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task VI

EIGHT EVACUATED COLLECTOR INSTALLATIONS

interim report for the IEA task on the performance of solar heating, cooling and hot water systems using evacuated collectors

November 1982

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PREFACE AND ACKNOWLEDGEMENTS

This is the first in a series of reports from the International Energy Agency Solar Heating and Cooling Programme's task on the Performance of Solar Heating, Cooling and Hot Water Systems Using Evacuated Collectors. The results given here are more narrowly focused than will be the case in later reports. A progression from specific to more general results is necessary in a task of great complexity in individual projects and collective activities such as this. Much careful planning and attention to detail is needed in the early stages if task goals are to be achieved. Nevertheless, this report makes an important advance in the collective reporting of the design and performance of evacuated collector systems, as well as solar energy systems in general, and provides significant new individual and comparative system and collector results.

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ABSTRACT

The cooperative IEA task on evacuated collector systems includes the following research and development projects: solar heated and cooled single family residences in Japan and the USA, a solar heated single family residence in the Netherlands, a solar heated multi-family unit in West Germany, a solar test facility in the United Kingdom, solar heated and cooled offices in Australia, a solar heated and cooled laboratory in Italy, an industrial process heat application in Canada, a solar heated and cooled university building in the USA and district heating systems in Sweden and Switzerland. The task covers the important evacuated collector applications. The same collectors are used in several installations and nearly all currently available evacuated collectors are used in at least one installation.

Exchange of performance results within the task has been greatly enhanced by adoption of a mandatory highly prescriptive common reporting structure. Detailed unambiguous performance comparisons are made which would otherwise be difficult or impractical. This report, the first in a series of reports that will be published through 1986, describes the system and climate at eight of the installations and illustrates and compares seasonal, monthly, daily and hourly performance of the installations in Japan, Sweden, the USA and West Germany.

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

Figure		Page

Figure		Page

Figure		Page

LIST OF TABLES

I. INTRODUCTION

1.1 OBJECTIVES AND BACKGROUND

1.1.1. Objectives and Approach

The objective of Task VI of the IEA Solar Heating and Cooling programme is to further the understanding of the performance of evacuated collectors in solar heating, cooling and hot water systems, and to study, document and compare the performance characteristics of such collectors in various systems and climates. The execution of the task emphasizes common reporting requirements, a variety of installations covering important evacuated collector applications, a comprehensive use of available evacuated collectors, use of the same collectors in several installations and some duplication in end uses. Cooperation in the task provides a means of reducing duplication in each participant's national program and a reference point for future evacuated collector systems research, development and commercialization activities.

Exchange of performance results within the task has been greatly enhanced by adoption of a mandatory common reporting structure utilizing the IEA performance reporting format that has been modified and made more specific and prescriptive. Performance comparisons can be made that would be difficult or impractical for non-coordinated projects. Thus, participants have as good or better access to, and gain as much or more information from each of the Task VI installations than if the installations were part of their national program.

1.1.2 Responsibilities of Participants

Each participant in this task is responsible for the operation and analysis of at least one evacuated collector solar heating and/or cooling system. At the first meeting, the participants defined the general characteristics of acceptable systems and installations and developed a detailed program of work.

The general characteristics of acceptable installations and detailed program of work is as follows:

a. General Requirements for Participating Installations

   1. Projects will provide the equivalent of one full-time data engineer responsible for instrumentation, data acquisition, and analysis. This individual, or equivalent, and the project support staff will identify and correct faults in the data collection and operating systems in a timely manner. This capability will be located on-site until system reliability and warning capability have been clearly established.

2. Continuity in project staff will be maintained, starting with installation design and continuing through data collection and reporting.

3. Projects will be sufficiently well instrumented to provide the required information at the specified accuracies.

4. A project minimum annual manning level of two years will be provided.

5. It is essential that the project be oriented toward the testing of the system, as opposed to collector testing.

b. Desired Features for Participating Installations

1. The relationship between the evacuated collector performance characteristics and system performance is important. Therefore this relationship should be well understood in the project design phase and should be further carefully explored throughout the experiment. These efforts should be coordinated with Task III.

2. The use of systems models, particularly simulation, as an integral part of the system design process and later to generalize the results to other locations and system variants is highly desirable. The study and use of models should be coordinated with Task I.

3. Excessive duplication of one type of project is undesirable. It is desirable to have a variety of different evacuated collector designs, working fluids, system applications, working temperature ranges, and climates.

4. Applications where temperature differences to ambient are reasonably high, above 40°C, in sunny climates and moderate, above 20°C, in cloudy climates, should be sought. Also, applications where temperature differences are highly variable are desirable.

5. Real loads are preferred as simulated loads do not have some operating problems that must be experienced and dealt with before reliable evacuated collector systems are developed, such as "accidents". However, one or two projects with simulated loads are desirable for more carefully controlled system experiments, identification of specific load factor influences, and the greater ease of conducting sensitivity analyses. The differences in capability between the real load projects and simulated load projects can be beneficial to the total task efforts.

6. It is desirable that projects accepted in this task be those for which the component suppliers and the project investigators not be the same organization.

c. Requirements for Instrumentation, Data Collection, and Performance Reporting

1. Well instrumented systems are required. Instrumentation will be sufficient to calculate the primary reporting quantities and sensors will be precise enough to provide the accuracies given in the December 1979 report of "Data Requirements and Thermal Performance Evaluation Procedures for Solar Heating and Cooling Systems".

2. The instrumentation and data recording plan will ensure high data collection reliability.

3. Meetings will be held semi-annually.

   i. Annual reports will follow the IEA format for reporting the performance of solar heating and cooling systems, as given in the February 1980 report, with modifications, made at the September 1980 Pingree Park meeting and approved at the December 1980 Task VI meeting.

   ii. Between annual reports, reporting for Task VI meetings should be patterned after the IEA format, if practical.

   iii. To provide for adequate review time, each participant will send his report to each of the other participants at least one month before task meetings.

   iv. The Operating Agent will summarize the annual reports in a report to be submitted to the IEA Executive Committee and participants at the conclusion of the task. The Operating Agent will also provide the required task status reports to the IEA Executive Committee.

   v. Task meetings of the participating installations will be held semi-annually for the purpose of discussing task and installation progress and results, exchanging information among participants, and reviewing proposals for new Task VI installations.

vi. The meeting date and location of the next meeting will be set at each meeting.

vii. The Operating Agent will set the meeting agenda and make any necessary adjustments in meeting dates to accommodate timing of individual projects.

1.1.3 Procedures for Reviewing Proposed Installations

a. Design and data collection plans of proposed installations will be presented at Task VI meetings and will be sufficiently detailed that the participants can evaluate if the proposals meet Task VI requirements. The participants will make recommendations on proposed installation designs and data collection plans. Approval of the plan for a proposed installation will be by consensus of the participants.

b. Revisions to projects that become necessary subsequently need not require approval of task participants. However, recommendations on such matters should be sought, whenever practical.

1.1.4 Task Duration

The task began officially in October of 1979. In view of the timing requirements of some of the installations, the participants agreed it would be desirable for the program to be extended from a three year term to a five or six year duration. An extension of the task to December 1985 was approved at the October 1981 Executive Committee meeting.

1.1.5 Publications Policies and the Role of Evacuated Tubular Collector Manufacturers in Task Activities

Collector manufacturers are encouraged to take part in task activities with supply of hardware, advice, evaluation and review. In such arrangements, the responsible participant in the task shall give full consideration to the manufacturer's advice and opinions and provide the manufacturer with the opportunity to review and advise on reports and papers. The findings and reports shall be the sole responsibility of the participant.

1.1.6 Task Participants

The Task participants and applications are:

Australia - Heating and Cooling of University Offices
Canada - Industrial Process Heat
Commission of the European Communities (CEC) - Cooling of a Solar Laboratory
Federal Republic of Germany - Multifamily Residential Heating and Hot Water Production
Japan - Single Family Residential Heating, Cooling and Hot Water Production
The Netherlands - Single Family Residential Heating and Hot Water Production

Sweden - District Heating
Switzerland - District Heating
The United Kingdom - Domestic Space Heating and Hot Water Production With Simulated Loads
USA - Single Family Residential Heating, Cooling and Hot Water Production

The CEC and Australia joined the task in 1982. Addresses and phone numbers of task national contact persons and responsible researchers can be found in Appendix A.

1.2 SCOPE OF REPORT

Seven of the ten current Task VI participants have been in the Task since it begain in October 1979. These are Canada, the Federal Republic of Germany, Japan, Sweden, Switzerland, the United Kingdom, and the United States. The Netherlands joined the task in October 1980, the CEC in May 1982 and Australia in October 1982. When the task began, only Japan, the Federal Republic of Germany and the United States had operational evacuated collector systems with thoroughly tested data acquisition systems. As of May 1982, the CEC had recently installed evacuated collectors, the Netherlands and Australia were installing evacuated collectors and the remaining participants' installations were operating and collecting data.

This report is for the period October 1979 through September 1981. The eight installations of Canada, Japan, the Netherlands, Sweden, Switzerland, the United Kingdom, the United States, and West Germany are reported on. All participants' installations, climates, loads, components, systems, experiments and future plans are described. Not all installations produced publishable data during the report period. October 1979 through September 1981 performance results for the installations in Japan, the United States, and West Germany are presented. In addition, performance results of Sweden's installation for August through November 1981 are included as are some results for the West German installation from before and after the report period.

Subsequent task reports will include descriptions and results from Australia and the Commission on European Communities and from second installations in Sweden, Switzerland and USA. Results will also be available from the present installations in Canada, the Netherlands, Switzerland, and the United Kingdom as well as from Japan, the United States, and West Germany.

2. INSTALLATION DESCRIPTIONS

The Task VI installations comprise a wide range of evacuated collector applications. As of January 1982 there were two district heating systems -- Sweden and Switzerland, two solar heated and cooled single family residences -- Japan and the US, a solar heated single family residence -- the Netherlands, a solar heated multifamily residence emphasizing solar DHW production -- West Germany, an industrial process heat application -- Canada, and a domestic space heating system with simulated load -- the United Kingdom.

Figures 2-1 through 2-8 are photographs of the installations. General descriptions of the installations are given in Table 2-1. Table 2-2 describes the installations' loads and Table 2-3 outlines the current activities of the installations.

