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A Solar Energy System for Space Heating and Space Cooling

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Abstract

To help reduce natural gas and electrical operating costs, a retrofit space heating and space cooling soalr energy system is integrated into the existing conventional heating and air handling systems serving the exhibit spaces. This installation would not only provide substantial energy cost savings to the Museum, but it would also provide a means of showing and explaining the operation of an actual working solar energy system to the large number of daily visitors to the Museum. This report explains the design, operation and performance of this solar energy system.

1. INTRODUCTION

1.1 The Museum of Science and Industry has a primary goal to show how science and industry have contributed to the American way of life. They feel that by the addition of a viable, practical solar energy space heating and space cooling system to their own building, they will better fulfill their goal, and at the same time, they also will: (1) reduce their natural gas and electricity operating costs, (2) reduce air and thermal pollution in the community because solar is "clean" energy which has no products of combustion such as hot flue gases with entrained pollutants, and (3) provide a working demonstration to the public of the practical use of solar energy as an alternative energy source to the diminishing fossil fuel sources. This project also demonstrates that the technology and "know-how" exist, which are needed to make use of solar energy in a commercial application.

1.2 If solar energy is applied to provide space heating and space cooling to a significant portion of the exhibit area frequented each day by the visitors to the Museum, it would play an important role in reducing their operating cost.

2. PROJECT INFORMATION

2.1 The Museum central pavillion is an existing three-story building which is the restored fine arts building from the World's Columbian Exposition of 1893 which was reopened in 1933 at the time of the Century of Progress Exposition in Chicago. It is considered one of the finest examples of classic Greek architecture. The exhibit areas cover approximately 14 acres depicting the laws of science and applications of technology in industry and other fields. The Museum is located in Chicago, Illinois, approximately 6 miles south of the downtown business district and adjacent to the scenic shoreline of Lake Michigan.

3. SOLAR ENERGY SYSTEM-SUMMARY DESCRIPTION

3.1 The solar energy system is representative of a typical retrofit commercial installation while it still retains flexibility as a demonstration system, including the capability for gathering test data. The system will provide long-term solar heating and cooling system performance and reliability data as well as serve as a functional entity in the Museum's mechanical operating systems.

The control of the solar energy system adheres to standard commercial practice in the type of temperature control components utilized. Two separate free-standing temperature control panels are included in the system. One panel, located in the immediate area of the mechanical equipment located on the ground floor, will contain a graphic system representation and the necessary control devices to permit the operating personnel to make manual selection and readjustments to the control points in the automatic operating modes. The second panel also will contain a graphic representation of the solar energy system which, being located in the visitor's area, will be incorporated into a solar energy display exhibit explaining the operation of the solar energy system to the public.

The solar collector units are assembled into an array located on the southwest flat roof portion of the central pavillion building. Please refer to the composite solar energy system diagram in Fig. 1.2-2. The solar collector array consists of 7,072 square feet of evacuated tube type solar collectors, consisting of 442 General Electric TC-100 units, each of which is approximately 4 feet x 4 feet in size. A 30% ethylene glycol/water solution is circulated through the collector array and then to the energy storage tank which is located in the equipment area on the ground floor. The circulating pumps, air heating and cooling coils, absorption water cooler and automatic controls are also located in the ground floor equipment area. From the energy storage tank, heat is supplied to either the heating coils in the System #7, #8 and #9 air handling units in the winter or to the hot water driven generator of the absorption water chiller in the summer. The chilled water is circulated to cooling coils in the System #7 and #9 air handling units and to a cooling coil in one zone duct of System #8 serving the employee's cafeteria zone. The energy storage tank has a capacity of 3,000 gallons and is used to store excess solar energy during the interim spring and fall seasons.

This installation was designed to furnish approximately 50% of the energy requirements for the spaces heated and cooled based on annual energy requirements for the spaces served by this system.

A flexible automatic temperature control system is provided for the solar energy system to allow for a variety of operating modes. Controls and modulating valves are provided and integrated with the existing systems, making use of existing manual and automatic controls to regulate heating and cooling supplied by the solar energy system. The interface between the solar energy system and the conventional mechanical systems is arranged so that hot water, required for both the heating and cooling cycles, can be supplied from either the solar system and/or the conventional back-up gas fired boiler to meet the heating and cooling load demands. The system is designed for automatic operation with monitoring by regular maintenance personnel.

The solar collector units are mounted on a structural frame which is connected into the existing steel structural framing of the building by penetrating the roof and attaching to the primary structural members. The collector units are arranged in 13 rows, each of which, after the front row, increases 10" in height. The collector units in each row are installed at a 45° angle with the horizontal. Clearance is provided under the collector structural support framing to provide access to the roof for its maintenance. Walkways and platforms will provide access to the collector units. The pumps, energy storage tank, absorption cold generator, heating and cooling coils, and temperature control equipment are closely grouped in the equipment area adjacent to the boiler room on the ground floor.

