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Site Analysis and Field Instrumentation for an Apartment Application of a Total Energy Plant

John B. Coble and Paul R. Achenbach

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U.S. DEPARTMENT OF COMMERCE, Rogers C.B. Morton, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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TOTAL ENERGY SYSTEMS TO HOUSING DEVELOPMENTS

By

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SITE ANALYSIS FOR THE APPLICATION OF TOTAL ENERGY SYSTEMS TO HOUSING DEVELOPMENTS

By

Paul R. Achenbach and John B. Coble

1. Introduction

Concurrent with the national effort to accelerate housing construction in the United States, there has been much concern about the continued availability of some forms of energy used in housing and the effects of energy use on environmental quality. Low reserves in electric generating capacity and natural gas exist in many highly populated areas of the country and the importation of oil is increasing rather sharply to meet growing requirements.

These and other factors have caused the Department of Housing and Urban Development to utilize a part of their Operation BREAKTHROUGH housing program for a field investigation of total energy systems as a means for saving fuel and reducing pollution and for making the electrical services independent of the local utility system. Initiated in mid-1970, the design and construction of about 2800 dwelling units* on eleven sites in the country to encourage industrialization and innovation in the home-building process. The National Bureau of Standards was requested to examine the feasibility of utilizing total energy systems for one or more of these eleven sites to develop reliable data on thermal efficiency, daily

* A dwelling unit is the housing facility for one family, irrespective of the kind of building in which it is incorporated.

and seasonal load patterns, reliability and stability of the utility services, the level of noise and pollution control, the maintenance and repair requirements, and the owning and operating cost. The number of sites used for the BREAKTHROUGH program was later decreased to nine. This program is a part of a broader program on utilities research being carried out by the Utilities Technology Division in the Office of the Assistant Secretary for Research and Technology of HUD.

2.0 Total Energy System Characteristics

2.1 Definition

A total energy system is characterized by four principal concepts:

a) The electric energy for the development is generated on site.

b) Waste heat from the electric generation equipment is recovered and used on site for heating, cooling, or process functions.

c) The plant is located within the confines of the site being served.

d) It serves a single building or a commercial, industrial, or residential site that is not traversed by public thoroughfares.

The constraint on distribution of electric energy across public thoroughfares is a part of the franchise agreements accorded to the electric utilities.

2.2 System Loads

The principal loads on a total energy system in a residential application are: electricity for lighting, motors, and appliances; space heating; space cooling; and domestic hot water heating. If there is community development associated with the site there will be other types of loads on the system that are characteristic of the particular facilities. There are daily, weekly, and seasonal cycles to the four principal components of the load in a residential application of a total energy system.

Under favorable conditions the electric energy requirements and the possible uses of the waste heat of a given application are so proportioned that the total amount of energy utilized by the total energy system is significantly less than would occur if electric energy were taken from a central utility system at a utilization efficiency of about 30 percent and the other energy requirements were supplied by fuel-burning equipment at the site. To the extent that this favorable balance of loads occurs, there is good potential for lowering fuel usage and, in come cases, overall annual cost for energy by utilizating a total energy system. Some capability for auxiliary heating and for dumping unneeded heat is usually provided in a total energy system. Certain types of loads from commercial or community facilities help to improve the overall balance between electrical demand and the demands for waste heat.

Corollary benefits sometimes claimed for total energy systems are: greater reliability in electric service, conservation of energy resources, and overall reduction in the discharge of heat and combustion products into the environment.

2.3 Equipment Combinations

Total energy systems could be designed to utilize a variety of fuels; however, nearly all systems now in operation use natural gas, diesel fuel, or a combination of gas and oil.

A total energy system can be made up of a wide variety of mechanical equipment assembled in various combinations. Internal or external combustion engines or turbines can be used for driving electric generators and air conditioning compressors. The latter equipment can be of either the reciprocating, rotary, or centrifugal type. Absorption water chillers can be used alone or in combination with compression water chillers to provide air conditioning. Space heating can be accomplished by electric resistance heating or by circulating steam or hot water. Space heating and cooling can be provided by heat pumps. Domestic water heating can be done by utilizing waste heat and a heat exchanger, or by using gas, oil, or electric energy directly as the heating source. Not all of these equipment choices lend themselves to an efficient utilization of waste heat or to attaining an optimum relation between electric energy requirements and waste heat requirements in a total energy system when considering the daily and seasonal load variations. Nevertheless, a number of combinations should be evaluated in engineering and economic terms for any given installation.

2.4 Current Applications [1/*]

There are approximately 550 total energy plants in operation in the United States at the present time ranging in size from 0.2 megawatts to more than 20 megawatts. Installations of total energy plants began about 1958 and reached a peak, in numbers of new plants installed, in 1967. However, the total electrical capacity of new plants installed annually has continued to rise. Total energy systems at present account for approximately 0.2 to 0.3% of the electrical generating capacity of the United States.

About 70% of the plants utilize reciprocating gas engines and an additional 15% employ gas-fired turbines as the prime movers. The remainder utilize diesel engines, steam turbines, or dual-fuel engines employing natural gas and fuel oil. A large majority of the total energy systems serve industrial and commercial applications, with only about 5% serving residential applications. At this time over 60% of existing plants have less than 1 megawatt generating capacity, but the plants installed in the last few years have averaged over 5 megawatts in capacity.

* See references at end of paper

A significant number[2] of total energy plants have been deactivated in recent years, with a high percentage of these having a capacity of 0.5 megawatt or less.

3.0 Site Ranking Parameters

Many factors have a bearing on the suitability of a housing development for the use of a total energy system. For the BREAKTHROUGH housing sites, these parameters were separated into three groups having primarily technical, administrative, and economic significance, respectively.

The parameters of a technical nature were: the number of dwelling units and their density and arrangement on the site; the summer and winter degree days and the design temperatures at the site; and the method of construction and assembly of the housing systems as related to the ease in bringing the utilities into the houses. The administrative considerations were: the number of different housing systems to be built on the site; the current and anticipated level of electric capacity reserves applicable to the site; the amount and kind of community development to be provided on the site; the time schedule for beginning of construction; and the knowledge and interest of the site planner and site developer in a pilot installation of a total energy system. The financial parameters were: the relative cost of purchased electrical, gas and oil energy at the site; the first cost difference between the total energy system and the conventional system which it might replace; and the cost of maintenance and repair.

Information was collected on the relative magnitude or importance of all of these parameters for the six BREAKTHROUGH sites that appeared to be better suited to total energy systems; namely, Jersey City, Memphis, St. Louis, Macon, Sacramento, and Indianapolis. The other five sites at

Wilmington, Houston, Kalamazoo, Seattle (2 sites) were eliminated because of the smaller number and lower density of the dwelling units on these sites.

3.1 Number and Density of Dwelling Units

Several housing system producers are constructing groups of dwelling units on each of the BREAKTHROUGH sites. The dwelling units on each site are distributed among four basic types of construction: multi-family high-rise(MFHR); multi-family low-rise (MFLR); single-family attached (SFA); and single-family detached (SFD). The six sites chosen for detailed consideration as experimental sites for total energy systems were those with the higher numbers of dwelling units, since a total energy system has usually been found to be uneconomical for developments of less than about 200 dwelling units and for low density housing.

Table 1 shows the size of the BREAKTHROUGH sites at Jersey City, Macon, Memphis, Indianapolis, St. Louis, and Sacramento; the total number of dwelling units being built, and the percentage of each of the several types of construction. The density of the housing ranges from a maximum of about 77 dwelling units per acre at Jersey City to a minimum of about 6 dwelling units per acre at Macon. For the six sites, the dwelling units in high-rise buildings range from 12 to 98 percent of the total. There are no single-family detached dwelling units on the three smaller sites. Since a total energy system delivers energy-related services from a central source, the unit cost of distribution is approximately proportional to the size of the site and inversely to the density of the dwelling units on the site.

Table 1. Site Size and Dwelling Unit Distribution on Six BREAKTHROUGH Sites

Site	Area, Acres	Total Units	Dwelling Unit Type, % of Total			
			MFHR	MFLR	SFA	SFD
Jersey City	6.35	488	98	2	---	---
Macon	50.0	287	20	23	52	5
Memphis	16.0	374	55	27	18	---
Indianapolis	42.9	287	12	5	48	35
Sacramento	33.0	407	28	24	42	6
St. Louis	15.5	464	44	10	46	---

3.2 Climatic Factors

Since the economy of a total energy system is dependent on making use of the waste heat from the engine-generator equipment used for electric power production, it is important that there be a reasonably steady demand for the waste heat throughout the year. Thus a total energy system would not usually be economical in a residential application unless some absorption air-conditioning is used, because the heating of domestic hot water may utilize less than one-third of the waste heat available during the four or five warmest months of the year.

The climatic factors that have a direct bearing on the economy and capacity of a total energy system for a residential development are the summer and winter outdoor design temperatures and the degree-days of heating and cooling for each site. The significant weather data for the six sites under consideration are shown in Table 2.

Table 2. Climatic Data for Six BREAKTHROUGH Sites

Site	Winter: Degree-days[a] 5/	Winter: Outdoor[b] Design Temp., °F 3/	Summer: Hours at 67°F WB or above 4/	Summer: Outdoor[c] Design Temp., °F 3/ DB	Summer: Outdoor[c] Design Temp., °F 3/ WB
Jersey City	4902	15	1290	89	76
Macon	1797	27	3069	96	79
Memphis	3006	21	2631	96	79
Indianapolis	5611	4	1462	91	77
St. Louis	4469	11	1866	94	78
Sacramento	2822	32	351	97	70

[a] Based on an indoor temperature of 65°F.
[b] Based on 97 1/2% of winter hours being at or above this temperature.
[c] Based on 2 1/2% of summer hours being at or above these temp.

•• •• ••

In cooler climates the size of the supplemental boiler will likely be determined by the maximum winter heating load, whereas in warmer climates the size of the supplemental boiler may be determined by the maximum cooling load, if absorption cooling is used. In warm and humid climates the number of hours during the summer when the outdoor wet-bulb temperature is at or above 67 °F is a good indicator of the amount of time that air conditioning will be required, but in hot and dry climates a dry-bulb temperature criterion is more reliable.

3.3 Analysis of Energy Usage

3.3.1 Space Heating and Cooling Loads

Calculations were made of the expected loads for space heating and cooling, domestic water heating, and miscellaneous electrical uses at each of the six BREAKTHROUGH sites. This information was needed to determine the approximate size of the total energy plants, the applicable energy rate schedules, the availability of appropriate system components, the differential in first costs, and the amount of space needed for the plant on the site. At the time of these calculations, the materials of construction, the size of each type of dwelling unit, and the number of each size of dwelling unit were known.