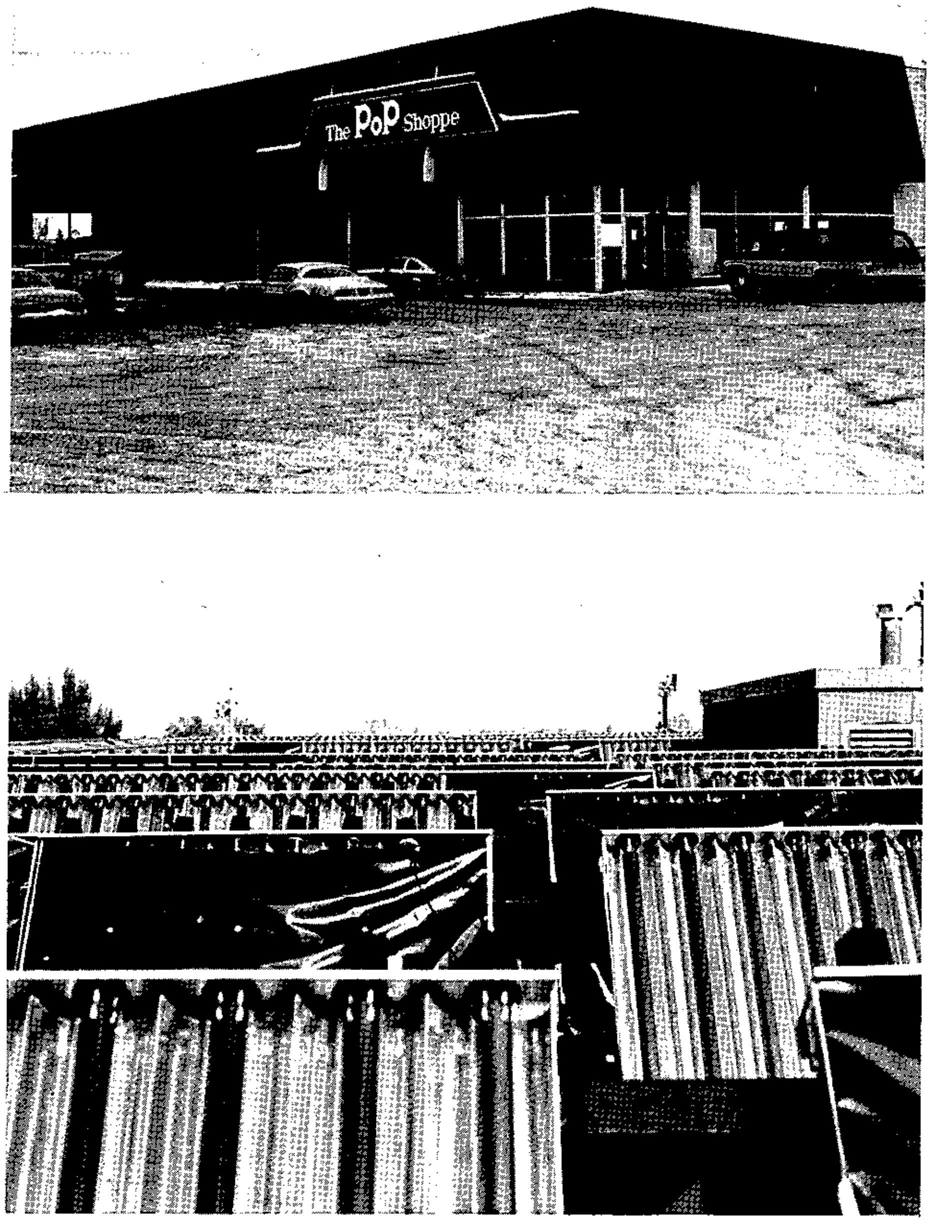


Figure 2-1. Mountain Springs Bottle Washing Facility
Edmonton, Alberta, Canada

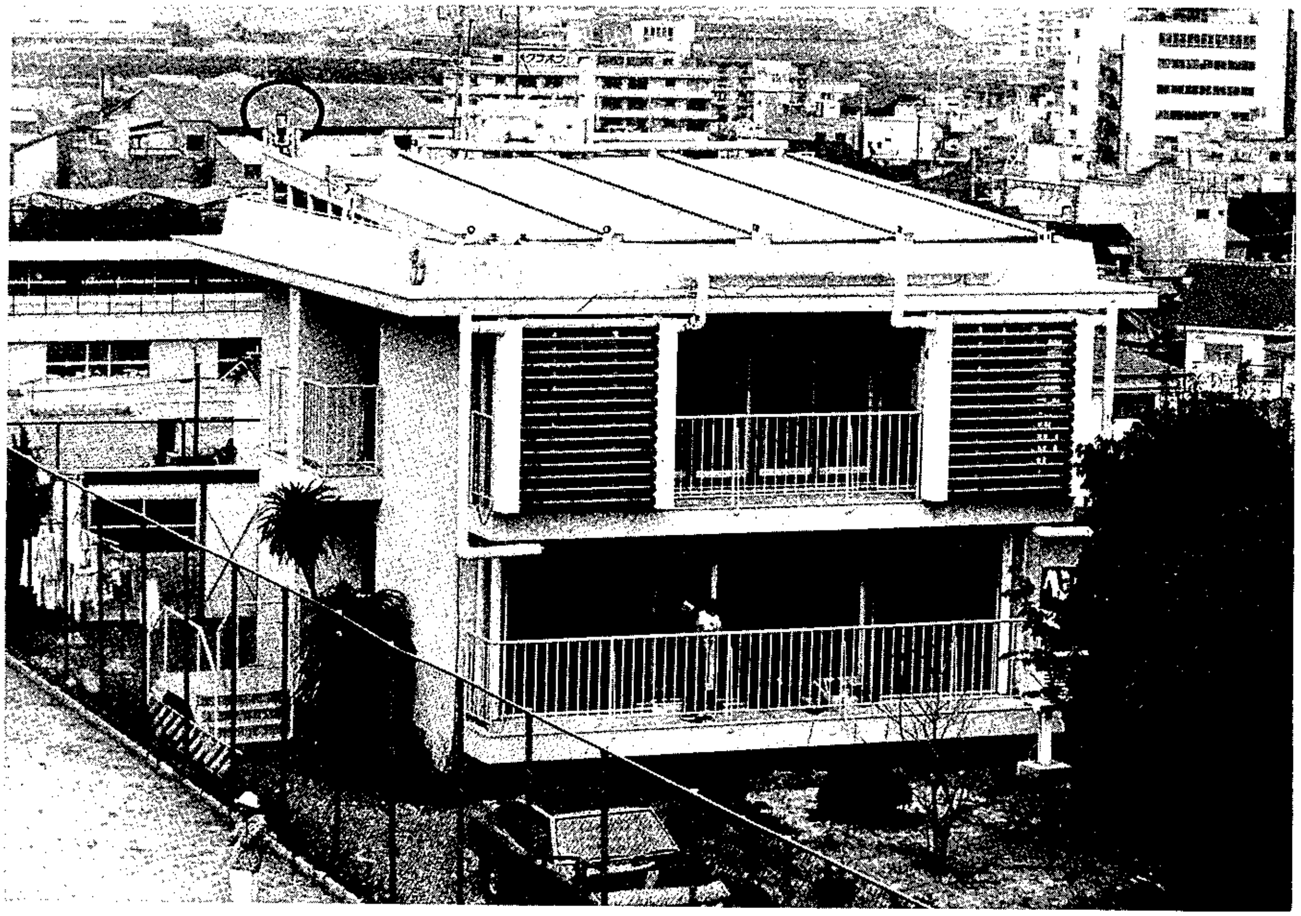


Figure 2-2. Osaka Sanyo Solar House
Osaka, Japan

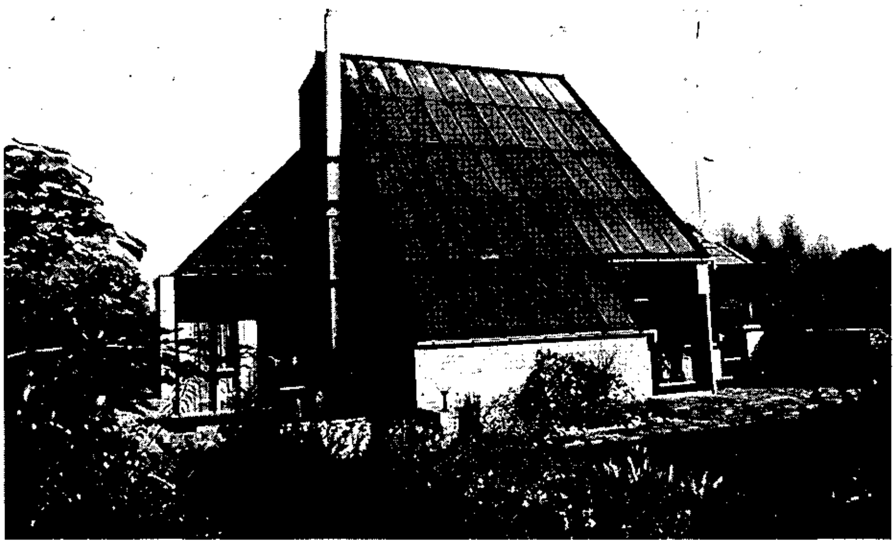


Figure 2-3. Eindhoven Technological University Solar House
Eindhoven, Netherlands

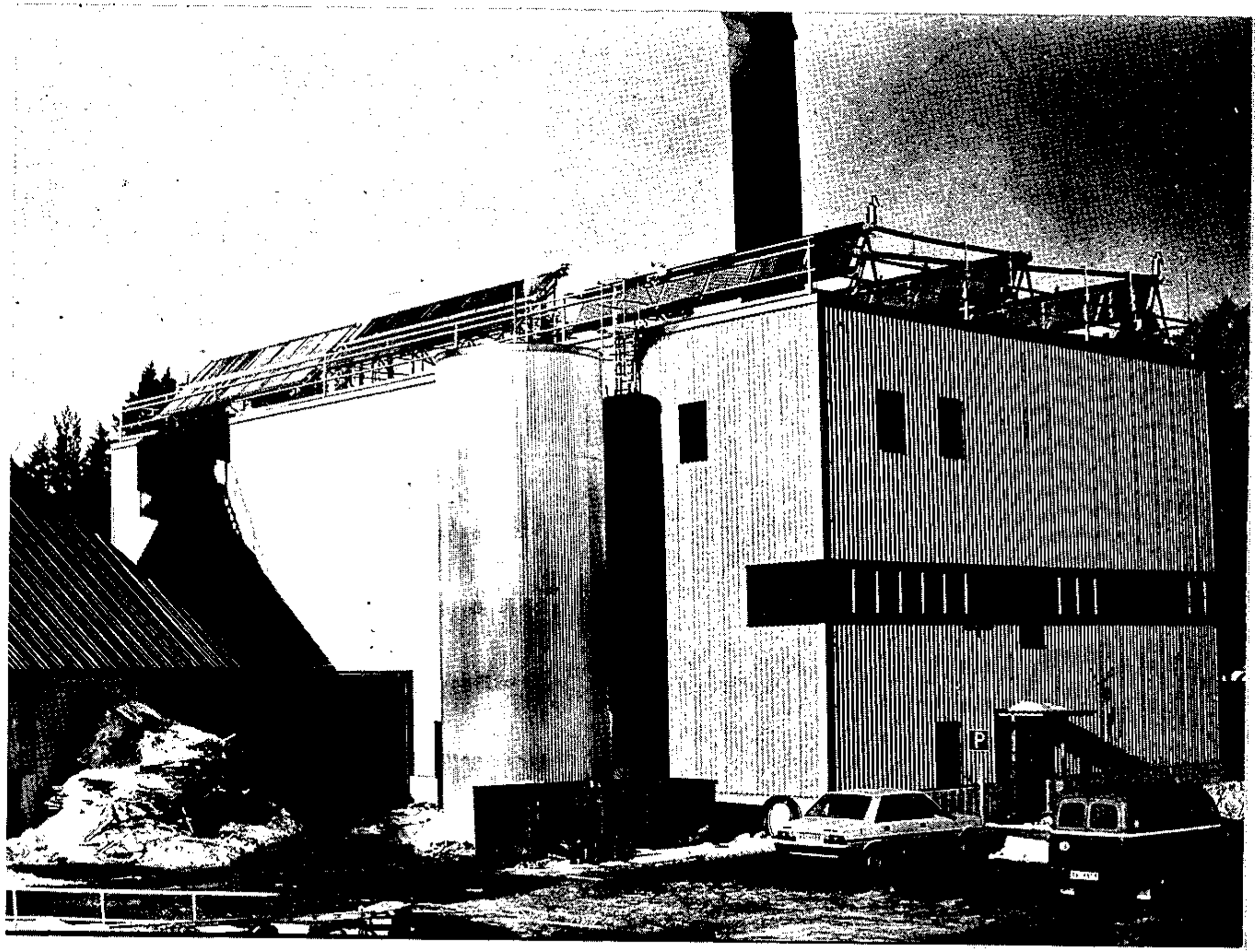


Figure 2-4. Knivsta District Heating Project
Knivsta, Sweden

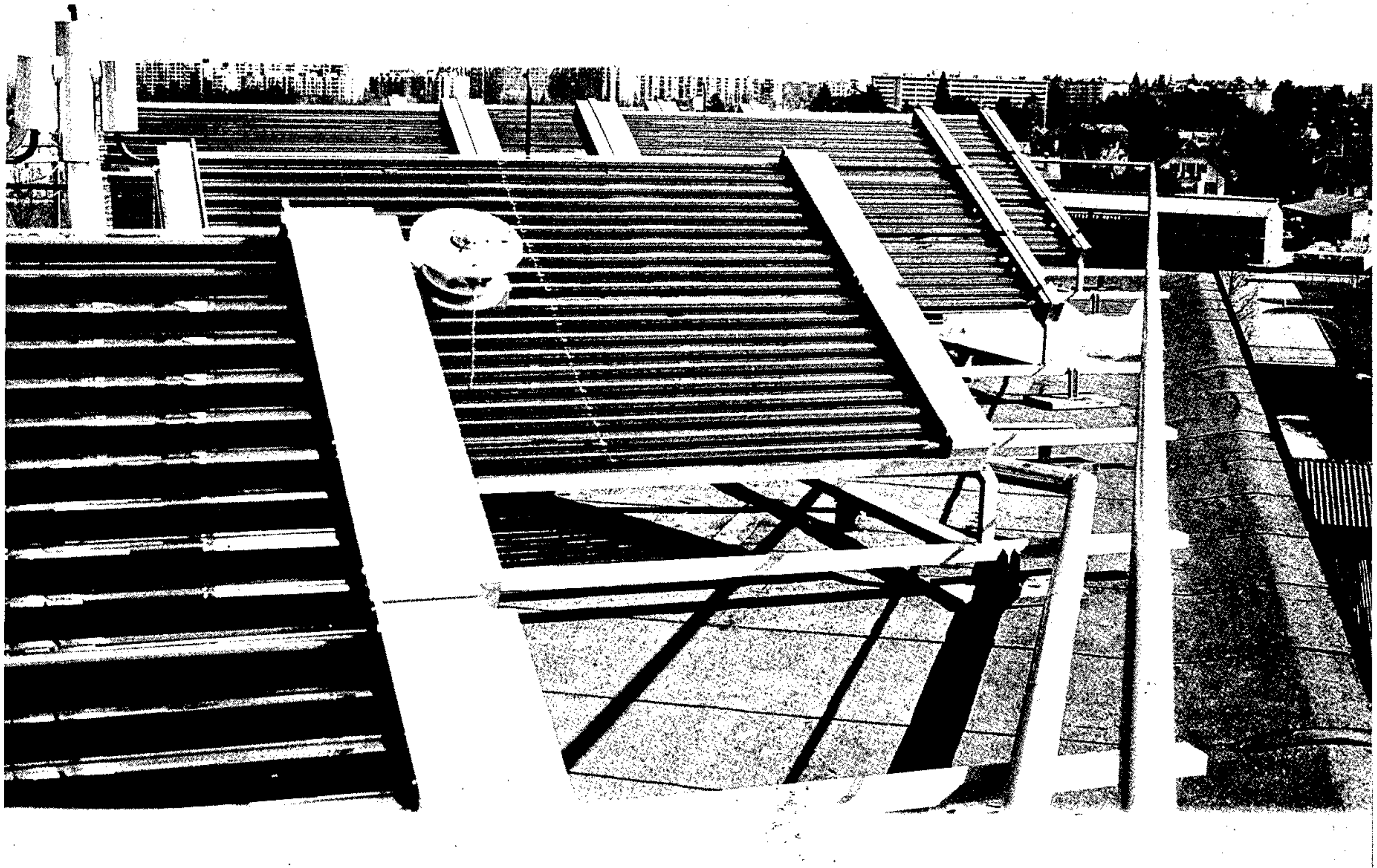
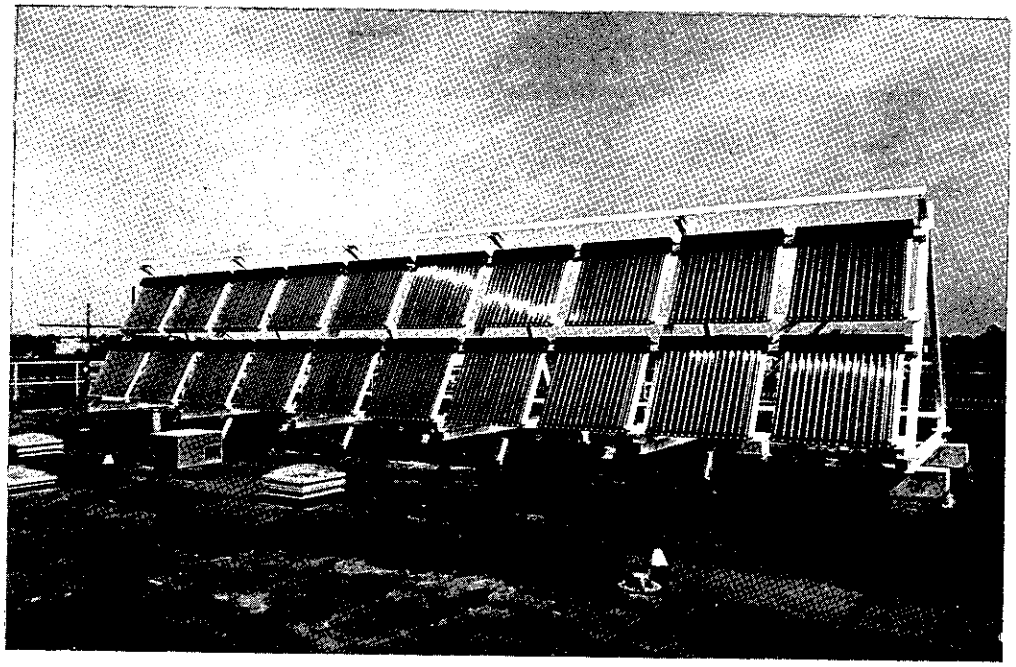


