psi design pressure	Bell & Gossett SU-84-4
2 psi steam, 500 MBH, 515 #/hr, 125 psi design pressure	Bell & Gossett TSC 1036
tamped and tested for 125 psi, provide w/12" transfer pipes	11' diameter x 36' long
125 psi, provide w/4" transfer pipes	8' diameter x 20' long
125 psi, provide w/8" transfer pipes	8' diameter x 15' long
	6' diameter x 12' high
	4' diameter x 6' high

FOLDOUT FRAME



BASED ON A DESIGN DAY IN AUGUST AND 0.9 KW/TON FOR ELECTRIC CHILLER

DAILY ELECTRICAL CONSUMPTION

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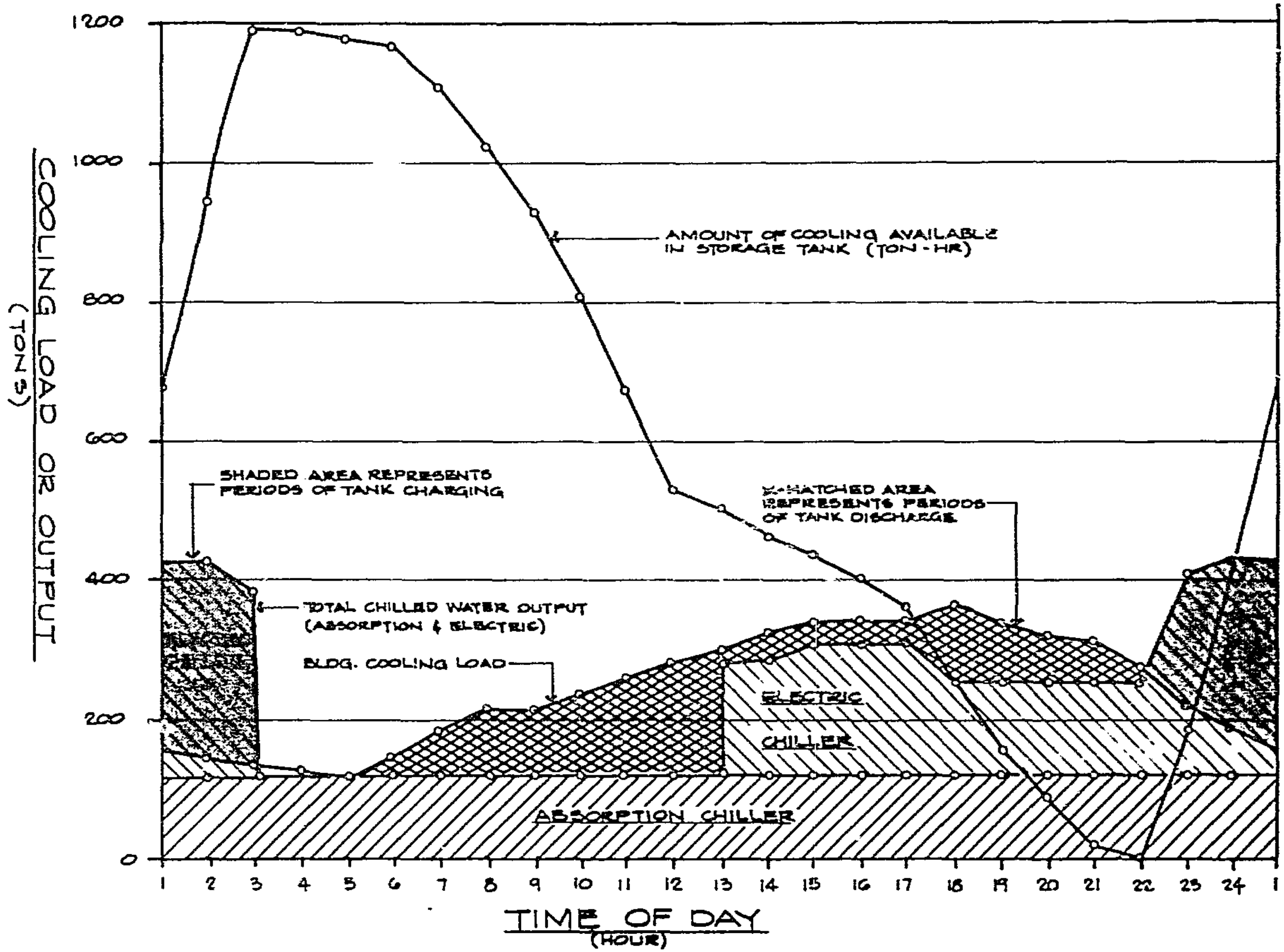
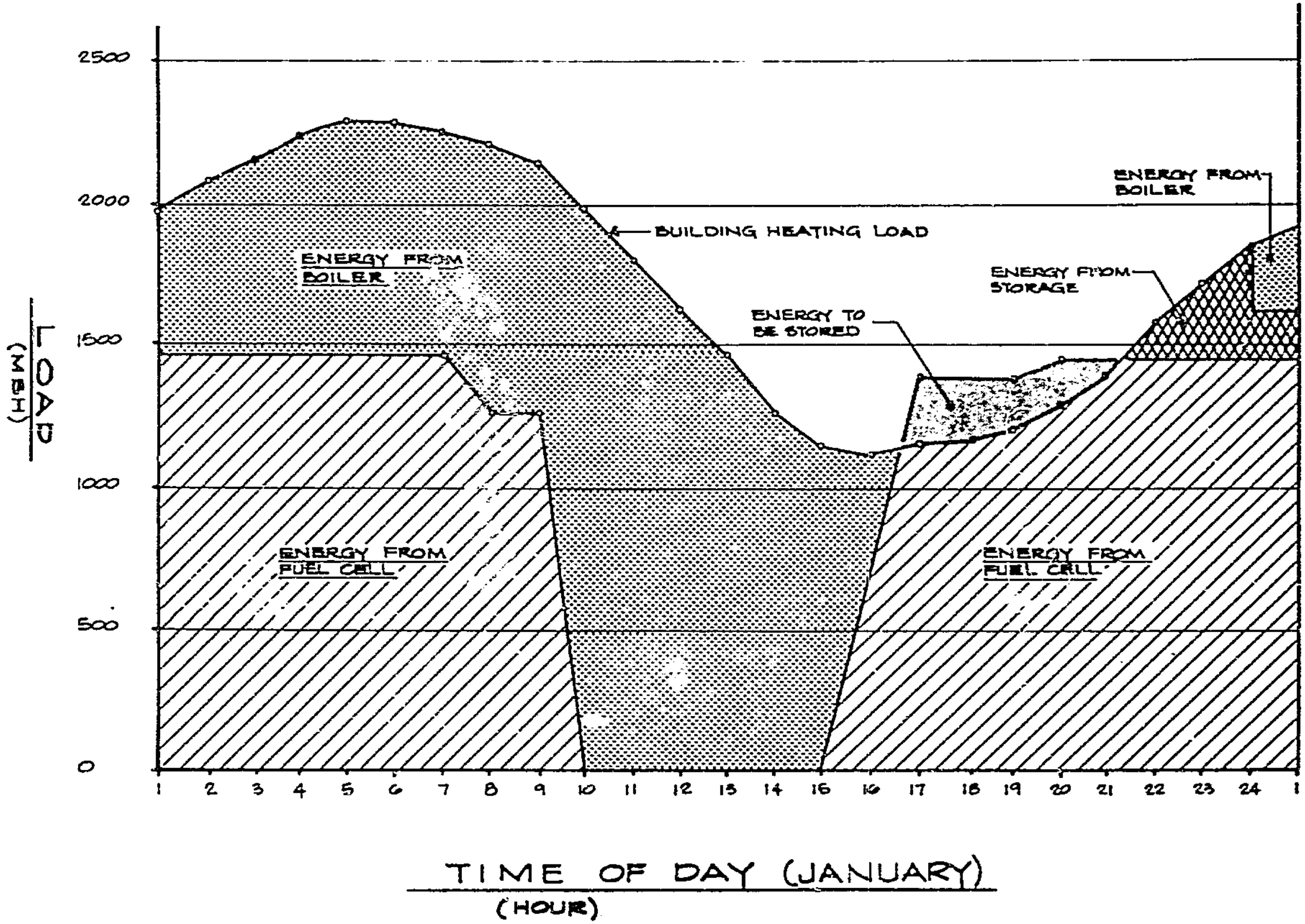
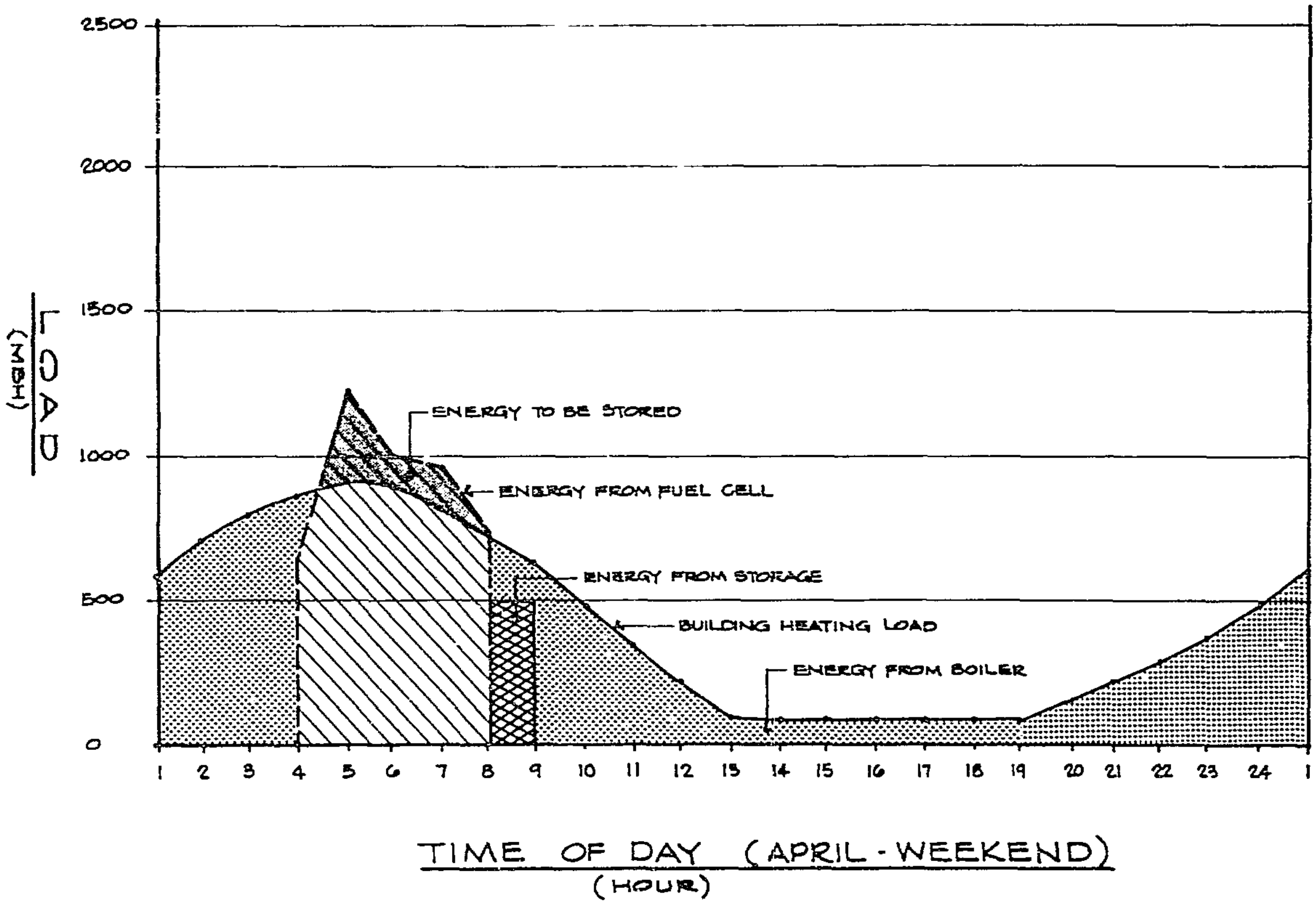