The gross monthly energy requirement for space heating and cooling and the maximum monthly energy demand rate were calculated for each site using the following procedures:

$$\text{Monthly Heating Energy Requirement, Btu} = \text{Monthly Heating Degree-Days} \times \Sigma(HL_i \times A_i) \qquad (1)$$

HL_i is the heat transmission for a type i building in Btu/ (ft^2 floor area) (degree-day). This quantity was calculated by a computer program using a transfer function technique to determine the dynamic response of the building to the total environment (temperature, wind, solar radiation, orientation, internal loads, etc.) The quantity HL_i was determined for five different types of buildings; namely, multi-family high-rise, multi-family low-rise, single-family attached, single-family detached, and non-residential. The non-residential classification included commercial buildings, school buildings, plant and public spaces.

A_i is the total floor area of each type of building in the development, ft^2.

$$\text{Monthly Cooling Energy Requirement, Btu} = \text{Monthly Cooling Degree-Days} \times \Sigma(CL_i \times A_i) \qquad (2)$$

CL_i was determined for each type of building using the computer technique that was used for calculating HL_i.

$$\text{Maximum Monthly Heating Load Demand, Btu/hr} = \frac{(75 - T_{min})}{(75 - 11\ )} \ \Sigma \ (HD_i \times A_i) \qquad (3)$$

HD_i is the maximum heating demand determined for the different building types in the Jersey City site for a steady outdoor temperature of 11 °F, which is the 99% design temperature for Newark, N.J., expressed in $Btu/(hr)(ft^2)$. The maximum monthly heating load demand calculated by equation (3) and the maximum monthly cooling load demand calculated by equation (4) were normalized on Jersey City because extensive calculations of the demands by the buildings for the Jersey City site had been carried out.

T_{min} is the 30-year average of the minimum daily temperature for the month and the site being considered.

The maximum monthly heating load demand was taken as zero, if equation (3) yielded a negative value.

$$\text{Maximum Monthly Cooling Load Demand, Btu/hr} = \frac{(T_{max} - 75)}{(\ 91 - 75\ )} \ \Sigma \ (CD_i \times A_i) \qquad (4)$$

CD_i was calculated similarly to HD_i based on data for Jersey City buildings and a maximum daily temperature of 91°F.

T_{max} is the maximum daily temperature (based on a 30-year average) for the month and site being considered.

The maximum monthly cooling load demand was taken as zero, if equation 4 resulted in a negative value.

3.3.2 Electricity and Domestic Hot Water Usage

Published information[6,7,8,9] on the usage of electricity for domestic hot water and for miscellaneous purposes in dwelling units in the United States was used as the basis for estimating these energy requirements at the various BREAKTHROUGH sites. From these sources it was estimated that the monthly electrical usage per dwelling unit for miscellaneous purposes would be 702 kilowatt hours and the daily usage of hot water would average 41 gallons per day. These estimates take into account the observed 6% annual increase in electrical use since the data were collected. The average hot water usage was adjusted for the storage losses. Monthly variations in electricity and domestic hot water usage were adjusted to agree with observations shown in the published reports referenced above.

3.3.3 Energy System Simulation

The overall energy requirement for a given housing development is different for different types of energy utilization systems. Considered in this analysis were seven different systems; three were different types of total energy systems, two were all-electric systems, and two were conventional systems.

An all-absorption air-conditioning system was assumed for one of the total energy systems, engine-driven centrifugal compressors were assumed for a second, and varying combinations of absorption and engine-driven compression air conditioning were assumed for the third. Other components were identical. One all-electric system used resistance heaters for space heating and motor-driven compression air conditioning; the other used individual air-to-air heat pumps in each dwelling unit for year-round space conditioning. The two conventional systems utilized electric energy from the municipal system and fossil fuel for heating functions. One conventional system used all-absorption air conditioning and the other motor-driven compressors for air conditioning.

A computer program was prepared to calculate the monthly and annual energy usage for each of the seven energy systems described above for the BREAKTHROUGH sites at Jersey City, Macon, Memphis, Indianapolis, Sacramento, and St. Louis. The equipment efficiencies and performance factors used in these computations were as follows:

Engine-Generator Efficiency,Total Energy Plant, %		25
Central Generating Plant Efficiency,(point of use) %		29
Waste Heat Recovery, % of Available		67
Boiler Efficiency, %		70
Absorption Chiller Coefficient of Performance		0.67
Centrifugal Chiller Coefficient of Performance		4.0
Engine-Compressor Efficiency, %		30
Individual Heat Pump Coefficient of Performance		2.3
Plant and Building Auxiliary Electric Load, for Jersey City, KW	Winter	443
	Summer	665

Table 3 shows the calculated energy requirements for the several different energy utilization systems. Four different combinations of absorption and compression air conditioning equipment were evaluated for the total energy concept, in addition to all-absorption and all-compression air-conditioning systems.

Table 3 shows that the total energy system using all-absorption air conditioning had the lowest overall energy requirement at Jersey City, whereas a combination of 40% absorption and 60% compression air conditioning in a total energy plant was most economical in energy use at four of the other sites. It is believed that the electrical energy requirements for the commercial and school areas and the electrical auxiliaries (pumps, blowers, etc.) in the total energy plant raised the level of available waste heat at the Jersey City site sufficiently to satisfy a high percentage of the thermal energy requirement of the absorption air conditioning system, thus making absorption cooling the best alternative at this site.

The most economical total energy plant saved from 28 to 40 percent of the energy required for a conventional system using absorption chillers for air conditioning at the several sites. It was assumed that electrical energy was purchased from the local electric utility system in the conventional plants.

TABLE 3

Calculated Annual Energy Requirements for Various Energy Systems, Btu x 10^9

Site	Total Energy Systems — Ratio: Absorption to Compression Cooling, %						All Electric Sys		Conventional Combinations	
	100/0	80/20	60/40	40/60	20/80	0/100	Resist Heating	Heat Pump	Comp Cooling	Absorp. Cooling
Jersey City	139	140	142	143	145	147	219	136	179	193
Macon	80	72	66	65	68	71	102	65	83	108
Memphis	64	60	56	56	58	60	108	69	73	89
Indianapolis	101	97	92	90	91	93	190	101	109	125
St. Louis	107	101	100	102	104	107	190	109	129	147
Sacramento	90	84	77	72	75	77	145	88	94	118

3.4 Energy Costs

Energy cost information for the six BREAKTHROUGH sites was obtained from the latest published schedules for gas and electricity and from quotations of local fuel oil dealers, as of April 1972. In each location the electric and gas utilities have established several rate schedules which apply to different residential, commercial, and industrial loads. For computing the monthly and annual energy costs at each site, those rate schedules which provided the lowest cost for energy and which were applicable to the particular utility system under consideration were used.

The rate information for gas, oil and electricity is summarized in Table 4. For each kind of energy, the costs cited include both the demand change and the energy consumption charges. For fuel oil,the unit cost is not dependent on the amount consumed when the fuel is delivered in bulk lots to the central utility plant.

Separate electrical energy costs are shown in Table 4 for single metering of all energy used in the development and for individual metering of the electrical energy used in each dwelling unit for three different energy systems; namely, heating and cooling with a heat pump in each dwelling, electrical resistance heating and a unitary air conditioner in each dwelling, and a fuel-fired heating unit and unitary air conditioner in each building. The range of unit electrical energy costs shown in each block of Table 4 covers the variations in monthly use throughout the 12 months of the year.

The costs shown in Table 4 represent a significant increase in comparison with those available in August, 1970, when the feasibility study was first made. Oil prices have increased an average of about

TABLE 4. UNIT ENERGY COST

Site	Oil	Gas	Electricity, Individual Meters			Electricity, Site or Bldg. Meters			
								Conv. Systems	
	Cents per gal.	Cents per therm	Misc Appliances Only	Individual Heat Pumps	Individual Resistance Heating	Individual Heat Pump	Individual Resistance Heating	Absorp Cooling	Compression Cooling
			Cents per KWH						
Jersey City	12.7	10.1	2.4-2.5	1.5-2.0	1.3-1.9	1.0-1.2	0.9-1.1	1.1-1.2	1.1-1.2
Macon	11.8	9.2	1.9	1.8-2.0	1.2-1.5	1.6-2.0	1.1-1.7	2.1-2.2	1.5-2.1
Memphis	12.3	4.7	1.5-1.6	1.1-1.4	1.0-1.2	0.9-1.2	0.8-1.0	1.0-1.1	1.0-1.1
Indianapolis	11.7	5.5	2.4-2.5	1.3-1.6	1.2-1.4	1.2-2.1	1.1-1.4	1.4-1.5	1.4-1.5
Sacramento	11.7	6.2	1.4-1.5	1.0-1.4	0.7-1.2	0.8-1.1	0.8-1.0	0.9-1.0	0.9
St. Louis	11.7	4.4	2.3-2.4	1.4-2.2	1.0-1.9	1.3	0.9-1.3	1.3	1.3

TABLE 5

Annual Energy Cost for Various Energy Systems, $K

Site / Energy Source	Total Energy Systems						All Electric Systems		Conventional Comb.	
	Ratio: Absorption to Compression Cooling, %									
	100/0	80/20	60/40	40/60	20/80	0/100	Resistance Heating	Heat Pump	Comp. Cooling	Absorp. Cooling
Jersey City										
Gas	139	141	142	144	146	148	-	-	173	188
Oil	127	128	130	132	133	135	-	-	167	180
Electric	-	-	-	-	-	-	197	133	-	-
Macon										
Gas	73	66	61	60	63	65	-	-	117	138
Oil	68	62	56	56	58	61	-	-	115	133
Electric	-	-	-	-	-	-	128	101	-	-
Memphis										
Gas	30	29	27	27	28	28	-	-	52	55
Oil	57	53	50	50	51	53	-	-	61	77
Electric	-	-	-	-	-	-	84	57	-	-
Indianapolis										
Gas	56	53	51	49	50	51	-	-	92	94
Oil	86	82	78	76	77	78	-	-	111	120
Electric	-	-	-	-	-	-	206	122	-	-
St. Louis										
Gas	47	45	44	45	46	47	-	-	109	108
Oil	90	86	84	86	88	90	-	-	130	142
Electric	-	-	-	-	-	-	185	121	-	-
Sacramento										
Gas	56	52	48	45	46	48	-	-	70	81
Oil	76	71	65	61	63	65	-	-	79	98
Electric	-	-	-	-	-	-	112	73	-	-

7 percent in the six cities, ranging from no increase in Macon to 11% in St. Louis and Sacramento. The cost of gas has increased an average of 22% in five of the cities, not including Macon, where the increase has been 104% in two years. This unusually large increase in Macon is largely due to the termination of a very favorable incentive-type schedule that was in effect when the previous information was collected in August, 1970.

The cost of electricity has increased from 30 to 40 percent at Jersey City, Indianapolis, St. Louis, and Sacramento during the last two years for large loads exceeding one million kilowatt-hours per month. The increases were even larger in Macon and Memphis, approximately 60% and 100% respectively, for a similar load range. The increases in lower load ranges are of the same order of magnitude.