Figure 2-5. SOLARCAD District Heating Project
Geneva, Switzerland



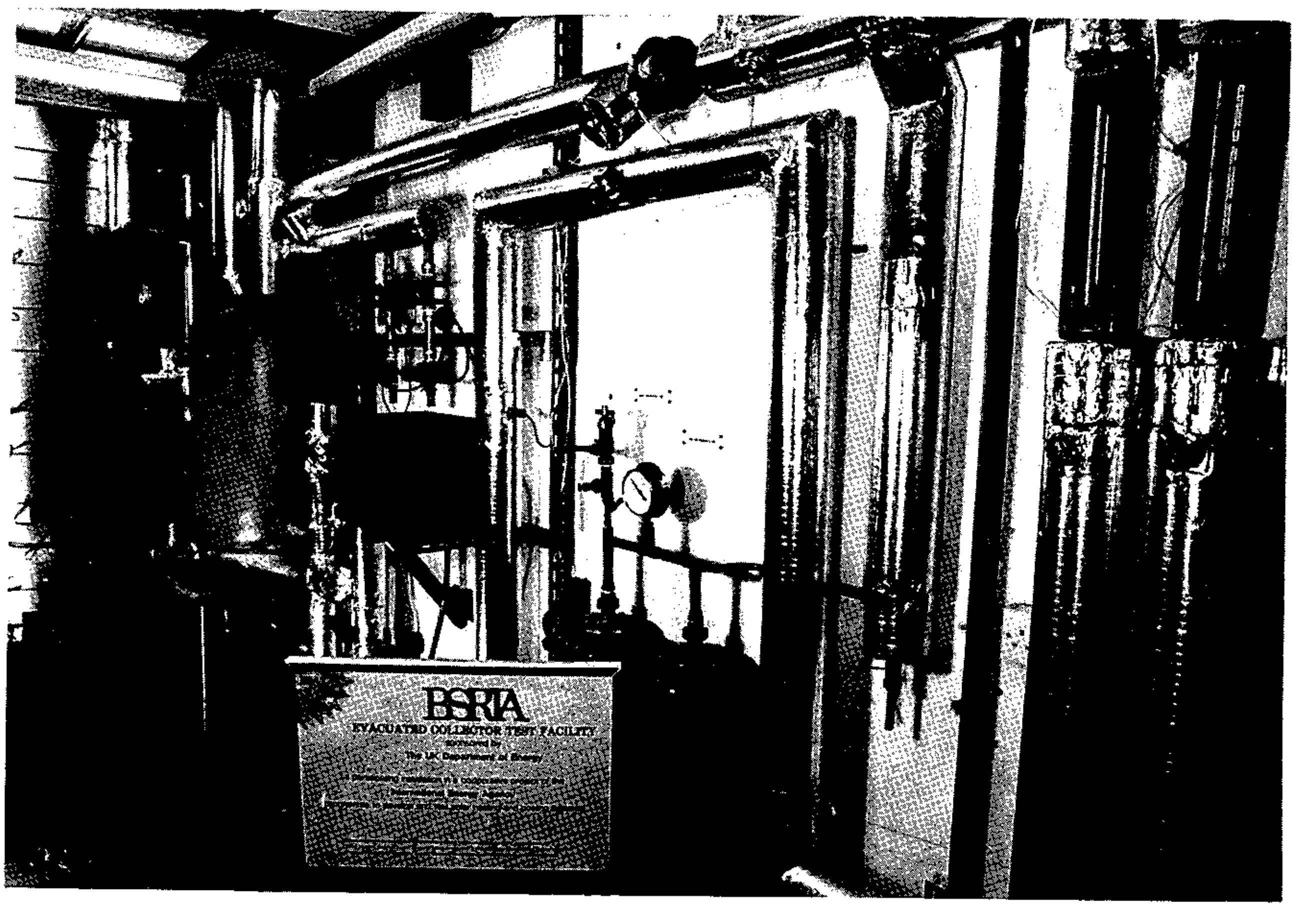


Figure 2-6. Evacuated Collector System Test Facility
Bracknell, United Kingdom

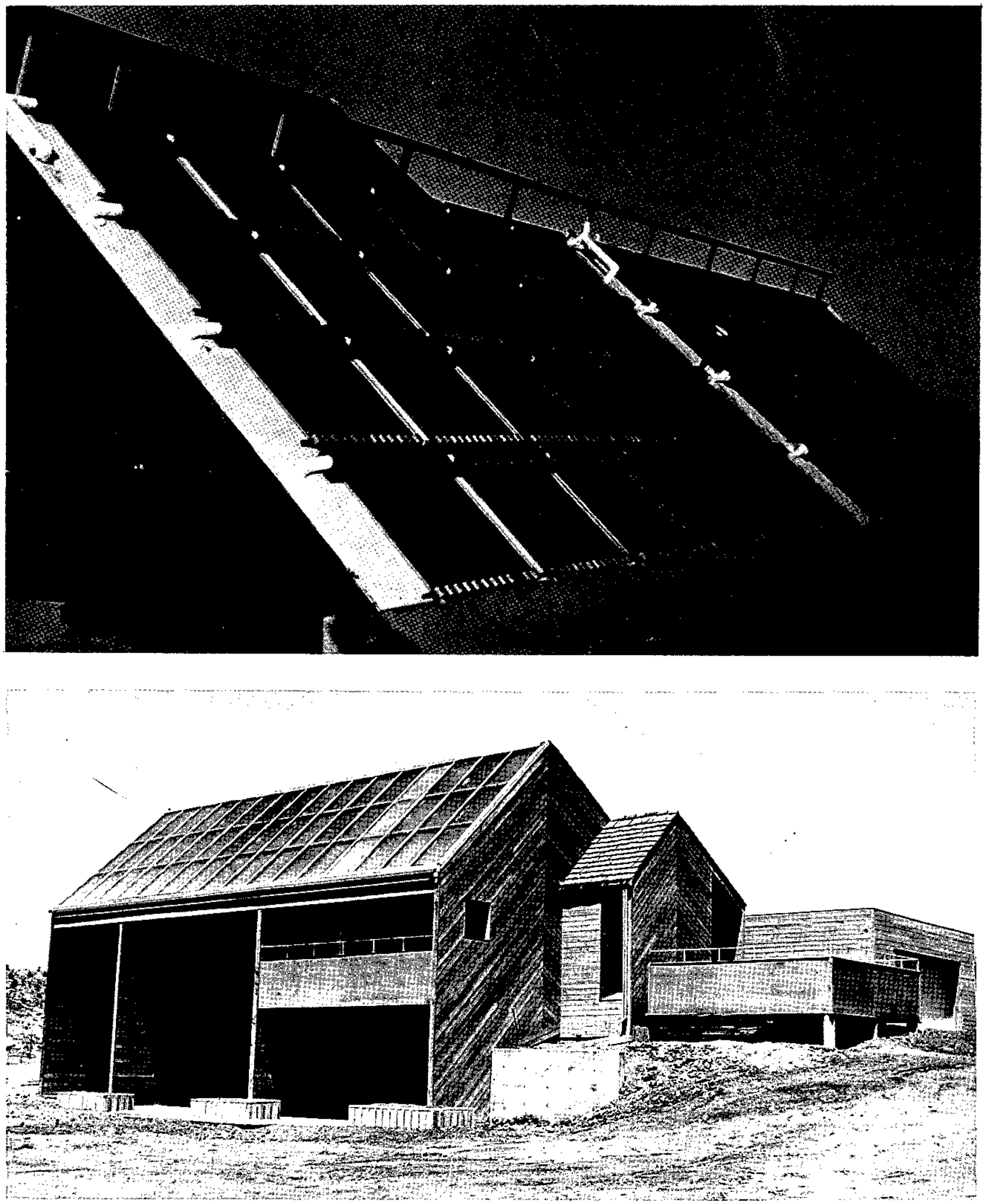


Figure 2-7. Colorado State University Solar House I
Fort Collins, Colorado, USA

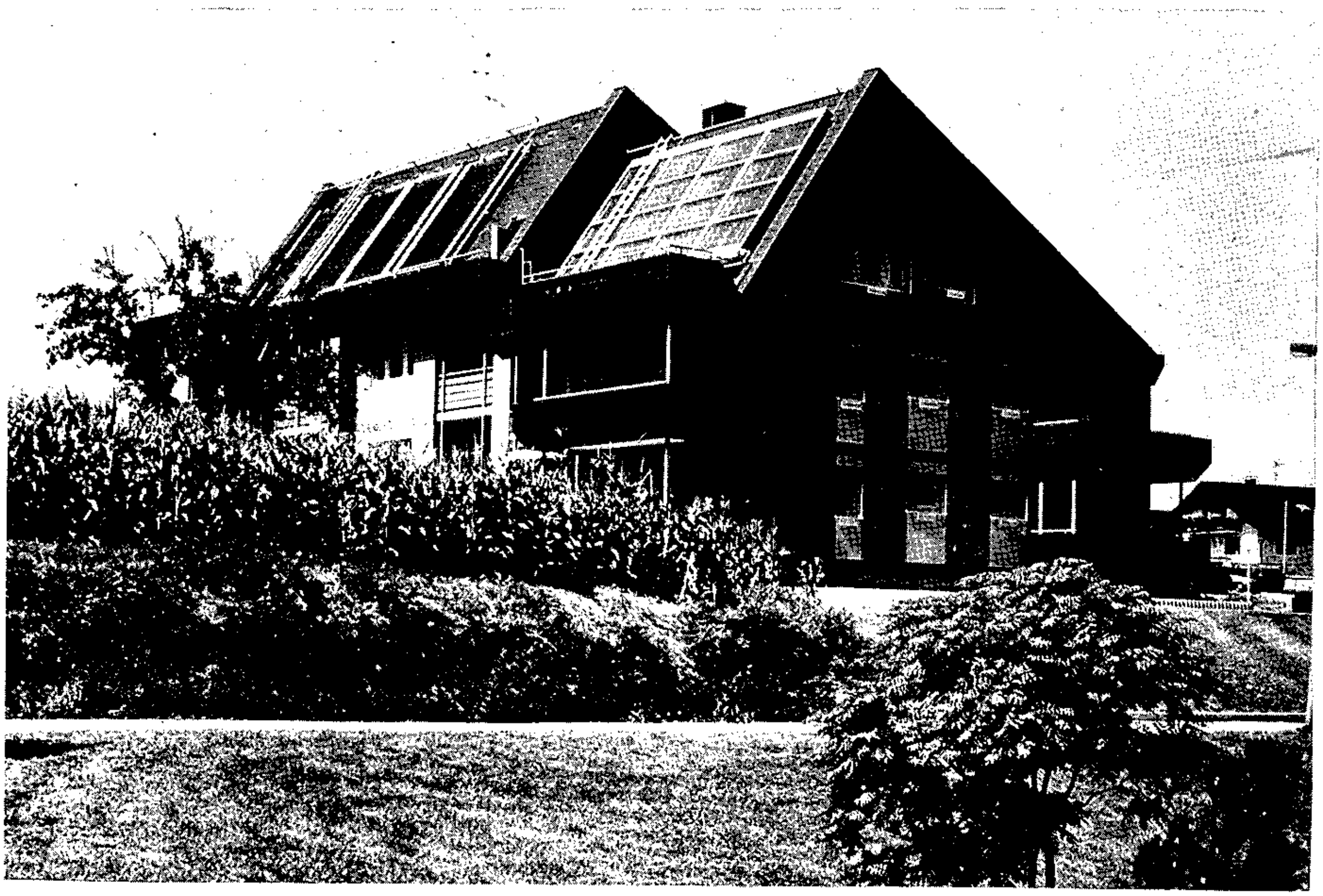


Figure 2-8. Solarhaus Freiburg
Freiburg, West Germany

TABLE 2-1. Installation Descriptions

Mountain Springs Bottle Washing Facility Edmonton, Alberta, Canada	The solar system was installed in a bottling plant building. It was designed to assist in maintaining a caustic soda solution used for the washing of reusable empty soft drink bottles at a temperature of 75°C.
Osaka Sanyo Solar House Osaka, Japan	The solar house, built in 1977, is a two-story, reinforced concrete building with a conditioned living area of 118.52 m^2. It was designed as a single family residence utilizing solar energy for space heating, space cooling and domestic hot water supplies.
Eindhoven Technological University Solar House Eindhoven, Netherlands	The solar house, built in 1976, has a conditioned living area of 220 m^2. It was designed as single family residence and is currently occupied by a family of three. Solar energy is utilized for space heating and domestic hot water supplies.
Knivsta District Heating Project Knivsta, Sweden	Three systems are installed in the district heating plant building in Knivsta. Since the heating load is always larger than the energy production from the collectors, there is no storage. The heat is transferred directly to the return line of the district heating system. The district heating plant supplies space heating and domestic hot water to surrounding buildings.
Solarcad District Heating Project Geneva, Switzerland	Two solar systems are connected directly, without intermediate storage, to the district heating network since the minimum heat demand is always much higher than the heat produced by solar. The district heating network supplies space heating and domestic hot water to surrounding buildings.
Evacuated Collector System Test Facility Bracknell, United Kingdom	The solar system is installed in the Building Services Research and Information Association building and is connected to space heating and domestic hot water storages in the laboratory. Heat is removed from the storages by systems which simulate the space heating and domestic hot water installations of a single family dwelling.
Colorado State University Solar House I Fort Collins, Colorado USA	Solar House I, completed in 1974, is a wood frame, two story, three bedroom, residential building utilized for offices. The conditioned living area is 249 m^2. Solar energy is used for space heating, space cooling and hot water.
Solarhaus Freiburg Freiburg, West Germany	The solar house is a three story apartment building with 652 m^2 of conditioned living area. Approximately twenty-five persons are permanently living in the 12 apartments. Solar energy is used for space heating and hot water.

