EXECUTIVE SUMMARY

Energy Engineering Analysis Program
for
Army Installations, Hawaii

October 1982

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ENERGY ENGINEERING ANALYSIS PROGRAM
USASCH INSTALLATIONS
Islands of Hawaii and Oahu, Hawaii

Frederick H. Kohloss & Associates and
Meckler Energy Group, a Joint Venture

Objective

To assist in attaining the Army's goals in reducing energy use while still accomplishing its military missions, this Energy Engineering Analysis has been performed for the USASCH Facilities on the Islands of Hawaii and Oahu, Hawaii. Objective of the study is to assist energy-conservation administration and policy by identifying measures to be developed into Energy-Conservation Investment Programs (ECIP) projects, operation and maintenance (O & M) alteration and/or construction projects, and recommendations for improving energy utilization by means requiring little or no capital expenditure.

Scope

The scope of the project included studies and field checks of buildings and utilities at each of ten designated installations under WESTCOM command, to see where most energy is used, and how its consumption can be reduced. Engineering analysis of the data was used to define technical requirments and costs of prospective ECIP projects generally requiring capital investment of more than $100,000 and evaluating their effectiveness by E/C ratio; the energy saved (millions of British Thermal Units, MBTU, per year) divided by the cost (thousands of dollars of capital) required.

The analysis also developed prospective O & M type projects, requiring capital expenditure of $100,000 or less, and defined them technically and economically.

From the data and analysis, a review was made to establish a list of recommendations for improving efficiency of energy usage by operating and maintenance practices which can be publicized and implemented through command channels, without alteration or construction, along with the continuing indoctrination of all personnel in avoiding energy waste and finding ways to save energy.

The prospective ECIP projects are listed in the order of their E/C (effectiveness) ratio, for each installation. This report contains Project Development Brochures (PDB's) and Military Construction Project Data Summaries (DD 1391 Forms) for each ECIP project. For the O & M type projects DD 1391 Forms are also provided.

Energy Conservation Opportunities

In contrast to most Army major commands, the WESTCOM area, (the Hawaiian Islands) has relatively few types of prospective energy saving. It also has fewer than the usual uses of fuel and energy and fewer available types of fuel and energy. It is therefore essential to focus conservation efforts on the large uses of energy, but not to neglect small uses.

The mild Hawaiian climate requires no space heating except at the little-populated high altitudes. The room-type electric space heaters formerly installed in some family housing at Schofield Barracks have been removed. Of the ten installations, only the very limited building areas of Pohakuloa Training Area and Kilauea Military Camp on the Island of Hawaii need heating, but they need little. They use no air-conditioning.

By far the most extensive use of energy in USASCH installations is in the form of electricity; primarily for air-conditioning, water heating, lighting, and housing appliances. Of the uses mentioned, the largest prospective saving in energy is reduction of energy use for air-conditioning. The most significant use of fossil fuels is in water heating, with some use in food preparation.

Since near-sea level Hawaii is semi-tropical, the weather is sufficiently warm that refrigerated air-conditioning is normally operated twelve months a year in family housing areas, and humidity/temperature sensitive areas, while USASCH policy mandates a June through September air conditioning period for other buildings. Due to the highly localized changes in weather patterns on the Island of Oahu, there are basically two different climates to be considered in analyzing energy used in air-conditioning: Honolulu and the Central Oahu Plateau.

Wheeler AFB, Schofield Barracks, and Helemano Military Reservations, on the Central Oahu Plateau, experience significantly cooler weather than the other installations on Oahu. Tripler Army Medical Center, Fort Shafter, Fort DeRussy and Kapalama Military Reservation are all generally subject to Honolulu's climate, with slight variations. There is slightly cooler, more rainy weather in the portions of Fort Shafter and Tripler Army Medical Center extending into the mountain valleys, (mostly family housing), than in the dryer, sunnier areas nearer the ocean. The large family housing installation in Aliamanu Crater has temperatures similar to Honolulu, but less wind velocity, which affects comfort adversely.

Air-conditioning use is fairly widespread. About 41% of the Army's Oahu buildings (on an area basis) are air-conditioned. (Table 1) The largest uses of air-conditioning are family housing and unaccompanied personnel housing.

TABLE 1
AREAS OF BUILDINGS, AIR-CONDITIONED AND NON-AIR-CONDITIONED

TOTAL BUILDING AREA (SQUARE FEET)

Location	Family Housing AC	Family Housing NAC	Other Bldg Types AC	Other Bldg Types NAC
Schofield	818,290	5,288,700	2,643,403	3,839,000
Wheeler Army Share)	0	0	71,320	121,423
Shafter	61,570	1,140,700	574,068	1,018,615
Aliamanu	4,343,453	0	5,184	0
De Russy	0	0	501,214	110,057
Kapalama	0	0	76,475	849,086
Helemano	0	54,400	63,440	121,650
Tripler*	68,072	295,800	227,131	322,383
Kilauea	0	0	0	140,057
Pokahuloa	0	0	0	223,275
TOTAL	5,292,015	6,779,600	4,162,235	6,745,546

AC - Air-Conditioned
NAC - Non Air-Conditioned
* Does not include hospital complex

Estimating Energy Used in Air-Conditioning

In accomplishing the scope of this project, a methodology was developed to estimate the average energy consumed by air-conditioning systems in Hawaii. Approximately 170 buildings, typical of the approximately 4000 in the ten installations were field-checked in detail. Data on their construction, heat transfer characteristics, lighting, appliances, water heating, ventilation, and air-conditioning were obtained from construction drawings and on-site investigations. The methodology developed to estimate energy consumption for air-conditioning sorted the buildings into two basic categories; 24-hour use (housing, primarily); and working-hours use (about ten hours per day, 5 days per week, such as administrative and operational facilities). Climate data, the building construction characteristics, and techniques of air-conditioning load calculation were then combined to provide a means of estimating air conditioning energy use. The method developed for this project was described in an engineering technical paper (Appendix 1).

Estimation of energy consumption was cross-checked. Although the installations studied usually had a single electrical meter for each post, check meters exist in certain family housing areas, and the electricity supply utility on Oahu, Hawaiian Electric Company, has compiled a significant amount of data of typical non-air-conditionied residential energy consumption (Table 2). Data from the air-conditioning energy use methodology were combined with utility data in estimating family housing energy use. This was compared with actual uses, and fairly close correlation was obtained.

Family housing (7,146 units) at USASCH installations consumes about half ($13.0 million in FY 82) of the Command's facilities energy. This area requires intensive management to include installation of meters to measure consumption of utilities with emphasis on electricity in accordance with the Department of the Army goal to have all family housing utilities metered by the end of CY 1989.

A check meter was installed on a typical air-conditioned unaccompanied personnel housing building, Quadrangle E at Schofield Barracks. The check-metered data were the basis for developing a typical daily energy use and a profile of air-conditioning load variation through the day and week for such occupancies, necessary to analyze certain prospective ECIP projects.

In Table 2 is listed the average electrical consumption of one family housing unit, non air-conditioned (no central air-conditioning installed). (Some, but very few, family housing units have individual room air-conditioners.) In those family housing units with central air-conditioning, the energy use varies: less use at Schofield Barracks, considerably more at Ft. Shafter and Tripler Army Medical Center and yet slightly more in the humid, relatively still air of Aliamanu Military Reservation. There is an existing USASCH policy permitting air-conditioning for personnel comfort to be used only in the hottest months of July through September. This does not apply to family housing.

Energy Used by Each Installation

The largest USASCH installation is Schofield Barracks Military Reservation. Schofield Barracks uses about one-half the total electricity. Aliamanu Military Reservation, totally air-conditioned family housing, uses about one quarter of the total electricity. Thus these two installations currently use three-quarters of the electricity consumed by the ten installations studied, and offer the greatest opportunity for energy saving. The other significant electricity users are Tripler Army Medical Center, Ft. Shafter, and Ft. DeRussy Military Reservations, aggregating 20% of the total. The five installations use 95% of the present total electrical energy, 216,640,000 kwh per year, as shown in Table 3.

There is no natural gas in Hawaii. Coal is not shipped in (except a small amount by barge loads direct to cement plant kilns), so two of the most commonly used U.S. fuels are not used in USASCH installations. Table 4 shows consumption of the various fuels used in the ten installations. All of these fuels are derived from oil imported into Hawaii, mostly refined on Oahu. With a conversion factor of 11,600 Btu per kwh, the total fuel used in the ten installations is equivalent to using 25,100,000 kwh of electricity per year (only 9% of the electrical energy which is used). Schofield Barracks uses about 43% of the fuel, Tripler Army Medical Center about 35% (Table 4). Prospective reduction in fuel use primarily involves reduction in hot water use, and the heating of water by solar means, by waste heat, or by heat pumps.

The isolation of urban, highly-populated Oahu from other areas and the high aircraft traffic volume makes jet aircraft fuel and land transport major users of light petroleum fractions. Fuel use at USASCH installations (synthetic natural gas, liquefied petroleum

TABLE 2
ESTIMATED ELECTRICAL CONSUMPTION
FAMILY HOUSING-NON-AIR-CONDITIONED
AVERAGE HOUSING UNIT*

	kWh/mo	kWh/yr
1. Food Preparation (Oven, Range, Dishwasher, Etc.)	150	1,800
2. Food Preservation (Refrigerator, Freezer)	340	4,080
3. Laundry (Clothes dryer, Washing machine, iron)	90	1,080
4. Water Heating	400	4,800
5. Home Entertainment (TV, Radio, Etc.)	40	480
6. Housewares, Lighting, Etc. (Clock, Vacuum Cleaner, Sewing Machine, (Hairdryer, Fan, Lighting)	150	1,260
TOTAL	1,125	13,500

*Developed from reports and notes from conferences with Hawaiian Electric Company customer service engineers and data from Edison Electric Institute.

NOTE: Since housing units are unmetered and energy is therefore obtained at no cost to the user, a 12.5% increase in consumption is assumed over typical private usage.