4. SOLAR ENERGY SYSTEM DESIGN

4.1 The Museum of Science and Industry offers a unique situation for application of a solar energy system because it is normally open to the public 364 days each year. The only day it is closed is Christmas Day. Because of this schedule it provides a unique situation of a continuing daily load demand throughout the year. This differs from the normal five-day operating week common to most establishments. Because of this, the requirements for energy storage are minimized, and at the same time, maximum use can be made of all available collected solar energy to meet the continuing daily demands. The normal daily operating hours for the Museum vary between the summer and winter seasons. Their summer season extends from May through September, during which time the Museum opens at 9:30 A.M. and closes at 5:30 P.M. each day. During their winter season, which extends from October through April, the operating hours are from 9:30 A.M. to 4:00 P.M. Monday through Friday, and from 9:30 A.M. to 5:30 P.M. weekends and holidays. The fan systems in the Museum are normally operated only during their open hours.

4.2 An analysis of the temperatures in Chicago was made using the Climatic Atlas of the United States as a reference source. A plot of temperatures, including maximum high and low temperatures and normal daily maximum, average and minimum temperatures, was made and plotted. There was found to be a distinct consistency among the normal daily maximum temperatures, normal daily average temperatures, and normal daily minimum temperatures when plotted over the entire year. By consistency it is meant, of course, that these curves very closely approach being parallel to each other. Further analysis and plotting of hourly temperatures on a daily basis was made to determine the hourly temperatures during the hours that the mechanical systems were operated. After these temperature values were computed, it was possible to determine monthly average outdoor temperatures for the hours of operation which were used further on in my determination of the heating and cooling loads and the subsequent determination of the equipment performance.

4.3 The three air handling systems, identified as Systems S-7, S-8 and S-9, were selected because they are typical fan systems in their physical arrangement and their combined capacities were compatible with the solar energy system's capability of collecting energy as will be shown in the evaluation of the combined performance of the solar energy system and the air handling systems which appears further on in my discussion. The air volumes delivered by Systems S-7, S-8 and S-9 are given in Tables #1 & 2.The total supply air quantities of the three Systems is utilized in conjunction with the solar energy system during the heating season. However, during the cooling season (summer) all of the supply air delivered by Systems S-7 and S-9 is cooled, but only 4900 CFM of the 17,625 CFM supply air delivered by System S-8 is cooled.

4.4 The heating of air in the three Systems is done by hot water heating coils which are installed upstream of the existing reheat coils in each System. The water/ ethylene glycol solution, heated in the solar collector, is circulated from the energy storage tank to each of the heating coils. There are 137 gallons per minute circulated by Pump P-2 to the three heating coils and distributed to each as follows: S-9 - 59 GPM, S-8 - 37 GPM, and S-7 - 41 GPM.

4.5 The cooling of air in the three air handling systems is done by circulating chilled water from the absorption unit to cooling coils installed downstream of the existing reheat coils in each System. There is a total of 200 gallons per minute circulated by Pump P-6 from the absorption unit to the cooling coils and distributed to each as follows: S-9 - 83 GPM, S-8 - 50 GPM, and S-7 - 67 GPM.

4.6 The solar heated water/ethylene glycol solution is circulated by Pump P-4 from the energy storage tank to the absorption generator to produce the chilled water. The quantity of solution circulated by Pump P-4 to drive the absorption unit is 173 gallons per minute.

4.7 The condensing water, which removes the heat from the absorption chiller unit, is circulated by Pump P-5 from the cooling tower basin through the condenser section of the absorption unit and back to the cooling tower. The quantity of condensing water circulated is 400 gallons per minute.

4.8 The structural support frame for the solar collector units is designed to withstand 100 m.p.h. wind load and 13 pounds per square foot snow load. The weight of the solar collector unit filled is 72 pounds per unit.

4.9 The solar collector array is comprised of 442 collector units. They are arranged in 13 rows with 34 units in each row. The main supply pipe connects to each row at its midpoint (17 collector units on each side of the supply connection) and feeds from the main supply pipe in the center of each row in opposite directions through the 17 collector units to the ends of the row. The main return headers (there are two) connect to the ends of each row and carry the fluid to the energy storage tank. Flexible connectors are used to make the two supply connections and the two return connections to each row. Service valves are installed at both supply connections and both return connections in each row making it possible to isolate each half of every row for maintenance and service requirements. This arrangement provides maintenance flexibility and it also enables the solar collector array to remain operational except for the portion (one half of one row) required to be isolated for maintenance. At the quarter points in each row are installed piping expansion compensators to accommodate movement in each row. In addition to providing ease of maintenance, this arrangement gives balance of fluid flow through each row of solar collector units because the collector units in each row are parallel connected to the supply and return branch extending laterally along each row. Referring again to Fig. 1.2-2, it can be seen that the fluid is drawn from the energy storage tank into Pumps P-1 (Pump P-1A is a stand-by pump) and circulated through the supply main, running perpendicular to the rows and connecting at each row midpoint, through the collector units, through the return mains at the ends of each row and back to the energy storage tank.