TABLE 2-2. Description of Loads

Mountain Springs Bottle Washing Facility Edmonton, Alberta, Canada	The hot water is used in the washing facility for the sterilization of empty bottles. The temperature of the caustic soda solution used for washing is maintained between 72°C and 82°C by a Schaffer gas-fired heater. The actual gas consumption used for the washing process is hard to determine as there is only one gas meter for the entire plant. Sample tests of gas consumption as a function of throughput bottles show that 2.05 MJ is required to sterilize one case of bottles. Thus the annual load for the plant is 1980 GJ or an approximate daily load of 6.7 GJ over a nine hour day.
Osaka Sanyo Solar House Osaka, Japan	Winter indoor design conditions of 20°C and 40% humidity produce an average daily heating load of 74.2 MJ/day during the heating season. Summer indoor design conditions of 28°C and 60% humidity produce an average daily cooling load of 114 MJ/day during the cooling season. The actual daily average DHW load ranged from 16.5 MJ/day to 25.4 MJ/day. Special energy saving designs include exterior wall insulation, with an overall heat loss coefficient of 0.36 $W/m^2{}^\circ C$, and the placement of the second storage tank inside the living space to take advantage of heat loss.
Eindhoven Technological University Solar House Eindhoven, Netherlands	The winter indoor design conditions of 20°C and 40% humidity require 400 MJ/day. The average daily load in former years was estimated to be 36 MJ/day using about 200 liters of 55°C water per day. Energy saving designs include low theoretical heat loss co-efficiencts of 0.4 $W/m^2{}^\circ C$ for both the roof and walls and double glazed windows with a heat loss coefficient of 3.2 $W/m^2{}^\circ C$. The storage vessel is also located inside the house. The calculated overall heat loss coefficient of the building is 0.4 $W/m^2{}^\circ C$.
Knivsta District Heating Project Knivsta, Sweden	The district heating plant is fired with biomass and the heating system has a peak demand of 12 MW. The average daily energy production during 1981 was 420 GJ/day where 30% was used for the DHW. The three solar collector systems that are connected to the return pipe in the district heating system produce a total of about 0.1% of the total energy production.
Solarcad District Heating Project Geneva, Switzerland	Three different networks deliver heat to surrounding buildings for space heating and domestic hot water purposes in combination so that separate loads cannot be identified. The present solar installation is connected to the Libellules network. The installed gas-fired furnace has a peak power capacity of 125 MW with delivered power ranging from 2 MWh per hour to 50 MWh per hour. The solar systems are connected to the return branch of the nearest network and have to operate above the corresponding temperature range of 80-120°C. The average daily load for the heating season is 190 GJ/day while in the summer season 35 GJ/day is required to meet the domestic hot water load.
Evacuated Collector System Test Facility United Kingdom	The load on the solar system is controlled by a computer according to the time of day and prevailing weather conditions. It is assumed that the temperature inside the dwelling is maintained at 20°C by heating with an overall heat loss coefficient of 200 W/°C and allowed to evolve freely up to 25°C when heating is not necessary. The domestic hot water load is 90 liters/day at 55°C distributed over 16 hours.

Colorado State University Solar House I Fort Collins, Colorado USA	The indoor winter design temperature of 21°C produces an average daily load ranging from 235 MJ/day to 305 MJ/day during the heating season. The summer indoor design temperature of 24°C produces an average daily load of about 445 MJ/day. Domestic hot water use is simulated by automatic dumping of regulated volumes at preset intervals. This quantity, about 300 liters per day, amounts to 55 MJ/day and is typical for a family of four persons. Special energy saving features include a wall heat loss coefficient of 0.51 $W/m^2 {}^\circ C$ and ceiling heat loss coefficient of 0.30 $W/m^2 {}^\circ C$, triple-glazed windows and reduced infiltration by use of a vestibule entry. The calculated overall heat loss coefficient of the building is 390 W/°C.
Solarhaus Freiburg Freiburg, West Germany	The indoor winter design conditions vary with each individual apartment, thus only the actual average daily heating loads are known and they ranged from 1341 MJ/day in 1980 to 1213 MJ/day in 1981. There is no summer cooling. The average daily domestic hot water consumption of 1300 liters requires 197 MJ/day. Special energy saving designs include improved thermal insulation, triple-glazed windows, a ventilation system and a micro-computer operated control system.

TABLE 2-3. Current Activities

Mountain Springs Bottle Washing Facility Edmonton, Alberta, Canada	During the commissioning process it was found that the system was deficient in several areas. The heat exchanger between the solar system and the caustic loop was found to have an operational effectiveness of 0.24. This low effectiveness was attibuted to a low fluid flow rate on the caustic side and the determination that the heat exchanger was thermodynamically undersized. This inability to transfer the required heat flux resulted in higher storage tank temperatures which often led to premature solar system shut down due to over-temperature of the storage tank. This problem is being remedied by the installation of a plate type heat exchanger and a new pump in the caustic loop. Interaction between the gas heater and the solar system resulted in the temperature of the soaker tank swinging below the required minimum. A control sensor on the gas heater was found to be improperly located between the exchanger outlet and the gas heater; this sensor is being moved to the return line from the soaker tank. These system alterations are expected to be completed by August 1982 at which time long term monitoring will commence. Work will continue in two areas of simulation. The upgrading and enhancing of the present system model and comparison of actual and measured data.
Osaka Sanyo Solar House Osaka, Japan	Current activities include continuation of performance studies of the Sanyo heat pipe evacuated tube collectors and application of the Sanyo amorphous silicon solar cells to operation of the collector pump.
Eindhoven Technological University Solar House Eindhoven, Netherlands	It is expected that the new solar system will be in operation at the beginning of September 1982. Besides testing the long term performance of evacuated tube collectors, retrofitting with evacuated collectors provides an opportunity to simplify the system design by making several changes. These are: improving the control strategy, making better use of the stratification in the tank, optimizing the capacitance flow ratio, integrating the auxiliary heater into the tank, using a thermal selective water off-tank for heating, eliminating the thermal expansion tank and instituting overheat protection. The system will be monitored during another three year period to provide performance and operational data for an evacuated tubular collector system under real load and a well validated comparison of conventional and evacuated collector system performance.
Knivsta District Heating Project Knivsta, Sweden	In Sweden solar energy without storage can supply up to 10 percent of the demand for heating and domestic hot water by feeding directly into a district heating network. In order to learn more about the use of solar energy on a large scale, UKAB, the district heating company in Uppsala, has designed a central solar heating plant with seasonal storage for 550 flats with construction starting in 1981 - the Lyckebo project. It consists of a solar array of 20,000 m^2, a rock storage of 100,000 m^3 filled with water and a distribution system for heat and domestic hot water supply. In this project evacuated tube collectors are an interesting choice. As a first step the performance of such collectors are being studied in the actual environment. Evacuated collectors from three different manufacturers were installed at the Knivsta heating plant. Results will be used to select the particular collector type for the installation in Lyckebo project.

Solarcad District Heating Project Geneva, Switzerland	Presently Corning collectors are mounted and connected through a heat exchanger to the district heating system. The installation has just started operation with a preliminary control system. A more refined control strategy using a micro-computer is under investigation. The Sanyo collectors have operated for one year with rough measurements. New sensors will be installed and connected to the data acquisition system. The data acquisition system is based on the INTEL SBC 86 16 bit micro-computer. Specially designed and handmade circuits are assembled with standard commercial units to provide two systems. One for the solar installations and the other for programming and checking data. Special attention has been focused on the sensors in order to ensure precise measurements for all parameters. Precision on the other of 0.05°C has been achieved with handmade sensors using standard 100 ohm platinum resistances.
Evacuated Collector System Test Facility Bracknell, United Kingdom	Several modifications are being considered for the 1982-83 heating season. These include: reduction in the number of tubes per collector module and in the total number of modules, changes in collector circuit flow rate, reduction in space heating storage size, changes in the solar circuit control strategy, and changes in the simulated domestic hot water and space heating loads. These changes will be examined using the preliminary validated model with typical weather data and the system will then be adjusted nearer to an optimum design. The modelling and validation work is being carried out by Pilkington Brothers Research and Development Laboratories. The computer model was originally based on an Oscar Faber (Version II) flat plate solar program with several modifications introduced by Pilkington. These include: a collector module based on a "characteristic curve" approach; a second storage to accommodate both space and DHW collection; stratified storage modelling; and a linking with standard data systems. Preliminary comparisons are noted in the conclusion.
Colorado State University Solar House I Fort Collins, Colorado USA	The system being installed in Solar House I uses a new Philips VTR 361 water heat pipe evacuated tube collector with ripple reflectors, a pressurized water tank of 3,785 liter capacity to provide heat at a design temperature of 110°C and a Carrier air-cooled absorption chiller. Winter space heating will use the same system with a liquid-to-air heat exchanger. Provision is also made for domestic water heating, but the connection will not be made the first summer. Two types of storage and two types of load service combine to permit testing and evaluation of four different systems. Modeling activities include detailed TRNSYS simulations, extension of the DAYSIM model and development of a new daily simulation based on collector input/output curves.

Solarhaus Freiburg Freiburg, West Germany	Current activities still follow the basic objectives of the experiment, i.e. performance evaluation and testing of two evacuated tubular collectors, and include the development and application of computer simulation models and their validation. The influence of various energy saving components, such as improved thermal insulation and the effect of various operational modes of the system, are observed. Other activities include the replacement of the Philips Mark IV collector with the Philips VTR 261 evacuated tube collector in March of 1982. The extension of simulation studies to other solar applications and the extension of the statistical study of collector performance to non-stationary operating conditions are planned. Further study of the energy and frequency distributions with respect to the temperature of a collector operating in a solar system will lead to the general assessment of the quality of the system.

3. CLIMATE

Long term average climate information for each of the task locations is given in Table 3-1. Climate varies substantially among installations. Elevation varies from sea level to almost 1600 meters. Heating loads vary from about 1400°K-days to about 5200°K-days. Daily horizontal insolation for January varies from about 1.3 MJ/m^2 to about 8.7 MJ/m^2 and for July, from about 15.8 MJ/m^2 to about 23.3 MJ/m^2. Diffuse radiation varies from 37 percent to 79 percent. Average daily temperatures vary from -15°C to +27°C.

TABLE 3-1. CLIMATE AT THE TASK VI LOCATIONS

	Edmonton Alberta Canada	Osaka Japan	Eindhoven Netherlands	Knivsta Sweden	Geneva Switzerland	Bracknell England	Fort Collins Colorado USA	Freiburg West Germany
latitude	53.55°N	34.79°N	51.48°N	59.44°N	46.2°N	51.40°N	40.6°N	47.58°N
longitude	113.28°W	137.67°E	5.51°E	17.48°E	8.55°E	0.77°W	105.1°W	7.47°E
elevation (meters)	676	18	15	30	377	70	1585	220
Heating Degree Days (18°C)	5201	1379	2785	4180	2740	2700	3666	3127
Heating Season	NA	Dec-April	Oct-April	Sept-May	Oct-May	Sept-May	Oct-May	Sept-May
Cooling Degree Days (23.9°C)	NA	183	NA	NA	NA	NA	239	NA
Cooling Season	NA	July-Sept	NA	NA	NA	NA	June-Oct	NA
Typical Daily Insolation								
January (MJ/m² on horizontal)	3.72	7.8	2.09	1.29	3.5	2.23	8.69	2.56
July (MJ/m² on horizontal)	22.62	17.1	15.81	19.61	19.5	16.93	23.30	16.67
Percent Diffuse								
January (%)	62	48.	79	45	68	73	39	71.2
July (%)	37	52.	62	38	40	58	38	52.7
Typical Average Daily Temperature								
January (°C)	-15.0	5.6	1.6	-4.1	1.0	3.4	-3.3	0.7
July (°C)	17.4	27.0	17.1	16.4	19.0	16.5	20.8	18.5
Average Maximum* Daily Temperature								
January (°C)	10.7	9.1	4.9	-1.0	11.0	11.6	4.8	12.8
July (°C)	23.0	31.2	22.0	21.8	33.0	28.3	29.9	32.8
Average Minimum* Daily Temperature								
January (°C)	-19.2	2.2	0.3	-4.7	-7.0	-6.8	-10.4	-10.1
July (°C)	11.8	23.7	13.4	14.0	6.0	6.8	13.8	9.2
Seasonal Climate Description	Continental climate with dry winters wetter summers	humid micro-thermal continental warm summers	humid meso-thermal marine	humid meso-thermal marine, cool summers	humid meso-thermal forest, cool summers	temperate oceanic	steppe or semi arid	meso-thermal forest, constantly moist, rainfall all year

NA - not applicable
*NOTE: These data not necessarily calculated in a consistent manner.

4. COMPONENTS AND SUBSYSTEMS

The focus of Task VI work is on evacuated collector "systems". Thus, the most important component is the evacuated collector. Though there are a few additional evacuated collector concepts still in the early stages of development, Task VI installations are presently using, or plan to use, nearly every evacuated collector type that has reached commercial development. Also, many of those collector types are used in more than one installation. See Table 4-1 for collector types used.

4.1 COLLECTION

Collector characteristics, such as design, and materials, show wide variation. See Table 4-2 for collector specifications. Details specific to each application, such as tilt and total collector area, are given later in this section.

4.1.1 Definition of Collector Aperture Area

The Task definition of collector aperture area is:

$$A100 = L \times W \times \cos\phi$$

Where L = exposed transparent part along the collector tubes (excluding boxes or black cups or headers, etc), and

W = the width of the collector module. This is taken as:

$W = n \times p$.

Where n = number of tubes, and p = the pitch of the tubes, or the distance between the centers of adjacent tubes.

ϕ = tilt angle of absorber surface with respect to the collector plane. For non-planar geometries of the absorber surface, $\phi = 0°$.

Figure 4-1 illustrates several of these points.

4.1.2 Aperture Area Correction Ratios for Each Installation

Table 4-3 lists the corredtion factors for aperture area for each installation. The correction factor is the ratio of the aperture area used at the installation divided by the aperture area as defined by Task VI.

Table 4-1. Evacuated Tube Collector--Installation Reference

	Corning Cortec 'A'	Corning Cortec 'B'	General Electric TC-100	Owens-Illinois Sunpak	Philips VTR 141 *	Philips VTR 261 *	Philips VTR 361 *	Philips Mark IV	Sanyo STC-CU250	Sanyo	Sanyo Heat pipe	Solartec	Sunmaster (O-I tubes)
Mountain Springs Bottle Washing Facility-Canada												●	
Osaka Sanyo Solar House-Japan			●						●	◒	◌		
Eindhoven Technological University Solar House-Netherlands						●							
Knivsta District Heating Project-Sweden			●	●	●								
Solarcad District Heating Project-Switzerland	●	●							●				◌
Evacuated Collector System Test Facility-United Kingdom					●								
Colorado State University Solar House I-USA	○				●		◒	○					◌
Solarhaus Freiburg-West Germany	●					◒		●					

Key
● ≡ used during reporting period
○ ≡ previously used
◌ ≡ planned or under consideration
◒ ≡ in operation (summer 1982)
* = The nomenclature of the Philips collectors refers to tube type, not collector construction.