(13,500 kWh/yr)(1.125) = 15,180 kWh/yr
or 1,265 kWh/mo

Location	Family Housing-AC (AC&Lights)	Family Housing AC (APP&DHW)	Family Housing NAC	Other Bldg Types AC	Other Bldg Types NAC
	$\frac{(kWh \times 10^6)}{(yr)}$	$\frac{(kWh \times 10^6)}{(yr)}$	$\frac{(kWh \times 10^6)}{(yr)}$	$\frac{(kWh \times 10^6)}{(yr)}$	$\frac{(kWh \times 10^6)}{(yr)}$
	$\frac{(Btu \times 10^{10})}{(yr)}$	$\frac{(Btu \times 10^{10})}{(yr)}$	$\frac{(Btu \times 10^{10})}{(yr)}$	$\frac{(Btu \times 10^{10})}{(yr)}$	$\frac{(Btu \times 10^{10})}{(yr)}$
Schofield	8.00 9.28	2.00 2.32	52.00 60.32	24.00 27.84	18.00 20.88
Wheeler (Army Share)	0 0	0 0	0 0	0.25 0.29	0.47 0.55
Shafter	0.60 0.70	0.10 0.12	7.60 8.82	6.50 7.54	4.20 4.87
Aliamanu	36.24 42.04	20.70 24.01	0 0	0.09 0.10	0 0
DeRussy	0 0	0 0	0 0	7.20 8.35	0.70 0.81
Kapalama	0 0	0 0	0 0	0.58 0.67	1.19 1.38
Helemano	0 0	0 0	0.49 0.57	0.66 0.77	0.45 0.52
Tripler	0.43 0.50	0.21 0.24	1.70 1.97	0.65 0.75	0.77 0.89
Kilauea	0 0	0 0	0 0	0 0	1.09 1.26
Pohakuloa	0 0	0 0	0 0	0 0	0.93 1.08
TOTAL	45.27 52.52	23.01 26.69	61.79 71.68	39.93 46.31	27.80 32.24
%Total	20.90%	10.60%	28.50%	18.50%	12.80%

AC - Air Conditioned APP - Appliances

NAC - Non Air Conditioned DHW - Domestic Hot Water

*Schofield Barracks electrical consumption - 115 x 10^6 - 10 x 10^6 (WAFB) = 105 x 10^6 kW

** Tripler Medical Center electrical consumption - 16 x 10^6 includes 12.05 x 10^6 kWh/yr

TABLE 3

①

Other Bldg ypes NAC	Misc.	Metered Total	% Total
kWhx10^6) / (yr)	(kWhx10^6) / (yr)	(kWhx10^6) / (yr)	
Btux10^{10}) / (yr)	(Btux10^{10}) / (yr)	(Btux10^{10}) / (yr)	
18.00	1.00	105.00*	48.50
20.88	1.16	121.80*	
0.47	2.30	3.02	1.40
0.55	2.67	3.50	
4.20	0.20	19.20	8.10
4.87	0.23	22.27	
0	0.47	57.50	26.60
0	0.55	66.70	
0.70	1.80	9.70	4.50
0.81	2.09	11.25	
1.19	0.13	1.90	0.90
1.38	0.15	2.20	
0.45	0.30	1.90	0.90
0.52	0.35	2.20	
0.77	0.24	16.00**	7.40
0.89	0.28	18.56**	
	+12.05**		
	+13.92**		
1.09	0	1.09	0.50
1.26	0	1.26	
0.93	0.40	1.33	0.60
1.08	0.46	1.54	
27.80	18.84	216.64	100%
32.24	21.86	251.28	
12.80%	8.70%	100.00%	

105 x 10^6 kWh/yr; 121.80 Btu x 10^{10}
x 10^6 kWh/yr for hospital complex; 13.92 Btu x 10^{10}

②

TABLE 4
1979 FUEL CONSUMPTION DATA

Location	Synthetic Natural Gas (SNG)	Propane (LPG)	Light Oil (DF-2)	Heating Oil (DFM/FS-5)	Kerosene	Total	Equiv + Total
	(MBTU)/(yr)	(MBTU)/(yr)	(MBTU)/(yr)	(MBTU)/(yr)	(MBTU)/(yr)	(MBTU)/(yr)	(kWhx10^{6})/(yr)
	(kWhx10^{6})/(yr)	(kWhx10^{6})/(yr)	(kWhx10^{6})/(yr)	(kWhx10^{6})/(yr)	(kWhx10^{6})/(yr)		(kWhx10^{6})/(yr)
Schofield	0	64,956	36,841	23,500	0	125,297	-
	0	5.60	3.18	2.03	0	-	10.80
Wheeler	0	0	0	0	0	0	-
	0	0	0	0	0	-	0
Shafter	25,500	0	0	0	0	25,500	-
	2.20	0	0	0	0	-	2.20
Aliamanu	0	0	0	0	0	0	-
	0	0	0	0	0	-	0
De Russy	15,686	0	119	0	0	15,805	-
	1.35	0	0.01	0	0	-	1.36
Kapalama	0	0	0	0	0	0	-
	0	0	0	0	0	-	0
Helemano	0	240	4,830	0	0	5,070	-
	0	0.02	0.42	0	0	-	.44
Tripler*	0	215	1,847	98,300	0	100,362	-
	0	0.02	0.16	8.47	0	-	8.65
Kilauea	0	350	5,443	0	3,900	9,693	-
	0	0.03	0.47	0	0.34	-	0.84
Pohakuloa	0	0	2,277	0	4,935	9,489	-
	0	0	0.20	0	0.43	-	0.63
Total (MBTU)/(yr)	41,186	65,761	51,357	121,800	8,835	291,216	25.10
Equiv + Total kWhx10^{6}	3.55	5.67	4.44	10.50	0.77	-	24.93

* Data for Tripler Army Medical Center includes hospital complex.
+ Equivalent kwh obtained using 11600 BTU = 1 kwh.

gas, diesel fuel, or heating oil) also comes from the desirable lighter fractions of oil. Almost all electricity consumed by USASCH installations is generated from the heavy residual oil, which is the least desirable product of the oil refineries.

Reduction in use of light oil in Hawaii is strategically and economically to the advantage of the United States, since reduction in use of light petroleum fractions directly lowers imports from foreign countries. Residual oil, however, can be burned only in central electrical generating plants, and is available on Oahu in proportionately greater quantity, after the more expensive lighter fractions are refined.

The use of electricity rather than imported fuel will offer further future strategic energy saving since the electric utility on Oahu now purchases a small amount of electrical power from wind energy, and has plans for increased purchases of power from wind energy sources. It purchases some electricity from co-generation plants burning sugar cane trash, with prospective future use of municipal refuse to generate power. Increase in the proportion of energy used as electricity offers more opportunity for other alternative energy sources to replace light petroleum fractions.

Energy Consumption Present and Historical

Energy consumed per square foot of building area under WESTCOM is one of the lowest of any Army major command, and far lower than average, due to the lack of space heating requirements, the mild peak hot weather, and an average outdoor temperature close to ideal with little variation. This gives less opportunity for saving than a highly variable climate.

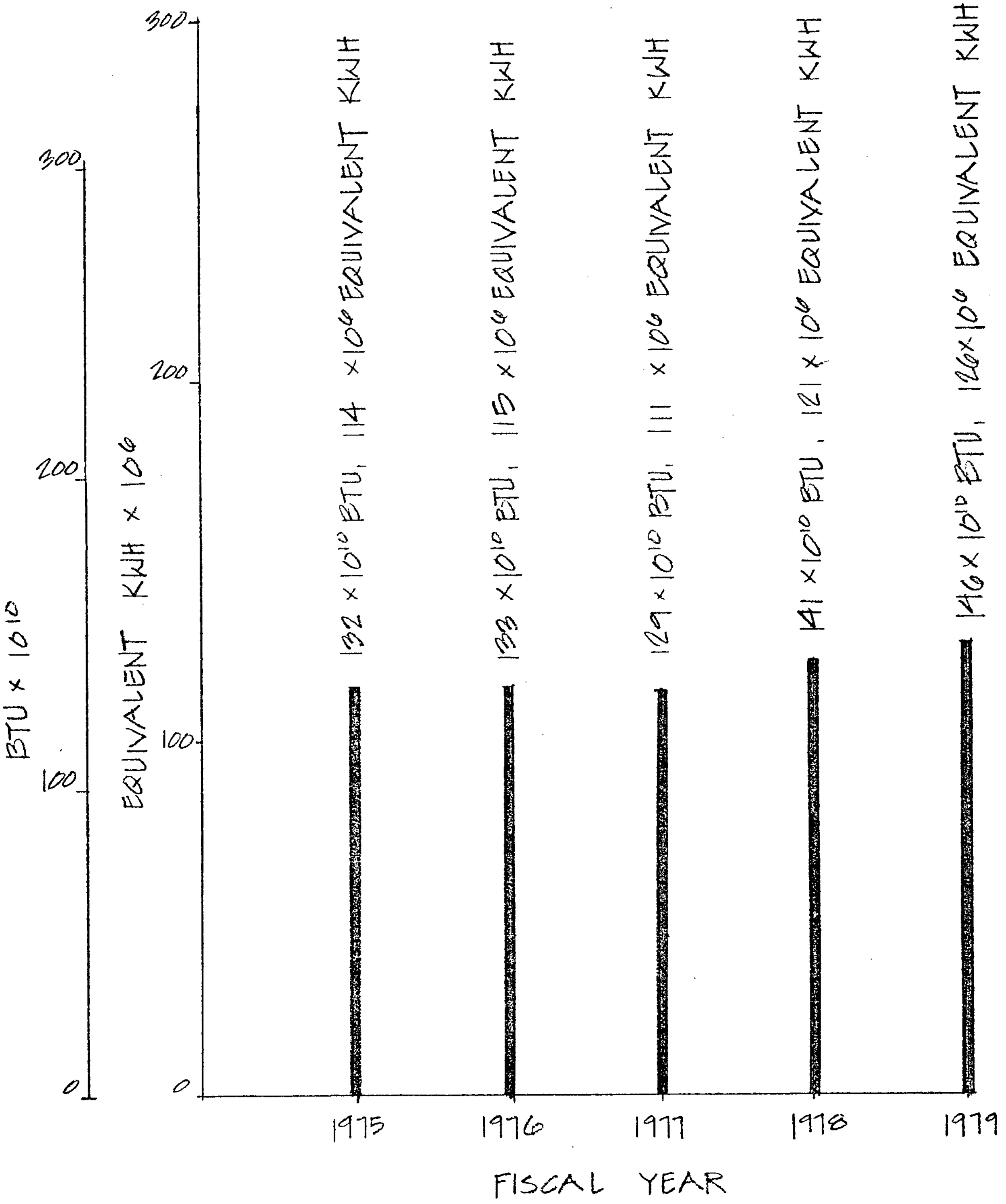
Further affecting WESTCOM are three very significant recent occurrences which increase energy needs. First, the major all-air-conditioned Aliamanu Family Housing project has been added to the load since FY 75, which is the Department of the Army's base year for energy measurement. Second, the largest buildings of troop housing, the Schofield Barracks Quadrangles, have been converted to air-conditioned unaccompanied enlisted personnel quarters and unit operational facilities. Third, an all air conditioned, twenty-four-hour operated tunnel complex, the Field Station Kunia, was activated in October 1981. Fourth, a new sewage effluent pumping station for the Schofield Barracks wastewater treatment facility was placed in service in mid-1981. Fifth, a new Army Reserve Training Center and maintenance facility was constructed since 1975 at Fort DeRussy. Sixth, a maintenance facility at Fort Shafter was constructed since 1975. Seventh, a major addition and rehabilitation of Tripler Army Medical Center is under construction, which will add tremendous air-conditioning loads. Eighth, several new construction and expansion projects are under construction or programmed for construction at Schofield Barracks. These include the expansion of the main Post Exchange facility, the thirty-eight (38) chair Dental Clinic, the new Auto Craft Center, four new Tactical Equipment Maintenance Shops, and a new Aviation Facility at Wheeler Air Force Base.