4.10 The plane of installation of the solar collector units was chosen as 45 degrees with the horizontal since this is the most advantageous angle for maximizing energy collection throughout the entire year. This angle is very close to the latitude (41.4° North) of the site. Furthermore, using a 45° installation angle facilitates erection of the structural support framing for the collector units. Using this installation angle, the row spacing of 7'6" between each row, and the 10" increase in elevation of the second through the thirteenth rows, an analysis was made of the shading of the collector surface area that would occur throughout the year. It was determined that when the sun was at a 22 degree true altitude angle there was no shading on the collector surface. Evaluated for the latitude at which this project is located, the true altitude angle of the sun during the daily hours of energy collection is not less than 22 degrees true altitude for the months of March through September. Therefore, no shading would occur during this period. However, from October through February, there are times during the day when the true altitude angle of the sun was less than 22 degrees. Taking into account the true angles of the sun, a percent of the collector area being shaded was calcu - lated. This percent of shading was then applied to determine the percent loss of total available energy collected daily. These results were tabulated and are **included with other data. Table # 4** shows the computations on a month-by-month basis to determine the total solar energy collected for the year. The values in the first column (A) take into account the amount of available insolation each month, less the amount lost because of cloud cover, smog, and haze appropriate specifically for the Chicago area. You will note that column (E) accounts for the energy loss due to shading. The values in this chart in column (B) were provided by the solar collector unit manufacturer (General Electric) based on their empirical test data of the Model TC-100 unit.

5. ENERGY CONSERVATION CONSIDERATIONS

5.1 To maximize the effectiveness of the solar energy system, it is very important to reduce to a minimum energy losses not only from the solar energy system, but also from the mechanical systems with which the solar energy system interfaces. Generally, this is accomplished by the application of thermal insulation. All piping, ductwork and equipment items such as absorption chiller, expansion tanks, energy storage tank, heat exchangers and pumps will be insulated with no less than 1 1/2" thickness heavy density fiberglas insulation with appropriate jacket. All piping and accessories exterior to the building at the solar collector will be insulated as stated above and in addition, will have a moisture proof, weather tight covering applied over the insulation. This amount of properly applied insulation will substantially reduce the heat losses so that they will approach approximately 2%.

5.2 It was noted that the stack for the existing boilers was located in the corner of the building adjacent to the solar collector and related solar energy system equipment. The boiler equipment is operated all year round to meet the needs of the Museum, including the large public and smaller employee cafeterias. Therefore, the vertical supply and return piping serving the solar collector will be installed in a shaft immediately adjacent to the stack in order to take advantage of the elevated temperatures (160° to 180°) which will exist in the adjacent pipe shaft. With this arrangement the heat losses from the vertical risers from the ground floor (equipment area) to the roof (solar collector area) are practically nil.

5.3 The existing boiler room ventilation system consists of an exhaust air system which is balanced with a make-up supply air system. An analysis of the energy recovery possibilities was made of the existing boiler room ventilation system. With the addition of a "run-around" system, consisting of a coil in the exhaust air outlet and a coil in the outside air inlet and a pump circulating an ethylene glycol solution around the closed piping loop between the coils, a significant savings could be gained as is shown on **Table # 5, Column H.**

5.4 At the present time all the fan systems are manually turned on and off at their individual locations in the building at the beginning and end of each day. There is a current plan underway to incorporate an automatic system to turn on and off each fan at a central location at specified times for each day of the year. Since it requires an operator to spend approximately 20 to 30 minutes twice a day to accomplish this, not only will the manhours be saved, but also the fan operating times will be reduced with subsequent reduction in electrical energy consumption.

6. AUTOMATIC TEMPERATURE CONTROL SYSTEM

6.1 The automatic temperature control system contains control components and operational sequences that are commonly found in commercial automatic temperature control systems. Because of the limitation in length for this report the listing of all of the automatic temperature control components was not included. The automatic temperature control system schematic diagrams and the description of the Sequences of Operation of the various control groupings were also deleted at this time for the same reason.

7. CALCULATION OF DESIGN LOADS

7.1 Using the developed average outdoor temperatures during operating hours, previously referred to, and the air quantities for Systems #7, #8 and #9, previously referred to, the design cooling loads and the design heating loads were determined and were tabulated on Table # 1 and Table # 2 respectively. The information in the column headings define the items and, using the alphabetical nomenclature for the columns, show the algebraic relationships, where appropriate, used to determine the values.