The annual energy requirements shown in Table 3 and the unit energy and fuel costs shown in Table 4 for the different types of service at the six sites were used to calculate annual energy costs for each of the different utility systems. These annual energy costs are shown in Table 5 for six different equipment combinations in a total energy plant and for both oil and gas. For the all-electric systems and the conventional systems using a combination of fossil fuel and purchased electricity it was assumed that all of the electrical energy was metered by one meter.

Table 5 shows that oil was the more economical fuel at Jersey City and Macon, and gas was more economical at the other four sites for both the total energy and conventional systems. The most economical total energy system at each site saved from 25 to 60 percent of the energy cost for the comparable conventional plant using motor-driven compression cooling and from 30 to 59 percent of the energy cost for the comparable conventional plant using absorption cooling. The calculated cost saving at Jersey City was the lowest of the six sites, because commercially produced electricity and oil are more competitively priced in Jersey City than at the other sites.

3.5 Owning and Operating Costs

Precise determination of typical owning and operating costs for utility systems is difficult to develop at present because the costs of machinery, materials, fuel, and labor are all changing rather rapidly. At any given time the costs of gas and electricity are published, but new schedules are appearing at irregular intervals so future costs will change accordingly.

The first costs for the total energy system at Jersey City are summarized in Table 6. There is some uncertainty in the figure cited for the cost of the building since it will house both the total energy system and the solid waste collection, compacting, and loading system. Half of the total building cost was allocated to the total energy system in Table 6.

The design and construction management costs are relatively high for the Jersey City installation for a number of reasons, including the following:

a) Coordination of the plans for at least four different building types,

b) Redesign of some of the buildings and changes in housing system producers,

c) Incorporation of an innovative waste disposal system on the site,

d) Provision for installation of data collection equipment and for field experimentation on both the total energy system and the solid waste disposal system,

e) Provision of more standby electric-generating equipment than typical and provision of some additional space for future installation of innovative components.

The cost data in Table 6 show that the investment cost for the total energy system will be about $4,900 per dwelling unit, if the cost is pro-rated between the residential area and commercial facilities in proportion to floor area. The overall investment cost for providing the on-site generating facility is estimated at $720,000 or $240 per kilowatt of installed capacity. This figure includes the purchase cost of the engine-generators and controls and pro-rated costs for system design, equipment building, installation costs, and construction management costs. This value of cost per kilowatt of installed capacity can be used for estimating first cost differences between a total energy system and a conventional central heating and cooling plant at the five other BREAKTHROUGH sites under consideration, since they are all similar in size.

Sufficient data on the cost of maintenance and service costs for total energy systems are not available to cite a reliable average value. However, a limited number of published reports indicate that contracts for maintenance and service of engine-generators, with either turbine or reciprocating engine drive, are in the range of 0.3 to 0.4 cent per kilowatt hour of energy produced. The annual contract cost of maintenance and service for heating and cooling equipment is in the range from $20 to $30 per ton of installed refrigeration capacity. These figures apply to plants in the size range needed for the BREAKTHROUGH housing sites.

Table 6

Costs of Total Energy System at
Jersey City, New Jersey

Purchase Cost	
Engine-Generators	$315,000
Generator Controls	91,000
Cooling Towers	57,000
Central Equipment Building, Prorated	249,000
Construction, Total Energy Plant, including purchase of heating/cooling equipment	1,093,000
Subtotal	1,805,000
Utility Distribution System	367,000
Design and Management Costs	
Total Energy System	125,000
Site Utilities	141,000
Central Equipment Building	57,000
Construction and Contract Management	175,000
Subtotal	498,000
Overall Total Cost	2,670,000

3.6 Adaptability of Housing Systems to Total Energy

Nineteen of the twenty-two housing system producers will be building dwelling units on the six BREAKTHROUGH sites under consideration in this report. The number of different systems on one site ranges from three on the Jersey City and Memphis sites to eight on the Indianapolis site.

Constructions that provide cavity walls or sandwich constructions made of wood, foamed insulation, gypsum board and other materials that can be readily cut provide the greatest flexibility in introducing conduits and ducts into the structure. Constructions of masonry and concrete panels that provide for pipe chases at the joints offer an intermediate level of flexibility for conduits for electricity, water and drainage systems. Factory prefabricated volumetric modules must in most cases incorporate a completely preplanned arrangement of service systems, especially if made of masonry.

Every dwelling unit must provide for distribution of electricity and domestic hot and cold water ; and for an adequate drain, waste, and vent system, whether the site is equipped with a total energy system, central or individual heating and cooling systems. If individual heating and cooling units are used, electricity and gas or oil must be brought to this equipment. If a total energy system or a central hot-and-chilled water system provides for space conditioning, two to four water pipes of relatively small size and electric service must be brought to the central unit in each house. These additional pipes (one to three) can readily be accommodated in cavity walls, pipe chases at panel joints, or in the special utility chases that must be provided in volumetric module housing designs. Thus the adaptation of the total energy concept to the variety of proposed housing systems does not appear to offer any new or major type of design problem.

3.7 Community Development

The addition of retail stores and certain types of community development to the load on a total energy system is usually considered to be advantageous because it raises the electrical load factor of the system and permits a larger fraction of the thermal energy requirements of the development to be provided from recovered waste heat.

Only the Jersey City and Macon developments incorporated any retail facilities, with the Jersey City floor area being larger by a factor of at least five. The community facilities planned for the Jersey City site are as follows:

Retail stores	45000 sq ft
Schools	19500 " "
Swimming pool	5000 " "
Public Spaces	3000 " "
Community Center	2500 " "

The residential floor area planned for the Jersey City site totals 508,000 square feet.

3.8 Environmental Factors

An analysis was made of the characteristics of a total energy system with respect to thermal environment, noise and vibration inside the plant; the transmission of noise and vibration to the surrounding occupied space; and the likelihood of creating unacceptable air pollution in the community.

Visits to several installations of total energy systems indicated that noise and vibration control was essential in a residential community. Excessive noise and vibration transmission from a total energy plant can occur by direct transmission of engine room noise through windows, lightweight walls, and engine room ventilation ducts; from the pulsating exhaust of reciprocating engines; from air or water flow in the cooling tower; and by transmission of vibration through the foundations of reciprocating or rotating machinery to surrounding buildings. All of these features of noise and vibration control require specific attention in the design of the plant, but none is an insurmountable problem.

Federal, state, and municipal limitations on the amount of particulates and sulfur dioxide that may be discharged into the atmosphere with combustion gases essentially dictate the use of gas or No. 2 fuel oil in residential areas. The problems of fuel storage, ash handling, and particulate and sulfur dioxide discharge make it impractical to use coal in a total energy plant on a BREAKTHROUGH site. Combustion gases from a gas- or oil-burning plant must be discharged at a height that will promote diffusion into the upper atmosphere and at a location that will not allow the prevailing winds to carry them into nearby dwellings, recreation areas, or other occupied spaces. Likewise, the water vapor emanating from the cooling tower should not create objectionable mist, fog, or frost deposits in occupied areas or traffic areas of the site. These latter problems related to discharge of combustion gases and water vapor dissipation are no different for a total energy plant than for a conventional central heating and air conditioning plant.

3.9 Energy Resources

There are inadequate reserves of electric power generating capacity in wide areas of the United States. Especially critical are the eastern seaboard states from New York to Florida and the cities of Chicago, St.

Louis, Minneapolis, and St. Paul.[10] The electrical power shortage emphasizes the relevance of a study of alternative utility options for new housing developments. Concurrently, there are shortages of natural gas. In Baltimore no new industrial customer can obtain natural gas service if his requirements exceed 300,000 cu ft per day, and no current customer can increase his requirements by more than 300,000 cu ft per day, whereas in Washington, D.C. no new customers can be connected at all. The importation of gas from Algeria and Canada is being implemented, but is not expected to meet the growing demand.

Because of insufficient reserve generating capacity in several areas of the country, the application of total energy systems to the BREAKTHROUGH sites in Jersey City, St. Louis, Memphis, and Macon may serve as good and prudent examples of conservation of scarce resources in these particular areas as well as worthwhile experiments for wider consideration. The gas utility serving Jersey City is not able to furnish gas for a total energy plant at that site. Since fuel oil is a little cheaper than gas in Jersey City at the present time, and because New Jersey is near the end of the gas distribution pipeline from the Texas fields, Jersey City would be a good choice for an experimental oil-burning total energy system. There appear to be adequate gas reserves at Macon, Memphis, and St. Louis for the BREAKTHROUGH sites.

3.10 Site Planner and Developer Attitudes toward Total Energy Systems

The site planner and developer for the Macon site have shown the greatest initiative and interest in the application of a total energy system to the BREAKTHROUGH development. In fact, the planner proposed that they be authorized to make a feasibility study, produce a design, and carry out field studies of performance after installation.

The site planner for the Jersey City site expressed a positive attitude about a total energy system there, and was encouraged and supported in this approach by one of the housing system producers. This producer envisions replacing an initial fuel-burning total energy system in a few years with fuel cells as a direct means for converting chemical energy into electricity. Fuel cells are not sufficiently developed as yet.

The site planner at St. Louis was willing to consider the installation of a total energy system provided it did not entail higher capital costs for the developer and did not delay the time schedule. Rouse-Wates, the only housing system producer on the eastern parcel of the St. Louis site, had a feasibility study of total energy and several other utility systems made to determine economic feasibility. That study and a second study of the economic feasibility of a total energy plant on the Rouse-Wates development reached contradictory conclusions.

The planners and developers at the Memphis, Sacramento, and Indianapolis sites took no initiative in exploring or promoting application of total energy systems to their respective developments.

4. Recommendations and Implementation

When the feasibility study was made two years ago, none of the BREAKTHROUGH sites were under construction and the types of buildings, the materials to be used, and the housing system producers were in an early stage of identification. The sites at Memphis and Jersey City were recommended as the two best sites for a total energy plant, partly because they would have the largest number of dwelling units, a high density of dwelling units, and more high-rise construction than the other sites. Jersey City was given preference because it was to have the only large amount of commercial development, and because the planner and one of the housing system producers were interested in the use of a total energy system. Jersey City did not then have a particularly favorable ratio between the costs of fossil fuels and electricity.

As the design and construction of the various BREAKTHROUGH sites have developed, the number of dwelling units at Memphis has been reduced by 21 percent and the percentage of high-rise units has been lowered from 61 to 55 whereas the percentage of high-rise units at Jersey City has risen from 43 to 98.

The costs of all fuels have risen significantly since mid-1970. The price of electricity has risen more than that of oil and gas, and the price of oil has risen the least -- 10 percent or less in the six cities considered in this study. Gas was not available in Jersey City for a total energy plant so the plant has been designed for oil. The ratio of prices between oil and electricity in Jersey City has become more favorable to the installation of a total energy plant during the last two years.