BASED ON A DESIGN DAY IN AUGUST

CHILLED WATER SYSTEM OPERATION

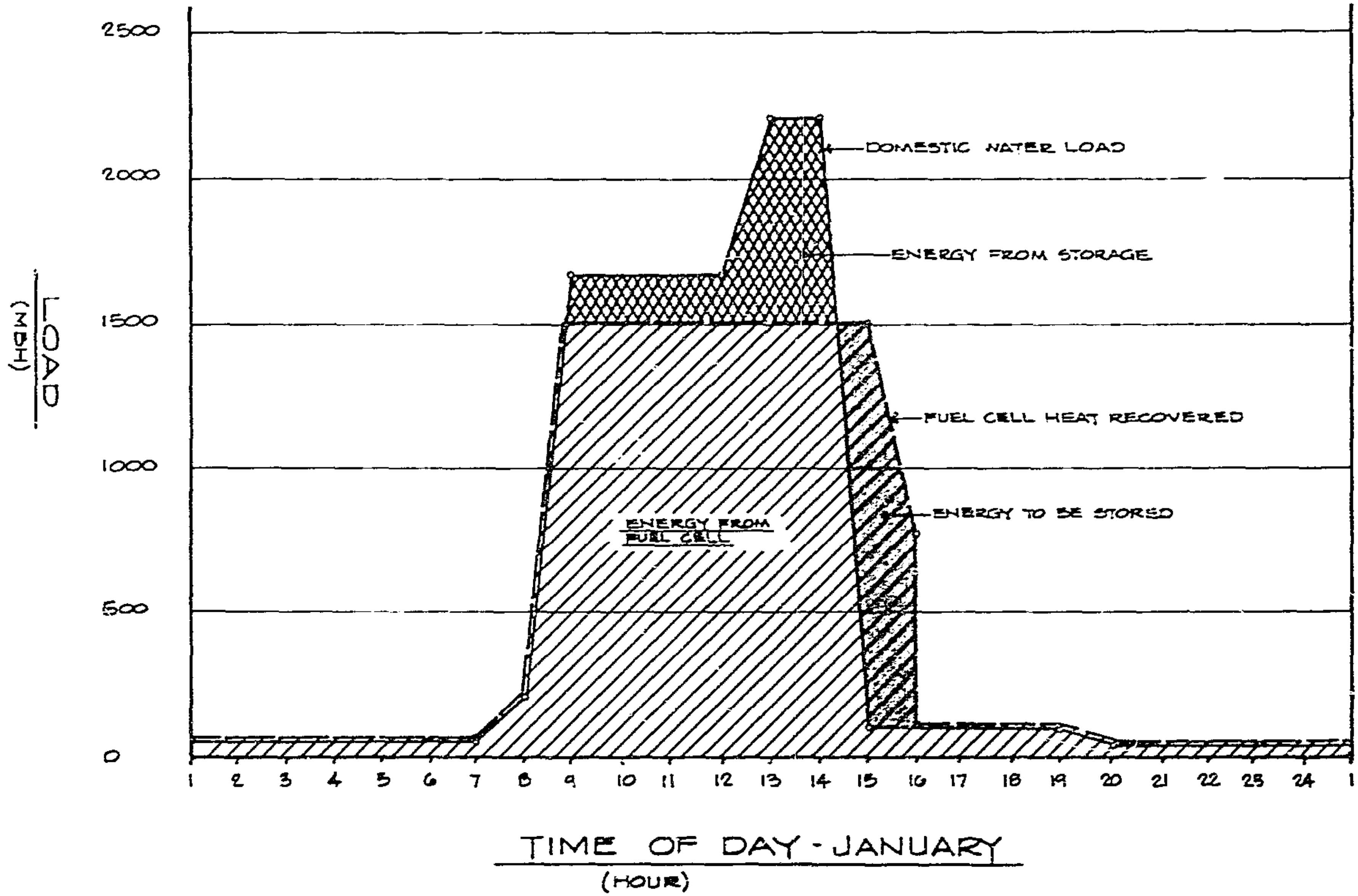


HEATING SYSTEM OPERATION - WINTER

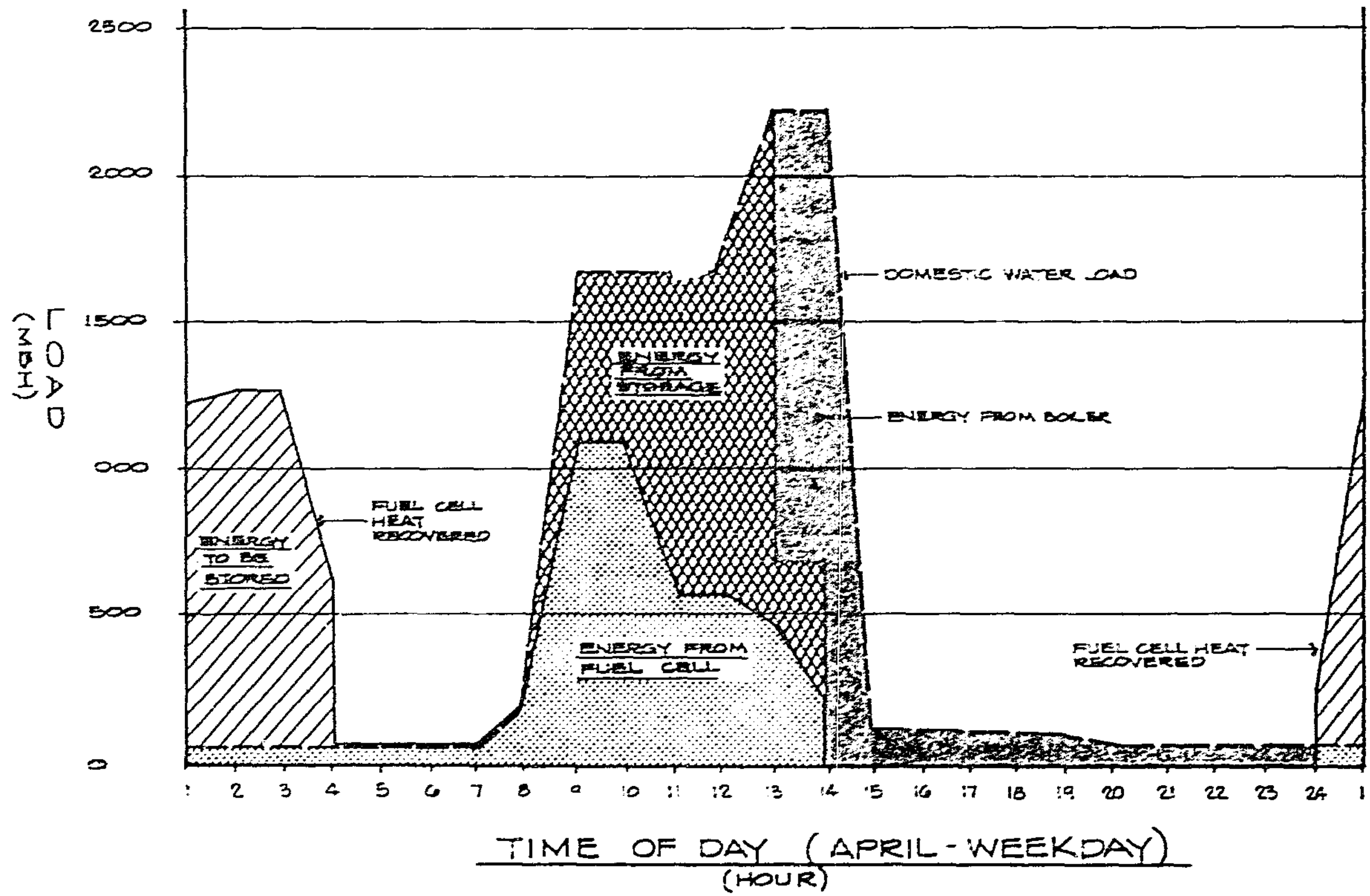


HEATING SYSTEM OPERATION - SPRING

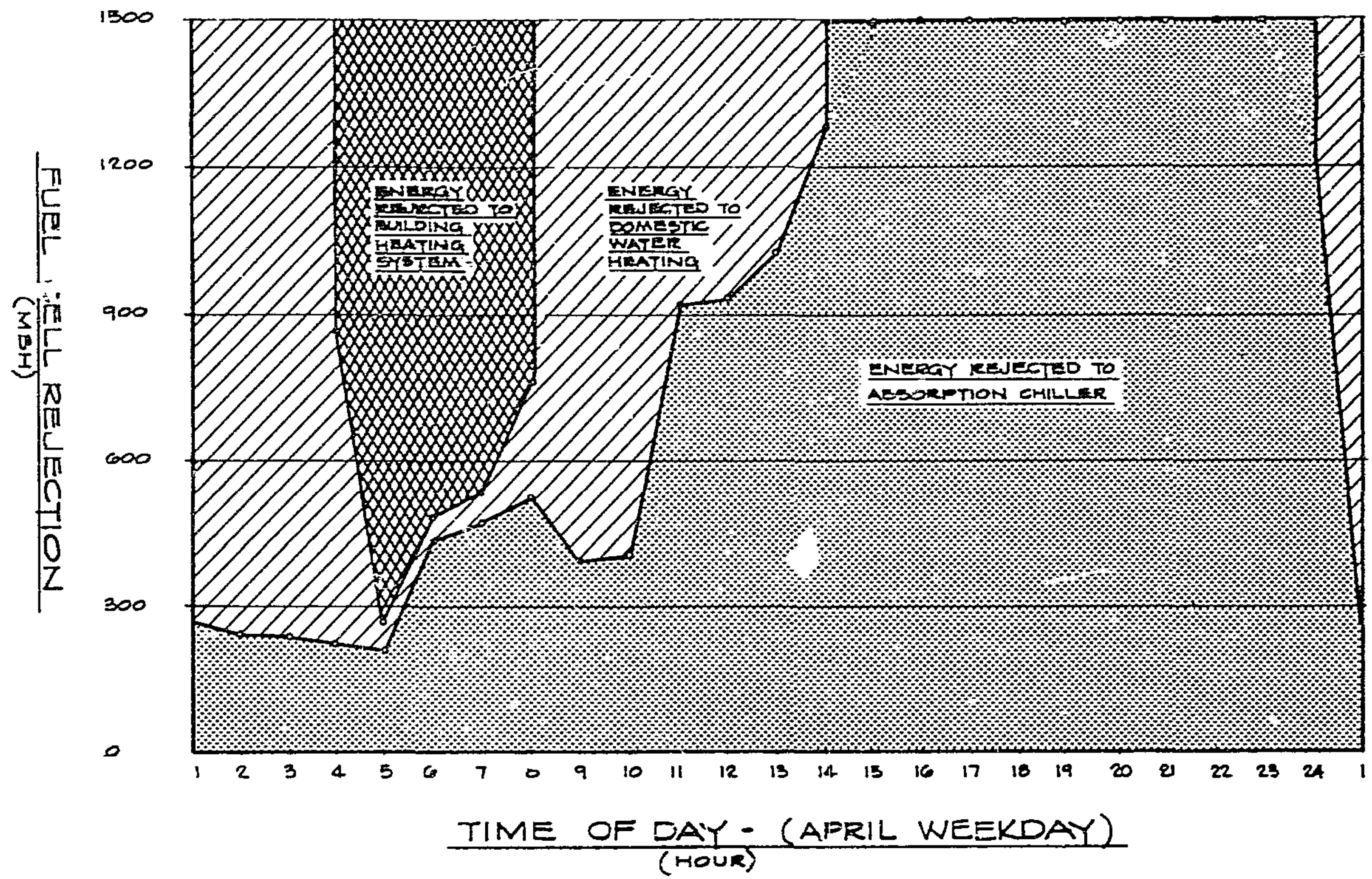
C-2



DOMESTIC WATER SYSTEM OPERATION - WINTER



DOMESTIC WATER SYSTEM OPERATION - SPRING



FUEL CELL HEAT REJECTION USAGE - SPRING

ICE STORAGE VS. WATER STORAGE COMPARISON

(Based on 1200 ton-hrs of storage - pressurized water storage system)

	ICE STORAGE	WATER STORAGE
Mech. Space Req'd. Cost ($30/Sq. Ft.)	900 Sq. Ft. $27,000	2320 Sq. Ft. $69,600
Storage Volume Req'd. Cost	4370 Ft^3 $55,000	13,333 Ft^3 $95,000
Primary Cooling Equip. Cost	(3) 100 Ton Water Cooled Condensing Units $95,000	300 Ton Centrifugal Water Chiller $81,000
Cost of Additional Refrigeration Accessories, Piping and Controls	$20,000	$0
TOTAL COST	**$197,000**	**$245,600**

D. TRACE RUN SUMMARIES

TABLE F1
EFFECT OF FUEL CELL COST
1985 INSTALLATION

RUN	SYSTEM	FUEL CELL COST ($/KW)	INCR. INST'D. COST ($)	1985 UTIL. COST ($)	SPB (YRS)	NPV ($)	IRR (PCT)
HOSPITAL (400 KW)							
CON. ED. RATES							
7	CTV	-	-	741,500	-	-	-
7	FC/CTV/H	980	454,330	532,400	2.2	559,500	36.4
7	FC/CTV/H	1470	650,300	532,400	3.1	380,200	26.2
7	FC/CTV/H	1960	846,300	532,400	4.0	220,400	20.6
40	FC/CTV/H	2940	1,238,300	532,400		-157,400	12.0
COM. ED. RATES							
10	CTV	-	-	528,700	-	-	-
10	FC/CTV/H	980	454,300	444,700	5.4	-130,000	5.3
41	FC/CTV/H	1960	846,300	444,700		-488,600	0.0
41	FC/CTV/H	2940	1,238,300	444,700		-847,000	0.0
APARTMENT (50 KW)							
CON. ED. RATES							
20	CTV	-	-	192,800	-	-	-
20	FC/CTV/H	980	58,450	171,500	2.7	44,700	29.2
42	FC/CTV/H	1960	107,500	171,500	5.0	-735	14.8
42	FC/CTV/H	2940	156,500	171,500	7.3	-45,140	7.5
COM. ED. RATES							
43	CTV	-	-	149,300	-	-	-
43	FC/CTV/H	980	58,450	138,700	5.5	-14,200	4.7
43	FC/CTV/H	1960	107,500	138,700	10.1	-59,700	0.0
RETAIL STORE (65 KW)							
CON. ED. RATES							
28	CTV	-	-	253,600	-	-	-
28	FC/CTV/H	980	76,500	222,300	2.4	73,900	32.7
44	FC/CTV/H	1960	140,200	222,300	4.5	14,300	17.3
44	FC/CTV/H	2940	203,800	222,300	6.5	-47,200	9.2
COM. ED. RATES							
45	CTV	-	-	172,200	-	-	-
45	FC/CTV/H	980	76,500	158,500	5.6	-23,400	3.4
45	FC/CTV/H	1960	140,200	158,500	10.3	-83,100	0.0
45	FC/CTV/H	2940	203,800	158,500	14.9	-144,600	0.0
OFFICE BUILDING (85 KW)							
CON. ED. RATES							
24	CTV	-	-	193,200	-	-	-
24	FC/CTV/H	980	95,500	168,900	3.9	-6,263	12.8
46	FC/CTV/H	1960	178,800	168,900	7.3	-85,300	0.0
46	FC/CTV/H	2940	262,100	168,900	10.8	-159,100	0.0

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TABLE F2
EFFECT OF FUEL CELL CAPACITY

HOSPITAL (PRIV. OWNED), WASHINGTON,DC
CON. ED. ELECTRIC RATES
$980/KW FUEL CELL COST IN 1985

RUN	SYSTEM	LOAD PROFILE (KW)	FUEL CELL CAPAC. (KW)	INCREM. INST'D COST ($)	1985 UTILITY COST ($)	SPB (YRS)	NPV ($)	IRR (PCT)
2	CTV		-	-	741,500	-	-	-
2	FC/CTV	387(B)	400	436,000	544,400	2.2	495,900	35.2
		579(A)	590	643,100	490,400	2.6	493,100	30.1
		855(P)	940	1,024,600	494,800	4.2	-104,700	11.7
4	FC/ABS1	393(B)	400	517,400	621,000	4.3	-76,600	10.2
		553(A)	520	648,200	560,500	3.6	83,600	18.2
		796(P)	700	844,400	503,400	3.5	137,200	19.0
5	FC/ABS2	396(B)	400	553,600	565,300	3.1	247,300	24.0
		544(A)	520	684,400	514,700	3.0	334,500	24.7
		775(P)	700	880,600	469,500	3.2	313,600	22.6
31	FC/CTV/ABS2							
		344(B)	400	506,500	510,000	2.2	609,600	35.5
		514(A)	520	643,600	476,300	2.4	602,300	32.0
		784(P)	700	851,900	451,000	2.9	444,100	25.7
- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
3	FC/CTV/H	387(B)	400	454,300	532,400	2.2	559,500	36.4
48			460	519,700	512,800	2.2	572,900	34.6
48			520	585,100	496,500	2.3	567,200	32.8
48		579(A)	590	661,400	481,800	2.3	535,500	30.5
	FC/CTV/ABS2/H							
32		344(B)	400	515,500	503,800	2.2	644,800	36.0
54			440	561,000	488,500	2.2	655,000	35.0
54			480	607,900	473,300	2.3	654,900	34.2
54		514(A)	520	652,600	460,600	2.3	645,000	33.4

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TABLE F2
EFFECT OF FUEL CELL CAPACITY