8. PERFORMANCE SUMMATION

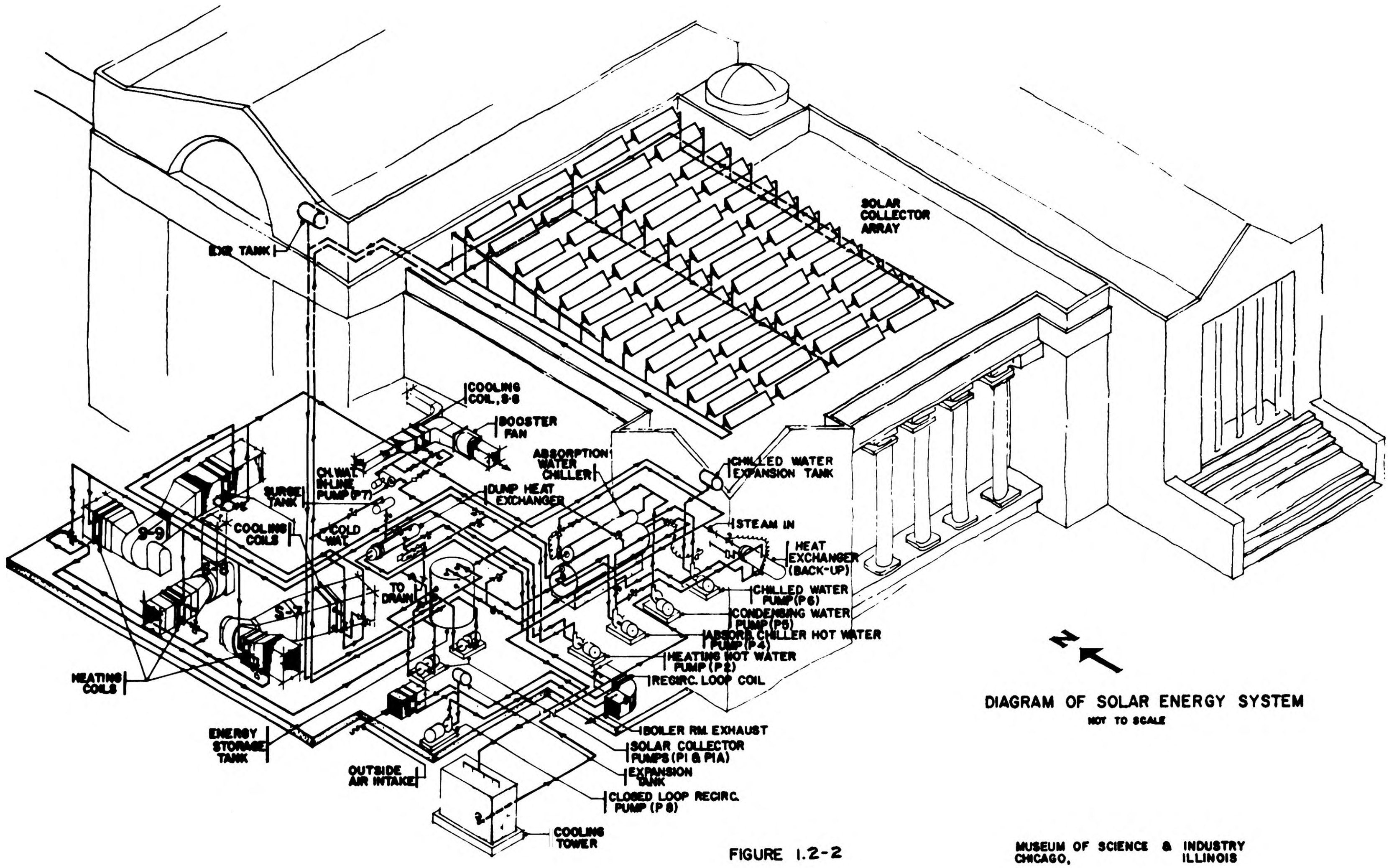
8.1 Finally, an energy saving computation was made including: the useful solar energy combined with the energy recovered and saved by elimination of operation of conventional equipment no longer required; and with deductions for energy losses and additional energy requirements for operation of solar energy system equipment. The results of these computations were tabulated and are shown on Table #5.

9. BIOGRAPHY

Mr. McNamara is a graduate mechanical engineer having earned his bachelor's degree from the University of Illinois, Champaign, Illinois which he attended subsequent to his serving for two years in the United States Marine Corps. Upon graduation he worked for a mechanical contractor as an HVAC system designer for one and one-half years and then as their chief engineer for one and one-half years. He then served as an application system designer for a control valve manufacturer for three years. He then went back into HVAC system design for seven years for a governmental agency before serving as their chief mechanical engineer for the next four years. He has been the chief mechanical engineer and solar energy specialist in a private consulting firm, V.A. Scavo & Associates, for the last five and one-half years.

Mr. McNamara has been involved with commercial, institutional and residential solar energy system designs for the last five and one-half years and is a member of the American Society of Heating, Ventilating and Air-Conditioning Engineers and the International Solar Energy Society, American Section. He is a registered professional engineer in the State of Illinois.

Mr. McNamara has lectured on solar energy for the Chicago Chapter of the National Association of Power Engineers, for the East-Central Chapter of the American Society of Heating, Refrigerating and Air-Conditioning Engineers in Flint, Michigan, and at the Solar Heating and Cooling National Forum in Miami Beach, Florida.