The housing and the total energy plant at the Jersey City site are under construction at the present time and occupancy is expected for the spring of next year. Another paper in this conference describes the details of the field studies that will be made on this site and the instrumentation to be used for gathering performance data.

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DESCRIPTION OF EQUIPMENT AND INSTRUMENTATION FOR A FIELD STUDY OF A TOTAL ENERGY SYSTEM IN AN APARTMENT DEVELOPMENT

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ABSTRACT

The Department of Housing and Urban Development selected the BREAK-THROUGH site at Jersey City, N. J. as the location for an installation and field study of a total energy system. This development covers six acres, and is comprised of four buildings containing 488 dwelling units, a small building for commercial use, two small schools, a swimming pool, and the total energy plant. The field study of this installation is being carried out by the National Bureau of Standards to produce much-needed authoritative information on engineering performance, maintenance requirements, and load-and-cost data for total energy systems.

The central plant and the individual buildings are being extensively instrumented to provide digital data on fuel utilization, the generation of electrical and thermal energy, the excess heat rejected, and the utilization of electrical and thermal energy by all major segments of the load. A separate analog data system is being employed to obtain recordings of transient conditions of voltage, frequency, current, power factor, and load division during sudden load changes and to record interruptions of service due to overload or malfunction of equipment. The environmental impact of the total energy plant with respect to noise, vibration, air pollution, and aesthetics is also being evaluated.

KEY WORDS: data acquisition system; electrical power system; energy conservation; fuel utilization; thermal efficiency; thermal energy system; total energy system; utility system performance; waste heat recovery.

DESCRIPTION OF EQUIPMENT AND INSTRUMENTATION FOR A FIELD STUDY OF A TOTAL ENERGY SYSTEM IN AN APARTMENT DEVELOPMENT

By

John B. Coble and Paul R. Achenbach

1. Introduction

This paper describes the program that will be conducted by the National Bureau of Standards, under sponsorship of the Department of Housing and Urban Development (HUD), for analyzing the performance of a 3 megawatt total energy system on the Operation BREAKTHROUGH site at Jersey City, N. J. On this six-acre site, electricity and energy for heating and cooling will be produced by a central plant using number two fuel oil in diesel engine-generators and boilers. The site has 488 residential dwelling units in four medium- and high-rise buildings. Also on the site are a school, pre-school, commercial areas and a swimming pool. The National Bureau of Standards is installing an extensive data-collection system to analyze the electrical and thermal performance of the total energy plant and the energy use by the buildings of the development.

When the National Bureau of Standards started this program in April, 1970, very little data on the economic and engineering aspects of total energy systems had been published. Most total energy systems were installed in areas where the price of natural gas was low enough relative to the cost of electricity to make such a system attractive to the client. Many systems were operated by the maintenance staffs of the local gas utilities. Since the majority of these plants have less than one megawatt installed capacity, only enough instrumentation was installed for operational purposes. In most cases, the instrumentation was inadequate for an engineering determination of thermal efficiency, load diversity, and reliability.

The continuing depletion of gas reserves and the widespread shortage of reserve electrical generating capacity in the United States made it highly desirable to determine the potential of a total energy system for providing reliable thermal and electrical utility service to new developments with lower usage of fuel. Consideration was given to the instrumentation of an existing total energy plant for this study. However, it would have been difficult to place the flowmeters, temperature sensors, and electrical instruments into an existing system. Furthermore, such a study would have constituted an after-the-fact determination and disclosure of the engineering, economic, reliability, environmental, and maintenance aspects of a system not designed in response to a performance specification and not intended for such detailed analysis.

By contrast, the BREAKTHROUGH program of the Department of Housing and Urban Development offered an opportunity to analyze widely distributed sites for their suitability for a demonstration plant. The financial and management guidelines for the BREAKTHROUGH program also provided considerable latitude in specifying the desired performance of the system and the degree to which it would be instrumented and evaluated.

After feasibility studies of eleven BREAKTHROUGH sites for the installation of a total energy plant had been completed, and the Jersey City site had been selected, a performance specification for the plant was prepared. This specification set forth, in performance language, the requirements for the plant with respect to load determination, standby capacity, system reliability, stability of electrical services, maintenance, safety, and its environmental impact in terms of noise, vibration, air pollution, magnetic interference suppression, and aesthetic treatment. This performance specification became a part of the guideline documents for the engineering firm, "Gamze-Korobkin-Caloger", which then designed the demonstration plant. The feasibility study is described in another paper being presented at this conference.

It was decided that the Jersey City BREAKTHROUGH site would also be used for a demonstration installation of a pneumatic trash collection system (PTC) sometimes also called a vacuum solid waste collection system. This system was designed by another firm using a separate specification and is the subject of another paper. However, the solid waste collection, compaction, and loading equipment will be combined with the total energy plant in a single central equipment building. Figure 1 shows the locations of the boilers, chillers, engine-generators and the pneumatic trash collection system in the central equipment building, which is approximately 50 feet by 143 feet in size.

2. Site Utility System

All electrical and thermal energy for the Jersey City site will be produced on site. The electricity will be generated by diesel-engine-driven generators. Hot water for space heating and domestic hot water will be produced by recoverable waste heat from the engine-generators and by two supplementary boilers. During the air-conditioning season, hot water will be used in absorption refrigeration machines to produce chilled water. The electricity, heating hot water and chilled water will be distributed to the buildings on the site through underground conduits. Figure 2, a schematic of the site, shows the location of the electrical, chilled and hot water, and penumatic trash collection systems.

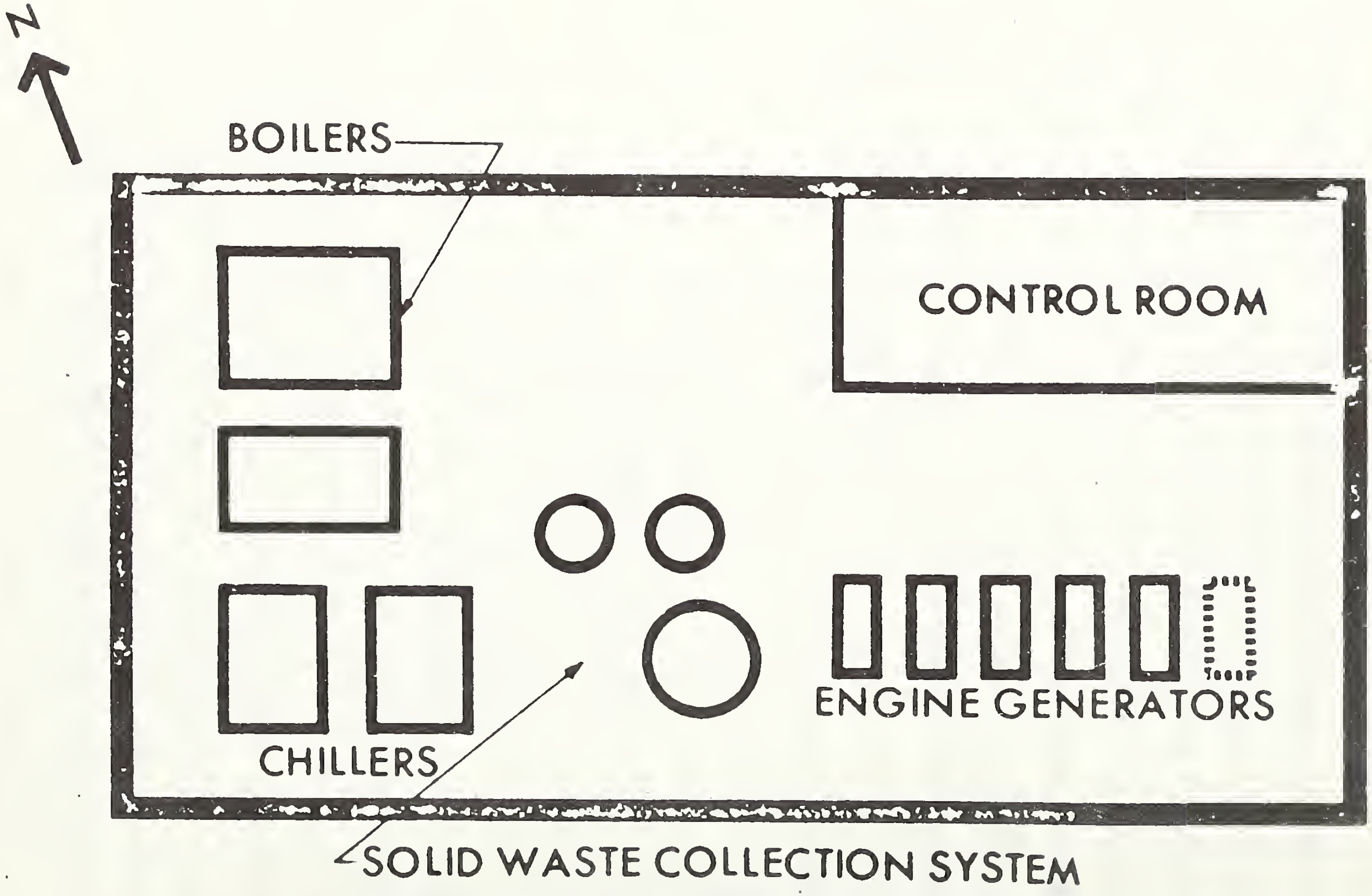


Fig. 1 Machine Locations in the Central Equipment Building.