HOSPITAL (PRIV. OWNED), WASHINGTON,DC
CON. ED. ELECTRIC RATES
$980/KW FUEL CELL COST IN 1985

RUN	SYSTEM	LOAD PROFILE (KW)	FUEL CELL CAPAC. (KW)	INCREM. INST'D COST ($)	1985 UTILITY COST ($)	SPB (YRS)	NPV ($)	IRR (PCT)
2	CTV		-	-	741,500	-	-	-
2	FC/CTV	387(B)	400	436,000	544,400	2.2	495,900	35.2
		579(A)	590	643,100	490,400	2.6	493,100	30.1
		855(P)	940	1,024,600	494,800	4.2	-104,700	11.7
4	FC/ABS1	393(B)	400	517,400	621,000	4.3	-76,600	10.2
		553(A)	520	648,200	560,500	3.6	83,600	18.2
		796(P)	700	844,400	503,400	3.5	137,200	19.0
5	FC/ABS2	396(B)	400	553,600	565,300	3.1	247,300	24.0
		544(A)	520	684,400	514,700	3.0	334,500	24.7
		775(P)	700	880,600	469,500	3.2	313,600	22.6
31	FC/CTV/ABS2							
		344(B)	400	506,500	510,000	2.2	609,600	35.5
		514(A)	520	643,600	476,300	2.4	602,300	32.0
		784(P)	700	851,900	451,000	2.9	444,100	25.7
- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
3	FC/CTV/H	387(B)	400	454,300	532,400	2.2	559,500	36.4
48		.	460	519,700	512,800	2.2	572,900	34.6
48			520	585,100	496,500	2.3	567,200	32.8
48		579(A)	590	661,400	481,800	2.3	535,500	30.5
	FC/CTV/ABS2/H							
32		344(B)	400	515,500	503,800	2.2	644,800	36.0
54			440	561,000	488,500	2.2	655,000	35.0
54			480	607,900	473,300	2.3	654,900	34.2
54		514(A)	520	652,600	460,600	2.3	645,000	33.4

TABLE F3
EFFECT OF SYSTEM TYPE

WASHINGTON, DC; CON. ED. ELECTRIC RATES
$980/KW FUEL CELL COST IN 1985

BUILDING RUN	SYSTEM	FUEL CELL CAPAC. (KW)	HOT STOR. CAPAC. (E6 BTU)	INCREM. INST'D COST ($)	1985 UTILITY COST ($)	SPB (YRS)	NPV ($)	IRR (PCT)
HOSPITAL (PRIV. OWNED)								
2	CTV	-	-	-	741,500	-	-	-
2	FC/CTV	400(B)	0	436,000	544,400	2.2	495,900	35.2
3	FC/CTV/H	400(B)	6.5	454,300	532,400	2.2	559,500	36.4
33	FC/CTV/H/C	400(B)	6.5	554,400	519,000	2.5	593,700	33.6
31	FC/CTV/ABS2	400(B)	0	506,500	510,100	2.2	609,600	35.5
32	FC/CTV/ABS2/H	400(B)	3.2	515,500	503,800	2.2	644,800	36.0
52	FC/CTV/ABS1	400(B)	0	485,300	540,000	2.4	439,200	31.8
52	FC/CTV/ABS1/H	400(B)	2.0	490,900	536,800	2.4	455,600	32.0
5	FC/ABS2	520(A)	0	684,400	514,700	3.0	334,500	24.7
35	FC/ABS2/H	520(A)	6.4	702,400	500,800	2.9	410,600	26.2
4	FC/ABS1	700(P)	0	844,400	503,400	3.5	137,200	19.0
APARTMENT								
19	CTV	-	-	-	192,800	-	-	-
19	FC/CTV	135(A)	0	147,200	138,600	2.7	101,300	28.6
49	FC/CTV/H	135(A)	1.4	151,150	135,900	2.7	114,920	29.5
21	FC/ABS1	235(P)	0	281,500	135,300	4.9	-80,500	3.9
36	FC/ABS1/H	235(P)	4.2	293,300	125,800	4.4	-25,400	12.6
RETAIL STORE								
27	CTV	-	-	-	253,600	-	-	-
27	FC/CTV	65(B)	0	70,850	228,100	2.8	39,570	26.9
28	FC/CTV/H	65(B)	2.0	76,500	222,300	2.4	73,900	32.7
29	FC/ABS1	300(P)	0	381,200	201,600	7.3	-277,100	0
36	FC/ABS1/H	300(P)	3.8	391,900	192,100	6.3	-225,200	0
OFFICE BLDG								
23	CTV	-	-	-	193,200	-	-	-
23	FC/CTV	85(B)	0	92,650	169,200	3.9	-6,400	12.6
24	FC/CTV/H	85(B)	1.0	95,500	168,900	3.9	-6,260	12.8
25	FC/ABS1	165(A)	0	195,900	151,100	4.6	-57,640	0
37	FC/ABS1/H	165(A)	0.2	199,400	150,600	4.7	-58,420	0

FC = FUEL CELL
CTV = 'CENTRAVAC' ELECTRIC CHILLER
ABS1 = SINGLE STAGE ABSORPTION
ABS2 = TWO STAGE ABSORPTION
H = HOT SIDE THERMAL STORAGE
C = COLD SIDE THERMAL STORAGE

SPB = SIMPLE PAYBACK PERIOD
NPV = NET PRESENT VALUE (15%)
IRR = INTERNAL RATE OF RETURN (AFTER TAX)

TABLE F4
EFFECT OF LOCATION

HOSPITAL (PRIV. OWNED), 400 KW FUEL CELL
$980/KW FUEL CELL COST IN 1985

RUN	LOC.	ELEC. UTILITY	SYSTEM	INCR. INST'D. COST ($)	1985 UTILITY COST ($)	SPB (YRS)	NPV ($)	IRR (PCT)
13	NY	CON. ED.	CTV	-	741,000	-	-	-
			FC/CTV/H	454,330	524,200	2.1	607,800	37.6
17	ATL	GEO. PWR.	CTV	-	682,700	-	-	-
			FC/CTV/H	454,330	478,600	2.2	521,000	35.3
14	BOS	BOS. ED.	CTV	-	675,100	-	-	-
			FC/CTV/H	454,330	475,600	2.3	516,400	34.8
18	NEWK	N.J.P.S.	CTV	-	632,100	-	-	-
			FC/CTV/H	454,330	465,800	2.7	329,600	28.8
16	CHIC	COM. ED.	CTV	-	561,000	-	-	-
			FC/CTV/H	454,330	461,200	4.6	-31,870	13.1
15	L.A.	SO.CAL.ED.	CTV	-	513,500	-	-	-
			FC/CTV/H	454,330	422,100	5.0	-119,900	4.9

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TABLE F5
EFFECT OF RATE STRUCTURE ONLY

ALL CASES FOR WASHINGTON, DC CLIMATE
HOSPITAL (PRIV. OWNED), 400 KW FUEL CELL CAPACITY
$980/KW FUEL CELL COST IN 1985

RUN	ELEC. UTILITY	SYSTEM	INCR. INST'D. COST ($)	1985 UTILITY COST ($)	SPB (YRS)	NPV ($)	IRR (PCT)
3	CON. ED.	CTV	-	741,500	-	-	-
		FC/CTV/H	454,330	532,400	2.2	559,500	36.4
11	GEO. PWR.	CTV	-	701,000	-	-	-
		FC/CTV/H	454,330	482,500	2.1	611,500	37.8
8	BOS. ED.	CTV	-	677,500	-	-	-
		FC/CTV/H	454,330	491,600	2.4	430,700	32.3
12	N.J.P.S.	CTV	-	632,600	-	-	-
		FC/CTV/H	454,330	474,600	2.9	278,200	27.1
9	SO.CAL.ED.	CTV	-	580,600	-	-	-
		FC/CTV/H	454,330	453,300	3.6	108,700	20.4
10	COM. ED.	CTV	-	528,700	-	-	-
		FC/CTV/H	454,330	444,700	5.4	-130,000	5.3

TABLE F6
EFFECT OF TAXES

HOSPITAL, WASHINGTON, DC
CON. ED. ELECTRIC RATES
400 KW FUEL CELL CAPACITY
$980/KW FUEL CELL COST IN 1985

RUN	SYSTEM	OWNERSHIP	TAX RATE (PCT)	INCR. INST'D. COST ($)	1985 UTILITY COST ($)	SPB (YRS)	NPV ($)	IRR (PCT)
1	CTV	TAX-EXEMPT	0	-	741,500		-	-
	FC/CTV	TAX-EXEMPT	0	436,000	544,400	2.2	1,076,000	47.7
2	CTV	PRIVATE	46	-	741,500	-	-	-
	FC/CTV	PRIVATE	48	436,000	544,400	2.2	495,900	35.2

EFFECT OF ENERGY PRICE ESCALATION RATE

HOSPITAL (PRIV. OWNED), WASHINGTON, DC
CON. ED. ELECTRIC RATES
$980/KW FUEL CELL COST IN 1985
FC/CTV/H SYSTEM, 400 KW FUEL CELL

RUN		ENERGY PRICE ESCALATION 1985-90 (PCT)	AFTER 1990 (PCT)	SPB (YRS)	NPV ($)	IRR (PCT)
3	NAT. GAS	12	9			
	ELECTRIC	9	7	2.2	559,500	36.4
3A	NAT. GAS	12	9			
	ELECTRIC	12	9	2.2	669,500	38.6

E. SAMPLE TRACE OUTPUT SUMMARY
(Selected Pages)

BASE SYSTEM

SYSTEM		1	2	3	4
CFM - TOTAL	MAIN	10024.7	[illegible]	[illegible]	[illegible]
	SKIN	0.0	0.0	0.0	0.0
CFM - OUTSIDE AIR	MAIN	[illegible]	[illegible]	[illegible]	[illegible]
COOLING TONS	MAIN	[illegible]	[illegible]	[illegible]	[illegible]
	SKIN	0.0	0.0	0.0	0.0
COOLING SUPPLY AIR DRY BULB	MAIN	55.0	55.0	55.0	55.0
	SKIN	0.0	0.0	0.0	0.0
HEATING MBH	MAIN	210.6	[illegible]	[illegible]	1514.5
	SKIN	0.0	0.0	0.0	0.0
HEATING SUPPLY AIR DRY BULB	MAIN	0.0	[illegible]	[illegible]	[illegible]
	SKIN	0.0	0.0	0.0	0.0

MONTHLY ENERGY CONSUMPTION

MONTH	ELEC KWH PEAK	ELEC KWH OFFPK	GAS THERM PEAK	WATER 1000 G PEAK	DEMAND KW PEAK
JAN	167319.	[illegible]	[illegible]	114.	652.
FEB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MARCH	[illegible]	[illegible]	[illegible]	127.	701.
APRIL	[illegible]	[illegible]	13035.	[illegible]	710.
MAY	[illegible]	[illegible]	10740.	[illegible]	740.
JUNE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
JULY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
AUG	[illegible]	[illegible]	9752.	[illegible]	844.
SEPT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
OCT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NOV	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DEC	[illegible]	[illegible]	[illegible]	113.	[illegible]
TOTAL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] ENERGY CONSUMPTION = [illegible] BTU / CONDITIONED SQUARE FEET / YEAR. [illegible] FOOTAGE = [illegible]
SOURCE ENERGY CONSUMPTION = [illegible] BTU / CONDITIONED SQUARE FEET / YEAR.

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BASE SYSTEM

SYST #		1	2	3	4
CFM – TOTAL	MAIN	10024.7	38490.5	10665.0	136624.9
	SKIN	0.0	0.0	0.0	0.0
CFM – OUTSIDE AIR	MAIN	[illegible]0.0	1[illegible]0.0	[illegible]0.0	2215.0
COOLING TONS	MAIN	44.9	231.1	2[illegible].9	2[illegible].7
	SKIN	0.0	0.0	0.0	0.0
COOLING SUPPLY AIR DRY BULB .	MAIN	55.0	55.0	55.0	55.0
	SKIN	0.0	0.0	0.0	0.0
HEATING MBH	MAIN	210.6	2166.5	2[illegible].5	1514.5
	SKIN	0.0	0.0	0.0	0.0
HEATING SUPPLY AIR DRY BULB .	MAIN	0.0	[illegible].9	[illegible]	1[illegible].1
	SKIN	0.0	0.0	0.0	0.0

MONTHLY ENERGY CONSUMPTION

MONTH	ELEC KWH PEAK	ELEC KWH OFFPK	GAS THERM PEAK	WATER 1000 G PEAK	DEMAND KW PEAK
JAN	167019.	203909.	29650.	114.	652.
FEB	161[illegible]27.	178526.	25586.	110.	658.
MARCH	187412.	193228.	22587.	127.	701.
APRIL	172[illegible].	205725.	13035.	242.	710.
MAY	205[illegible].	217[illegible]2.	10740.	240.	740.
JUNE	22[illegible]519.	233597.	[illegible]520.	575.	815.
JULY	[illegible].	268550.	[illegible]14.	[illegible]	517.
AUG	245252.	250544.	9752.	755.	844.
SEPT	197[illegible].	240432.	9455.	461.	755.
OCT	200[illegible].	21[illegible].	11[illegible].	[illegible]	727.
NOV	177120.	1[illegible]705.	1[illegible].	[illegible]	[illegible]
DEC	160[illegible].	211490.	29[illegible].	113.	[illegible]
TOTAL	2[illegible]77.	26[illegible].	15[illegible]7.	35[illegible].	[illegible]44.

[illegible] = [illegible] BTU / CONDITIONED SQUARE FEET / YEAR. [illegible] FOOTAGE = 1[illegible].

SOURCE ENERGY CONSUMPTION = [illegible]1. BTU / CONDITIONED SQUARE FEET / YEAR.

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[illegible]
440 KW FC/CTV/ABS2/H-25. 7060 [illegible] STCH

440 KW FC/CTV/ABS2/H SYSTEM

SYSTEM		1	2	3	4
CFM - TOTAL	MAIN	10334.7	34400.0	106[illegible]5.0	126624.5
	SKIN	0.0	0.0	0.0	0.0
CFM - OUTSIDE AIR	MAIN	[illegible]0.0	26400.0	320.0	[illegible]
COOLING TONS	MAIN	44.9	231.1	25.5	202.7
	SKIN	0.0	0.0	0.0	0.0
COOLING SUPPLY AIR DRY BULB .	MAIN	55.0	55.0	55.0	55.0
	SKIN	0.0	0.0	0.0	0.0
HEATING CFM	MAIN	210.0	2166.5	335.5	151[illegible]
	SKIN	0.0	0.0	0.0	0.0
HEATING SUPPLY AIR DRY BULB .	MAIN	0.0	[illegible]	[illegible]	[illegible]
	SKIN	0.0	0.0	0.0	0.0

MONTHLY ENERGY CONSUMPTION

					FUEL CELL				NET
MONTH	ELEC KWH PEAK	ELEC KWH OFFPK	GAS THERM PEAK	WATER 1000 G PEAK	COGEN KWH PEAK	COGEN KWH OFFPK	COGEN KWH SELCH	CHATH THERM PEAK	DEMAND KW PEAK
JAN	157[illegible]1.	152017.	40830.	146.	129360.	15[illegible]00.	0.	[illegible]	216.
FEB	152272.	167921.	35645.	144.	122200.	172480.	0.	88.	221.
MARCH	175471.	162475.	36654.	155.	141[illegible]0.	18[illegible]0.	0.	87.	221.
APRIL	159364.	150087.	32555.	354.	122200.	154[illegible]00.	0.	53.	224.
MAY	187166.	191686.	32966.	467.	58080.	220560.	28720.	54.	2[illegible].
JUNE	209452.	158272.	34050.	773.	58[illegible]0.	22[illegible]00.	38720.	[illegible]2.	321.
JULY	151[illegible]7.	227769.	35750.	974.	5[illegible].	23[illegible]0.	252[illegible].	80.	222.
AUG	228314.	224558.	36106.	587.	60720.	226160.	40480.	80.	328.
SEPT	183272.	204421.	33423.	642.	52800.	200[illegible]00.	35200.	82.	305.
OCT	183716.	18[illegible].	33003.	440.	121[illegible]0.	1[illegible]1[illegible]0.	0.	54.	227.
NOV	161233.	155215.	33488.	21[illegible].	125[illegible]0.	1[illegible].	0.	[illegible]	[illegible]
DEC	151407.	159376.	39255.	10[illegible].	1[illegible]3200.	264180.	0.	87.	221.
TOTAL	2130986.	2361653.	424678.	5404.	11[illegible]000.	247[illegible]80.	188270.	1045.	32[illegible].