SOLAR COLLECTOR ARRAY
EXP. TANK
COOLING COIL, S-8
BOOSTER FAN
ABSORPTION WATER CHILLER
CHILLED WATER EXPANSION TANK
CH. WAT. IN-LINE PUMP (P7)
SURGE TANK
DUMP HEAT EXCHANGER
COOLING COILS
COLD WAT.
STEAM IN
HEAT EXCHANGER (BACK-UP)
TO DRAIN
CHILLED WATER PUMP (P6)
CONDENSING WATER PUMP (P5)
ABSORB. CHILLER HOT WATER PUMP (P4)
HEATING HOT WATER PUMP (P2)
RECIRC. LOOP COIL
S-9
S-7
HEATING COILS
BOILER RM. EXHAUST
ENERGY STORAGE TANK
SOLAR COLLECTOR PUMPS (P1 & P1A)
EXPANSION TANK
OUTSIDE AIR INTAKE
CLOSED LOOP RECIRC. PUMP (P 8)
COOLING TOWER
N
DIAGRAM OF SOLAR ENERGY SYSTEM
NOT TO SCALE
FIGURE 1.2-2
MUSEUM OF SCIENCE & INDUSTRY
CHICAGO, ILLINOIS

FIG. 1.2-2

CALCULATION OF DESIGN HEATING LOADS

TABLE I

MONTH	SYSTEM	A	B	C	D	E	F	G	H	I	J		K	L	DESIGN HEATING LOADS (K x L) J
		RECIRC-ULATED AIR VOLUME $m^3 s^{-1}$	RECIRC-ULATED AIR TEMP. °C	OUTSIDE AIR VOLUME $m^3 s^{-1}$	OUTSIDE AIR AVER. TEMP. °C	MIXED OUTSIDE & RECIRC. AIR VOL. $m^3 s^{-1}$	MIXED AIR TEMP $\left(\frac{AB + CD}{E}\right)$ °C	SUPPLY AIR TEMP. °C	TEMP. DIFF. AIR THRU HEATING COIL (G-F) Δ°C	HEATED AIR VOLUME (A + C) $m^3 s^{-1}$	TIME IN OPERATION 6-1/2 HR. DAY HRS.	TIME IN OPERATION 8 HR. DAY HRS.	TIME IN OPERAT. TOTAL ($\Sigma J \times 3600$) S	TOTAL HEATING CAPACITY ($H \times I \times 1.0 \times 1201.38$) $J s^{-1}$	
JAN.	SYSTEM 7	5.423	22.8	5.229	-0.40	10.652	11.42	21.10	9.68	10.652	140.85	74.64	775,764	123,876	96,099 x 10^6
	SYSTEM 8	3.776	22.8	4.543	-0.40	8.318	10.14	21.10	10.96	8.318	140.85	74.64	775,764	109,524	84,965 x 10^6
	SYSTEM 9	6.036	22.8	7.853	-0.40	13.899	9.66	21.10	11.44	13.899	140.85	74.64	775,764	191,025	148,190 x 10^6
	TOTALS	15.235		17.625		32.869				32.869				424,425	329,254 x 10^6
FEB.	SYSTEM 7	5.423	22.8	5.229	0.32	10.652	11.77	21.10	9.33	10.652	140.85	50.64	689,364	119,397	82,308 x 10^6
	SYSTEM 8	3.776	22.8	4.543	0.32	8.318	10.54	21.10	10.56	8.318	140.85	50.64	689,364	105,527	72,747 x 10^6
	SYSTEM 9	6.036	22.8	7.853	0.32	13.899	10.07	21.10	11.03	13.899	140.85	50.64	689,364	184,179	126,966 x 10^6
	TOTALS	15.235		17.625		32.869				32.869				409,103	282,021 x 10^6
MAR.	SYSTEM 7	5.423	22.8	5.229	5.16	10.652	14.12	21.10	6.98	10.652	140.85	74.64	775,764	89,324	69,294 x 10^6
	SYSTEM 8	3.776	22.8	4.543	5.16	8.318	13.15	21.10	7.95	8.318	140.85	74.64	775,764	79,445	61,631 x 10^6
	SYSTEM 9	6.036	22.8	7.853	5.16	13.899	12.84	21.10	8.26	13.899	140.85	74.64	775,764	137,925	106,997 x 10^6
	TOTALS	15.236		17.625		32.869				32.869				306,694	237,922 x 10^6
APR.	SYSTEM 7	5.423	22.8	5.229	12.66	10.652	17.83	21.10	3.27	10.652	140.85	66.64	746,964	41,847	31,258 x 10^6
	SYSTEM 8	3.776	22.8	4.543	12.66	8.318	17.22	21.10	3.88	8.318	140.85	66.64	746,964	38,773	28,962 x 10^6
	SYSTEM 9	6.036	22.8	7.853	12.66	13.899	17.05	21.10	4.05	13.899	140.85	66.64	746,964	67,627	50,515 x 10^6
	TOTALS	15.235		17.625		32.869				32.869				148,247	110,735 x 10^6
OCT.	SYSTEM 7	5.423	22.8	5.229	15.99	10.652	19.40	21.10	1.70	10.652	140.85	74.64	775,764	21,755	16,877 x 10^6
	SYSTEM 8	3.776	22.8	4.543	15.99	8.318	19.06	21.10	2.04	8.318	140.85	74.64	775,764	20,386	15,815 x 10^6
	SYSTEM 9	6.036	22.8	7.853	15.99	13.899	18.95	21.10	2.15	13.899	140.85	74.64	775,764	35,901	27,851 x 10^6
	TOTALS	15.235		17.625		32.869				32.869				78,042	60,543 x 10^6
NOV.	SYSTEM 7	5.423	22.8	5.229	7.40	10.652	15.25	21.10	5.85	10.652	140.85	66.64	746,964	74,863	55,920 x 10^6
	SYSTEM 8	3.776	22.8	4.543	7.40	8.318	14.34	21.10	6.76	8.318	140.85	66.64	746,964	67,553	50,460 x 10^6
	SYSTEM 9	6.036	22.8	7.853	7.40	13.899	14.08	21.10	7.02	13.899	140.85	66.64	746,964	117,220	87,559 x 10^6
	TOTALS	15.236		17.625		32.869				32.869				259,636	193,939 x 10^6
DEC.	SYSTEM 7	5.423	22.8	5.229	1.30	10.652	12.20	21.10	8.90	10.652	140.85	74.64	775,764	113,894	88,355 x 10^6
	SYSTEM 8	3.776	22.8	4.543	1.30	8.318	11.03	21.10	10.07	8.318	140.85	74.64	775,764	110,630	78,065 x 10^6
	SYSTEM 9	6.036	22.8	7.853	1.30	13.899	10.66	21.10	10.44	13.899	140.85	74.64	775,764	174,327	136,237 x 10^6
	TOTALS	15.235		17.625		32.869				32.869				388,851	301,657 x 10^6