Due to these occurrences, WESTCOM's own objective for 1985 is a five (5) percent energy use reduction from 1975, in comparison to a Department of the Army goal of 20 percent energy use reduction. In 1979 there was about a 40 percent increase over 1975's total energy use in USASCH buildings, and in 1980 a 35 percent increase over 1975. Building area had increased in 1980 to about 39% more than in 1975. Annual goal for WESTCOM is 2% reduction from the previous year's total energy use.

Table 3 shows the metered total use of electricity, and the calculated use by each installation. The table also shows the estimated breakdown of energy use between family housing and other buildings, air-conditioned and non-air-conditioned.

Table 4 shows all fuel use, by installations.

As an indication of the use of electricity and the consumption of the various fuels used, year-by-year graphs from 1975 to 1979 for Schofield Barracks, installation with largest consumption, are presented. (Figs 5a, b, c, d and e). They are typical of the ten installations. (Graphs for all ten installations are in the full report.) In addition, a month-by-month plot of electricity use and electricity cost is presented for Schofield Barracks for three years, June, 1977 through May, 1980 (Fig. 6). Some of the variation in use is due to weather (summer peaks). The monthly meter readings are not at exactly the same intervals (varying from about 28 to 32 days), but the graph is based on normalized 30.4 day monthly basis.

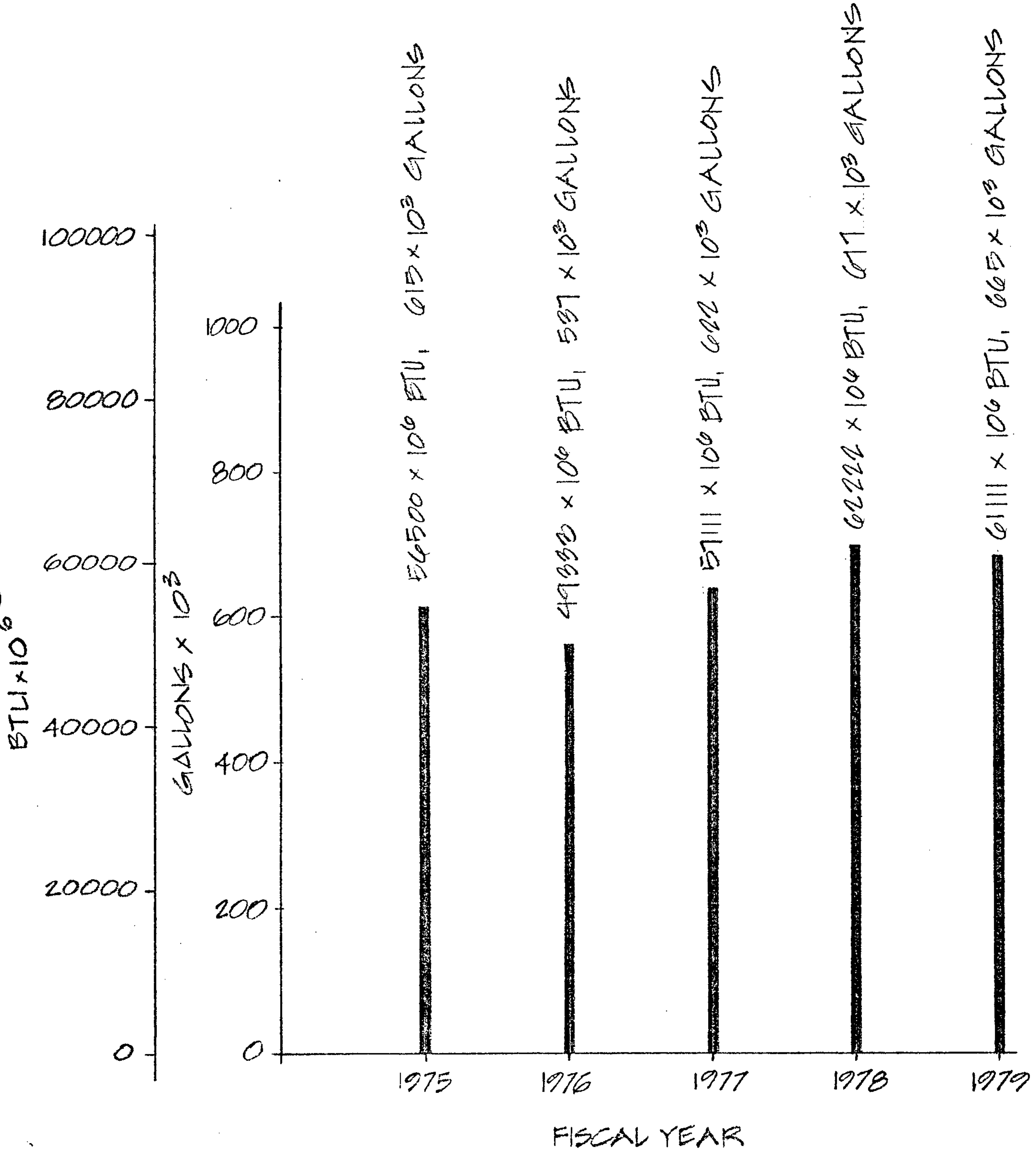


TOTAL ENERGY CONSUMPTION - SCH. BRKS.