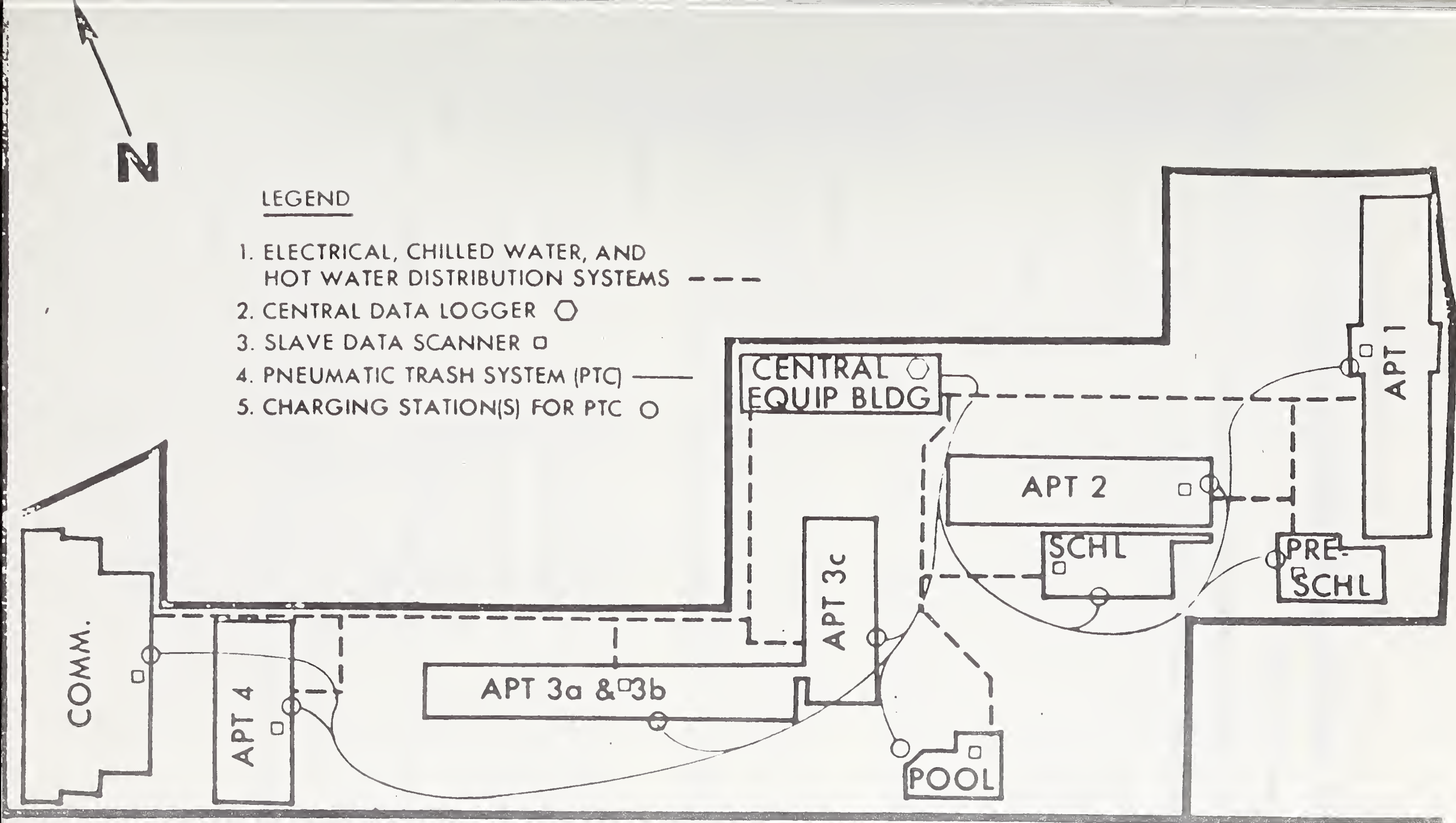


Fig. 2 A schematic layout of the buildings and the utility distribution systems on the Jersey City BREAKTHROUGH site.

The central pneumatic trash collection system will pull all trash from the site into a single compactor-type receptacle in the central equipment building.

Electricity at 480 volts, 60 hertz, three-phase, will be distributed from the total energy plant to each building.

2.1 Engine-Generators

The central utility building will contain five 600-KW engine generators, each rated 480 volts, three-phase, 60 hertz,750 KVA at 0.8 p.f. The engines are rated at 860 HP and are designed for ebullient cooling. However, the engines will be water-cooled, and are designed for a flow rate of 300 gpm of primary hot water entering the jackets at 225°F and leaving at 236°F under full load conditions. About 43% of this water (130 gpm) will be circulated through the exhaust heat recovery muffler, where it will be heated from 236°F to 252°F. The water leaving the heat recovery muffler will be mixed with the remaining jacket water and will enter the primary hot water loop at about 241°F. Figure 3 shows the primary hot water system in the central utility plant.

During the warmest and coldest months of the year, the heat recovered from the engine-generators will provide from 40 to 50% of the total thermal requirements, while the remainder will be supplied by the boilers.

2.2 Boilers

Two boilers, each rated at 13,390,000 Btu/hr, will supply all of the heat not obtainable from the engine-generator recovery system. The boilers will be installed in series with each other and with the engine jacket water circuit, as shown in Figure 3 and are used to "top off" the primary hot water temperature. The control system senses the chiller and hot water heat exchanger loads to maintain the primary hot water in the range from 225°F to 245°F. During periods of low hot water usage, the boilers will not be used if enough heat is provided by the heat recovery system on the engines.

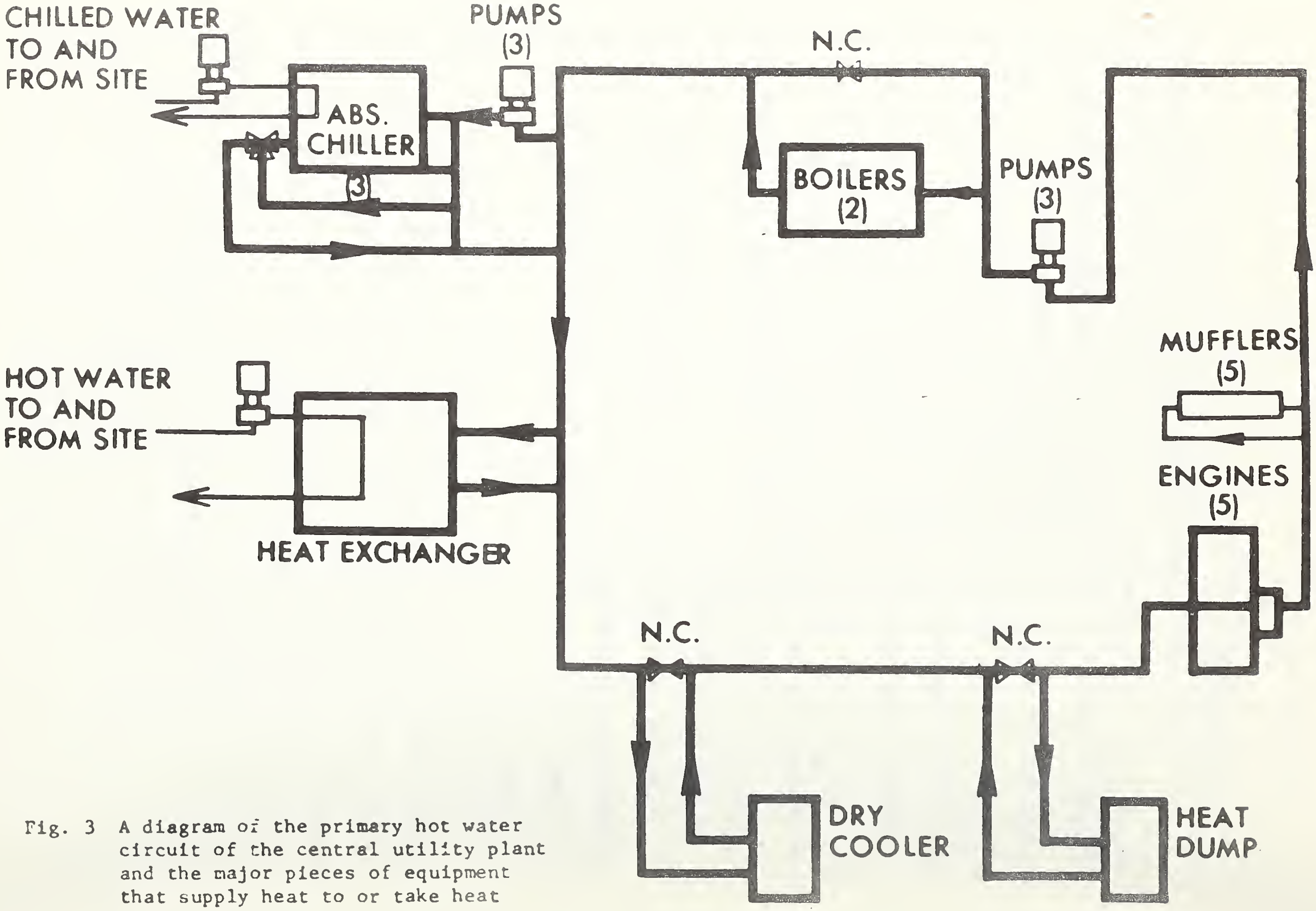


Fig. 3 A diagram of the primary hot water circuit of the central utility plant and the major pieces of equipment that supply heat to or take heat from this circuit.

2.3 Absorption Chillers

Two 526-ton absorption chillers will provide chilled water for air conditioning of the entire site.

The absorption chillers are to be installed in parallel. The chilled water control system controls the operation of the chillers as the load demands. Each chiller requires 826 gpm of primary hot water entering at 245°F and leaving at 222°F to produce 936 gpm of chiller water leaving at 44°F and returning at 58°F under full load conditions. The chillers require a constant volume of primary hot water and will use a 3-way valve to modulate the hot water temperature during low loads.

2.4 Dry Coolers and Heat Dump

When one or more engine-generators are operating to satisfy the electrical requirements and there is little need for either space heating or cooling, the return water to the engine jackets may become too hot for safe engine operation. Two dry coolers (water to air heat exchangers) connected in parallel, have been provided in the design to dispose of excess heat. These dry coolers will be mounted on the roof and are equipped with fans that operate whenever the return water entering the engine jackets reaches a temperature of 230°F. If, for any reason, the fans in the dry coolers fail to operate, a second set of heat exchangers (heat dump) cooled by city water, will be activated when the return jacket water reaches a temperature of 235°F.

2.5 Electrical Distribution System

Electricity will be distributed by a three-wire delta system with two separate feeders serving each building on the site. One feeder, labeled a normal load feeder (PN), will supply electricity for the individual dwelling units, miscellaneous power, and for all elevators except one in each building. The second feeder, labeled an essential load feeder (PE), will supply power for the corridor and stairway lighting, one elevator in each building, heating and cooling water pumps, sump pumps, domestic water pumps, and fire pumps. The sump pumps, heating and cooling water pumps, and domestic water pumps, will be electrically interlocked with the fire pumps to limit the demand on the distribution and generation system.

Three motor control centers (MCC) and one lighting power circuit (LP 1) will furnish all of the electric power for the auxiliaries and lighting requirements of the central equipment building. A separate feeder (PTC) will furnish electric power to the pneumatic trash collection system in the central equipment building (See Figure 4).

The circuit connecting the total energy system to the municipal power system will normally be open. This switch, illustrated in Figure 4, will be closed in case all of the five engine-generators are inoperative and have been shut down. Only enough power would be taken from the municipal system to serve the essential load circuits on the site.

3. Data Collection System

The total energy system at Jersey City is being extensively instrumented to produce engineering, reliability, maintenance, and load-and-cost data that are not generally available at the present time. It is anticipated that the data collected from this installation can be reliably extrapolated to larger housing developments, other climates, other fuel cost situations, and some other building occupancies.