TABLE 1

CALCULATION OF DESIGN COOLING LOADS

TABLE 2

MONTH	SYSTEM	A	B	C	D	E	F		G	H	I		J	K	L	
		RECIRCUL-ATED AIR VOLUME $m^3 s^{-1}$	RECIRC. AIR TEMP. °C	OUTSIDE AIR VOLUME $m^3 s^{-1}$	OUTSIDE AIR AVER. TEMP. °C	MIXED OUTSIDE & RECIRC. AIR VOL. $m^3 s^{-1}$	MIXED AIR DRY BLDG. TEMP. °C	MIXED AIR WET BLDG. TEMP. °C	AIR BY PASS AROUND COOLING COIL VOL. $m^3 s^{-1}$	AIR THRU COOLING COIL VOLUME $m^3 s^{-1}$	AIR LEAVING COOLING COIL DRY BLDG. TEMP. °C	AIR LEAVING COOLING COIL WET BLDG. TEMP. °C	ENTHALPY CHANGE $\Delta J g^{-1}$	TOTAL COOLING CAPACITY (H x J x 1201.38) $J s^{-1}$ or W	TIME IN OPERA-TION S	DESIGN COOLING LOADS (K x L) J
MAY	SYSTEM 7	5.423	28.3	5.229	19.22	10.652	23.88	16.8	2.629	8.023	13.2	13.0	12.09	116,532	892,800	104,040 x 10^6
	SYSTEM 8	3.776	28.3	4.543	19.22	8.318	23.34	16.52		2.313	13.2	13.0	9.53	26,482	892,800	23,643 x 10^6
	SYSTEM 9	6.036	28.3	7.853	19.22	13.899	23.17	16.4	4.686	9.203	13.2	13.0	9.30	102,824	892,800	91,801 x 10^6
	TOTALS	15.235		17.625		32.869			7.315	19.539				245,838		219,484 x 10^6
JUNE	SYSTEM 7	5.423	28.3	5.229	25.38	10.652	26.88	19.4	2.629	8.023	13.3	13.2	18.48	178,123	864,000	153,898 x 10^6
	SYSTEM 8	3.776	28.3	4.543	25.38	8.318	26.88	19.3		2.313	13.3	13.2	18.25	50,713	864,000	43,816 x 10^6
	SYSTEM 9	6.036	28.3	7.853	25.38	13.899	26.66	19.3	4.686	9.203	13.3	13.2	18.13	200,452	864,000	173,191 x 10^6
	TOTALS	15.235		17.625		32.869			7.315	19.539				429,288		370,905 x 10^6
JULY	SYSTEM 7	5.423	28.3	5.229	27.85	10.652	28.08	20.48	2.629	8.023	13.42	13.25	21.62	208,389	892,800	186,050 x 10^6
	SYSTEM 8	3.776	28.3	4.543	27.85	8.318	28.05	20.48		2.313	13.42	13.25	21.62	60,078	892,800	53,638 x 10^6
	SYSTEM 9	6.036	28.3	7.853	27.85	13.899	28.05	20.48	4.686	9.203	13.42	13.25	21.62	239,038	892,800	213,413 x 10^6
	TOTALS	15.235		17.625		32.869			7.315	19.539				507,505		453,101 x 10^6
AUG.	SYSTEM 7	5.423	28.3	5.229	26.75	10.652	27.54	20.0	2.629	8.023	13.36	13.2	19.99	192,677	892,800	172,022 x 10^6
	SYSTEM 8	3.776	28.3	4.543	26.75	8.318	27.45	20.0		2.313	13.36	13.2	19.99	55,548	892,800	49,594 x 10^6
	SYSTEM 9	6.036	28.3	7.853	26.75	13.899	27.41	19.94	4.686	9.203	13.36	13.2	19.76	218,473	892,800	135,053 x 10^6
	TOTALS	15.235		17.625		32.869			7.315	19.539				466,698		416,669 x 10^6
SEPT.	SYSTEM 7	5.423	28.3	5.229	22.34	10.652	25.43	18.15	2.629	8.023	13.25	13.1	14.41	138,893	746,964	103,748 x 10^6
	SYSTEM 8	3.776	28.3	4.543	22.34	8.318	25.07	18.0		2.313	13.25	13.1	13.95	38,764	746,964	28,955 x 10^6
	SYSTEM 9	6.036	28.3	7.853	22.34	13.899	24.95	17.85	4.686	9.203	13.25	13.1	13.48	149,039	746,964	111,327 x 10^6
	TOTALS	15.235		17.625		32.869			7.315	19.539				326,696		244,030 x 10^6