TABLE 4-2. Specifications for Evacuated Tube Collectors Used in Task VI Installations

Evacuated Tube Collector Type	No. tubes per module/ pitch (mm)	$F'\tau\alpha$ [1]	$F'U_L$ ($W/m^2 °C$) [1]	aperture area per module (m^2) [2]	absorber area per module (m^2)	absorber surface material	collector/ heat pipe fluid	location	fluid volume per m^2 (ℓ/m^2)	glass material	reflector
Corning Cortec 'A'	6/113	0.71	1.38	1.45	1.12	black chrome	any	Switzerland	0.58	Pyrex	none
Corning Cortec 'B'	6/113	0.71	<1.38	1.45	1.12	black chrome front & back of absorber	any	Switzerland	0.58	Pyrex	none
General Electric TC-100	8/145	0.58	2.10	1.62(3)	1.38	GE Proprietary coating	any	Japan Sweden	1.2	soda glass	compound parabolic cusp
Owens-Illinois Sunpak	24/102	0.70	1.25	2.97(3)	2.55	O-I Proprietary	any	Sweden	11.5	borosilicate glass	Semicylindrical Al reflector
Philips VTR-141 (19 tube module)	19/75	0.56*	1.68	1.37	1.05	cobalt sulfide-oxide	isobutane	Sweden	0.58	soda glass	none
Philips VTR 141 (15 tube module)	15/75	0.70*	2.35	1.11	0.831	cobalt sulfide-oxide	isobutane	UK	0.15	soda glass	diffuse
Philips VTR-141 (12 tube module)	12/95	0.61*	1.80	1.15	0.665	cobalt sulfide-oxide	isobutane	USA	0.15	soda glass	diffuse
Philips VTR 261	16/82	0.65*	1.7	2.05	1.45	cobalt sulfide-oxide	neopentane	Netherlands	0.13	soda glass	Tedlar-coated aluminum film
Philips VTR 261	14/104	0.66*	1.87	2.27	1.27	cobalt sulfide-oxide	neopentane	West Germany	0.22	soda glass	ripple
Philips VTR 361	14/104	0.65*	1.37	2.27	1.27	cobalt sulfide-oxide	water	USA	0.20	soda glass	specular reflector
Philps Mark IV	108/65	0.71	2.18	7.37(4)	6.77	cobalt-sulfide oxide	any	USA West Germany	1.53	soda glass	no

*Calculated from solar simulator tests, with 45% diffuse.

Sanyo STC-CU250	10/93	0.91(5)	3.0	2.42	1.75	nickel-base	any	Japan	0.95	soda glass	no
SANYO	7/124	0.87(5)	3.5(5)	1.47	1.13	chrome black	any	Japan	NA	soda glass	no
Solartec	8/152	0.51	1.43	1.30	0.85	O-I Proprietary coating	any	Canada	6.92	borosilicate glass	nonimaging compound parabolic cusp
Sunmaster (O-I tubes)	4/152	0.51	1.43	0.65	0.43	O-I Proprietary coating	any	-	NA	borosilicate glass	compound parabolic cusp
*Miromit flat-plate Model 210	NA	0.77	4.32	1.84	1.67	black nickel	any	USA	2.22	white water single glaze	no

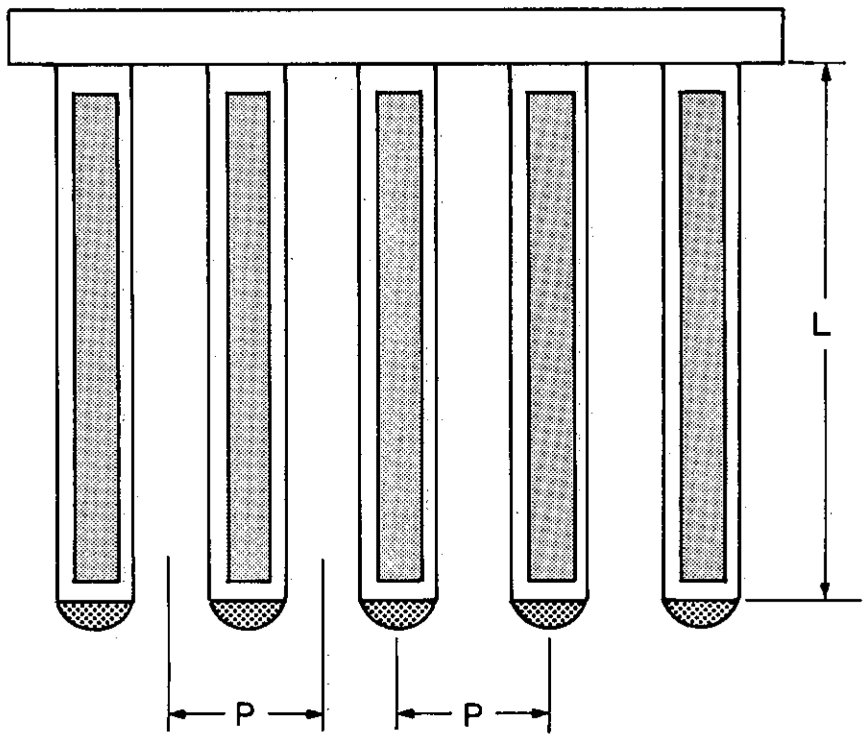
(1) Values are for one module based on aperture area and manufacturer information.

(2) Aperture area is based on the standard Task VI aperture area definition accepted at the May 1982 Genevá Meeting unless otherwise noted.

(3) Aperture area = length of reflector area * width of reflector.

(4) Aperture area = sum of the area of four front cover panes.

(5) Based upon absorber area.



Area $A001 = W \times L \cos \phi$

$W = nP$

$n = 5$ Tubes

$\phi = 0$ (for horizontal planar absorbers)

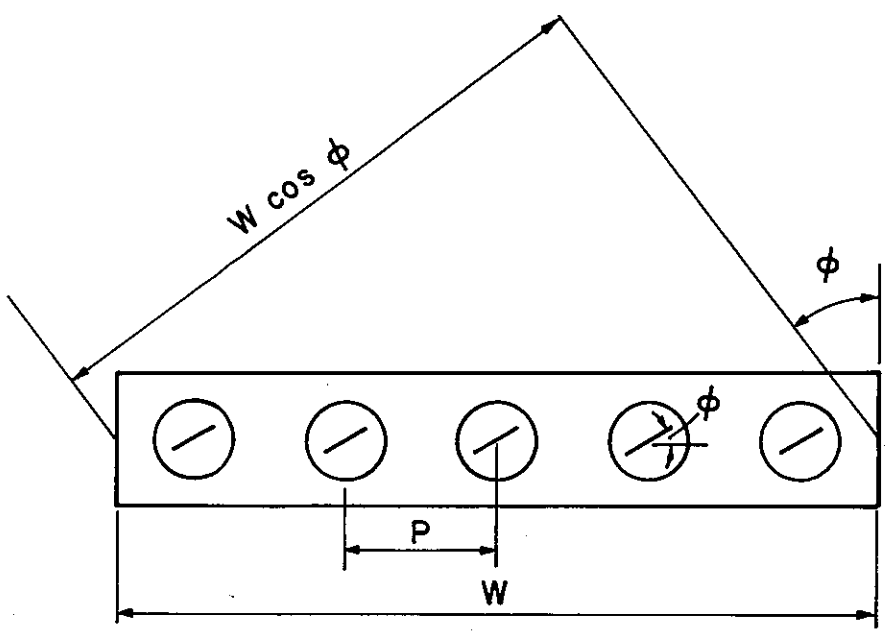


Figure 4-1. Aperture Dimensions

Table 4-3. Aperture Area Correction Ratios

Canada	Solartec	
Japan	GE Sanyo	1.0 1.0
Netherlands	Philips VTR261	1.0
Sweden	GE O-I (Sunpak) Philips VTR141 (19 tube)	0.99 1.0 1.05
Switzerland	Corning Cortec (A and B) Sanyo STC-CU250	1.0 1.0
United Kingdom	Philips VTR141 (15 tube)	1.07
United States	Philips VTR141 (12 tube)	1.0
West Germany	Corning Cortec A Philips MKIV	0.96

4.1.3 Incident Angle Modifiers

Performance data most often quoted for evacuated tubular collectors are at a solar incidence angle normal to the plane of the collector. The geometry of these collectors is different from that of flat plate collectors, and the performance under non-normal incident radiation will differ. The relative performance data of various collector types, from an angle of 0° (normal) to 60° are given in Table 4-4. The angle is measured perpendicular to the azimuthal axis. Performance at 0° is taken as 1.

4.1.4 Task VI Collector Designs

Figures 4-2 through 4-21 provide more detailed information on the task collectors. Cross sections, photographs, isometrics and manufacturer efficiency curves are given.

Table 4-4. Incident Angle Modifiers

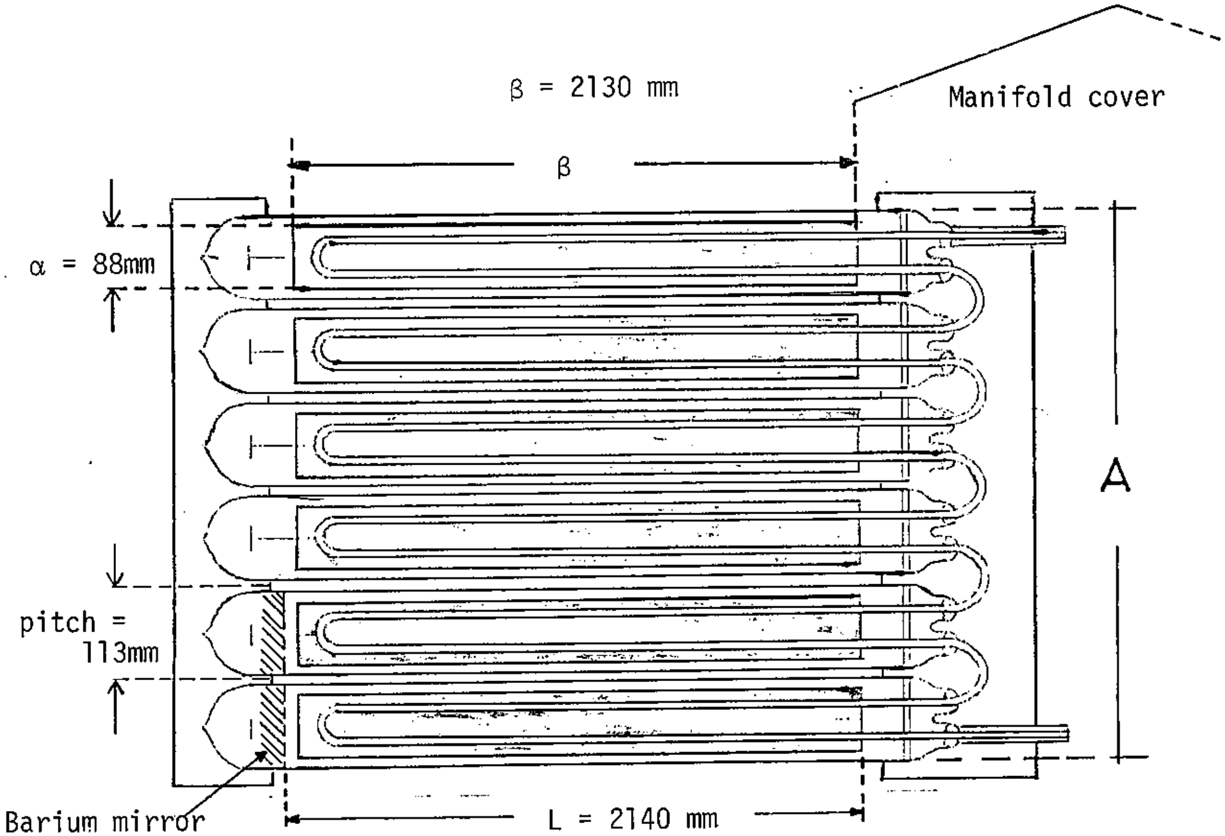
Collector Type	Comments	Incident Angle Modifier 0°	15°	30°	45°	60°	Orientation N-S E-W
G.E. TC100	Swedish Report	1	0.94	0.81	0.69	0.68	N-S (Sweden)
O-I Sunpak	O-I Brochure	1	1.09	1.15	1.11		N-S (Sweden)
	Boeing Test	1	0.90	0.82	0.79	1.02	N-S
	Boeing Test	1	0.92	0.97	0.94	0.82	E-W
Philips VTR361		1		0.98	1.0	0.99	N-S (U.S.)
Sanyo STC-CU250	Boeing Test	1	1.02	1.04	1.00	0.96	E-W (Swiss)
(large)	Boeing Test	1	1.0	1.02	1.04	1.09	N-S
Solartec	Canadian Report	1	1.01	1.05	1.05	0.80	N-S (Canada)
Sunmaster (O-I)		1	1.09	1.15	1.11		

4.2 STORAGE

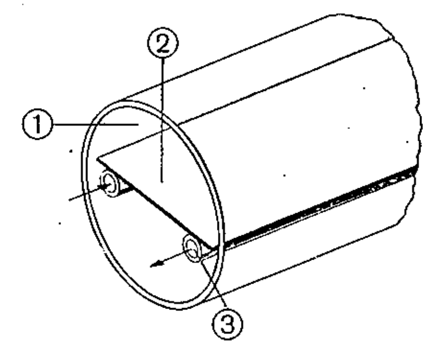
Storage is the next most important subsystem in most solar energy systems. A description of the storage systems used by each of the installations is given in Table 4-5. Storage subsystems range from no storage to several two tank systems. Any additional storage features, such as stratification enhancement devices, are also described.

4.3 SITE SPECIFIC COLLECTOR INFORMATION AND DETAILS OF OTHER SUBSYSTEMS

Table 4-6 provides collection information that is specific to each installation and details of other components and subsystems. In addition, this table provides information on other special items that are peculiar to each installation.



Cross section schematic of the Corning collector.



1. Evacuated glass tube.
2. Absorbing surface.
3. Fluid tube.

Absorber area	= 6 * α * β	= 1.12 m^2 per module.
SHF aperture area	= A * L	= 1.39 m^2 per module.
IEA Task VI aperture area	= 6 * pitch * L	= 1.45 m^2 per module.