FREDERICK H. KOHLOSS AND ASSOCIATES, INC.
CONSULTING ENGINEERS

PREPARED
APPROVED
PROJECT SCH. BRKS. - TOTAL ENERGY
SHEET
DATE 9/14/82

Fig. 5A

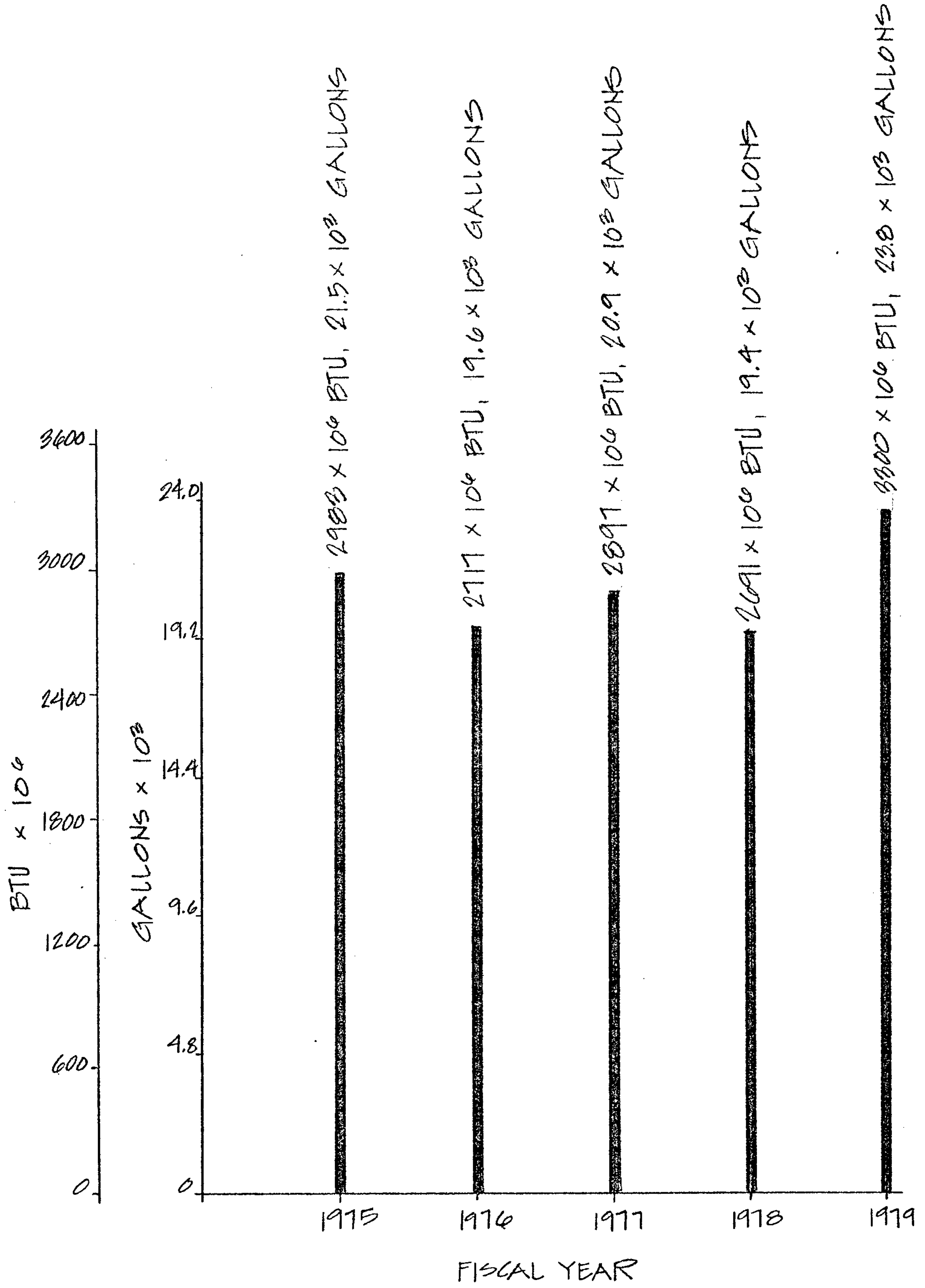


LIQUIFIED PETROLEUM GAS (LPG) CONSUMPTION

FREDERICK H. KOHLOSS AND ASSOCIATES, INC.
CONSULTING ENGINEERS

PREPARED RAULS APPROVED
PROJECT SCH. BRKS LPG CONSUMPTION
SHEET DATE 3/10/81

Fig. 5B



HEATING OIL (DFM/FS-5) CONSUMPTION

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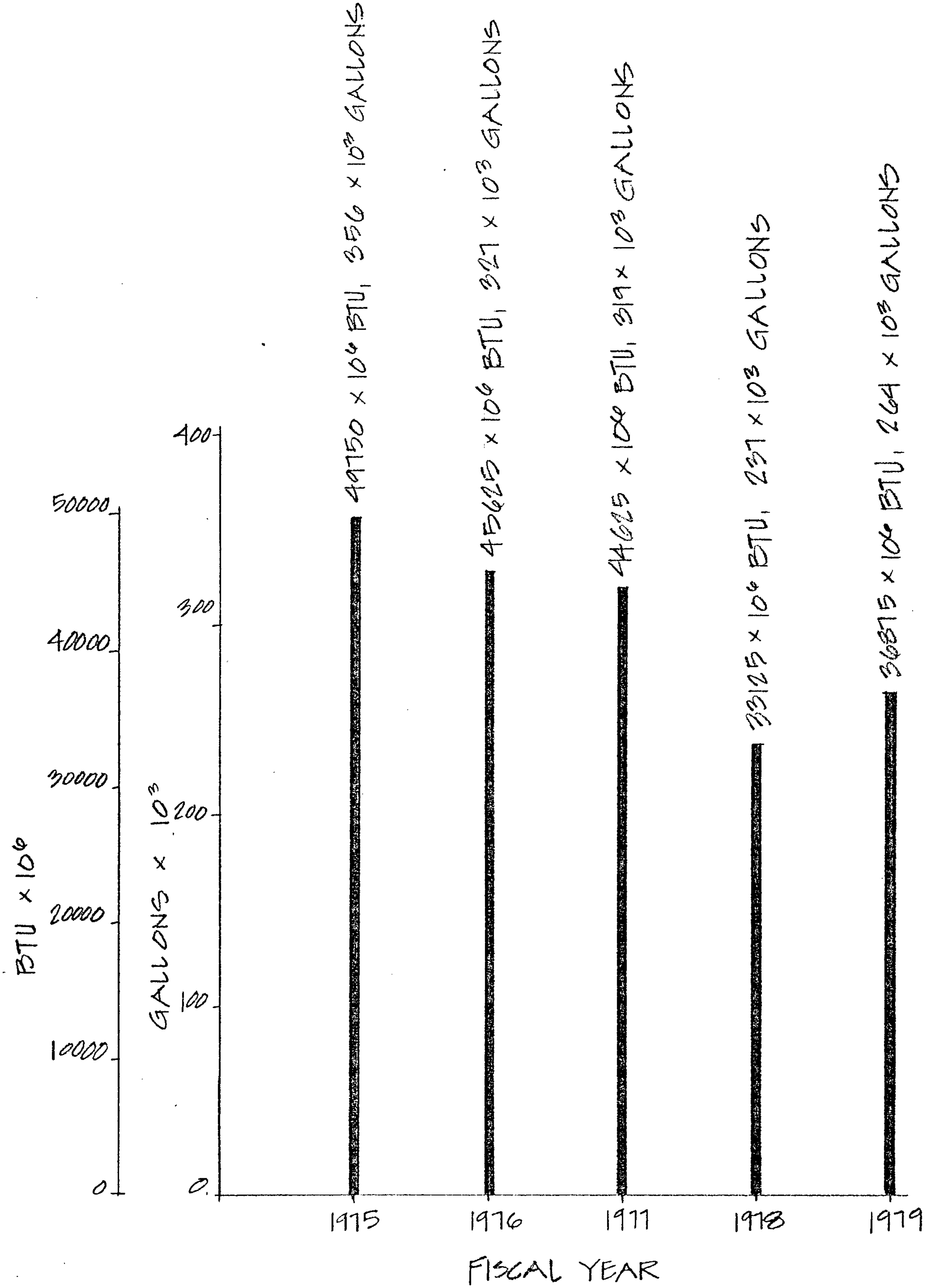
CONSULTING ENGINEERS

PREPARED RAULS
APPROVED
PROJECT SCH. BRKS. DFM/FS-5 CONSUMP
SHEET
DATE 3/10/81

Fig. 5C



LIGHT OIL (DF-2) CONSUMPTION

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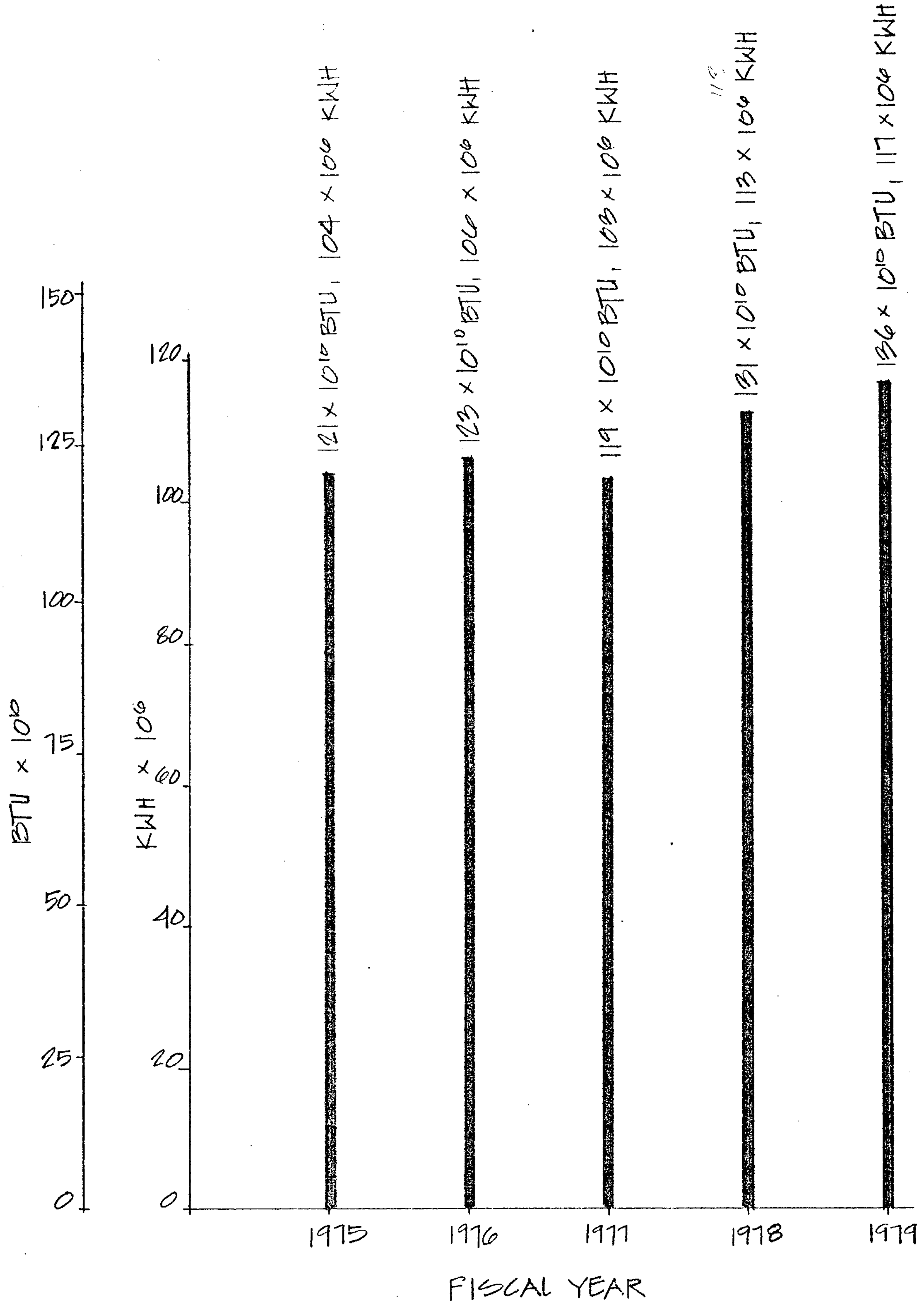
SHEET
DATE 3/11/81

Fig. 5D



ELECTRICAL ENERGY CONSUMPTION

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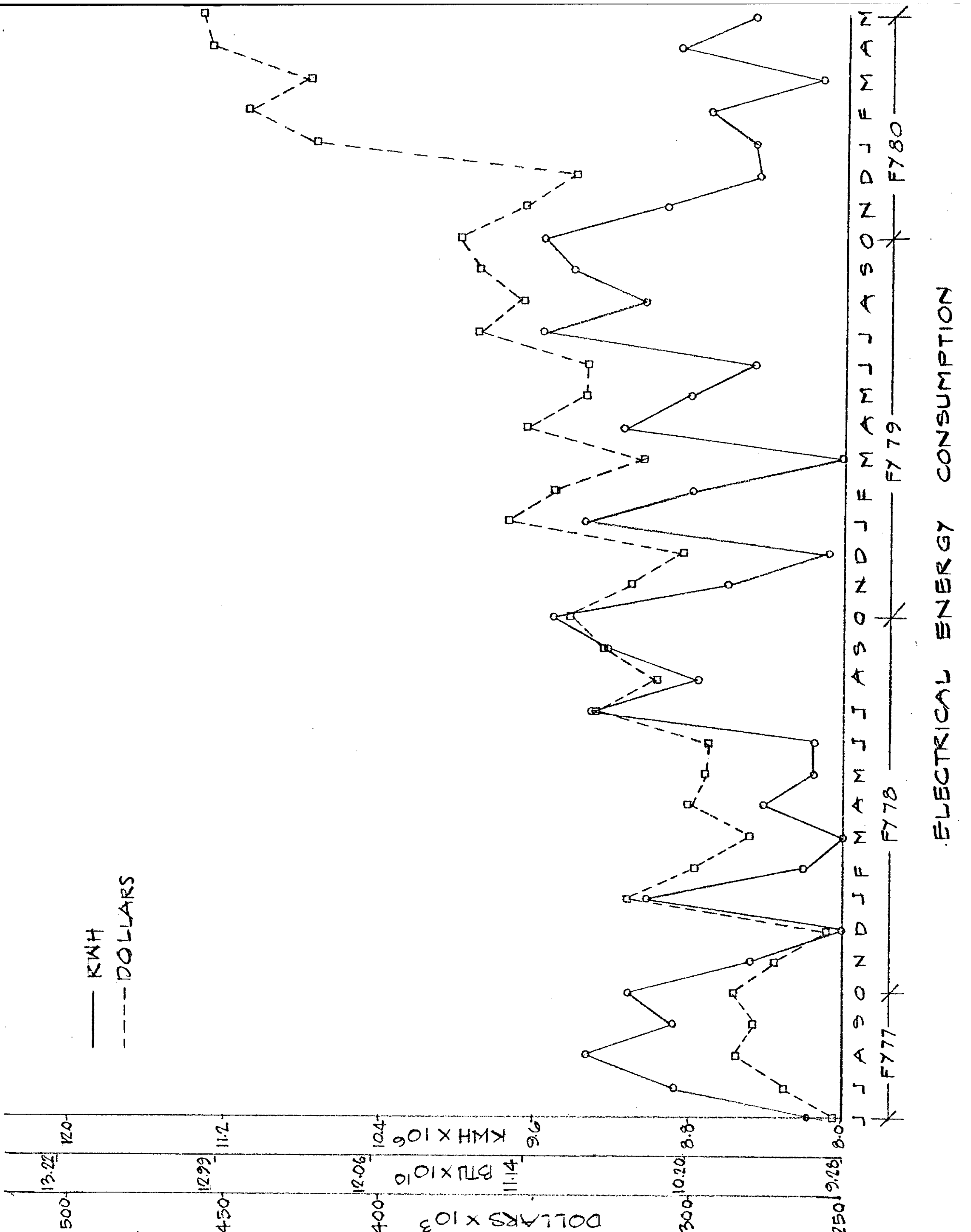
	PROJECT SCH. BRKS. ELEC. CONSUMPTION
	SHEET DATE 3/10/81

Fig. 5E



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CONSULTING ENGINEERS

PROJECT SCHOFIELD BKS LOAD PROFILE

SHEET DATE 3/7/81

Fig. 6

Energy Conservation Investment Projects

ECIP projects and operations and maintenance projects are presented in tabular form in descending order of E/C ratio. E/C ratio is defined as Energy Saved (millions of Btu per year) divided by Cost (thousands of dollars, based on current working estimate). (Note: Some of the projects are mutually exclusive as they apply to the same energy conservation opportunities.