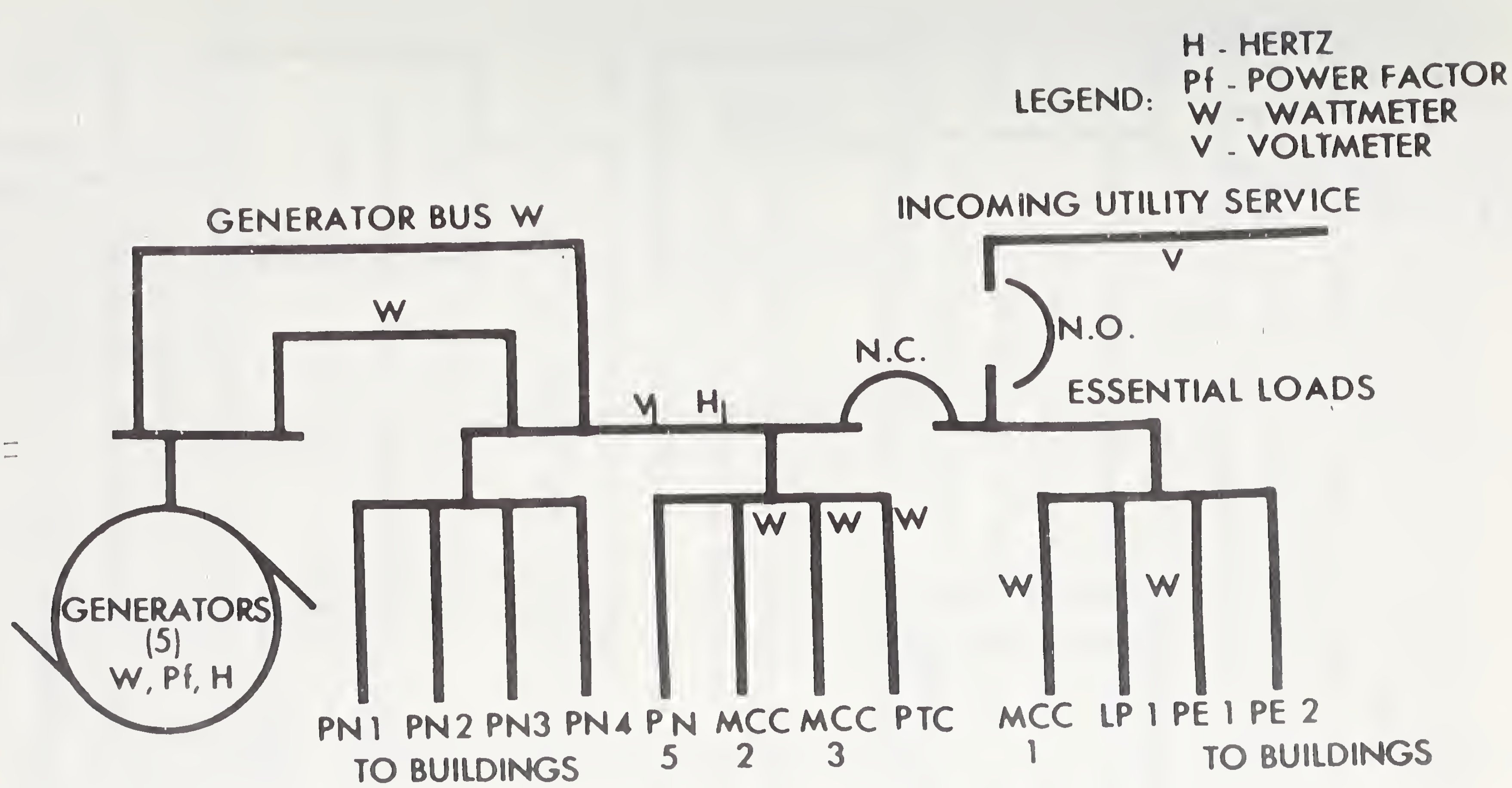


Fig. 4 A diagram of the electrical distribution system in the central utility plant showing the normal supply of electrical energy from the five engine-generator sets and the emergency connection to the municipal electric system. PN1 to PN5 are five feeder circuits serving normal loads and PE1 to PE2 are two feeder circuits serving essential loads, respectively, in the individual buildings. MCC1 to MCC3 are three motor control circuits serving normal and essential loads and LP1 is a lighting feeder, resepctively, for the central utility plant. PTC is a feeder circuit serving the vacuum trash collection system.

The instrumentation being installed will provide for detailed analysis of the fuel used, the electrical and thermal energy generated, the utilization of energy by all major segments of the load, the performance of all major plant components, the stability of the electrical service, the reliability of the several services, maintenance requirements, environmental conditions in and near the plant, fuel and operating costs, and weather data. The target end-to-end accuracy for this measurement system is 1% which means that the individual transducers need to have accuracies on the order of 0.1% to 0.25%. This level of accuracy is important because of the large number of integrated measurements of energy use that are required.

The data collection system is comprised of two major components; namely,

a) a central data logging system that will scan, transmit, and record 300 channels of data on magnetic tape every five minutes. This system collects data directly from the central plant and via satellite units from each of the buildings on the site. The satellite units transmit data on electrical and thermal energy usage to the central data logging system.

b) an analog system consisting of a strip chart data logger to record transient variations in the electrical service, interruptions of the utility services, and malfunctions or overloads on the system.

3.1 <u>Central Data Logging System</u>

The central data logging system is installed in the central utility building. It scans and records the 300 data channels in the power plant at a rate of up to 30 channels per second. The components of the central data logging system are shown on Figure 5. The central controller directs

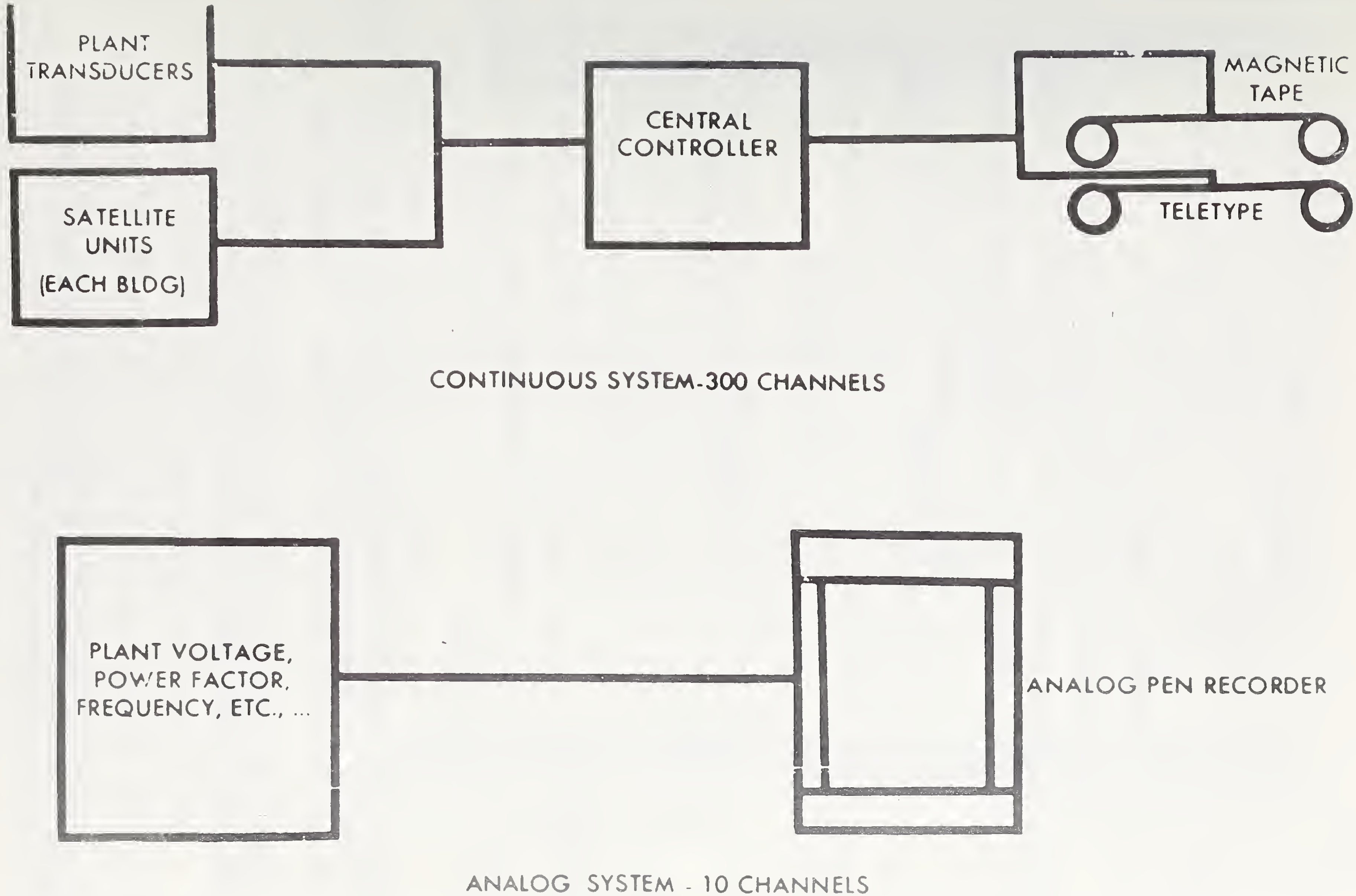


Fig. 5 A schematic showing of the continuous analog-digital data collection system and the analog system for recording short term phenomena in the total energy system.

system operation including sequencing of channels for scan, scan rate, analog-to-digital conversion, etc. The master scanner output of the central controller is printed every five minutes on magnetic tape or optionally on a manually-controlled teletype printout.