L = manifold cover to barium mirror distance.

Figure 4-2. Corning glass collector.

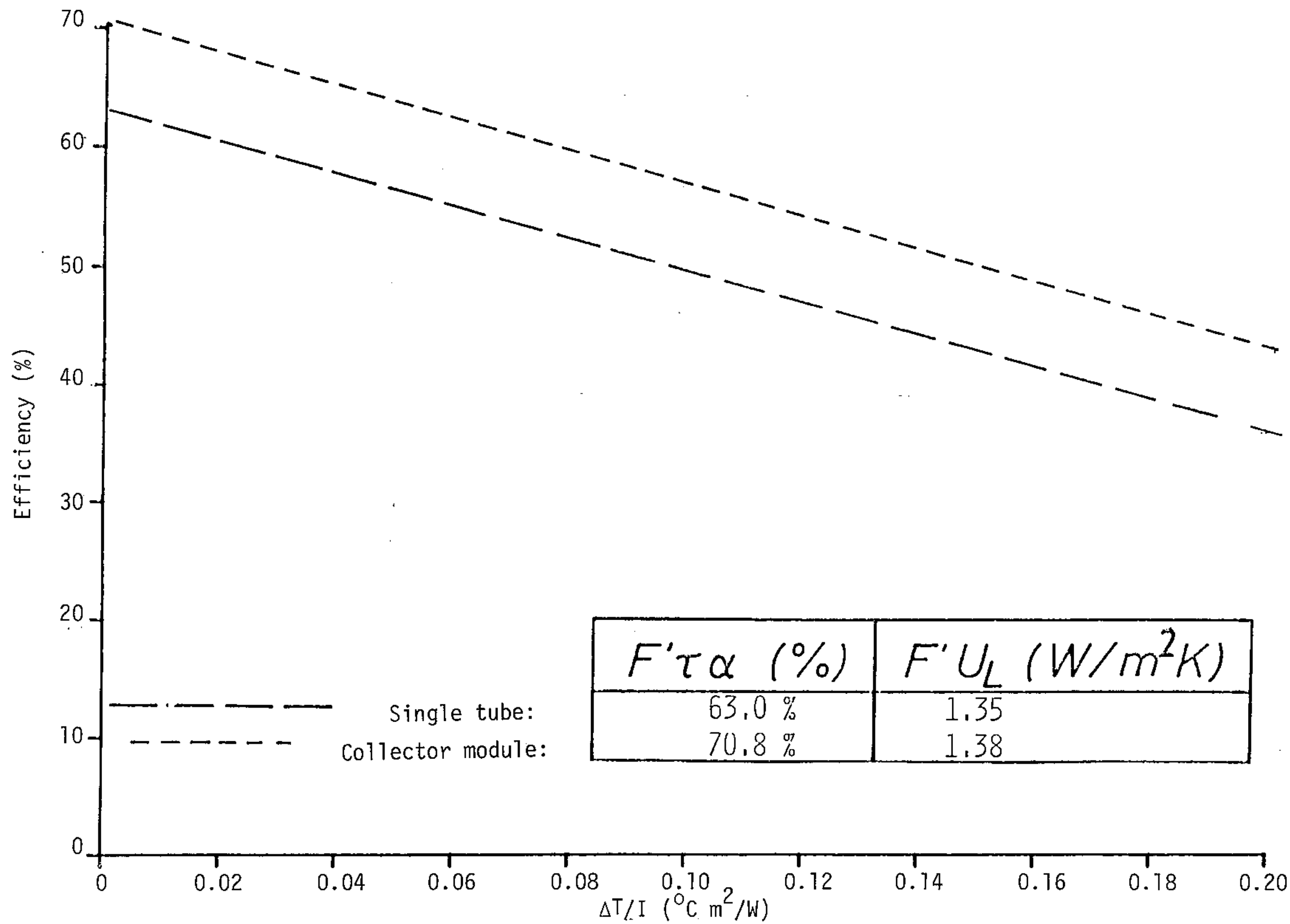


Figure 4.3. Corning glass evacuated tubular solar collector efficiency test data.

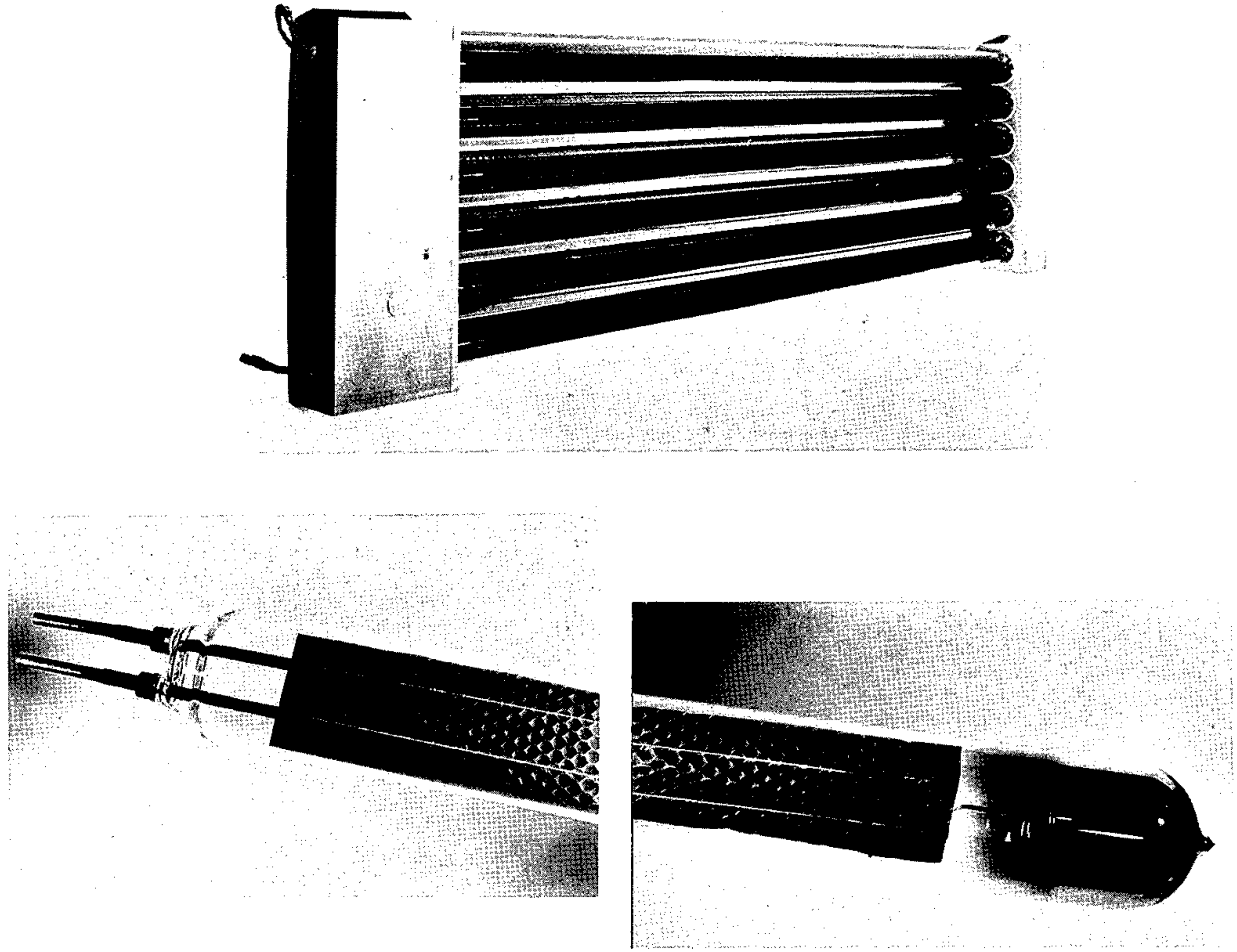


Figure 4.4. View of the Corning glass evacuated tubular collector.
Top: module assembly
Bottom: single tube.

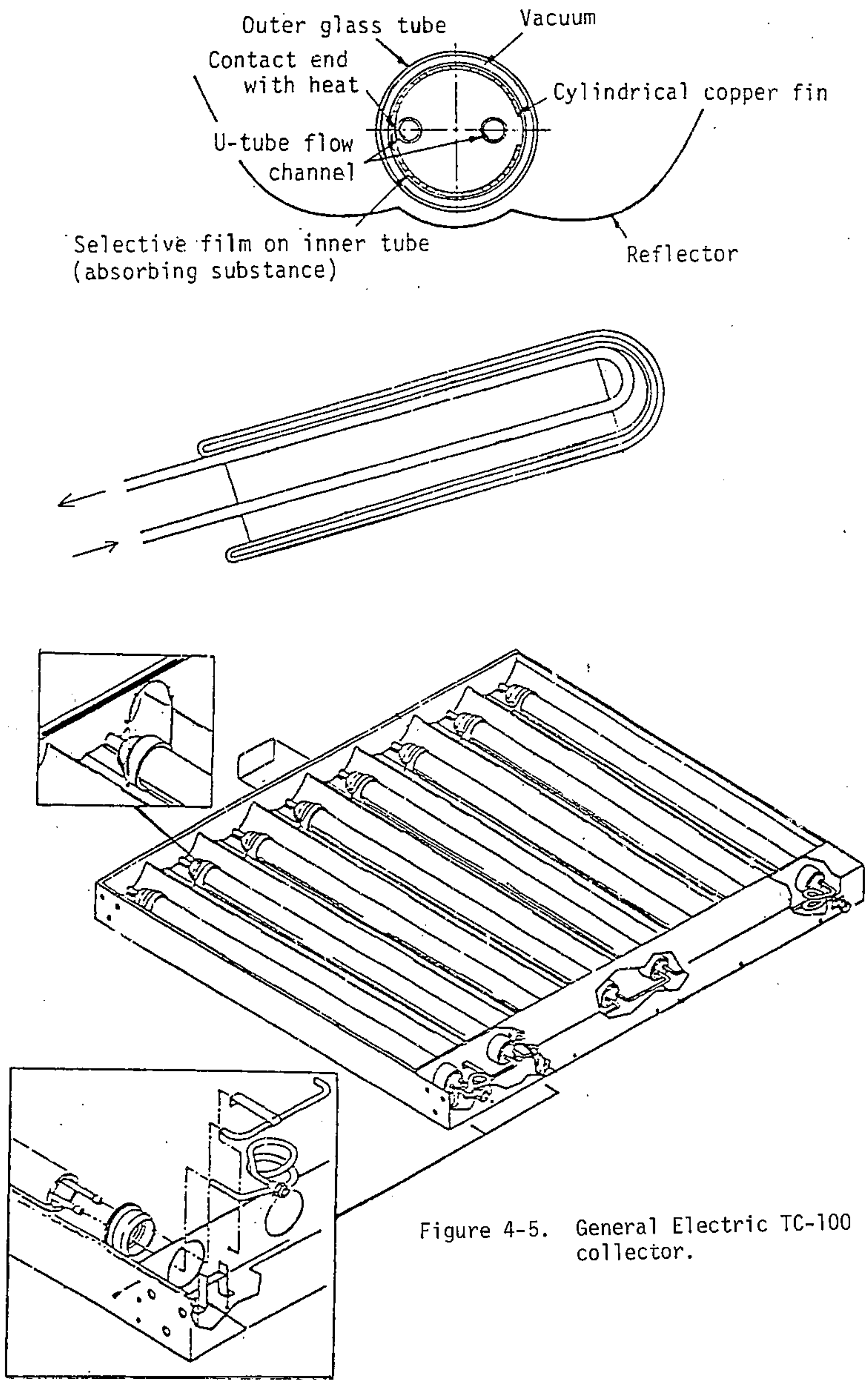


Figure 4-5. General Electric TC-100 collector.