BUILDING ENERGY CONSUMPTION = 25[illegible]. BTU / [illegible]
SOURCE ENERGY CONSUMPTION = 4[illegible]301. BTU / [illegible]

SQUARE FOOTAGE = 156400.

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BASE SYSTEM

MORTGAGE LIFE:	20 YEARS	DEPRECIATION METHOD:	
MORTGAGE INTEREST:	15.00%	TAX	DECLINING BALANCE
PERCENT FINANCED:	80.00%	BOOK	STRAIGHT LINE
PROPERTY TAXES:	1.00%		
INSURANCE:	0.50%	DECLINING BALANCE RATE:	
INCOME TAX RATE:	46.00%	TAX	200.%
COST OF CAPITAL:	15.00%		

SYSTEM	FIRST COST	ADDITIONAL FIRST	COST TOTAL	MAINTENANCE	MAINTENANCE TOTAL
1	$ 0.0 / TON	$ 0.	$ 0.	$ 28.00 / TON	$ 1257.
2	$ 0.0 / TON	$ 0.	$ 0.	$ 28.00 / TON	$ 6471.
3	$ 0.0 / TON	$ 0.	$ 0.	$ 28.00 / TON	$ 836.
4	$ 0.0 / TON	$ 0.	$ 0.	$ 28.00 / TON	$ 5676.
TOTALS		$ 0.	$ 0.		$ 14240.

MONTHLY UTILITY COST IN DOLLARS

MONTH	ELECTRIC	GAS	OIL	STEAM	CU CHC	CCG ENERGY	CCG CAPACITY	DEMAND
JAN	31104.	24713.	0.	0.	0.	0.	0.	5105.
FEB	28597.	20981.	0.	0.	0.	0.	0.	9183.
MAR	32126.	16516.	0.	0.	0.	0.	0.	9223.
APR	[illegible]	10688.	0.	0.	0.	0.	0.	[illegible]
MAY	36681.	8807.	0.	0.	0.	0.	0.	24456.
JUNE	38624.	7806.	0.	0.	0.	0.	0.	26912.
JULY	35539.	8047.	0.	0.	0.	0.	0.	26582.
AUG	42123.	7557.	0.	0.	0.	0.	0.	27874.
SEPT	36729.	7756.	0.	0.	0.	0.	0.	21923.
OCT	35173.	9056.	0.	0.	0.	0.	0.	9568.
NOV	31125.	15254.	0.	0.	0.	0.	0.	[illegible]
DEC	31067.	23159.	0.	0.	0.	0.	0.	9155.
TOTAL	$ 414767.	$ 162415.	$ 0.	$ 0.	$ 0.	$ 0.	$ 0.	$ 196492.

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BASE SYSTEM

YEAR	UTILITY COST	MAINT COST	INTEREST COST	PRINCIPAL COST	PROPERTY TAXES	INSURANCE COST	REPLACE EXPENSE	DEPRECIATION TAX	DEPRECIATION BOOK	CASH FLOW EFFECT
1	773675.	14740.	0.	0.	0.	0.	0.	0.	0.	434716.
2	864740.	15237.	0.	0.	0.	0.	0.	0.	0.	452154.
3	942337.	16304.	0.	0.	0.	0.	0.	0.	0.	495024.
4	1041767.	17445.	0.	0.	0.	0.	0.	0.	0.	550790.
5	1150536.	18606.	0.	0.	0.	0.	0.	0.	0.	607570.
6	1270648.	19573.	0.	0.	0.	0.	0.	0.	0.	671133.
7	1365335.	21371.	0.	0.	0.	0.	0.	0.	0.	721054.
8	1467151.	22667.	0.	0.	0.	0.	0.	0.	0.	774669.
9	1576657.	24469.	0.	0.	0.	0.	0.	0.	0.	832582.
10	1694430.	26150.	0.	0.	0.	0.	0.	0.	0.	894717.
11	1821120.	28013.	0.	0.	0.	0.	0.	0.	0.	961549.
12	1957405.	29974.	0.	0.	0.	0.	0.	0.	0.	1033437.
13	2103092.	32072.	0.	0.	0.	0.	0.	0.	0.	1110769.
14	2261782.	34317.	0.	0.	0.	0.	0.	0.	0.	1193964.
15	2431496.	36719.	0.	0.	0.	0.	0.	0.	0.	1282472.
16	2614133.	39290.	0.	0.	0.	0.	0.	0.	0.	1379780.
17	2812672.	42040.	0.	0.	0.	0.	0.	0.	0.	1483410.
18	3022135.	44983.	0.	0.	0.	0.	0.	0.	0.	1594929.
19	3245842.	48131.	0.	0.	0.	0.	0.	0.	0.	1714946.
20	3484877.	51500.	0.	0.	0.	0.	0.	0.	0.	1844117.

LIFE CYCLE COST AT 15.000% COST OF CAPITAL FOR 20 YEARS . . . . $ 4970026.

440KW FC/CTV/ABS2/H SYSTEM

[illegible]

[illegible] LIFE:	20 YEARS	DEPRECIATION METHOD:	
MORTGAGE INTEREST:	15.00%	TAX	DECLINING BALANCE
PERCENT FINANCED:	80.00%	BOOK	STRAIGHT LINE
PROPERTY TAXES:	1.00%		
INSURANCE:	0.50%	DECLINING BALANCE RATE:	
INCOME TAX RATE:	48.00%	TAX	200.%
COST OF CAPITAL:	15.00%		

SYSTEM	FIRST COST	ADDITIONAL	FIRST COST TOTAL	MAINTENANCE	MAINTENANCE TOTAL
1	$ 0.0 / TON	$ 561000.	$ 561000.	$ 452.[illegible] / TON	$ 10253.
2	$ 0.0 / TON	$ 0.	$ 0.	$ 28.00 / TON	$ 6471.
3	$ 0.0 / TON	$ 0.	$ 0.	$ 28.00 / TON	$ 826.
4	$ 0.0 / TON	$ 0.	$ 0.	$ 28.00 / TON	$ 5676.
TOTALS		$ 561000.	$ 561000.		$ 23276.

MONTHLY UTILITY COST IN DOLLARS

MONTH	ELECTRIC	GAS	OIL	STEAM	CG CHG	CG ENERGY	CCG CAPACITY	DEMAND
JAN	3668.	23451.	0.	0.	1000.	-855.	216.	2628.
FEB	3665.	25229.	0.	0.	1000.	-751.	211.	2503.
MAR	4225.	25584.	0.	0.	1000.	-811.	211.	2912.
APR	4526.	26555.	0.	0.	1000.	-637.	227.	2544.
MAY	6277.	27652.	0.	0.	1000.	-5[illegible].	220.	7757.
JUNE	6151.	27554.	0.	0.	1000.	-71[illegible].	158.	10541.
JULY	6584.	28[illegible]7.	0.	0.	1000.	-[illegible].	15[illegible].	10[illegible]0.
AUG	11174.	2[illegible]7.	0.	0.	1000.	-14[illegible].	15[illegible].	11151.
SEPT	7680.	27415.	0.	0.	1000.	-534.	197.	1006[illegible].
OCT	5[illegible]1.	27[illegible]0.	0.	0.	1000.	-[illegible].	227.	25[illegible]5.
NOV	4[illegible]1.	27[illegible]1.	0.	0.	10[illegible].	-[illegible].	[illegible].	3[illegible].
DEC	[illegible]7.	2[illegible]2.	0.	0.	10[illegible].	-[illegible].	211.	2910.
TOTAL	$ [illegible].	$ [illegible].	$ 0.	$ 0.	$ 12720.	$ -[illegible]7.	$ 251[illegible].	$ 70722.

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FC/CTV/ABS2/H SYSTEM

YEAR	UTILITY COST	MAINT COST	INTEREST COST	PRINCIPAL COST	PROPERTY TAXES	INSURANCE COST	REPLACE EXPENSE	DEPRECIATION TAX	DEPRECIATION BOOK	CASH FLOW EFFECT
1	[illegible]	33276.	67273.	4281.	5810.	2605.	-477[illegible]	53044.	46922.	138143.
2	[illegible]	35436.	6[illegible]	5025.	6063.	3091.	0.	76511.	46922.	275958.
3	618678.	38098.	65907.	5756.	6423.	3211.	0.	62161.	46922.	316206.
4	[illegible]	40765.	65038.	[illegible]	6872.	3436.	0.	52032.	46922.	362010.
5	7[illegible]	43619.	64035.	7662.	7354.	3677.	0.	42562.	46922.	407152.
6	[illegible]	46672.	62889.	8412.	7868.	3934.	0.	33375.	46922.	456222.
7	927[illegible]	49939.	61548.	10133.	8419.	4210.	0.	29544.	46922.	500877.
8	1006[illegible]	53435.	60044.	11653.	9008.	4504.	0.	29611.	46922.	546256.
9	1051237.	57175.	58390.	13401.	9625.	4819.	0.	20566.	46922.	554345.
10	1143[illegible]	61177.	56285.	15412.	10314.	5157.	0.	57771.	46922.	627562.
11	1262741.	65460.	53576.	17723.	11036.	5518.	742493.	114054.	83427.	1272230.
12	1392[illegible]	70042.	51315.	20382.	11808.	5904.	0.	124558.	83427.	706937.
13	151[illegible]	74945.	48262.	23439.	12635.	6317.	0.	100[illegible]	83427.	736203.
14	1636715.	80191.	44746.	26955.	13519.	6760.	0.	80657.	83427.	865644.
15	1777[illegible]	85804.	40703.	30998.	14465.	7233.	0.	65024.	83427.	949190.
16	192[illegible]	91810.	26053.	35648.	15478.	7739.	0.	52439.	83427.	1037720.
17	2092[illegible]	98237.	30706.	40995.	16561.	8281.	0.	42325.	83427.	1132384.
18	2271295.	105113.	24557.	47144.	17721.	8860.	0.	34202.	83427.	1233121.
19	2468773.	112471.	17485.	54216.	18961.	9481.	0.	27665.	83427.	1341676.
20	2678[illegible]	120344.	9353.	62348.	20288.	10144.	0.	124451.	83427.	1435635.

LIFE CYCLE COST AT 15.000% COST OF CAPITAL FOR 20 YEARS . . . . $ 2686394.

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ALTERNATIVE 2 [illegible]

FIRST COST DIFFERENCE (ALTERNATIVE 2 - ALTERNATIVE 1) . . . . $ 561000.
NET PRESENT VALUE OF INCREMENTAL CASH FLOWS . . . . $ 763625.
LIFE CYCLE COST DIFFERENCE . . . . $ 783622.
REVENUE PENALTY DIFFERENCE . . . . $ 0.

YEAR	CASH FLOW DIFFERENCE	CUMULATIVE CASH FLOW	DISCOUNTED CASH FLOW TO EQUAL FIRST COST DIFFERENCE
0			-561000.
1	271572.	271573.	156564.
2	177096.	448670.	93175.
3	182817.	631487.	69767.
4	190781.	822267.	52803.
5	200817.	1023085.	40320.
6	212311.	1235[illegible]5.	30553.
7	220211.	1456166.	23262.
8	228553.	1684[illegible].	17512.
9	237738.	1922[illegible].	13213.
10	267136.	218[illegible].	10709.
11	-416741.	1772[illegible]0.	-12187.
12	323500.	2056249.	6[illegible]1.
13	324566.	[illegible]815.	4[illegible]3.
14	328220.	2749135.	3664.
15	334281.	33[illegible]416.	2705.
16	340050.	342[illegible]475.	2666.
17	361327.	[illegible]2.	14[illegible].
18	361906.	41[illegible]10.	1115.
19	372270.	4511[illegible]3.	826.
20	434412.	[illegible]	7[illegible].

PAYBACK ON INVESTMENT . . . 3. YEARS INTERNAL RATE OF RETURN 37.27%

BASE FC/KTV/ABS2/H

SUMMARY OF ECONOMIC DATA	ALTERNATIVE 1	2	3	4
INSTALLED COST	0.	561000.	607500.	652600.
UTILITY COST (FIRST YEAR)	772675.	[illegible]	413430.	466629.
UTILITY COST (FINAL YEAR)	3494879.	[illegible]	[illegible]	[illegible]
MAINTENANCE COST (FIRST YEAR)	14240.	23276.	35347.	36733.
LIFE CYCLE COST	[illegible]	[illegible]	[illegible]	3635123.