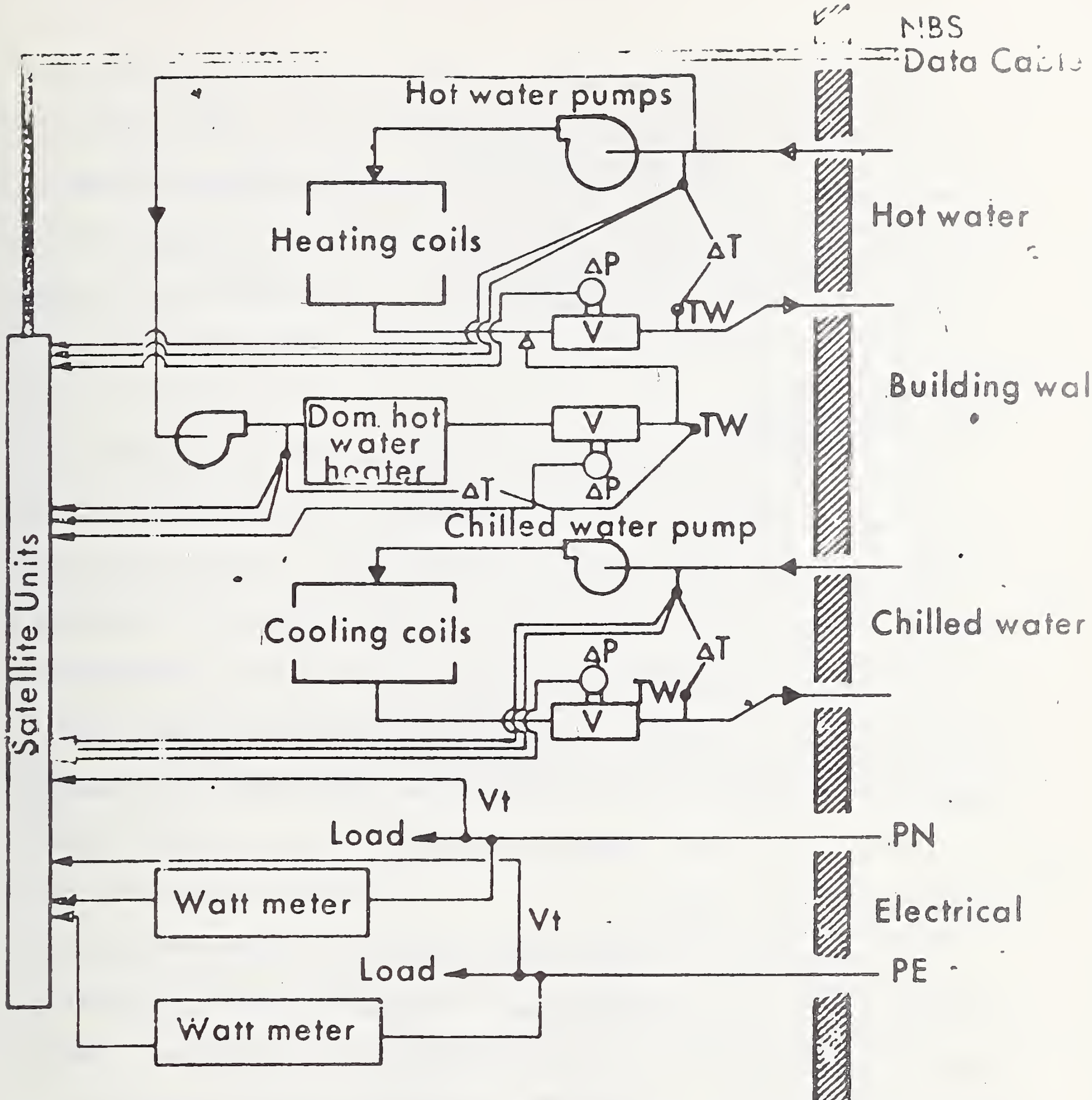
In sequence and as part of each central utility plant scan, the central data logging system controls the satellite units so that the data channels in each building are recorded on the central data logging system. The satellite units do not record data. On signal from the central controller they scan the electrical and water flow meters and the temperature sensors in each building every five minutes. The actual data retrieval requires only about one second per building. Thirteen channels of data are to be recorded, but the system is expandable to 30 channels per building.

Figure 6 shows a schematic of the typical electrical and piping system, including data collection instrumentation in each building. The data collection system is designed to measure and record integrated electrical energy usage and instantaneous readouts of the flow rates and temperatures of chilled water, heating hot water, and domestic hot water in each building.

3.1.1 Electrical Metering

Figure 4, a one-line diagram of the electrical distribution system in the central utility plant also shows the location of the electrical metering points in the central equipment building. On both the normal PN1-to-PN5 and essential PE1 and PE2 load feeders, energy usage will be measured and recorded every five minutes in the individual buildings.

The instantaneous electrical power will be measured by a "Hall effect" watt transducer, and the energy use will be integrated by an auxiliary device being designed and built at the National Bureau of Standards. The wattmeters are to be installed on the 208-volt four-wire (WYE) side of the building transformers.



LEGEND: TW - thermocouple, ΔP - Differential Pressure/, transmitter
ΔT - Differential (Thermopile) Temperature, V - Venturi
Vt - Voltage

Fig. 6 A schematic drawing of the instrumentation in the individual buildings for determining the thermal and electrical energy usage on a continuous basis.

In order to analyze the quality of electrical service, the line voltage on the 208-volt side of the transformers will be recorded continuously. It was decided to record the secondary rather than the primary voltage because the secondary voltage is more responsive to load phenomena in the building. The primary voltage depends more on what happens in the central utility plant.

3.1.2 Water Metering

The flow rates of chilled and hot water, and the return temperatures and temperature differences, will be recorded at 5 minute intervals in each building. Most water flow rates are to be measured by venturi meters using an electronic differential pressure cell as the flow transducer. Thermocouples are to be used to measure the actual temperatures of the hot and chilled waters entering the building. Thermopiles will be used to measure the temperature differences of the hot and chilled water entering and leaving the building. The actual leaving temperatures will be calculated during data analysis. (See Figure 6)

For large water flow rates venturi meters were selected because they are sensitive to the anticipated minor variations in flow rates and they have high efficiency and low pressure drop under these conditions. The ASME standard venturi meters were selected rather than the short-form venturi meters or orifice plates because of greater metering accuracy for flow measurement.

The maximum inaccuracy of each venturi meter in the design flow range is specified as ± 0.25%. Each venturi meter was individually calibrated and has a calibration curve over the design flow range. In order to obtain accurate pressure-drop data from the venturi flowmeters, electronic differential pressure cells were selected. These cells have an error of ± 0.10% or less. The differential pressure transducers generate a dc voltage which is proportional to differential pressure.

Turbine flow meters will be used on pipe lines smaller than two inches, and on the domestic hot water piping in the commercial, school, and pre-school buildings. These meters will be protected by 5-micron mesh strainers and have an error of ± 0.10% or less. A pulse counter is to be used to convert the turbine pulses to volume flow since each pulse corresponds to the passage of a known amount of water by calibration. The pulse counter signal is converted from digital to analog mode, providing a dc voltage that is proportional to integrated count total. Turbine flow meters were considered for the larger pipe sizes but were ruled out because of high cost. However, turbine flow meters for the smaller pipe sizes cost less than venturi meters fitted with the electronic differential pressure cells.

3.1.3 Temperature Measurement

All temperatures are to be measured by calibrated copper-constantan thermocouples, using an electronic reference junction. The thermocouples transmit a dc voltage which is proportional to the actual temperature.

Temperature differences are to be measured by multi-junction differential thermopiles in order to obtain higher dc voltages for the small temperature differences likely to occur. The dc voltage output is proportional to temperature difference. The temperature measurement system will have the potential of measuring differential temperatures as small as 0.05 °F.

4.2 Analog Recording

The analog strip chart recorder system will record all abnormal performance in the total energy plant, including transient electrical characteristics, engine malfunctions, operation of any of the safety or protective devices on the system, and the time and duration of overloads on the electrical system.

As an example of its function, whenever the voltage on the main bus drops ten percent below rated voltage, the electrical control system goes into a "system dump" sequence. This system-dump signal starts the analog recorder. During the system-dump sequence, all electrical loads except the essential loads are disconnected sequentially; that is, the normal feeders to the buildings, the air conditioning system, street lighting, etc., until the functioning generators are able to carry the remaining load. If the voltage keeps dropping, the total energy plant will be shut down and the emergency public utility feeder for the essential loads of the site will be energized. The total energy plant will remain shut down until manually checked and restarted. If during system-dump sequence the voltage stabilizes, all services will return automatically to normal operation. The analog recorder will record the electrical transients and generator phenomena during the overload period.

4. Special Data Collection Surveys

4.1 Air Pollution

The environmental effects of the total energy plant are part of the field study. During the design stage, the National Bureau of Standards studied existing and proposed regulations concerning emissions from diesel-operated power plants, in order to comply with air pollution regulations and to avoid neighborhood complaints.

For sulfur dioxide emission control, the State of New Jersey limits the amount of sulfur allowed in the fuel to 0.2% by weight for No. 2 fuel oil and lighter oils.[1] For plant emissions, New Jersey has only a smoke requirement of No. 2 Ringelmann on boiler stack emissions.[2] However, the New Jersey Air Pollution Control Administration has proposed a "no visible smoke emission" requirement from boilers and diesels.[3] The Environmental Protection Agency (EPA) has no regulations covering this plant, because of its small size. The EPA air pollution regulations cover all plants down to <u>250 x 10^6 Btu/hr.</u>[4]

1/ New Jersey Air Pollution Code, Chap. 10, Sulfur in Fuels, 5/1/68 0.2% sulfur effective 10/1/71.

2/ Ibid, Chap. 4, Smoke 1/1/58.

3/ Proposed Chapter 4, N. J. Air Pollution Code, 1/15/71.

4/ Federal Register, Vol. 36, No. 159, August 17, 1971, p. 15706.

The California truck diesel-engine emission standards[1/] for 1975 were the only standards available for study of exhaust pollution requirements for diesel prime movers. The limitations contained in these standards include the following:

1) hydrocarbons and oxides of nitrogen--5 grams per brake horsepower hour;

2) carbon monoxide--25 grams per brake horsepower hour.

The California emission requirements made no reference to diesel-engine driven stationary power plants--only to diesel engine-driven vehicles.

The specification prepared for the engine-generators to be installed in the Jersey City total energy plant cited the following maximum values for exhaust emissions at a generator loading of 600 KW:

1) unburned hydrocarbons -- 35 grams per hour;

2) carbon monoxide -- 700 grams per hour;

3) nitrous oxides -- 4500 grams per hour;

4) particulate matter -- 40 grams per hour;

5) smoke -- No. 1 Ringelmann maximum.

The emissions of each engine will be measured during pre-acceptance factory testing, and again during the on-site acceptance tests.

1/ California Exhaust Emission Standards, Test and Approval Procedures for Diesel Engine-driven vehicles in 1973, and subsequent Model Year Vehicles, Over 6,001 Pounds Gross Vehicle Weight, 11/19/70.

In addition, total emissions from the total energy plant will be measured. Exhaust emission sampling will be performed according to the Environmental Protection Agency standards 1/. Air samples at several locations on and adjacent to the site will be measured at selected time intervals. An air sampling survey of the site will be made before site operation. This survey will be the base line for comparison with future air-sampling surveys.

4.2 Noise Levels

Total energy plants can produce excessive noise outside the plant building unless properly designed. At one total energy plant, the National Bureau of Standards recorded sound pressure levels for informational purposes. It was found that the sound pressure level inside the equipment room between two engine-generators was 104 dB (A). On the roof of the same total energy plant about 30 feet from the cooling tower, the sound pressure level was 68 dB (A).

The NBS performance specification for total energy plants required that portable or permanent acoustic treatment be used to prevent exposure of working personnel to sound pressure levels in excess of 85 dB (A) 2/. In the control room the sound pressure level was limited to 70 dB (A) 2/.