TABLE 2

COMPUTATIONS FOR SOLAR ENERGY COLLECTED

TABLE 4

MONTH	A NET DAILY SOLAR ENERGY ON COLLECTOR AT 45° IN CHICAGO ILL. Jm^{-2}	B NET SOLAR ENERGY COLLECTED DAILY 45°, G.E. MOD. TC-100 Jm^{-2}	C COLLECTOR AREA m^2	D DAILY LOSS OF ENERGY BY SHADING OF COLLECT %	E DAILY ENERGY LOST BY SHADING OF COLLECTOR (D X B) Jm^{-2}	F NET DAILY SOLAR ENERGY COLLECTED (B – E) Jm^{-2}	G NET DAILY SOLAR ENERGY COLLECTED ON TOTAL COLLECTOR AREA (C X F) J	H DAYS PER MONTH	I TOTAL NET SOLAR ENERGY COLLECTED (G X H) J
JAN.	6809.58×10^3	2723.83×10^3	657.01	5.4	147.09×10^3	$2,576.74 \times 10^3$	$1,692.94 \times 10^6$	31	$52,481.14 \times 10^6$
FEB.	8511.98×10^3	3404.79×10^3	657.01	2.6	88.53×10^3	$3,316.26 \times 10^3$	2178.82×10^6	28	$61,006.96 \times 10^6$
MAR.	$11,042.87 \times 10^3$	4414.88×10^3	657.01	0	0	4414.88×10^3	2900.62×10^6	31	$89,919.22 \times 10^6$
APR.	$14,209.32 \times 10^3$	5685.99×10^3	657.01	0	0	5685.99×10^3	3735.75×10^6	30	$112,072.50 \times 10^6$
MAY	$20,201.75 \times 10^3$	8080.70×10^3	657.01	0	0	8080.70×10^3	5309.10×10^6	31	$164,582.10 \times 10^6$
JUNE	$24,151.31 \times 10^3$	9658.25×10^3	657.01	0	0	9658.25×10^3	6345.57×10^6	30	$190,367.10 \times 10^6$
JULY	$18,272.37 \times 10^3$	7308.95×10^3	657.01	0	0	7308.95×10^3	4802.05×10^6	31	$148,863.55 \times 10^6$
AUG.	$17,546.02 \times 10^3$	7013.87×10^3	657.01	0	0	7013.87×10^3	4608.18×10^6	31	$142,853.58 \times 10^6$
SEPT.	$12,994.95 \times 10^3$	5197.98×10^3	657.01	0	0	5197.98×10^3	3415.13×10^6	30	$102,453.90 \times 10^6$
OCT.	8602.77×10^3	3438.84×10^3	657.01	3	103.37×10^3	3335.67×10^3	2191.57×10^6	31	$67,938.67 \times 10^6$
NOV.	4721.31×10^3	1883.98×10^3	657.01	4.8	90.43×10^3	1793.55×10^3	1178.38×10^6	30	$35,351.40 \times 10^6$
DEC.	3915.51×10^3	1566.20×10^3	657.01	6.6	103.37×10^3	1462.83×10^3	961.09×10^6	31	$29,793.79 \times 10^6$
YEARLY TOTALS								365	$1,197,683.70 \times 10^6$