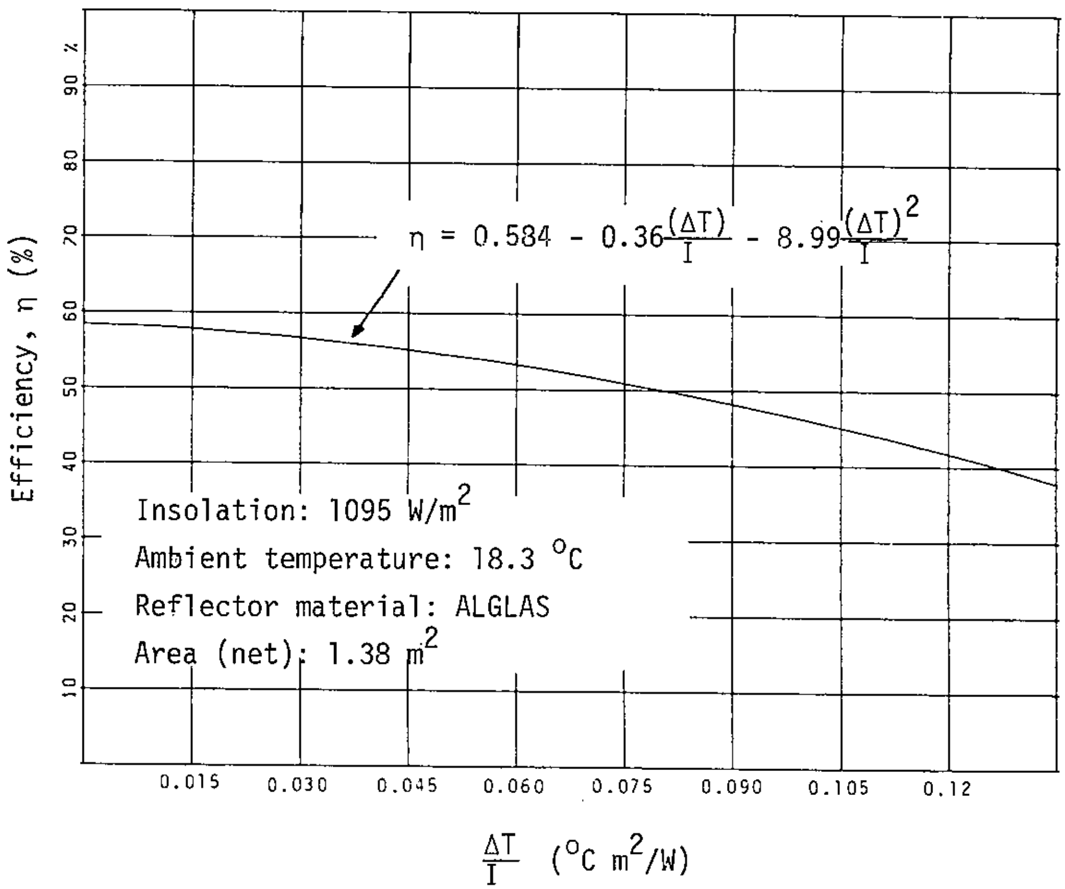


Figure 4-6. Efficiency curve of GE collector

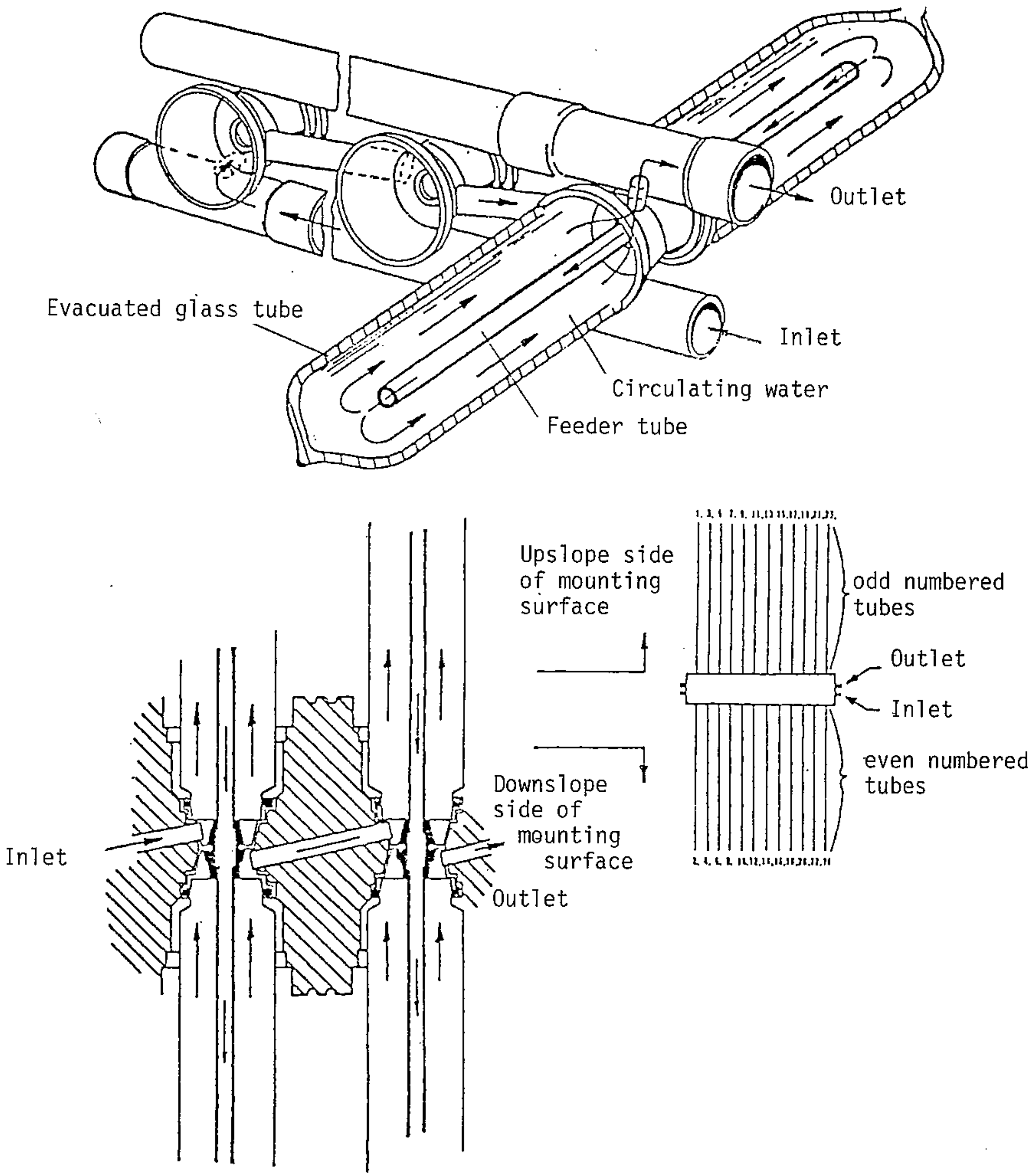
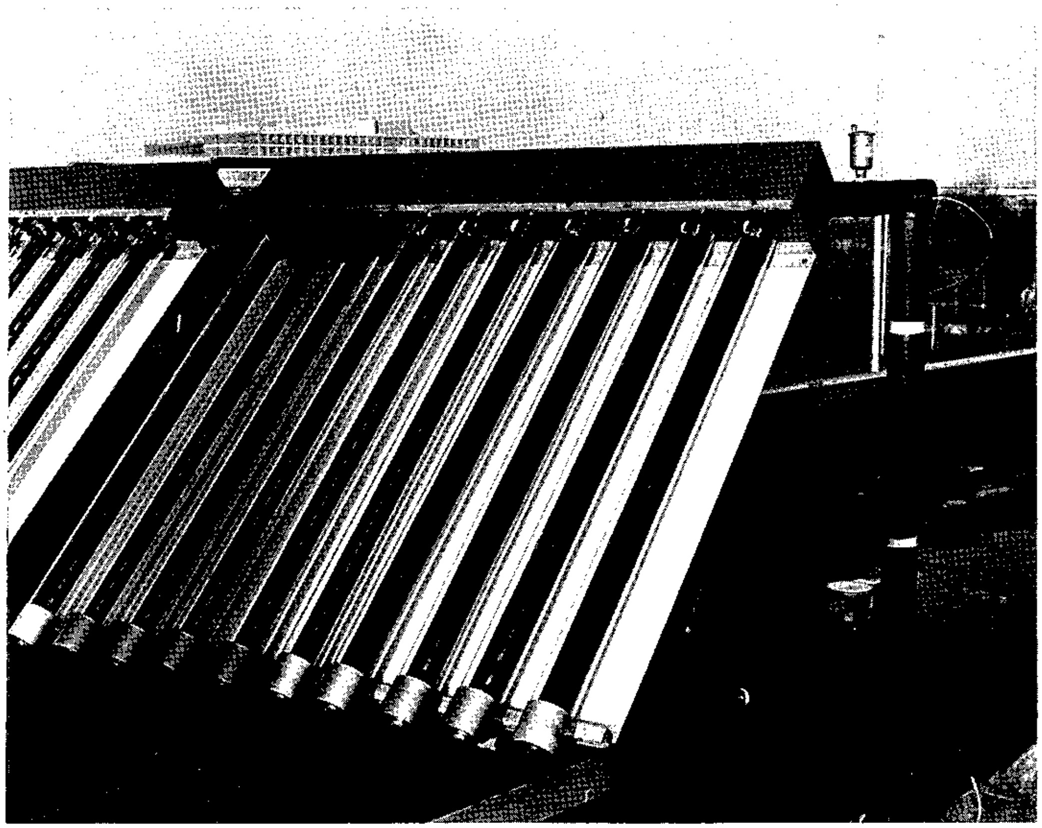


Figure 4.7. Owens-Illinois collector schematic.



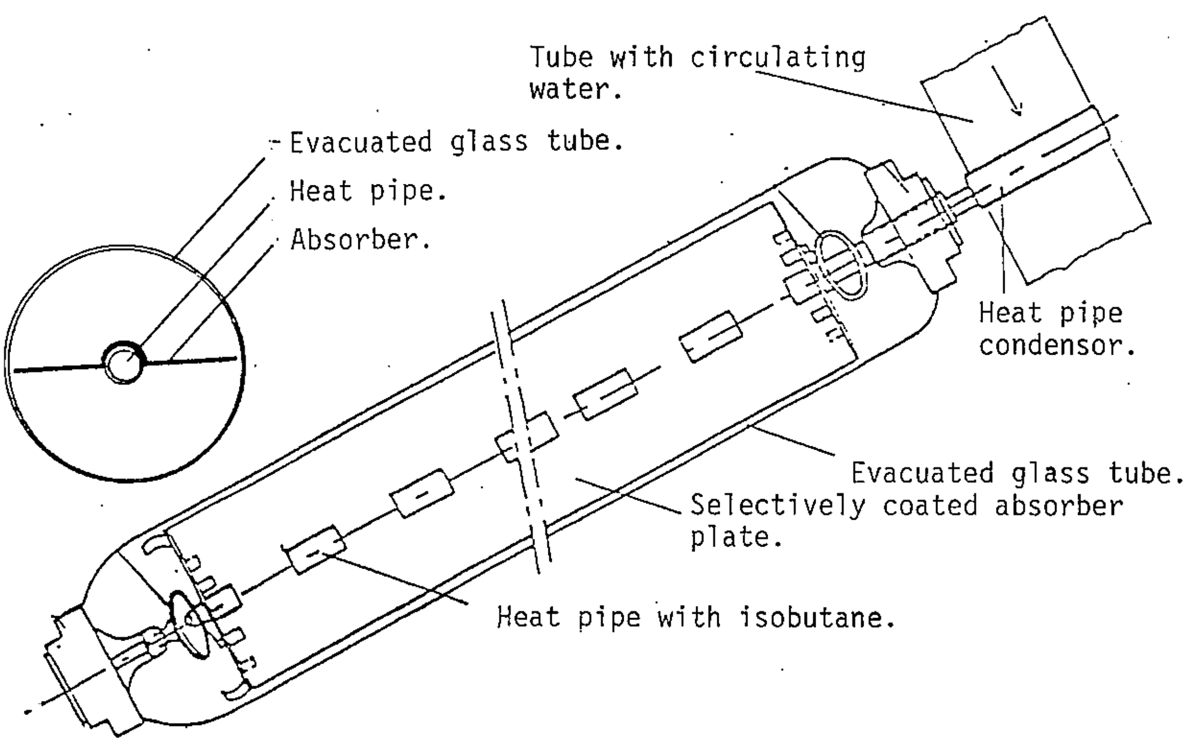
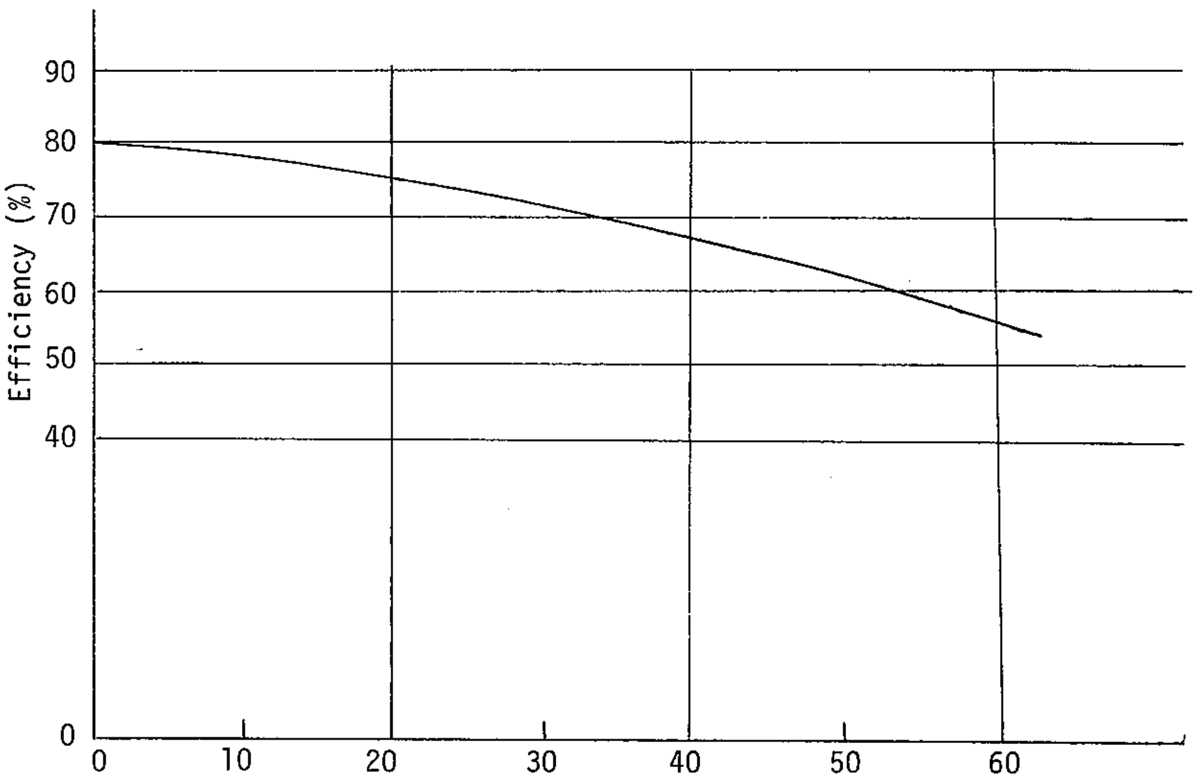


Figure 4.8. Philips VTR 141 collector. Various numbers of tubes per module and tube spacing are available.



Temperature difference between average manifold fluid and ambient...T100-T001 (°C) Note: this curve is only valid for condenser temperatures less than 130°C.

Figure 4-9. Efficiency of the 12 tube Philips VTR 141 collector module, based on the aperture area.