C O M P A R I S O N   O F   E C O N O M I C   D A T A

	FIRST COST DIFFERENCE ($)	PAYBACK PERIOD (YRS)	NET PRESENT VALUE ($)	INTERNAL RATE OF RETURN (%)
ALTERNATIVE 2 -- ALTERNATIVE 1	561000.	2.	763623.	37.67
ALTERNATIVE 3 -- ALTERNATIVE 1	607500.	3.	811210.	37.12
ALTERNATIVE 4 -- ALTERNATIVE 1	652600.	3.	836360.	36.39
ALTERNATIVE 3 -- ALTERNATIVE 2	46500.	4.	27675.	26.99
ALTERNATIVE 4 -- ALTERNATIVE 2	91600.	4.	47271.	25.50
ALTERNATIVE 4 -- ALTERNATIVE 3	[illegible]	4.	[illegible]	24.82

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EXAMPLE LOAD PROFILES

DAY: WEEKDAY

HOUR	CLG LOAD (TONS)	HTG LOAD (MBH)	ABSORP CHLR LOAD (TONS)	ELEC CHLR LOAD (TONS)	#1 BOILER LOAD (MBH)	#2 BOILER LOAD (MBH)	HOT TANK (MBH)	COLD TANK (TON-HRS)	HEAT REJECTED (MBH)	ELEC LOAD (KWH)	NET ELEC REQUIRED (KWH)
1	13.	1987.	13.	0.	656.	0.	0.	0.	0.	351.	-65.
2	12.	2084.	12.	0.	747.	0.	0.	0.	0.	351.	-84.
3	12.	2171.	12.	0.	828.	0.	0.	0.	0.	351.	-65.
4	12.	2246.	12.	0.	898.	0.	0.	0.	0.	351.	-65.
5	11.	2304.	11.	0.	953.	0.	0.	0.	0.	351.	-65.
6	26.	2703.	26.	0.	1054.	0.	0.	0.	0.	462.	43.
7	29.	2771.	29.	0.	1044.	0.	0.	0.	0.	572.	132.
8	31.	2793.	31.	0.	1170.	0.	0.	0.	0.	656.	216.
9	17.	3758.	17.	0.	2451.	0.	0.	0.	0.	527.	87.
10	15.	3574.	15.	0.	2253.	0.	0.	0.	0.	527.	87.
11	14.	3386.	14.	0.	2051.	0.	0.	0.	0.	527.	87.
12	15.	3242.	15.	0.	1926.	0.	0.	0.	0.	527.	87.
13	17.	3616.	17.	0.	2311.	0.	0.	0.	0.	526.	86.
14	18.	3465.	18.	0.	2107.	0.	0.	0.	0.	526.	85.
15	28.	1212.	28.	0.	0.	0.	[illegible]	0.	0.	531.	91.
16	48.	1186.	48.	0.	42.	0.	0.	0.	0.	537.	93.
17	32.	1221.	32.	0.	26.	0.	0.	0.	0.	526.	86.
18	40.	1226.	40.	0.	81.	0.	0.	0.	0.	571.	139.
19	38.	1265.	38.	0.	104.	0.	0.	0.	0.	575.	135.
20	35.	1276.	35.	0.	57.	0.	0.	0.	0.	579.	139.
21	36.	1397.	36.	0.	220.	0.	0.	0.	0.	579.	136.
22	20.	1536.	20.	0.	312.	0.	0.	0.	0.	446.	6.
23	17.	1741.	17.	0.	436.	0.	0.	0.	0.	354.	-86.
24	15.	1876.	15.	0.	556.	0.	0.	0.	0.	354.	-86.

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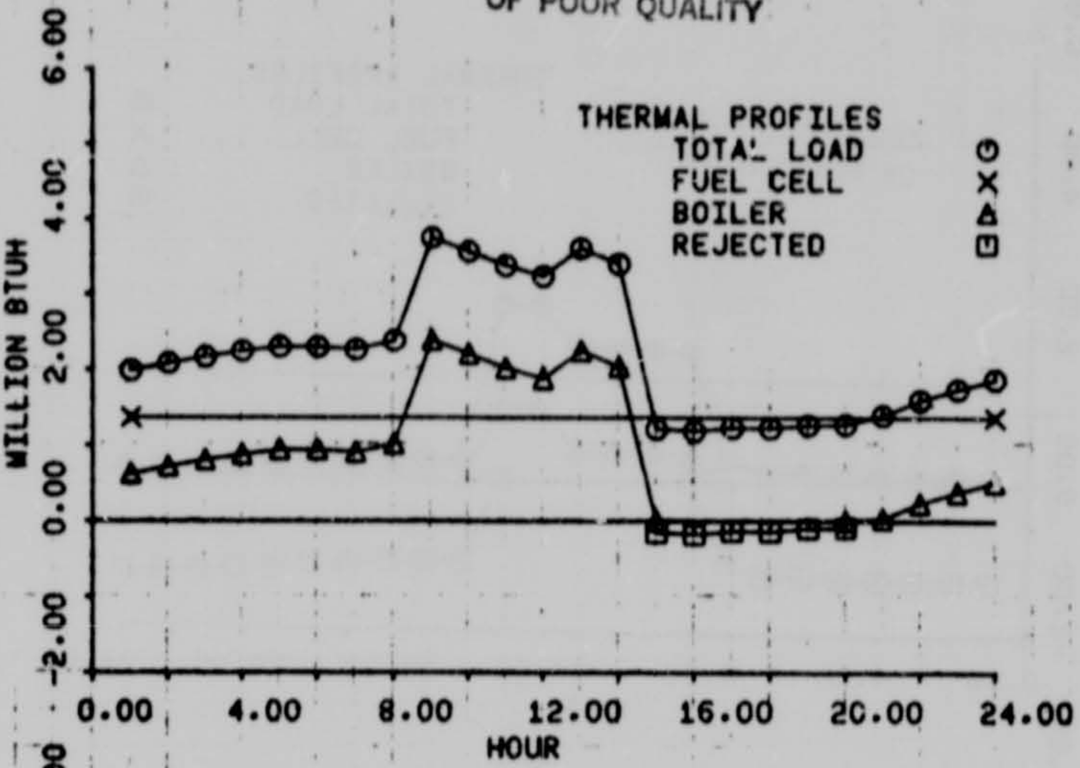
[illegible] AUGUST
DAY: WEEKDAY

EXAMPLE
LOAD PROFILES

HOUR	CLG LOAD (TONS)	HTG LOAD (MBH)	ABSORP CHLR LOAD (TONS)	ELEC CHLR LOAD (TONS)	#1 BOILER LOAD (MBH)	#2 BOILER LOAD (MBH)	HOT TANK (MBH)	COLD TANK (TONHRS)	HEAT REJECTED (MBH)	ELEC LOAD (KW)	NET ELEC REQUIRED (KWH)
1	172.	67.	125.	47.	0.	0.	[illegible]	0.	0.	451.	11.
2	153.	96.	115.	38.	0.	0.	278.	0.	0.	446.	2.
3	134.	67.	60.	36.	0.	0.	679.	0.	0.	443.	7.
4	123.	67.	89.	36.	0.	0.	1155.	0.	0.	440.	6.
5	123.	97.	123.	0.	0.	0.	1206.	0.	0.	366.	-60.
6	152.	130.	113.	36.	0.	0.	1511.	0.	0.	577.	127.
7	194.	123.	125.	55.	0.	0.	1567.	0.	0.	676.	236.
8	216.	200.	125.	61.	0.	0.	1451.	0.	0.	774.	234.
9	217.	1729.	125.	52.	150.	0.	0.	0.	0.	561.	221.
10	244.	1772.	125.	115.	1600.	0.	0.	0.	0.	666.	228.
11	264.	1777.	125.	141.	1662.	0.	0.	0.	0.	661.	241.
12	274.	1777.	125.	152.	1675.	0.	0.	0.	0.	697.	247.
13	300.	2327.	125.	175.	2245.	0.	0.	0.	0.	766.	266.
14	326.	2331.	125.	201.	2256.	0.	0.	0.	0.	717.	277.
15	336.	251.	125.	211.	158.	0.	0.	0.	0.	716.	275.
16	341.	258.	125.	216.	166.	0.	0.	0.	0.	722.	286.
17	354.	256.	125.	215.	157.	0.	0.	0.	0.	719.	279.
18	364.	237.	125.	235.	132.	0.	0.	0.	0.	776.	338.
19	339.	223.	125.	213.	173.	0.	0.	0.	0.	764.	324.
20	333.	153.	125.	158.	62.	0.	0.	0.	0.	754.	314.
21	316.	154.	125.	191.	73.	0.	0.	0.	0.	750.	310.
22	275.	120.	125.	150.	22.	0.	0.	0.	0.	547.	157.
23	223.	100.	125.	55.	0.	0.	0.	0.	0.	474.	34.
24	196.	58.	125.	71.	0.	0.	37.	0.	0.	461.	21.