TABLE 4

ENERGY SAVING & ENERGY CONSUMPTION COMPUTATIONS & SUMMARY

TABLE 5

MONTH	A HEATING AND COOLING DESIGN LOAD J	B SOLAR ENERGY COLLECTED J	C RATIO OF SOLAR ENERGY TO DESIGN LOAD $\left(\frac{B}{A}\right)$	D BOILER EFFICIENCY	E HEAT EXCHANGER EFFICIENCY	F CONVENTIONAL SYSTEM EQUIVALENT TO SOLAR ENERGY $\left(\frac{B}{D \times E}\right)$ J	G SYSTEM HEAT LOSSES J	H ENERGY RECOVERED IN BOILER ROOM CIRCUIT J	J ADDITIONAL EQUIPMENT ENERGY RECUIRMENTS J	K EXISTING A/C[1] UNITS ENERGY SAVED J	L EQUIVALENT NET ENERGY SAVED =(F+H+K)-(G+J) J
JAN	$329,254 \times 10^6$	$52,481 \times 10^6$	0.159	0.65	—	$80,740 \times 10^6$	$4,996 \times 10^6$	$32,474 \times 10^6$	$54,989 \times 10^6$		$53,290 \times 10^6$
FEB	$282,021 \times 10^6$	$61,007 \times 10^6$	0.216	0.65	—	$93,857 \times 10^6$	$4,861 \times 10^6$	$31,314 \times 10^6$	$48,841 \times 10^6$		$71,469 \times 10^6$
MAR	$237,922 \times 10^6$	$89,919 \times 10^6$	0.378	0.65	—	$138,337 \times 10^6$	$4,629 \times 10^6$	$23,301 \times 10^6$	$54,969 \times 10^6$		$102,040 \times 10^6$
APR.	$110,735 \times 10^6$	$112,073 \times 10^6$	1.012	0.65	—	$172,420 \times 10^6$	$4,291 \times 10^6$	$13,496 \times 10^6$	$47,512 \times 10^6$		$134,113 \times 10^6$
MAY	* $219,484 \times 10^6$	* $164,582 \times 10^6$	0.750	0.65	0.75	$337,604 \times 10^6$	$3,984 \times 10^6$	+ —	$63,264 \times 10^6$	$26,174 \times 10^6$	$296,548 \times 10^6$
JUNE	* $370,905 \times 10^6$	* $190,367 \times 10^6$	0.513	0.65	0.75	$390,496 \times 10^6$	$3,368 \times 10^6$	+ —	$56,949 \times 10^6$	$25,327 \times 10^6$	$356,236 \times 10^6$
JULY	* $453,101 \times 10^6$	* $148,864 \times 10^6$	0.329	0.65	0.75	$305,362 \times 10^6$	$3,300 \times 10^6$	+ —	$63,264 \times 10^6$	$26,172 \times 10^6$	$264,970 \times 10^6$
AUG	* $416,669 \times 10^6$	* $142,854 \times 10^6$	0.343	0.65	0.75	$293,034 \times 10^6$	$3,469 \times 10^6$	+ —	$63,264 \times 10^6$	$26,172 \times 10^6$	$252,473 \times 10^6$
SEPT	* $244,030 \times 10^6$	* $102,454 \times 10^6$	0.420	0.65	0.75	$210,162 \times 10^6$	$3,796 \times 10^6$	+ —	$53,929 \times 10^6$	$21,899 \times 10^6$	$174,336 \times 10^6$
OCT.	$60,543 \times 10^6$	$67,939 \times 10^6$	1.122	0.65	—	$104,522 \times 10^6$	$4,133 \times 10^6$	$12,125 \times 10^6$	$49,348 \times 10^6$		$63,166 \times 10^6$
NOV.	$193,939 \times 10^6$	$35,351 \times 10^6$	0.182	0.65	—	$54,386 \times 10^6$	$4,523 \times 10^6$	$21,931 \times 10^6$	$52,929 \times 10^6$		$18,865 \times 10^6$
DEC.	$301,657 \times 10^6$	$29,794 \times 10^6$	0.099	0.65	—	$45,837 \times 10^6$	$4,787 \times 10^6$	$30,260 \times 10^6$	$54,969 \times 10^6$		$16,341 \times 10^6$
TOTALS	$3,220,260 \times 10^6$	$1,197,685 \times 10^6$				$2,226,757 \times 10^6$	$50,346 \times 10^6$	$663,901 \times 10^6$	$663,207 \times 10^6$	$125,742 \times 10^6$	$1,803,847 \times 10^6$

(1) 15 TON & 20 TON WATER COOLED PACKAGE A.C. UNIT
\+ OUTSIDE AIR TEMPERATURE TOO HIGH FOR EFFECTIVE PERFORMANCE
* .... COOLING MODE

TABLE 5