After the Jersey City site is occupied and the total energy plant is operating, a sound pressure level survey of the site will be conducted. The results of this survey will be compared to the sound survey shown on Fig. 7, made on that site by the National Bureau of Standards in September, 1970. This survey was conducted over a 72-hour period (Thursday,

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1/ Federal Register, Vol. 36 No. 247, December 23, 1971, "Protection of the Environment, Standards of Performance for New Stationary Sources".

2/ A Performance Specification for a Total Energy Plant at the Jersey City BREAKTHROUGH I Site, P.R. Achenbach and J.B. Coble, NBS Report 10313 (Dec. 1970).

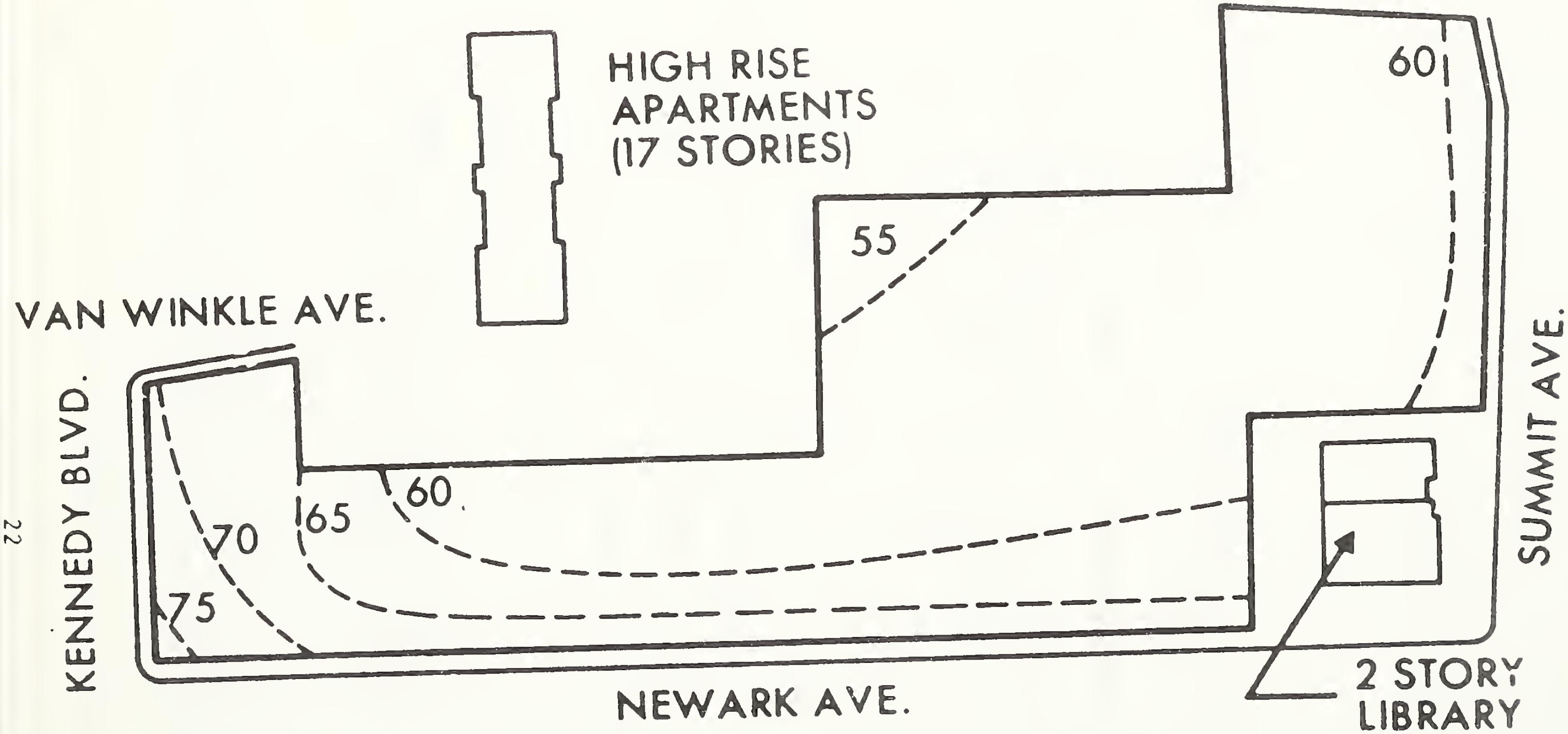

Fig. 7 The results of an acoustic survey taken on the Jersey City site before construction started. Those acoustic lines expressed in decibels on the A scale, db (A) are shown on the plot plan.

Friday and Saturday) and shows that the average sound pressure levels ranged from 55 to 75 dB(A) during the survey period. The higher readings were observed near the street where trucks and buses were the major noise contributors. The total energy plant is being installed where the measured sound pressure level approximated 55 dB(A). The allowable increase in sound pressure level over ambient sound pressure level due to operation of the total energy plant was limited to 5 dB(A) in the performance specification.

In order to comply with the specifications, extensive acoustical treatment is being provided for the engine exhausts. The waste heat recovery muffler is designed to reduce the sound level by 13 decibels in the frequency band of 4800/10,000 cycles per second. The exhaust muffler on the stack is designed to reduce the exhaust noise by 26 decibels in the frequency band of 37.5/75 cycles/sec and by 23 decibels in the frequency band of 4800/10,000 cycles/sec. Acoustical treatment is also being provided for the cooling towers which are mounted on the roof of the central utility plant.

5. Summary of Field Studies

The planned field studies are comprised of the following major subdivisions: (a) an energy use study, (b) performance of the principal plant components, (c) stability of the electrical service, (d) reliability of the services, (e) environmental conditions at the total energy plant, and (f) owning and operating costs.

5.1 Energy Use Study

Continuous measurement will be made for a year or more of the fuel oil used, electrical energy generated, thermal energy utilized, excess heat discarded, and the incremental use of electrical and thermal energy by all major segments of the load.

Fuel oil consumption will be measured for all engines and both boilers, and separately for each of two selected engines to provide a basis for determining typical engine performance.

Electrical energy will be measured at all major points of utilization including (a) the amount distributed to the site, (b) the amount used by each building, (c) that used by the commercial area, (d) that used by the schools, (e) the amount used by plant auxiliaries, and (f) that used by the central solid-waste collection system. The electrical energy generated by each of two of the engine-generators will be measured separately. The data collection system will also permit determination of the energy demand integrated over time periods of five minutes or any multiple thereof up to daily and weekly patterns. Diversity factors of energy use among the dwelling units in each apartment building can also be determined.

The thermal energy used in the absorption chillers, and in the primary hot water heat exchangers in the plant and that discharged through the water-to-air coolers (dry coolers) and through the engine-oil coolers will be recorded at five minute intervals and integrated by computer programs. Similarly the thermal energy used in each building for space heating and cooling and for domestic water heating will be recorded at five minute intervals and integrated.

5.2 Performance of Major Plant Components

The data collected on fuel use, electrical energy generation, thermal energy produced, and thermal energy utilized will permit determination of the thermal efficiency of the engine-generators, the heat recovery boilers, the absorption chillers, and the supplementary boilers. By analysis of these data at various load levels performance curves can be produced for all major types of mechanical equipment in the plant. Significant temperatures, pressures, speeds, and other operating parameters will be determined at the various load levels.

5.3 Stability of Electrical Service

Recordings will be made by the analog data system of transient conditions of voltage, frequency, power factor, and load division during sudden load changes on the system, during load-dumping conditions when overloads occur, and during the planned sequences of adding an engine-generator to the distribution system or disconnecting one from service. These data will not be collected continuously, but on a planned basis when the phenomena permit, or during short periods of emergency whenever these occur.

5.4 Reliability of Services

Detailed records will be made of the duration and characteristic parameters of interruptions to the electrical service and heating and cooling services caused by overload or malfunction of equipment. The functioning of all of the alarms and protective devices on the engine-chillers, boilers, and chillers will be monitored. These operating data, together with documented maintenance and repair operations, will constitute a record of reliability of the principal mechanical and electrical components of the plant.

5.5 Environmental Conditions at the Total Energy Plant

In addition to the air pollution and noise surveys described earlier in this report, noise and vibration measurements will also be made of each engine-generator after installation for comparison with similar data taken during factory tests and as a basis for estimating appropriate overhaul periods for the engines. Lubricating oil contaminant levels will also be monitored as a possible indicator of engine condition.

Illumination levels, thermal environment, and ventilation around major pieces of plant equipment and controls will be observed and compared with specification requirements.

5.6 Owning and Operating Costs

A complete record of owning and operating costs for the total energy plant will be kept including investment cost, financing costs and fees, fuel costs, costs for scheduled maintenance and overhaul, and for breakdown maintenance, costs for repair parts and inventory, plant operation and management, taxes, depreciation, insurance, and water; and credits for energy supplied to other facilities and for decreases in costs for other services such as solid-waste management. Records of maintenance, repair, and overhaul costs will be kept for a period of three to five years to properly evaluate the effect of the minor and major overhaul of engines on total costs.

The results from the Jersey City study are expected to constitute a good technical and economic base for evaluating the potential for wider application of total energy plants. This study and parallel market studies should provide sufficient data to consider whether total energy plants could be beneficially combined with waste treatment facilities or used as satellite systems interconnected with urban energy systems.

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15. SUPPLEMENTARY NOTES This NBS IR combines two talks given by J.B.Coble and P.R.Achenbach at the 7th Intersociety Energy Conversion Engineering Conference at San Diego, California, September 25-29, 1972.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Under sponsorship of the Department of Housing and Urban Development, the National Bureau of Standards developed criteria in a feasibility study to select a site for, and to evaluate the requirements of a total energy system on one or more OPERATION BREAKTHROUGH housing sites. The total energy system produces its own electrical, heating and cooling energy services independent of the local utility system. Six OPERATION BREAKTHROUGH sites were selected for the feasibility study: Jersey City,N.J.; Macon, Ga.; Memphis, Tenn.; Indianapolis, Ind.; St. Louis, Mo.; and Sacramento, Calif. Ranking parameters for final selection were: number of dwelling units, density of dwelling units, climatic factors, energy utilization, owning and operating costs, and developer's attitude.

The Jersey City site was chosen as the location for the installation, evaluation, and field study of the total energy system. The site covers six acres, has four apartment buildings containing 488 dwelling units, a 50,000-sq.ft commercial building, an elementary school, a swimming pool, and the total energy plant.

The buildings and the total energy plant are being extensively instrumented to provide data on fuel utilization, system efficiencies, electrical and thermal energy generation, energy utilized and rejected. The environmental impact of the total energy plant with respect to noise, vibration, air pollution, and esthetics is under evaluation. The installed system will be compared with several types of conventional energy systems.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Air conditioning; air pollution; central utility systems; data acquisition system; efficiencies; electrical power; energy conservation; energy costs; fuel utilization; heat recovery; total energy systems; utilities for housing; utility system performance.

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