SCHOFIELD BARRACKS MILITARY RESERVATION
ECIP PROJECTS

Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1. New Chilled Water Pumps Quads C, F, I & J	33,559	575,537	130,933	0.23	256.00
2. Chilled Water Loops - Quads I, J, & K	40,090	687,543	1,254,128	1.80	32.00
3. Installation of Heat Pump Barracks	38,035	1,022,538	2,345,101	2.30	16.20
4. Chilled Water Loop Quads C, D, E, & F	32,559	567,977	2,081,196	3.70	15.60
5. Roof Spray System	4,472	69,913	315,382	4.50	14.20
6. Installation of Frequency Changing Chiller Controls Quads F & I	1,763	36,986	127,346	4.00	11.90
7. Installation of Shading devices - Quads	8,854	154,752	1,062,253	6.90	8.34

FAMILY HOUSING ECIP PROJECTS

Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1. Installation of Water Flow Restrictors - Family Housing	87,410	1,585,897	380,093	0.24	223.00
2. Air Conditioning Removal - Family Housing	36,153	701,162	1,498,050	2.10	24.10
3. Installation of Heat Pumps - Family Housing	171,210	3,115,921	10,294,577	3.30	16.60
4. Installation of Solar Hot Water System - Family Housing	127,475	2,300,583	11,608,076	9.80	5.60

FORT SHAFTER MILITARY RESERVATION
ECIP PROJECTS

	Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1.	Installation of Heat Pumps - Barracks	2,184	101,305	355,206	4.5	8.9

FAMILY HOUSING ECIP PROJECTS

	Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1.	Installation of Heat Pumps - Family Housing	21,042	699,807	2,131,668	3.1	9.8
2.	Installation of solar Systems - Family Housing	21,549	655,843	4,687,851	7.1	4.6

ALIAMANU MILITARY RESERVATION
FAMILY HOUSING ECIP PROJECTS

	Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1.	Installation of Water Flow Restrictors - Family Housing	65,280	1,119,552	337,392	0.3	193.0
2.	Air Conditioning Removal - Family Housing	207,756	3,964,767	7,417,528	1.8	28.0
3.	Installation of Heat Pumps - Family Housing	129,285	2,182,303	7,710,285	3.5	16.7
4.	Install EMCS (Carrier Current)	35,315	605,052	2,336,354	3.9	15.1
5.	Installation of A/C Heat Exchangers for Domestic Hot Water - Family Housing	69,994	1,200,397	6,892,325	5.7	10.1
6.	Installation of Solar Systems - Family Housing	128,880	2,175,357	16,956,057	7.8	7.6

FT. DeRUSSY MILITARY RESERVATION
ECIP PROJECTS

Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1. Installation of Heat Pumps - Building #1	6,870	354,737	336,148	1.0	20.4

HELEMANO MILITARY RESERVATION
ECIP PROJECTS

Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1. Installation of Heat Pumps - Barracks	1,081	26,964	164,748	6.1	6.6

FAMILY HOUSING ECIP PROJECTS

Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1. Installation of Heat Pumps - Family Housing	1,623	27,396	96,756	3.5	16.8
2. Installation of Solar Hot Water Systems - Family Housing	1,617	23,819	212,782	8.9	7.6

TRIPLER ARMY MEDICAL CENTER
FAMILY HOUSING ECIP PROJECTS

	Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1.	Air Conditioning Removal - Family Housing	5,260	98,086	145,442	1.5	36.0 A
2.	Installation of Heat Pumps - Family Housing	11,357	191,704	667,295	3.5	16.8 B
3.	Installation of A/C Heat Exchangers for Domestic Hot Water - Family Housing	1,879	32,225	229,438	7.2	8.2 G
4.	Installation of Solar Hot Water Systems - Family Housing	11,321	191,086	1,489,473	7.8	7.6 MCA

Operation and Maintenance Projects

These projects are tabulated in a manner similar to the ECIP projects, in descending order of E/C ratio. (Note: Some of these projects are mutually exclusive, as the ECIP projects, and after review, will be handled in a manner similar to the ECIP project adjustments.)

SCHOFIELD BARRACKS MILITARY RESERVATION
O & M PROJECTS

	Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1.	Removal of Corridor Fan Coil Units - Quads	9,950	172,979	9,700	0.06	1,026.00
2.	Installation of Water Flow Restrictors - Quads	12,422	236,912	46,487	0.20	267.00
3.	Outdoor Air Ventilation Reduction	3,779	48,862	97,485	2.00	36.80
4.	Installation of Heat Pumps - Bldg. 580	18.6	208	3,093	14.90	6.00

FT. SHAFTER MILITARY RESERVATION
O & M PROJECTS, FAMILY HOUSING

	Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1.	Installation of Water Flow Restrictors - Family Housing	11,744	237,36	68,473	0.29	172.00
2.	Air Conditioning Removal - Family Housing	3,578	45,114	79,084	1.80	45.20

FT. DERUSSY MILITARY RESERVATION
O & M PROJECTS

	Project Title	Energy Savings		CWE	Payback	E/C
		MBTU/Yr.	$/Yr.	$	Period Yrs.	Ratio
1.	Installation of Water Flow Restrictors - Building #1	3,892	105,473	14,899	0.14	261.00
2.	Energy Monitoring and Control System	1,745	22,563	65,989	2.92	26.44
3.	Installation of Frequency Changing Chiller - Speed Controller	1,920	28,708	75,621	2.70	25.40
4.	Replace Water Chillers and Pumps, Bldgs. 198, 199 and 202	1,654	22,836	88,570	3.90	18.70
5.	Modify Electrical Wiring for Light Switching	500	6,460	30,258	4.70	16.50
6.	Roof Spray - Hale Koa	230	2,512	14,718	5.90	15.60
7.	Roof Spray - Bldgs. 198, 199 and 202	488	5,716	34,426	6.00	14.10
8.	Modify Window Area	95	1,228	11,700	9.53	8.12

HELEMANO MILITARY RESERVATION
O & M PROJECTS, FAMILY HOUSING

Project Title	Energy Savings MBTU/Yr.	Energy Savings $/Yr.	CWE $	Payback Period Yrs.	E/C Ratio
1. Installation of Water Flow Restrictors - Family Housing	819	10,590	2,969	0.28	275.00

Recommendations

1. To the degree funding will permit, implement the recommend ECIP projects and O & M projects.

CH-81-22 No. 4

OPPORTUNITIES TO SAVE ENERGY IN TROPICAL CLIMATES

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ABSTRACT

Energy conservation in tropical climate air-conditioning systems requires consideration of building envelope economics and air-conditioning system design with different weighting factors than those usually applied to temperate zone systems.

Year-round refrigeration use for cooling, very high humidity, low peak dry-bulb temperature, and narrow daily temperature range must be considered.

Occupant comfort must be planned considering light clothing, high-humidity, and desirability of some air motion. Reheat, using recovered energy, is often essential.

Avoidance of equipment over-sizing, permitting temperature swing at peak loads, and efficient selection of equipment for long hours of refrigeration operation all affect energy use.

Energy estimating methods widely used in temperate zones, based on correlations of outdoor temperature and load, are not applicable in the tropics. An example of one approach is presented.

Much attention has been given to the conservation of energy in temperate zone climates, but there has been considerably less published material on energy conservation in tropical climates. Further, in analysis of air-conditioning systems, to estimate annual energy consumption requires consideration of many factors, which in the tropics may have more or less effect than in the temperate zone.

Design of the building envelope for a warm, humid tropical climate has vastly different economic and technical constraints from what is considered usual in most of the U.S. and Canada:

1. The maximum temperature difference across walls and roof is far less, on the order of 9F to 15F (5°C to 9°C).
2. The daily temperature range is less, on the order of 9 deg F (5 deg C).
3. Solar load, even on opaque surfaces, is more significant by far than convective heat transfer due to temperature difference. This difference is striking when considering the year-round energy use, particularly with buildings occupied 24 h a day.

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4. The high humidity of the outdoor air makes condensation on interior cooled surfaces an ever-present problem, particularly with the number of air leakage paths normally present in building envelopes.

5. No provision need be made in the building design or in the air-conditioning system for heat loss to the surroundings.

A simple air-conditioning system's outdoor air, room air, mixed air entering the cooling coil, and supply air are shown in the psychrometric chart in Fig. 1. The comfort zone as defined in ASHRAE Standard 55-74 (Ref 1) is also shown.

The humid tropical outdoor air introduced by unintentional infiltration or intentional ventilation, causes a far greater outdoor air cooling load than in temperate climates, and will significantly raise an air-conditioning system's cooling coil entering air wet-bulb temperature. Coil entering air may be so humid that the coil cannot sufficiently dehumidify it to maintain interior conditions within the comfort zone. (see Fig. 2)

This is accentuated under part-load conditions, during which the evaporator is ill-matched to the high-latent, low-sensible load; since outdoor air humidity does not drop appreciably, while sensible loads may be lower due to less lighting or lower solar load. Fig. 3 shows a frequent condition in tropical air conditioning systems, extreme overcooling, with still too much relative humidity in the conditioned space.

Use of reheat is often essential to avoid overcooling and to achieve interior comfort in air conditioned tropical facilities. Due to the resulting higher first cost, reheat is often omitted even when its use is warranted. Obviously, to conserve energy, the reheat should come from waste energy. Commonly used reheat sources include "hot-gas" (refrigerant discharge vapor) and condenser water. If solar-heated water is available, it is also suitable. Rarely is other waste heat available unless in the form of process waste heat.

For refrigeration equipment, a tropical climate also alters the economic comparison between air-cooled condensing and evaporative heat rejection devices, due to the comparatively low peak dry-bulb temperatures, but relatively high wet-bulb temperatures. This tends to favor air-cooled condensing, rather than evaporative devices, but not to the exclusion of evaporative devices.