F. SAMPLE LOAD PROFILES



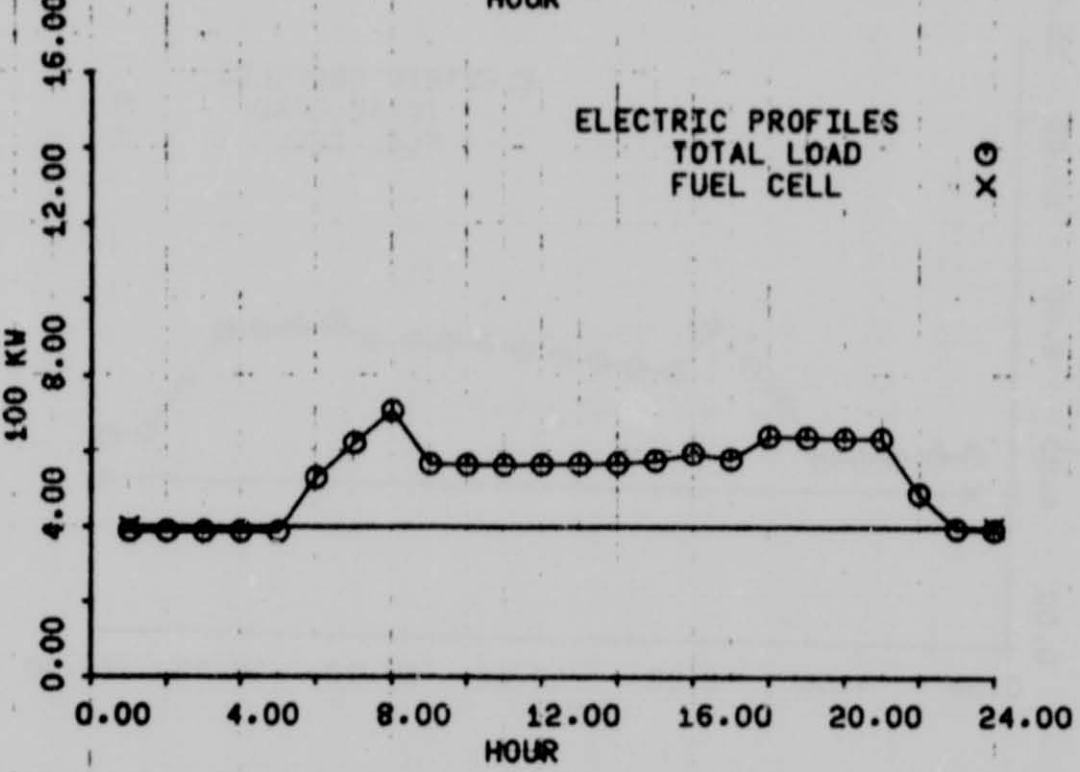


FIG. 1, JAN., WEEKDAY
400 KW FUEL CELL
FC/CTV SYSTEM
HOSPITAL, WASH DC

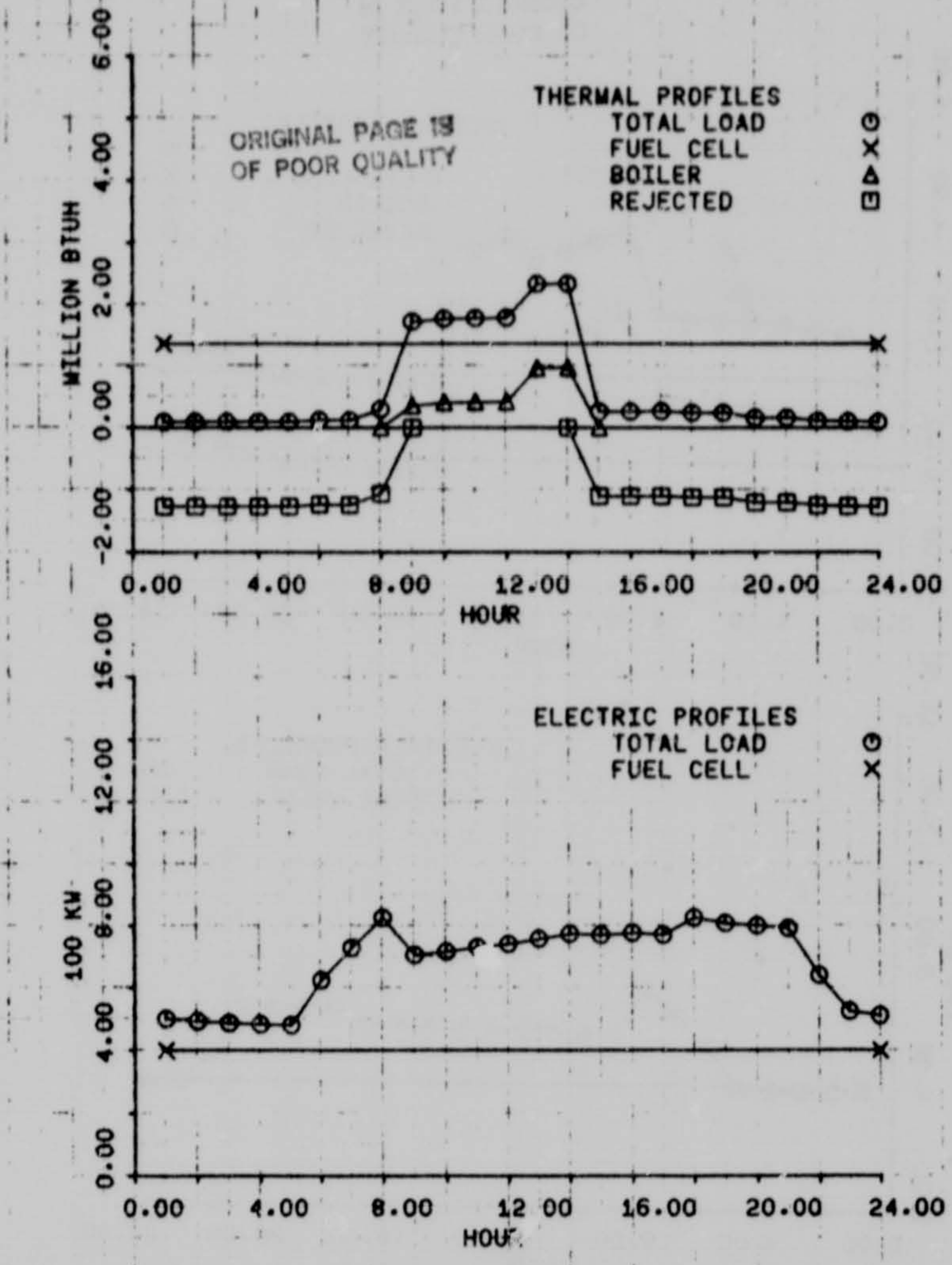


FIG. 2, JULY, WEEKDAY
400 KW FUEL CELL
FC/CTV SYSTEM
HOSPITAL, WASH DC

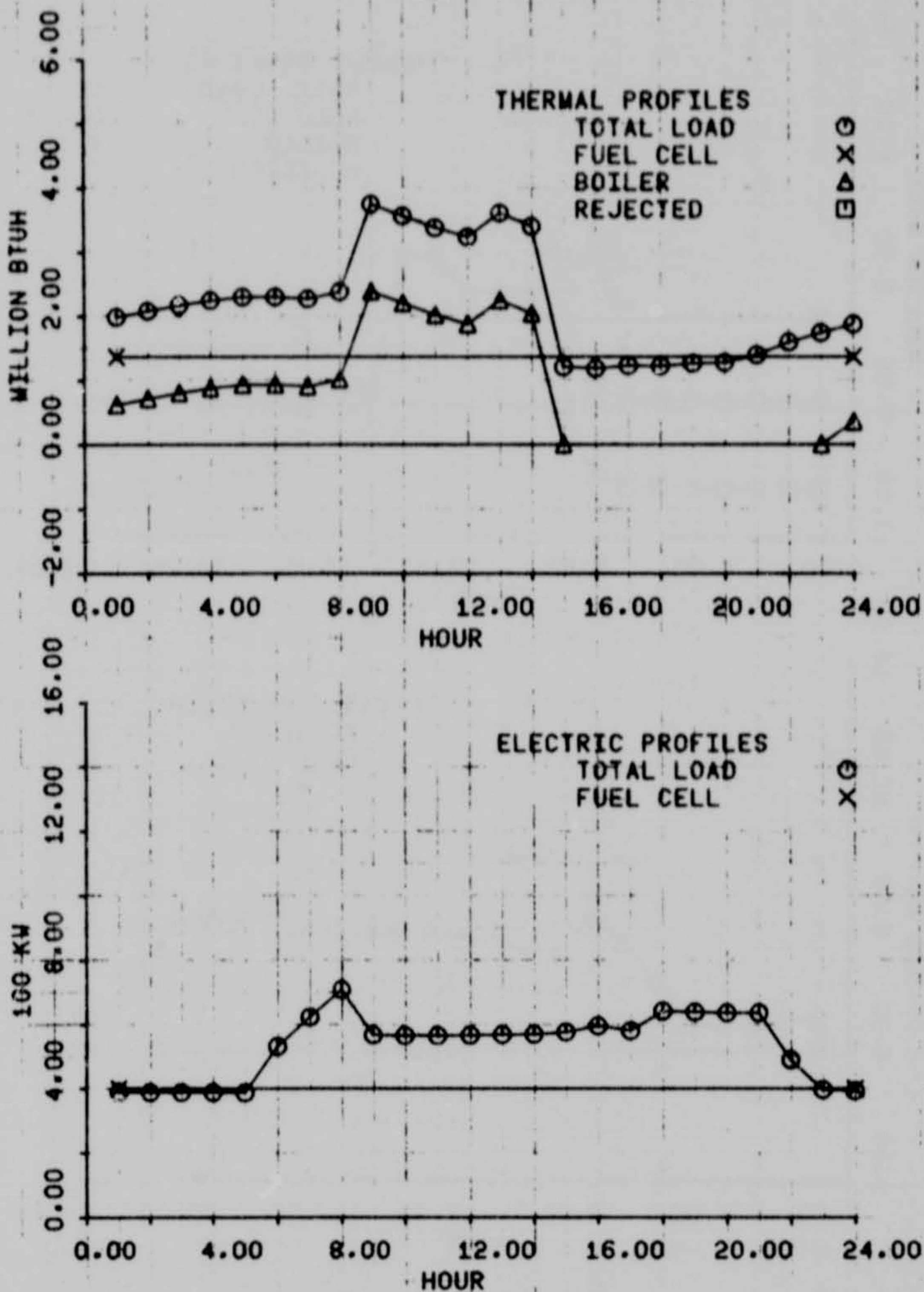
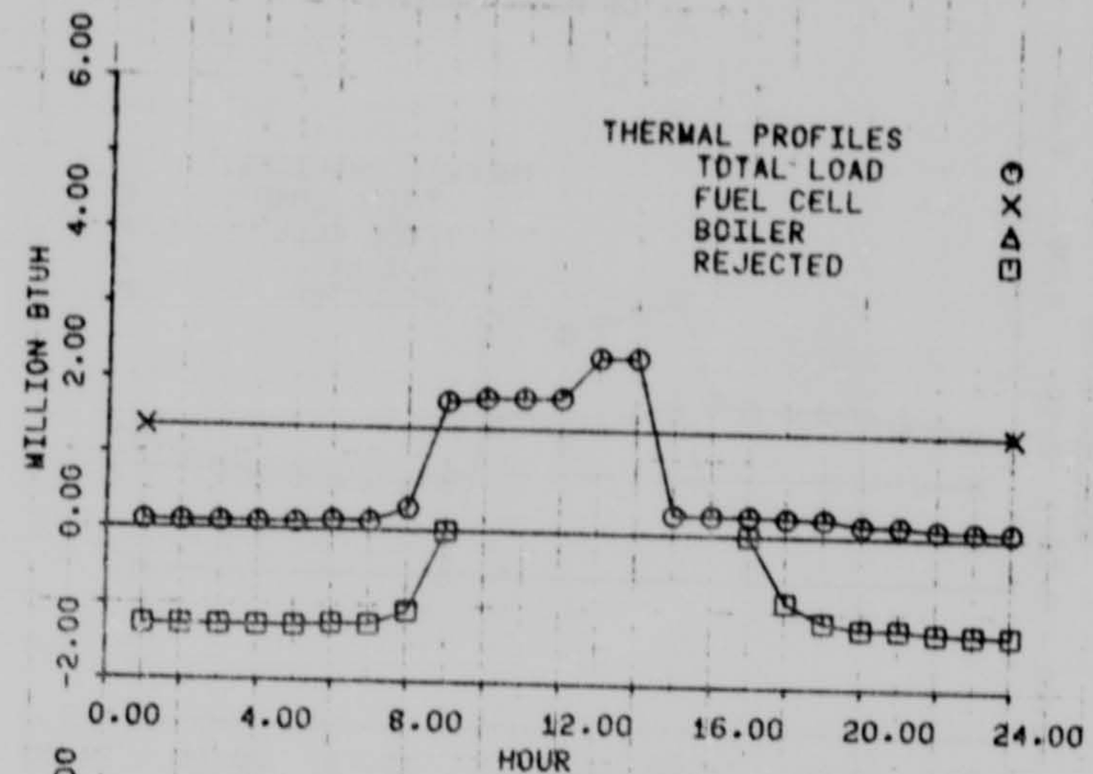


FIG. 3, JAN., WEEKDAY
400 KW FUEL CELL
FC/CTV/H SYSTEM
HOSPITAL, WASH DC



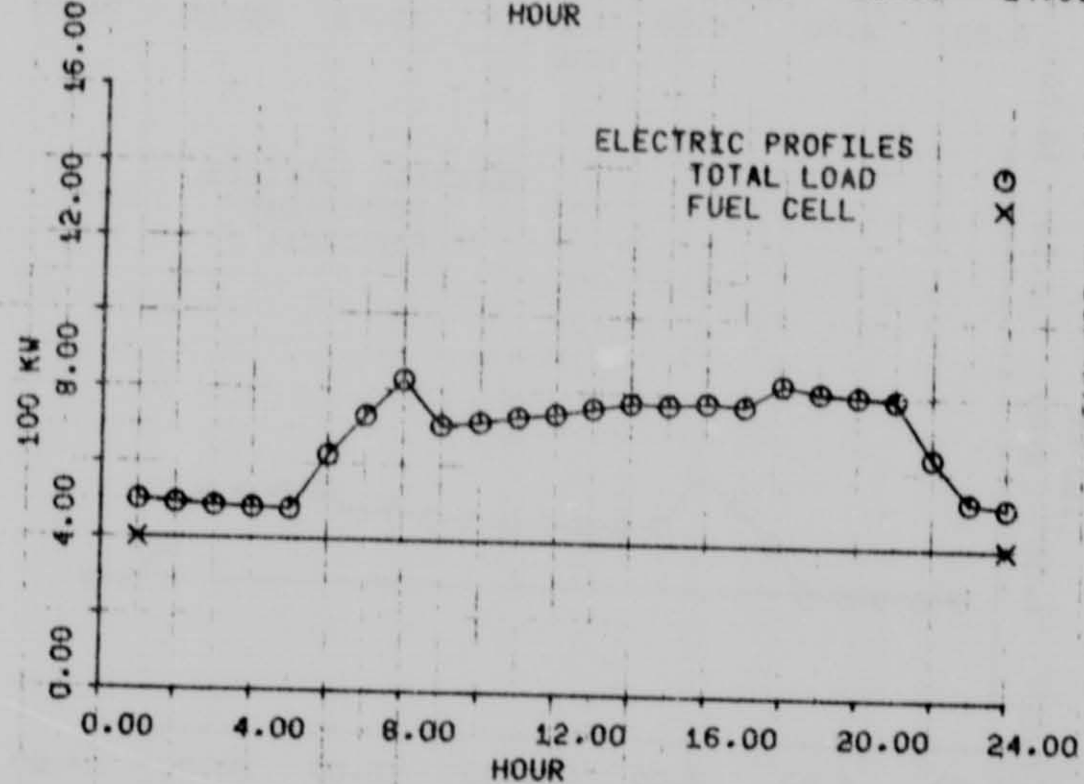
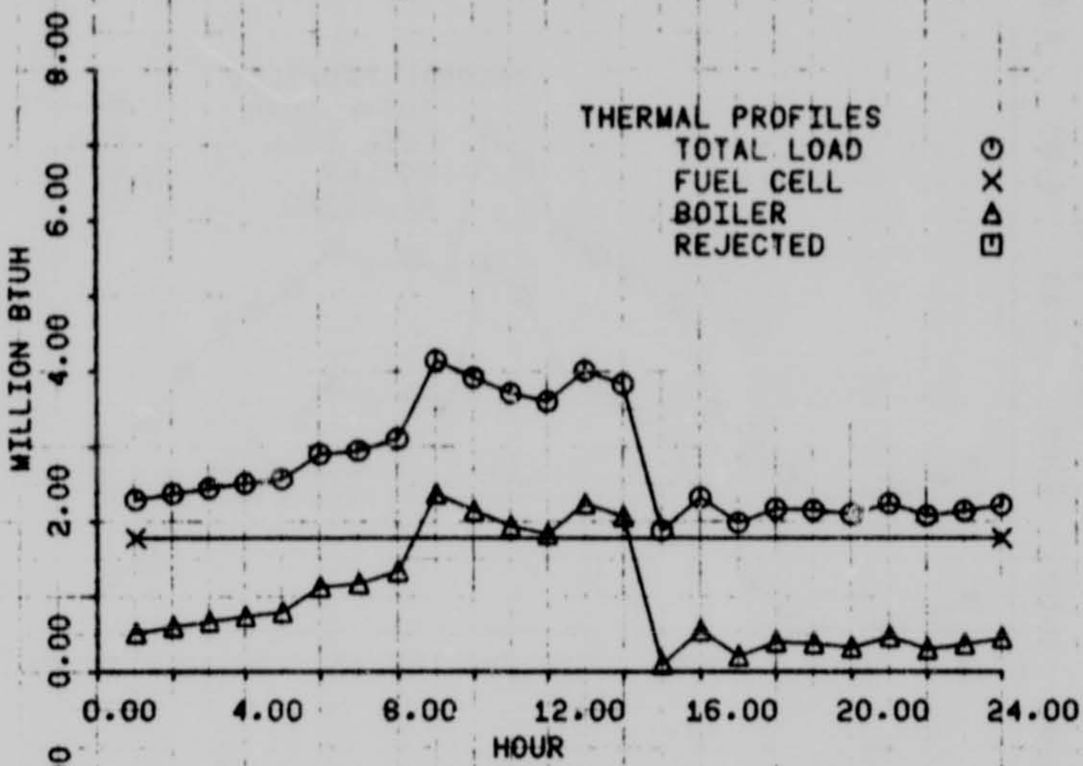