The economics of insulation are also affected by all of the above conditions. Generally, roof insulation is very desirable with the high sol-air temperature in the daylight hours, but the roof structure should be low-mass for buildings which are to be occupied in the evening. Due to the low daily temperature range, temperature in the evening remains fairly close to the afternoon peak, so sun load delayed by a roof mass is undesirable in the evenings if the space is occupied. Wall insulation is less economical than roof insulation due to its higher initial installed cost, the frequently smaller area of opaque wall than roof, and the fact that the direct sunlight is on a wall usually for fewer hours than for a roof.

With the always warm, humid outdoor air, evaporative cooling or ventilation will not provide the many low-energy-use hours of comfort per year in which they can substitute for refrigerated cooling in almost all U.S. and Canadian areas.

Solar heat gain is a year-round penalty. Exterior interception of solar radiation before it impinges on the fenestration is, therefore, essential for energy saving in the tropics. Further, the window shading must be effective from early morning to late evening. Many tropical sites are adjacent to the ocean or other large bodies of water, and the solar reflectance from water, particularly at low sun angles, adds solar load beyond what is usual (with the reflectance of only ordinary ground being considered in usual load computations). For glare reduction, tinted heat-absorbing glass is desirable and will reduce the air-conditioning cooling load.

Fortunately most tropical locations have less smoke and other dark particulate matter in the outdoor air than temperate zone industrial cities. Roofs and walls are commonly light-colored, and stay light longer. The use of a light color on buildings is a major energy saver.

An approach less frequently used than it should be, is deliberate under-sizing of cooling equipment. Since most architects, engineers and air-conditioning contractors don't like to be sued for providing systems with inadequate capacity, this is understandable. Too often, "safety factors" are piled onto load computations, and "worst case" assumptions are made as to simultaneous occurrence of exterior load peaks and interior load peaks. If the full written concurrence of the owner is received toward minimizing this practice, designers of air-conditioning systems can avoid the inefficiencies inherent in equipment sized to balance at peak loads beyond those usually encountered.

Over-sized systems can result in poor performance for several reasons. If the compressor-evaporator balance in direct-expansion systems is based on a too-high total load estimate, the compressor-evaporator balance will result in a low suction temperature, with high power input per unit of cooling. Worse, if control of space conditions is from dry-bulb temperature sensed by a space or return-air thermostat, the compressor will run partially unloaded if it has capacity control, or will start and stop frequently with fairly long off-cycles if it does not have capacity control. In chilled water systems, erratic control of chilled water temperature may also accompany high compressor power input per unit of cooling, and long off cycles.

In the tropics, due to the moisture in the entering air, the cooling surface is wetter than usual for temperate zone systems, so if a chilled water control valve (or a liquid refrigerant solenoid valve in a direct expansion system) closes, moisture re-evaporation from the coil will be significant as the supply fan continues to run. Thus over-sized systems can result in very high relative humidity indoors.

It is common in temperate zone residences, to accept under-sized air-conditioning systems. The industry-wide load calculation procedure (Ref 2) attempts to select unitary equipment which will result in a 3 deg F (1.7 deg C) rise in inside temperature at peak loads.

This principle can be accepted in commercial air-conditioning systems as well. It is recognized (Ref 3) that a rate of air temperature change of 4 deg F/h (2.2 deg C/h) is acceptable to sedentary occupants of a space, and rate of relative humidity change can be as high as 20% rh/h.

Examination of comfort conditions leads to another design approach to reduce energy consumption. The comfort zone of ASHRAE Standard 55-74 in Fig. 1 is based on light clothing, 0.5 to 0.7 clo, and office work (close to sedentary), 1 to 1.2 met activity (One met = 58.2 w/m^2, or 18.4 $Btu/h\text{-}ft^2$). It is also based on essentially still air, less than 45 ft/min (0.23 m/s) velocity, relative humidity of 40%, and air temperature equal to mean radiant temperature.

Typical clothing in the tropics is somewhat lighter, 0.3 to 0.6 clo. (For women, this may be a cool dress, pantihose, bra and panties, and shoes, which amount to 0.27 clo; for men, cool socks, briefs, short-sleeved woven shirt, cool trousers, and shoes, which amount to 0.57 clo.) Relative humidity in tropical air conditioned spaces is very frequently from 55 to 70%. This will result in a slight shift in comfort conditions (Fig. 5), redrawn and simplified from Ref 4.

From Fig. 5, with clothing at 0.45 clo, comfort (80% of occupants not dissatisfied) ranges from 73.5F (23.0°C) to 78.8F (26.0°C) ambient air temperature.

Fig. 6, redrawn and simplified from Ref 4, shows that the effect of increasing relative humidity has a minor effect on occupants' comfort. For example, a reduction in rh from 80 to 60, at an air velocity of 40 ft/min (0.2 m/s) has roughly a 1 deg F (0.5 deg C) decrease in the "perceived temperature" by the occupant.

Fig. 7, redrawn and simplified from Ref 4, shows that the effect of increasing air velocity relative to the occupant has a more significant effect than reduction in relative humidity. For example, at 20 ft/min (0.10 m/s) the air temperature of 78.8F (26.0°C) feels like 83F (28.3°C) at 150 ft/min (0.75 m/s). In other words, with the higher relative air velocity the occupant feels 4.2 deg F (2.3 deg C) cooler.

Air distribution systems can thus be designed for more "lively" air motion in the tropics provided sufficient mixing of supply air and room air occurs before the occupant senses the colder supply air. This is intuitively true, since persons in cold climates connote air motion with "cold draft," while persons in the tropics consider air motion a "cool breeze."

A very desirable feature for both limiting the relative humidity and for efficient system operation is to provide a separate cooling coil for the outdoor ventilating air, and to control it so that it is provided with chilled water or refrigerant whenever the system supply fan is running. To reduce cost, chilled water returned from space cooling coils can be used for the outdoor pre-cooling coil (see Fig. 4). This reduces the total chilled water flow rate required and allows the required refrigerant suction pressure to rise due to the greater chilled water cooling range, thus achieving higher average temperature for a given chilled water supply temperature. This of course improves the refrigeration cycle efficiency. Pre-cooled ventilating air can then be mixed with return air in a space cooling zone with reasonable limitation of relative humidity.

When faced with the problem of estimating energy consumption for air conditioning in the tropics, traditional temperate zone methods are not appropriate. First, there is no heating, so all heating-degree-day related methods are not relevant. Second, there are no intermediate seasons, where system type and control technique have a major effect on energy consumed. Third, there is little published substantiation of cooling degree-days or equivalent full-load hours.

An approach to estimating energy consumption which was found useful on a large military energy conservation project, was to devise a methodology for the local climate.

Consider the necessity to estimate energy consumed in the Honolulu area by air-conditioning in a large number of buildings, some office-type, some residential-type. Familiarity with typical buildings was obtained by energy audit procedures. The buildings were not separately metered for electricity consumption.

Local weather data (Ref 5) gave degree days above 65F (18.3°C), and temperature averages and extremes (Table 1). Further data are compiled in Ref 6, and are extracted in Table 2.

An average day is picked by inspection from Table 1. Annual cooling degree days are 4221, an average of 352 per month. November has 345, and the next closest month is March, 369. November is thus selected. Average daily maximum temperature for November is 83.2F (28.4°C), and average daily minimum is 69.8F (21.0°C). The annual mean is 76.6F (24.8°C). It appears reasonable to select 77F (25°C) as the average year-round outdoor temperature for energy analysis purposes. Annual mean relative humidity percentage at 2 AM, 8 AM, 2 PM, and 8 PM, respectively is 74, 71, 56, and 69%.

The average outdoor wet-bulb temperature can be estimated from assuming a sinusoidal variation in dry-bulb temperature, peaking at 3 PM, with an 11 deg F (6.1 deg C) daily range (Fig. 8).

When the average relative humidity at the four hours above are plotted (Fig. 8) and the resulting wet-bulb at those hours is also plotted, a smooth curve through the wet-bulb points shows the average wet-bulb temperature to be about 68F (20°C).

To adapt the typical day to average conditions for a 10-h occupancy office building, the dry-bulb and wet-bulb temperature averages were estimated for the period 7 AM to 5 PM from Fig. 8. (Office hours in Honolulu are usually early in comparison to many mainland cities). This results in 81F (27.2°C) dry-bulb and 70F (21.1°C) wet-bulb average outdoor conditions for office-type occupancy.

The temperatures are then used to determine the ventilation load for the 10-h and 24-h occupancies, per cfm:

	Outside db/wb	h/lbda (Btu)	Inside db/%rh	h/lbda (Btu)	Δ h/lbda (Btu)	h/cfm (Btu/h)
Office	81/70	34.09	78/55	31.03	3.06x60/13.8 =	14.34
Residence	77/68	32.42	78/55	31.03	1.39x60/13.8 =	6.52

The ventilation (or infiltration) load was estimated from the known floor area of the buildings: Assuming 1/2 air change infiltration per hour, and 8-ft. ceiling heights,

$$\text{Infiltration cfm} = \frac{8 \times \text{floor area, ft}^2}{2 \times 60} = \frac{\text{Area, ft}^2}{15}$$

(If occupancy was known to be high in a building, ventilation cfm = 5 x persons could be used, but was usually less than infiltration.)

ASHRAE's Cooling and Heating Load Calculation Manual (Ref 7) was used as a guide to developing estimating procedures.

To estimate heat gain through the opaque envelope, analysis of the buildings showed there were basically two types of roof construction, reinforced concrete and wood, similar to types 9 and 10, respectively, in Table 3.8 of Ref 7. The cooling load temperature differences can be added for the hours of occupancy from the table, and an average figure obtained:

Without Ceiling	24 h Total	Residential Average	8AM to 5PM Total	Office Average
Concrete	707/24 =	29	300/10 =	30
Wood	682/24 =	28	231/10 =	23
With Ceiling				
Concrete	698/24 =	29	229/10 =	23
Wood	710/24 =	30	236/10 =	24

This can be simplified by using an average TETD of 27 for all purposes. Roof U-values can be obtained from energy audit data. For rough values, U = 0.07 can be used for roofs with ceilings, U = 0.16 for roofs without ceilings, as a reasonable average. Roof area was available from audit data.

Wall heat gain can be approximated in a similar manner. Since the buildings involved were generally low-rise, the opaque wall heat gain is low when compared with roof gain. Most walls were concrete or frame, similar to Group E or G of Table 3.9 of Ref 7. From Table 3.10 of Ref 7 the values were averaged from Group E and G to get a TETD average by direction, then corrected by Table 3.12 of Ref 7 for 20° Latitude, November. The results are given in Table 3. All exposures were assumed equal in area since the buildings involved were of random shape and orientation. (Since wall load is small, even a rough approximation would introduce little error).

In Hawaii walls are not usually insulated, so an average U value of 0.25 can be used without serious error, along with the average TETD of 19 from Table 3. In all cases transmission gain or loss is neglected since it is very small.

To calculate the solar load, again areas and types of fenestration were obtained from energy audit procedures. As a rough approximation, 25% fenestration of single clear glass would be reasonable in the absence of more accurate information.

The data in Table 3.25 of Ref 7, for 20 deg North Latitude, for November were used to obtain maximum solar heat gain factors for each of eight orientations:

	N	NE/NW	E/W	SE/SW	S
Btu/h ft^2	29	48	197	249	211

For estimating solar gains for 24-h occupancies and for 10-h occupancies, Table 3.28 of Ref 7 was used, with interior shading:

	24-h total cooling load factors	per h	x max factors	Btu/h ft^2 average hrly gain	10-h total cooling load factors	per h	x max factors	Btu/h ft^2 average hrly gain
N	13.62/24 =	0.57 x	29 =	17	10.03/10 =	1.00 x	29 =	29
NE	5.13/24 =	0.21 x	48 =	10	3.33/10 =	0.33 x	48 =	16
E	5.50/24 =	0.23 x	197 =	45	3.83/10 =	0.38 x	197 =	75
SE	6.23/24 =	0.26 x	249 =	65	4.57/10 =	0.46 x	249 =	114
S	7.42/24 =	0.31 x	211 =	65	5.37/10 =	0.54 x	211 =	113
SW	6.20/24 =	0.26 x	249 =	65	4.76/10 =	0.48 x	249 =	119
W	6.47/24 =	0.27 x	197 =	53	3.91/10 =	0.39 x	197 =	77
NW	5.15/24 =	0.21 x	48 =	10	3.40/10 =	0.34 x	48 =	16

To allow for the fact that the sun is sometimes obscured by clouds the percent sunny hours was taken from Table 1, 68%, and it was assumed that 20% of insolation is received in cloudy weather: (0.68)(1) + (1 - 0.68)(0.20) = 0.744, which is then used as a multiplier on all the solar gains above, resulting in Table 4.

It was assumed that lights are on 10 h for commercial occupancy, at 80% installed wattage; and assumed lights are on 6 h for residential occupancy, at 30% installed wattage. Watts installed were obtained from energy audit procedures, in whose absence 2.5 watts per sq ft floor area can be used for offices, 1 watt per sq ft for residences, as installed figures.

People: Average occupancy was obtained from energy audit procedures. For rough approximations, 1 person per 300 sq ft floor area of offices, or per 1200 sq ft floor area of residences can be used as average figures during the 10-h office day and the 24-h residence day, at 400 Btu/h person.

Obviously such an approximation can be only a rough approach to an accurate figure, but so are all energy estimates. Where electricity is metered, closer comparisons can be made.

Where approx. 150 buildings had to be field checked, and their results used as a guide to about 4000 buildings, the energy estimating procedure described has been a means of obtaining a reasonable value.

In one particular pair of office buildings, as an example, the following data were available:

Total conditioned floor area (Part 1-story, part 2-story)	49,200 sq ft
Roof area (with ceiling)	34,700 sq ft
Net wall area	18,715 sq ft
NW glass	2,988 sq ft
NE glass	256 sq ft
SE glass	2,490 sq ft
SW glass	256 sq ft
Partition (neglect transmission)	9,530 sq ft

An average cooling load per operating hour can be approximated as follows:

Infiltration/Ventilation	49,200/15 x 14.34	= 47,000 Btu/h
Roof gain	34,700 x 27 x 0.07	= 65,600
Net wall gain	18,715 x 19 x 0.25	= 88,900
NW glass gain	2,988 x 12	= 35,900
NE glass gain	256 x 12	= 3,100
SE glass gain	2,490 x 85	= 211,700
SW glass gain	256 x 89	= 22,800
Lights	49,200 x 2.5 x 0.80 x 3.14 Btu/w	= 309,000
People	49,200/300 x 400	= 65,600
Average hourly load		826,800
		= 69 tons

The buildings were operating on one of two installed air-cooled reciprocating water chillers when field-checked.These buildings, typical of those built a few years ago, have poor efficiency of the refrigeration cycle and excess water transport power. This equipment is nearing the end of its economic life and may be replaced. Some areas are needlessly cooled, such as certain corridors. Arrangements can be made for switching off fan coil units in unoccupied areas. Other energy conservation approaches to be considered include: light switching to permit daylighting near windows; reduced lighting levels; confirmation of thermostats' calibration and locking the covers; consider starting equipment later in the morning; stopping earlier in the evening; replacing some glass with wallboard; verifying outdoor air damper minimum settings; and setting chiller controls for warmer chilled water.

The buildings were checked during somewhat hotter weather than average, but their occupancy was somewhat lower than a typical office building since some of the area is classrooms, mostly vacant. The chiller's nominal capacity is 85 tons at 95 ambient air. It is estimated that the chiller was running partly at full load and partly with one or two cylinders unloaded, which is a rough check that the methodology appears reasonable. (As designed, the buildings had two chillers, one of which was usually sufficient.) Obviously the more data which are available on an existing building, the closer an estimate of its load and air conditioning energy use can be.

For these buildings, air conditioned about 1974, the chiller has approx. 1.11 kW input per ton; with two 15 hp chilled water pumps, and mostly fan-coil units with total installed hp of 28. (Fan and pump hp is taken at 1 kW/hp.) Under the estimated conditions, (69 x 1.11) + (15) + (28) = 120 approx. kW input. A checkmeter can be installed to verify chiller and pump power input, if further refinement is needed.

In summary, the options for energy conservation in an all-refrigerated-cooling environment are fewer, but the opportunity for common sense savings exists. Ref 8 contains useful application data for tropical air-conditioning design. Good system design will be energy-efficient.

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Table 1

Honolulu, Lat. 21° 20' N.

NORMALS, MEANS, AND EXTREMES

	Temperatures °F					Normal degree days Base 65 F		Relative humidity pct.				Pct. of possible sunshine
	Normal			Extremes				Hour 02 (Local Time)	Hour 08 (Local Time)	Hour 14 (Local Time)	Hour 20 (Local Time)	
Month	Daily maximum	Daily minimum	Monthly	Record highest	Record lowest	Heating	Cooling					
J	79.3	65.3	72.3	87	53	0	226	80	80	62	73	63
F	79.2	65.3	72.3	87	53	0	204	77	76	59	69	65
M	79.7	66.3	73.0	88	55	0	248	75	72	58	70	68
A	81.4	68.1	74.8	89	59	0	294	74	69	57	68	66
M	83.6	70.2	76.9	89	63	0	369	73	67	55	67	69
J	85.6	72.2	78.9	90	65	0	417	72	66	54	67	70
J	86.8	73.4	80.1	90	67	0	468	71	66	51	66	73
A	87.4	74.0	80.7	92	67	0	487	71	67	53	67	73
S	87.4	73.4	80.4	92	66	0	462	71	66	52	66	75
O	85.8	72.0	78.9	91	64	0	431	72	68	55	67	68
N	83.2	69.8	76.5	89	58	0	345	78	74	59	71	60
D	80.3	67.1	73.7	89	54	0	270	78	77	60	71	59
YR	83.3	69.8	76.6	92	53	0	4221	74	71	56	69	68

Table 2

SUMMER DESIGN DATA, AIR CONDITIONING (F)

	1% db and mcwb	2-1/2% db and mcwb	5% db and mcwb	Mean Daily Range
Honolulu	87 73	86 73	85 72	11

(mcwb = mean coincident wet-bulb temperature) (x % of db = the dry-bulb temperature equaled or exceeded x % of the time during the warmest four months) (Mean Daily Range = daily maximum temperature minus daily minimum temperature)

Table 3

TETD FOR WALLS

		24 h Total	Corrected per h	10 h Total	Corrected per h
Concrete	N	287/24 = 12 - 3 =	9	106/10 = 11 - 3 =	8
	E	527/24 = 22 - 1 =	21	300/10 = 30 - 3 =	27
	S	412/24 = 17 - 2 =	15	172/10 = 17 - 3 =	14
	W	511/24 = 21 - 1 =	20	142/10 = 14 - 3 =	11
		Average =	16	Average =	15
Wood	N	298/24 = 12 - 3 =	9	186/10 = 19 - 3 =	16
	E	538/24 = 22 - 1 =	21	411/10 = 41 - 3 =	38
	S	413/24 = 17 - 2 =	15	311/10 = 31 - 3 =	28
	W	534/24 = 22 - 1 =	21	321/10 = 32 - 3 =	29
		Residential Average per h =	17	Office Average per h =	28

Table 4

SOLAR HEAT GAIN THROUGH FENESTRATION, BTU/H SQ FT

	Residential (24 h)	Commercial (10 h)
N	13	22
NE	7	12
E	33	56
SE	48	85
S	48	84
SW	48	89
W	39	57
NW	7	12

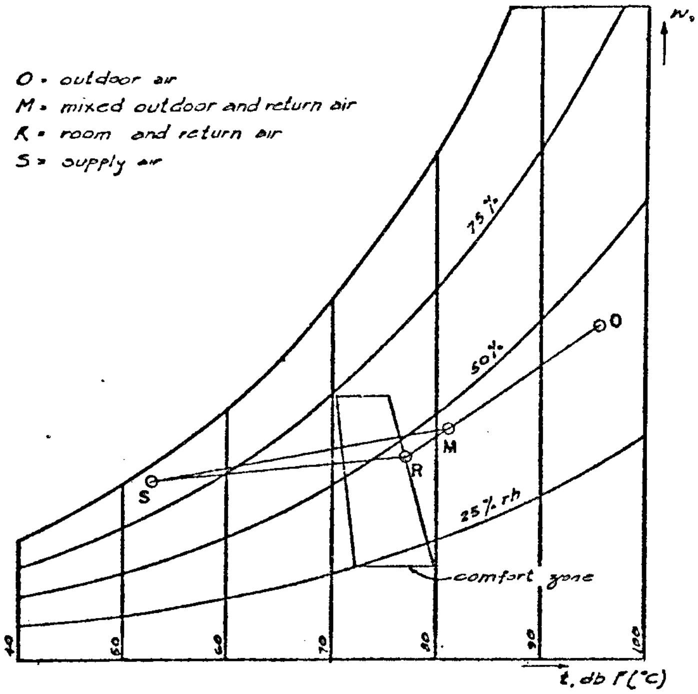

Fig. 1 Simple temperate zone air-conditioning system

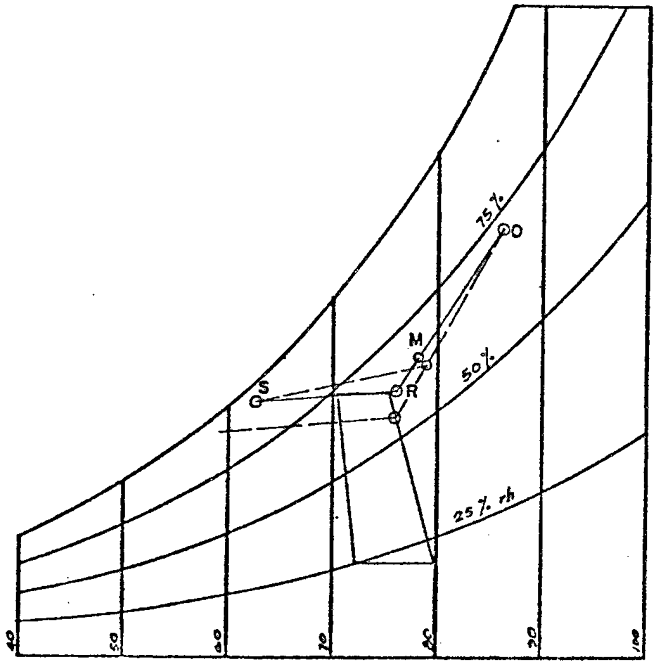

Fig. 2 Tropical air-conditioning system - room condition shifts to higher humidity than planned