FIG. 4, JULY, WEEKDAY
400 KW FUEL CELL
FC/CTV/H SYSTEM
HOSPITAL, WASH DC



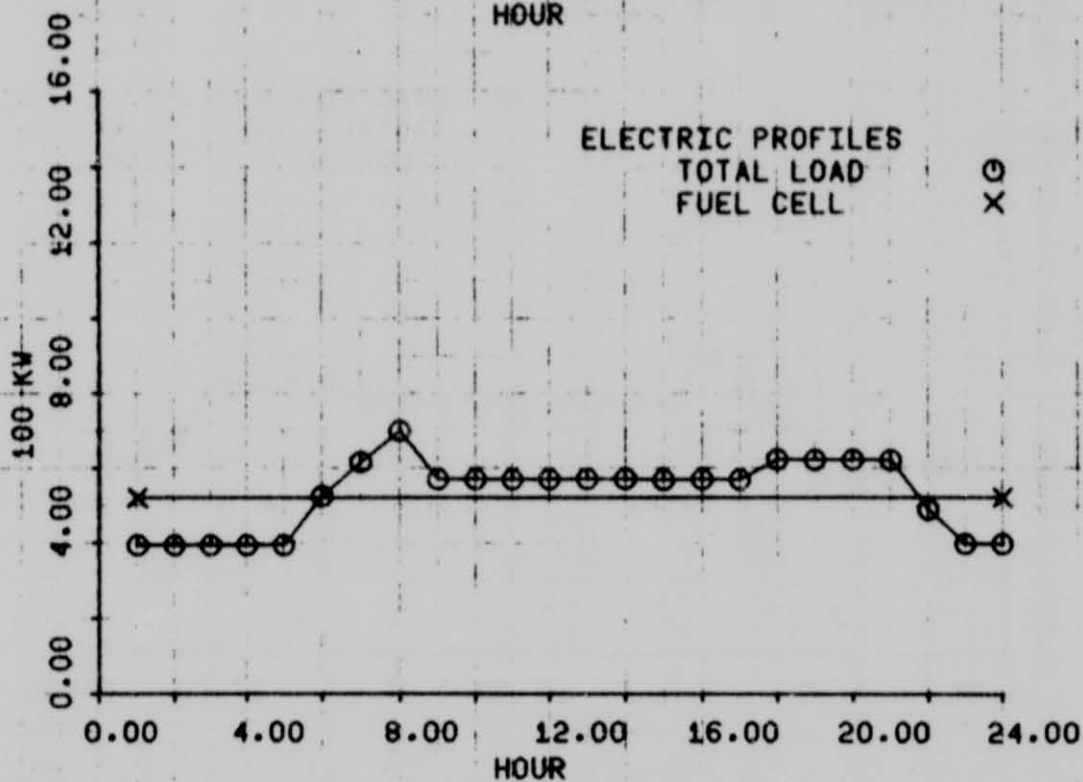


FIG. 5, JAN., WEEKDAY
520 KW FUEL CELL
FC/ABS1 SYSTEM
HOSPITAL, WASH DC

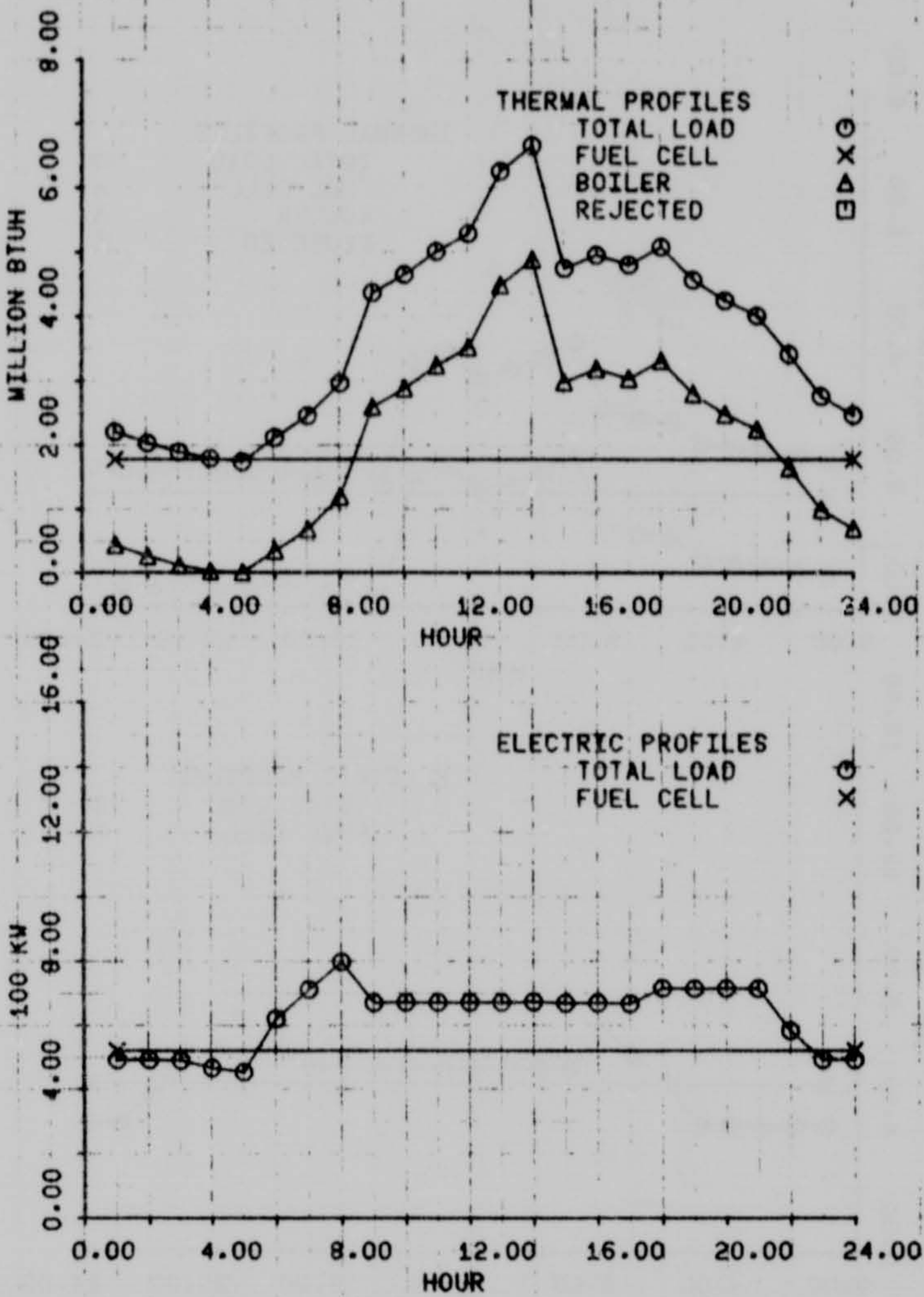


FIG. 6, JULY, WEEKDAY
520 KW FUEL CELL
FC/ABS1 SYSTEM
HOSPITAL, WASH DC

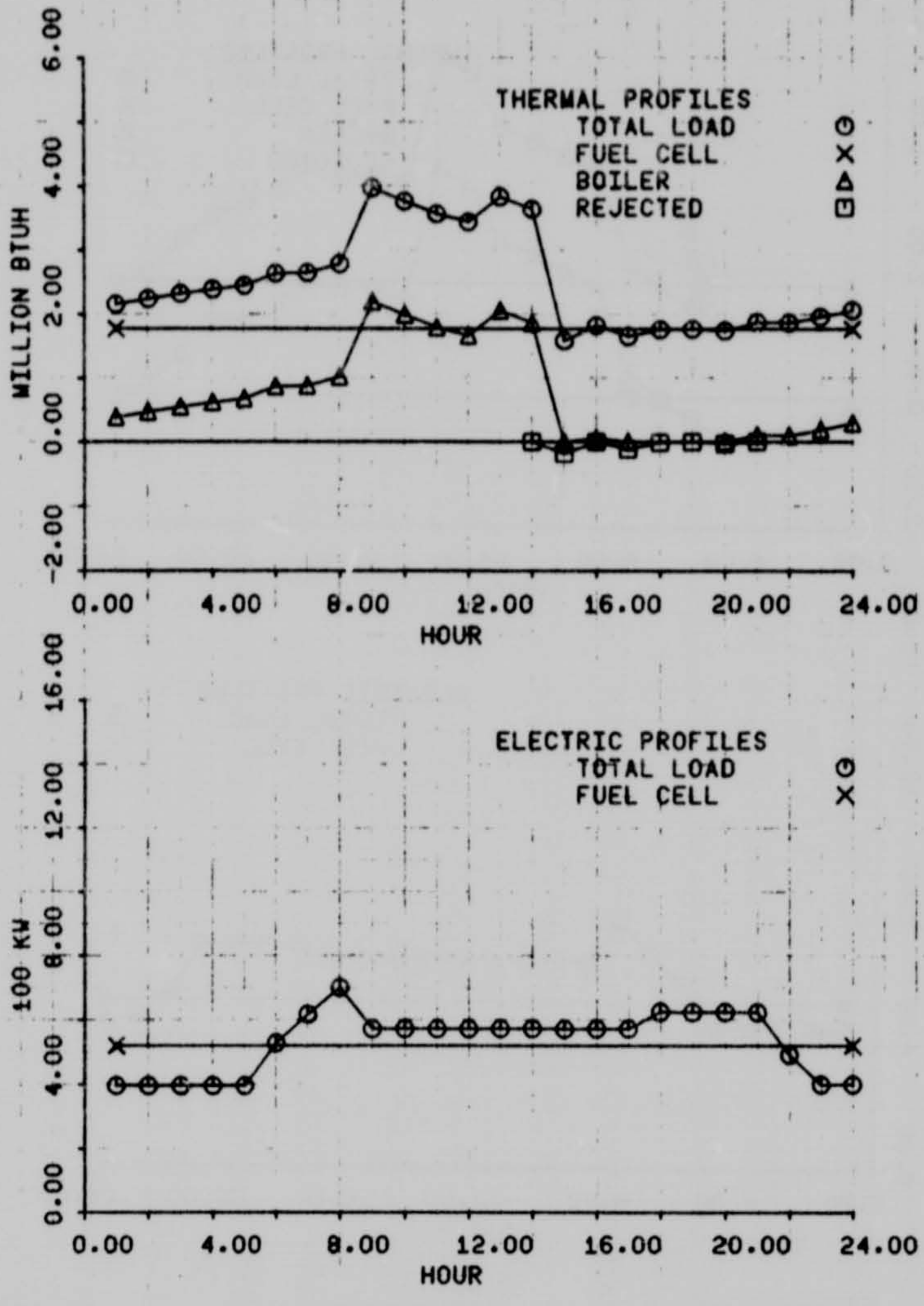


FIG. 7, JAN., WEEKDAY
520 KW FUEL CELL
FC/ABS2 SYSTEM
HOSPITAL, WASH DC

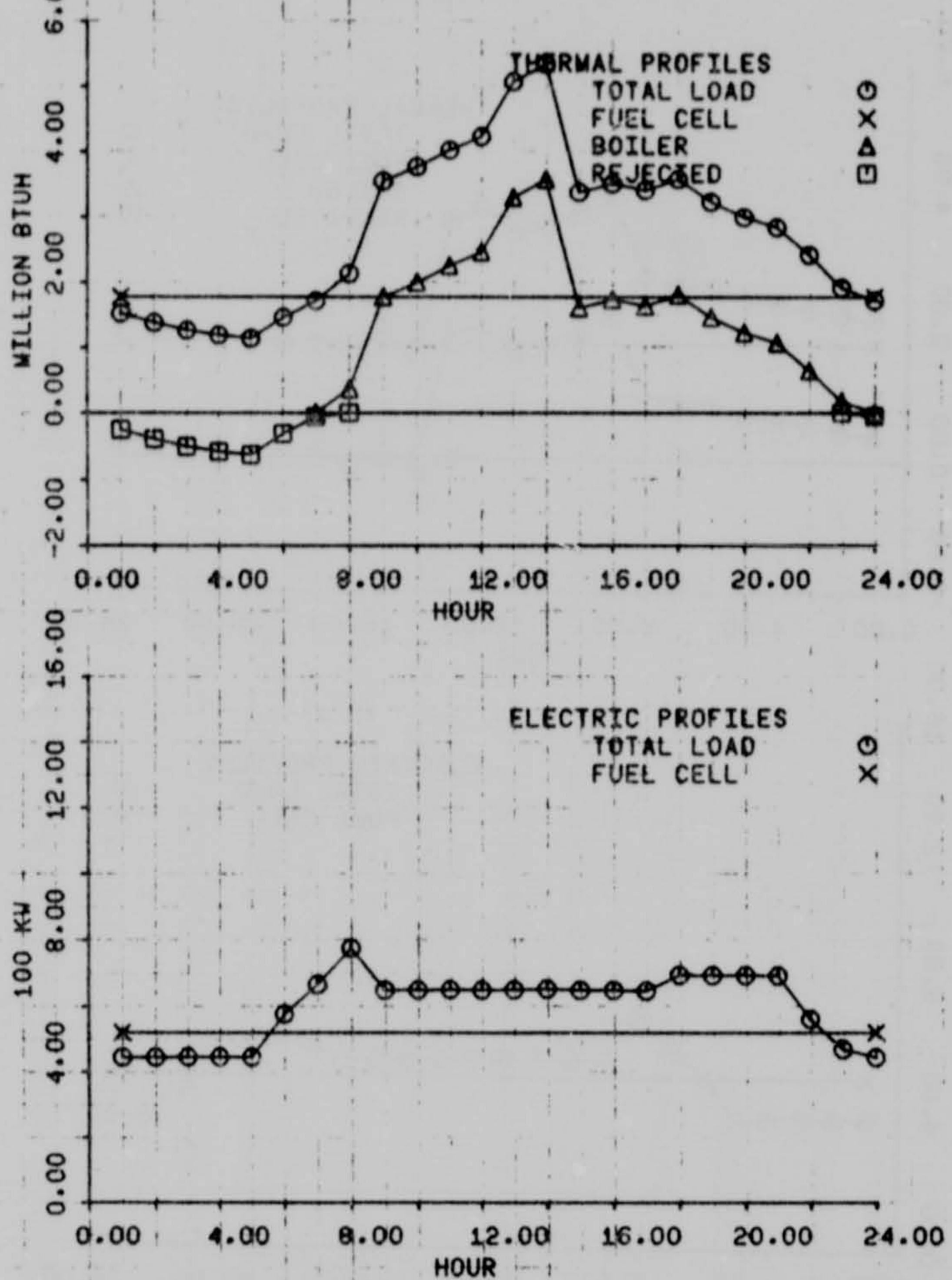
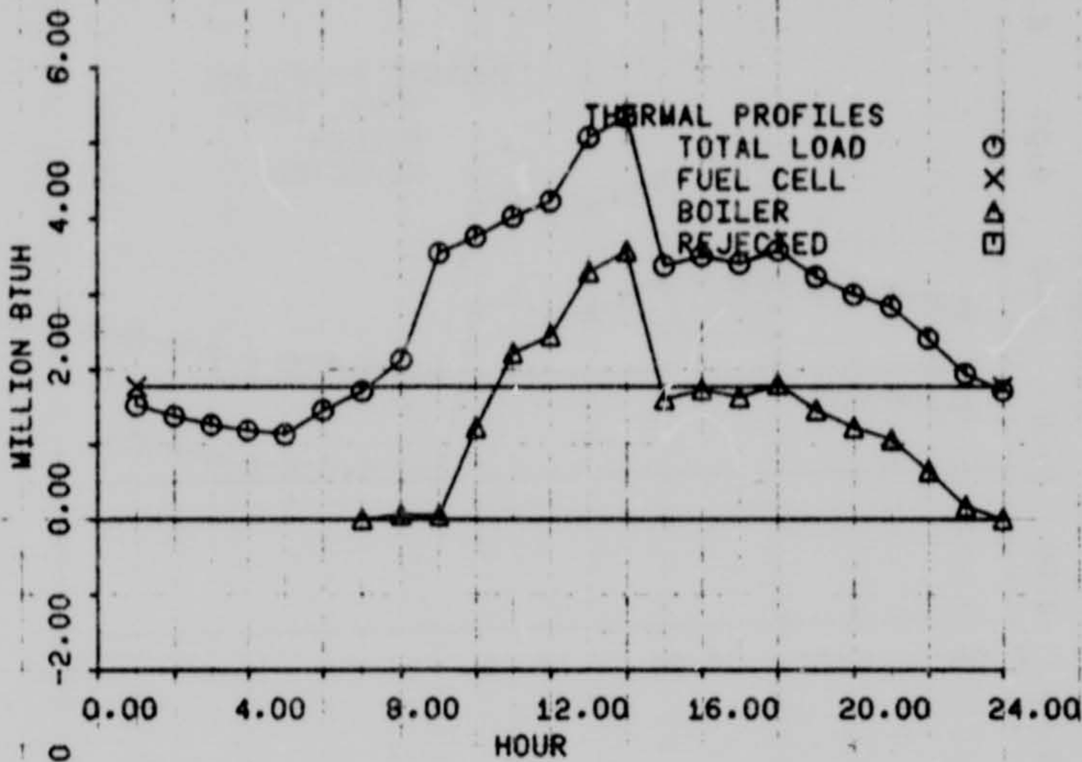