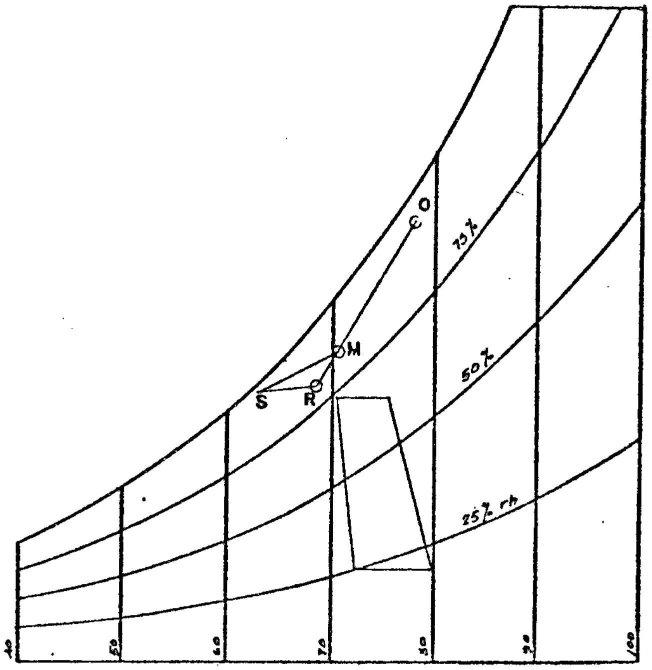

Fig. 3 Tropical air-conditioning system overcooling and very high room relative humidity

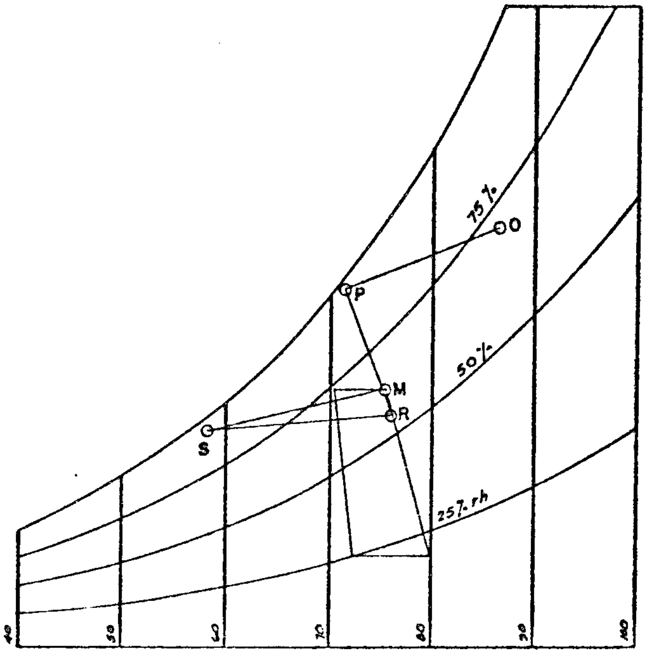

Fig. 4 Tropical air-conditioning system with outdoor air precooling

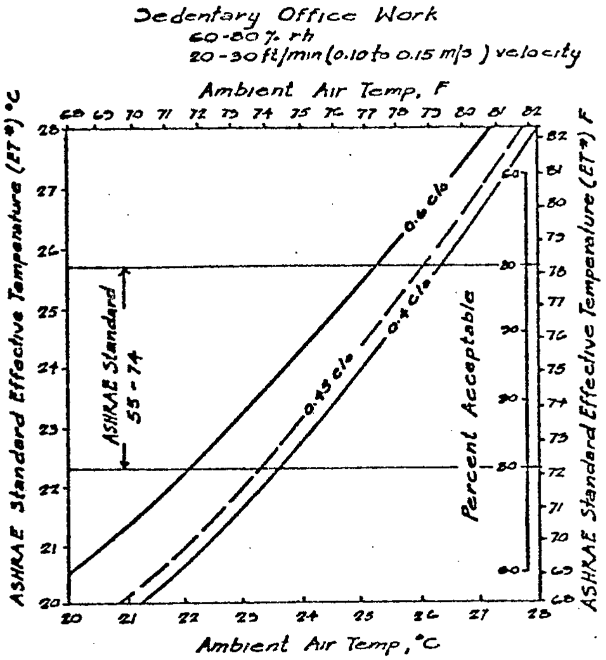

Fig. 5 Evaluation of ET* (Effective Temperature)

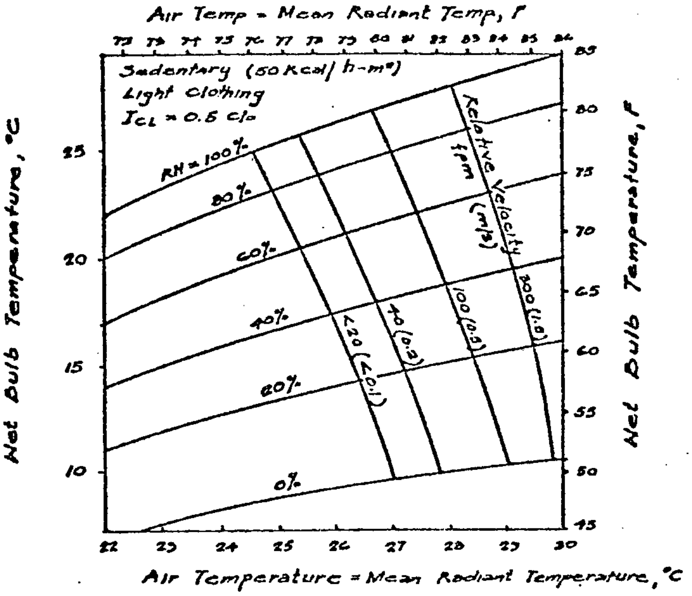

Fig. 6 Effect of relative humidity

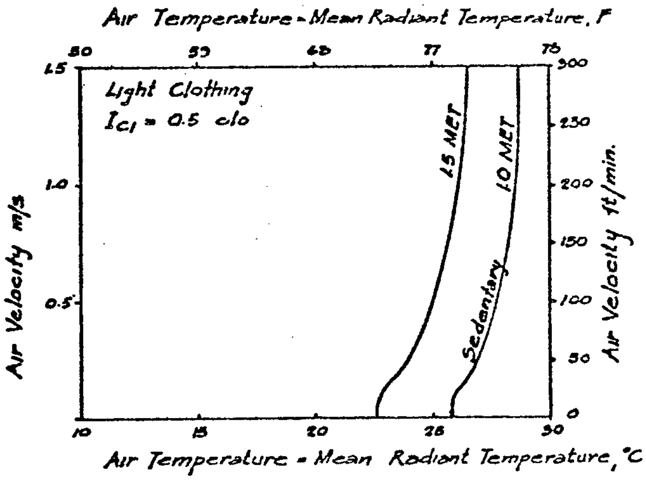

Fig. 7 Effect of air velocity

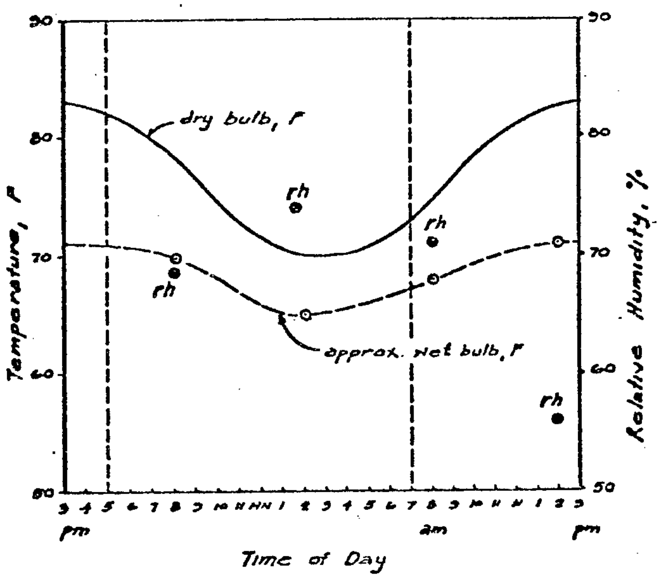

Fig. 8 Typical daily temperature range

DISCUSSION

CASTO J. DE BIASI, Mech. Engr., Naval Facilities Eng. Command, Alexandria, VA: Is reheat necessary for tropical area applictions, and how can you get it free?

FREDERICK H. KOHLOSS, P.E.: Reheat is not necessary for all tropical air conditioning, but is desirable in areas of high occupancy, required high outdoor-air ventilation rate, or other high latent load applications. It is required, essentially, where control of humidity is needed. Water-cooled condensers can provide reheat, preferably in a closed circuit or in an open circuit if the water is strained, cleaned, or otherwise made acceptable for use in a heating coil. Air-cooled condensers can have a parallel-connected refrigerant discharge (hot-gas) reheat coil. If solar heated water or waste process heat are available, they can also be used.

DE BIASI: Do you have to use all air systems or can you use fan coil units? Do you need to cool (o.a.) air with a seperate cooling coil before mixing with r.a.?

KOHLOSS: Whether a system is all-air or air-and-water such as fan-coil units is not as critical as the selection and application of the coil, the air flow quantity, and the control. There must be dehumidifying ability in the main cooling coil. The need for the main cooling coil to be able to dehumidify is lessened (and the application of fan coil units is far easier) if outdoor air is separately precooled. The precooling of outdoor air is very desirable to avoid bypassing humid outdoor air into the conditioned space.

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