FIG. 8, JULY, WEEKDAY
520 KW FUEL CELL
FC/ABS2 SYSTEM
HOSPITAL, WASH DC



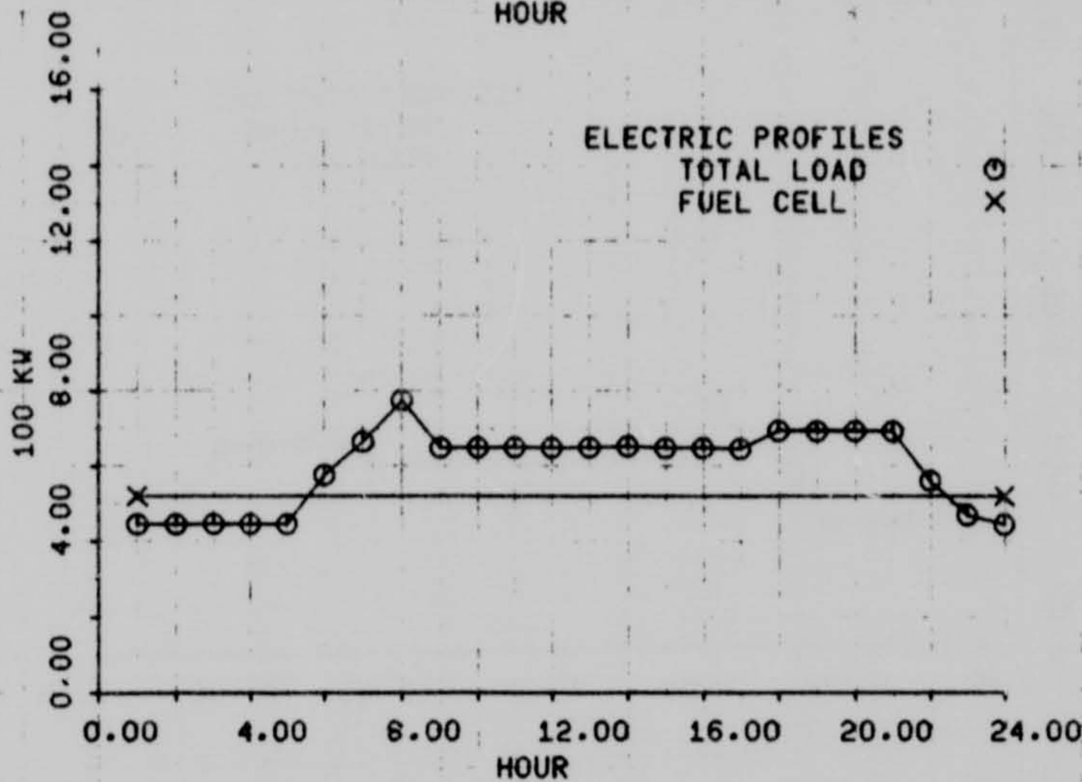


FIG. 9, JULY, WEEKDAY
520 KW FUEL CELL
FC/ABS2/H SYSTEM
HOSPITAL, WASH DC

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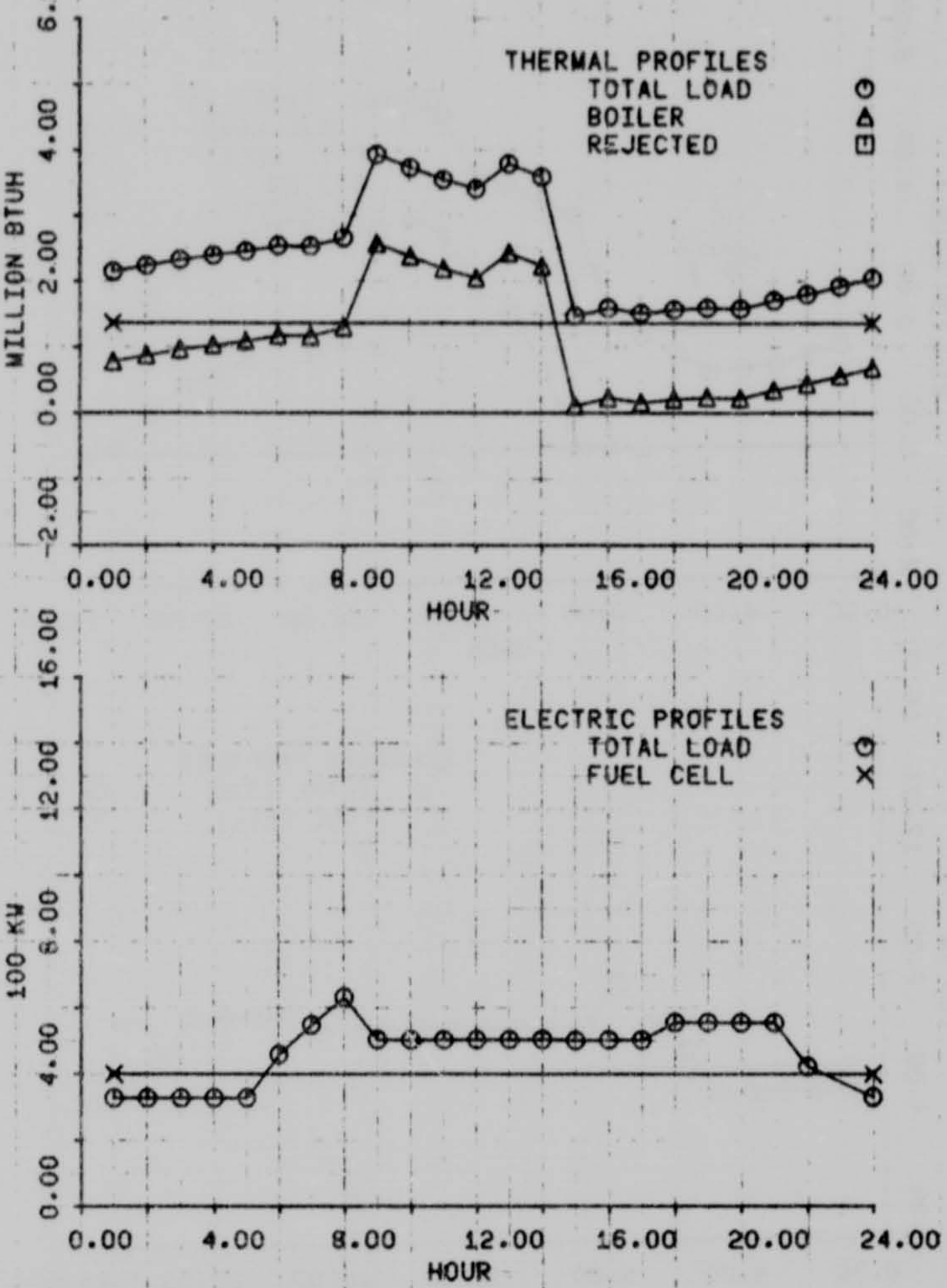
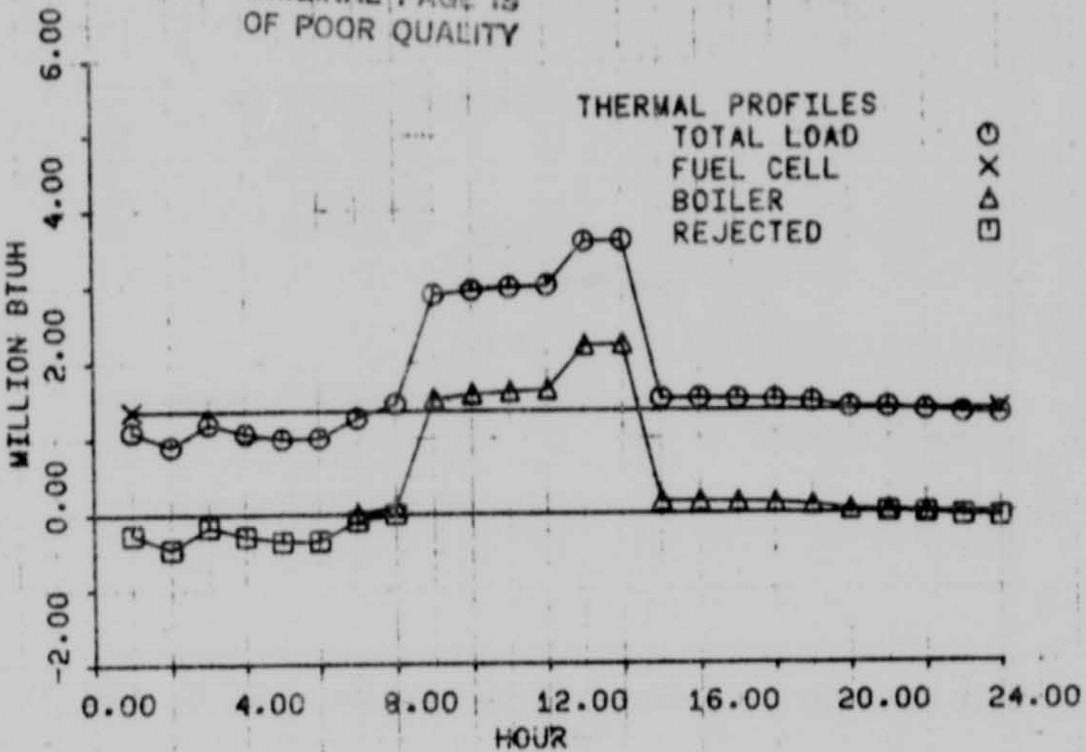


FIG. 10, JAN., WEEKDAY
400 KW FUEL CELL
FC/CTV/ABS2 SYSTEM
HOSPITAL, WASH DC



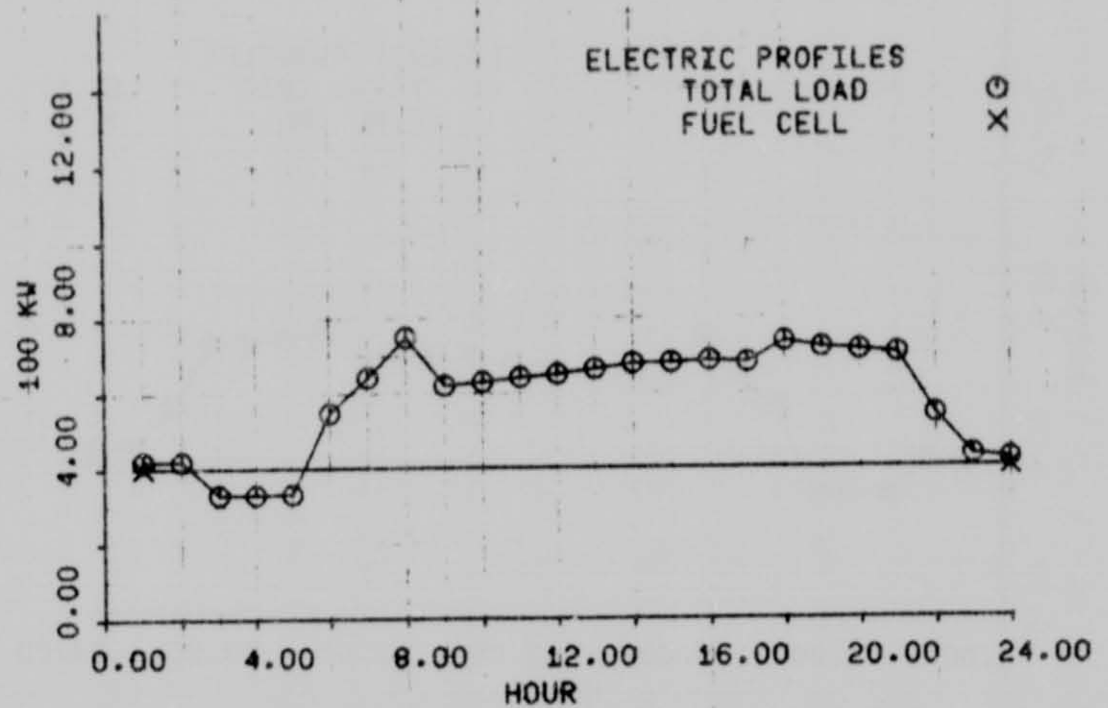


FIG.11, JULY, WEEKDAY
400 KW FUEL CELL
FC/CTV/ABS2 SYSTEM
HOSPITAL, WASH DC

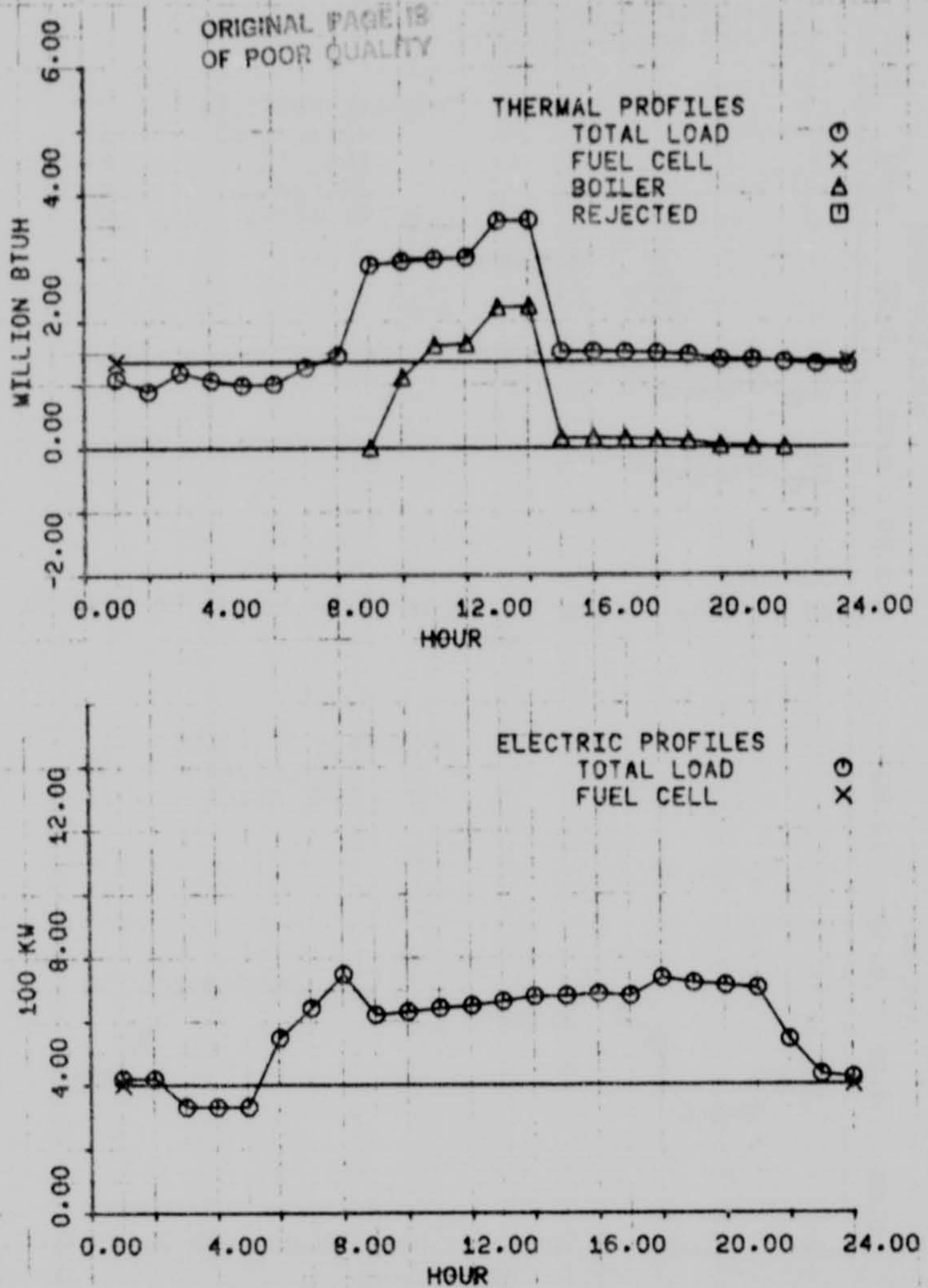


FIG. 12, JULY, WEEKDAY
400 KW FUEL CELL
FC/CTV/ABS2/H SYSTEM
HOSPITAL, WASH DC