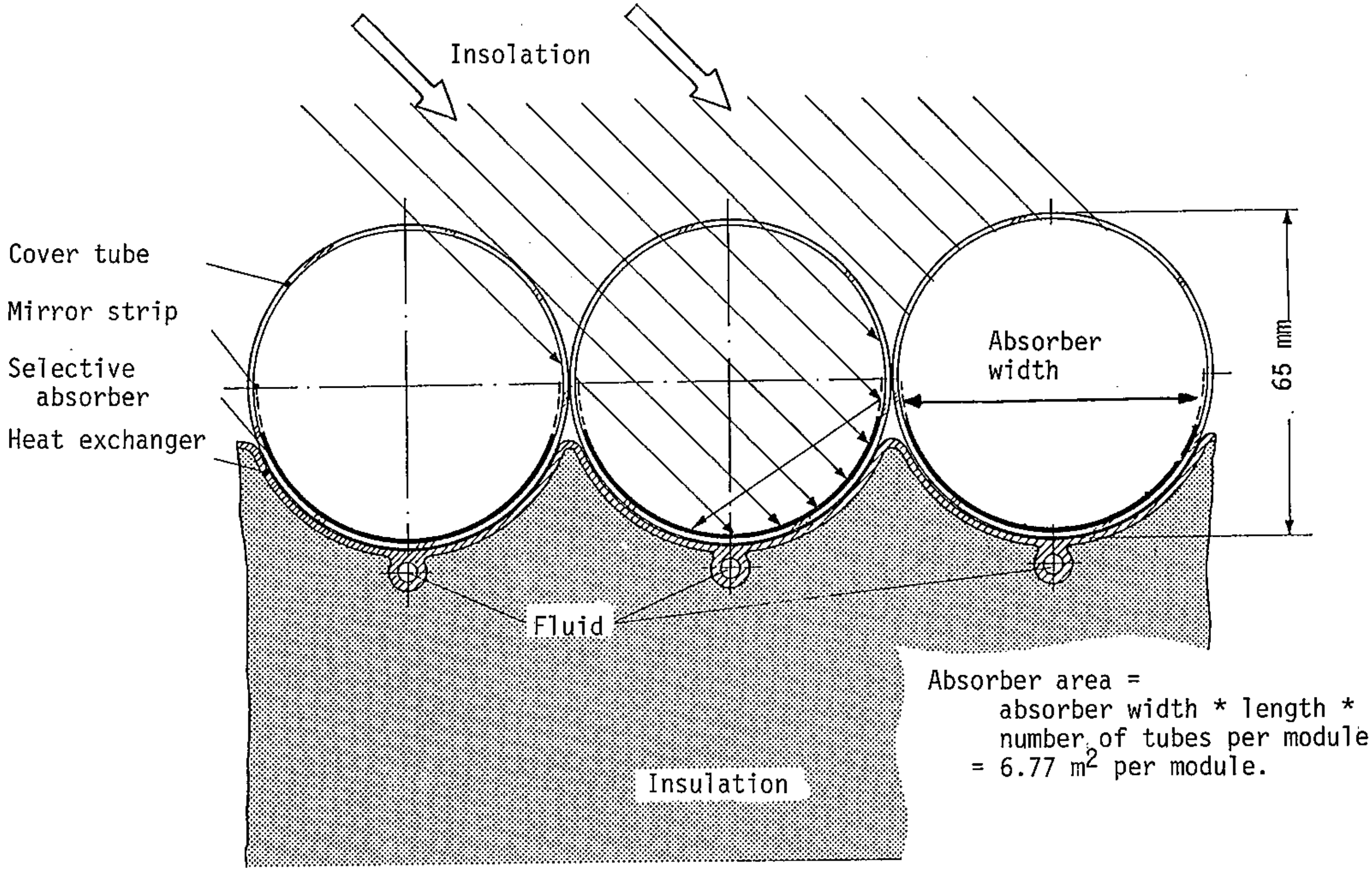
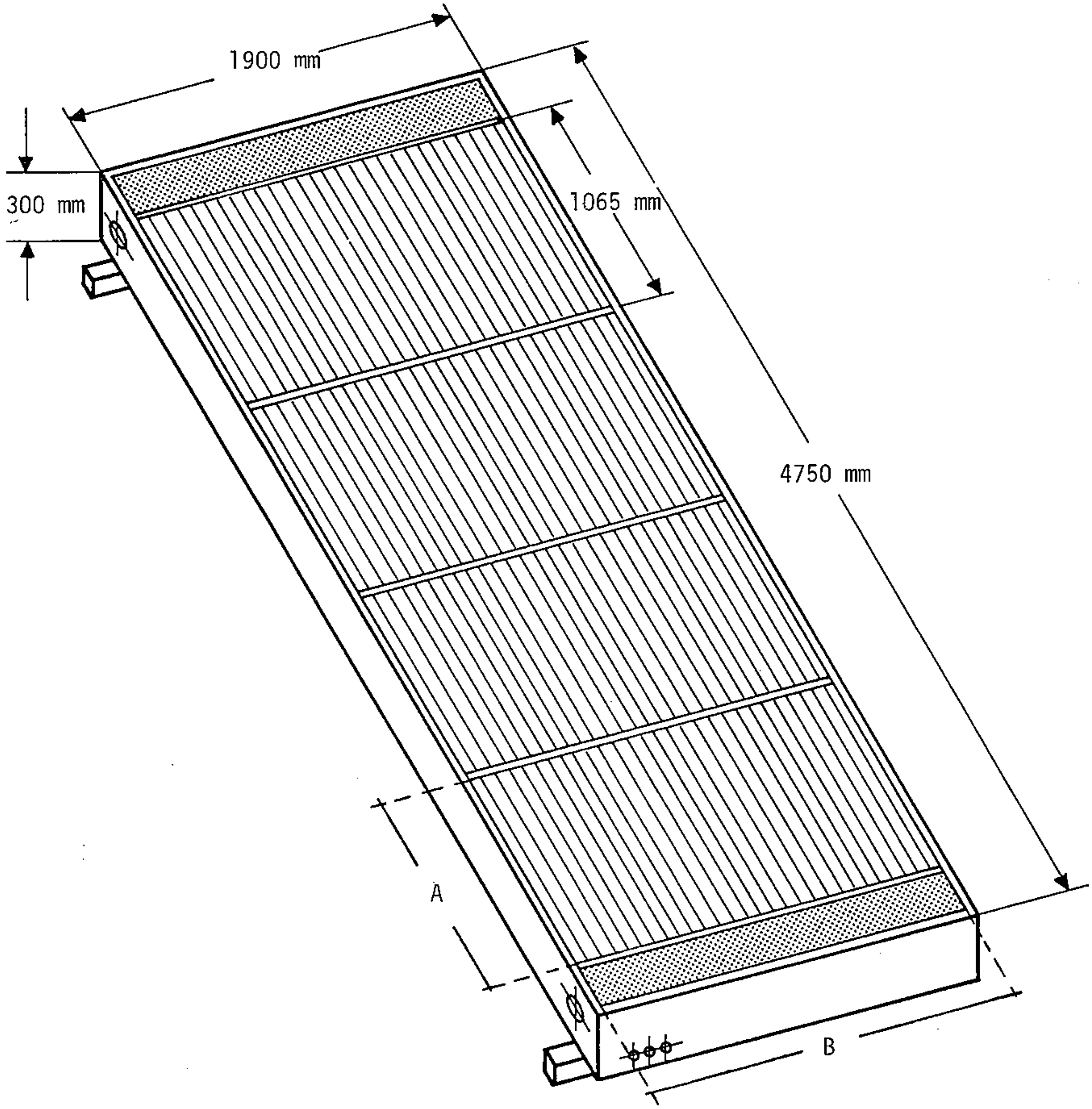


Figure 4-10. Philips MK IV evacuated tubular collector: cross section schematic and definition of absorber area



Definition of aperture area = A * B = 7.37 m^2 per module.

Figure 4-11. Philips MK IV collector. View of module assembly and definition of aperture area.

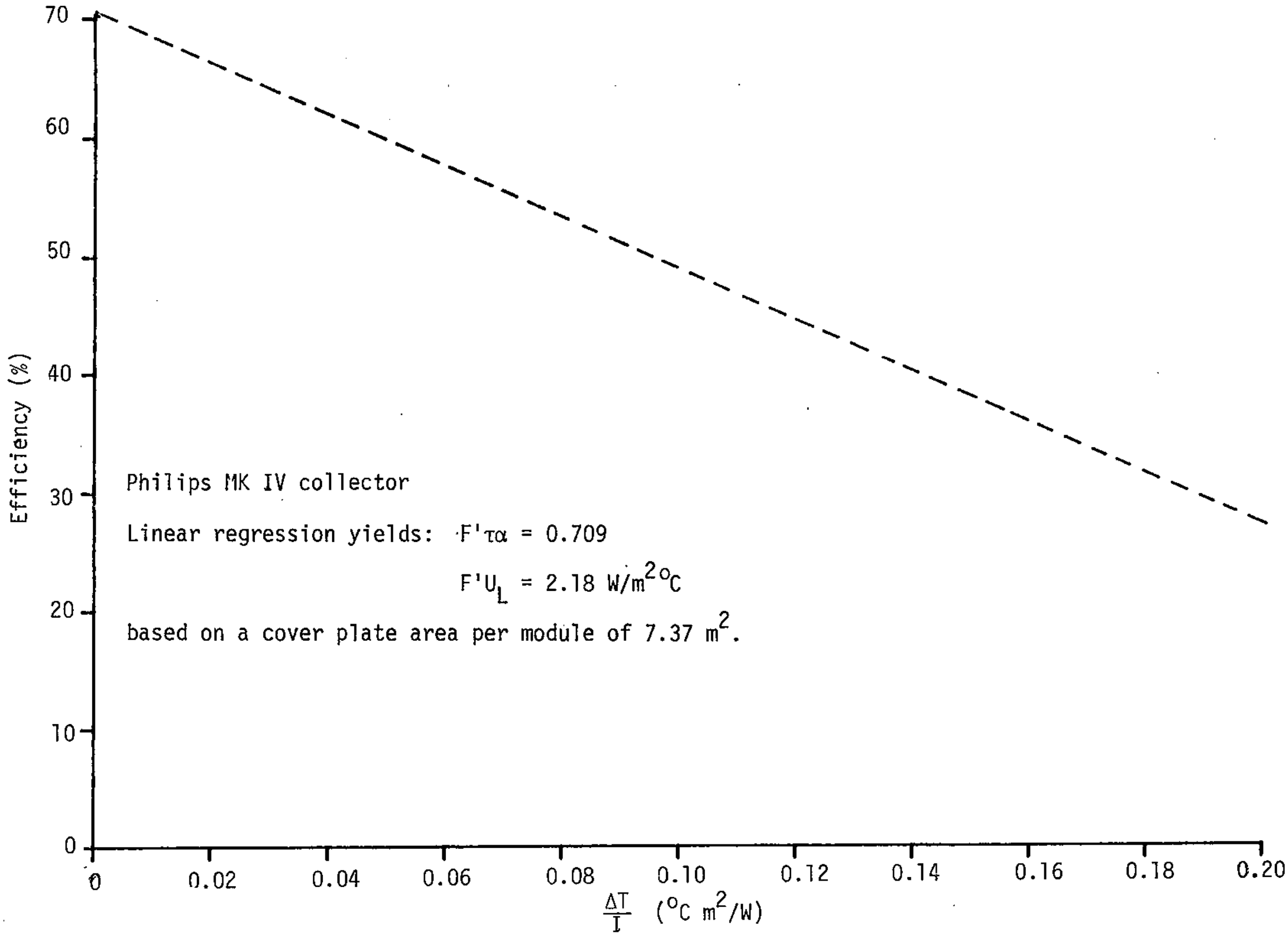


Figure 4-12. Philips MK IV collector, test data.

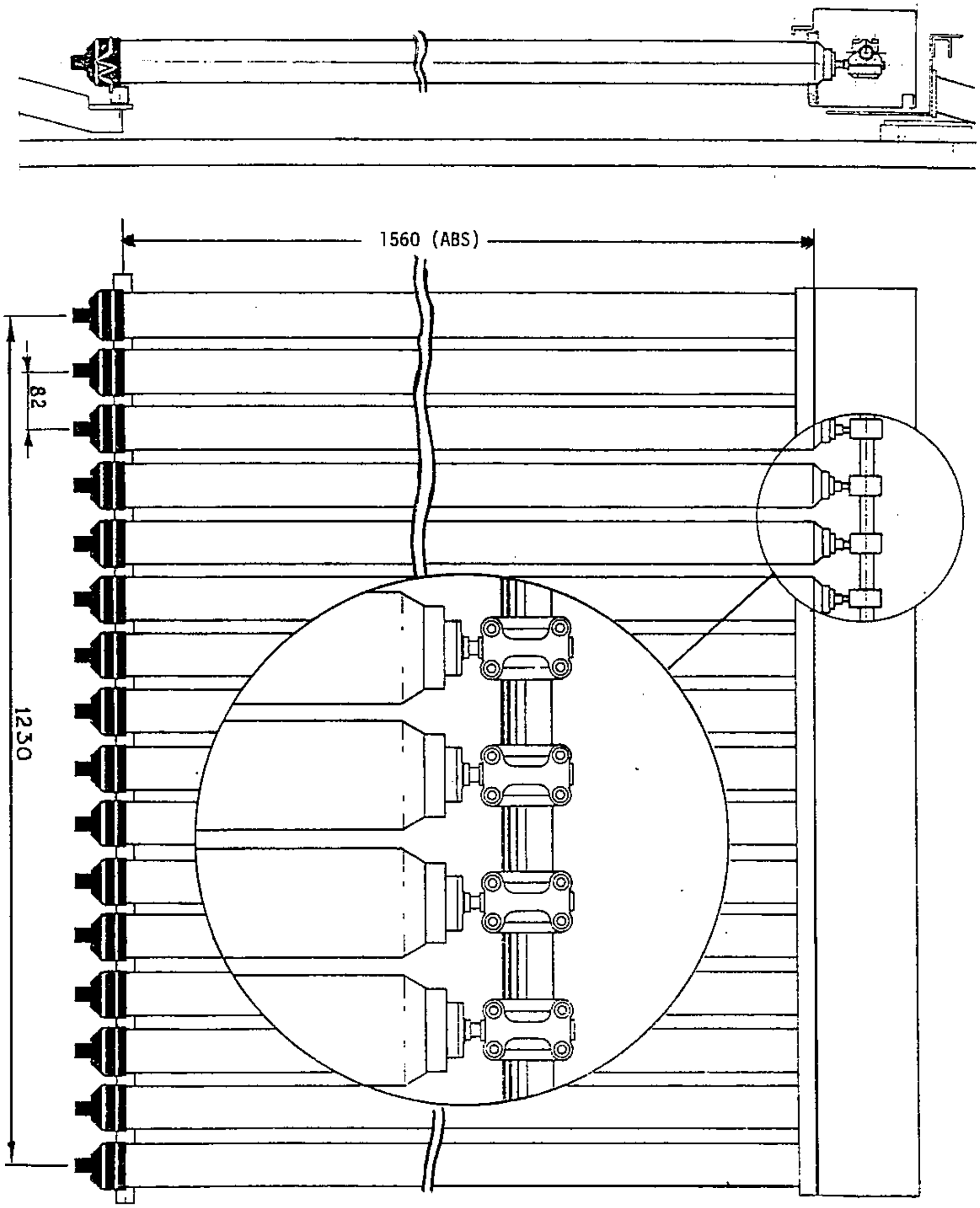


Figure 4-13. Philips VTR 261 heat pipe collector.

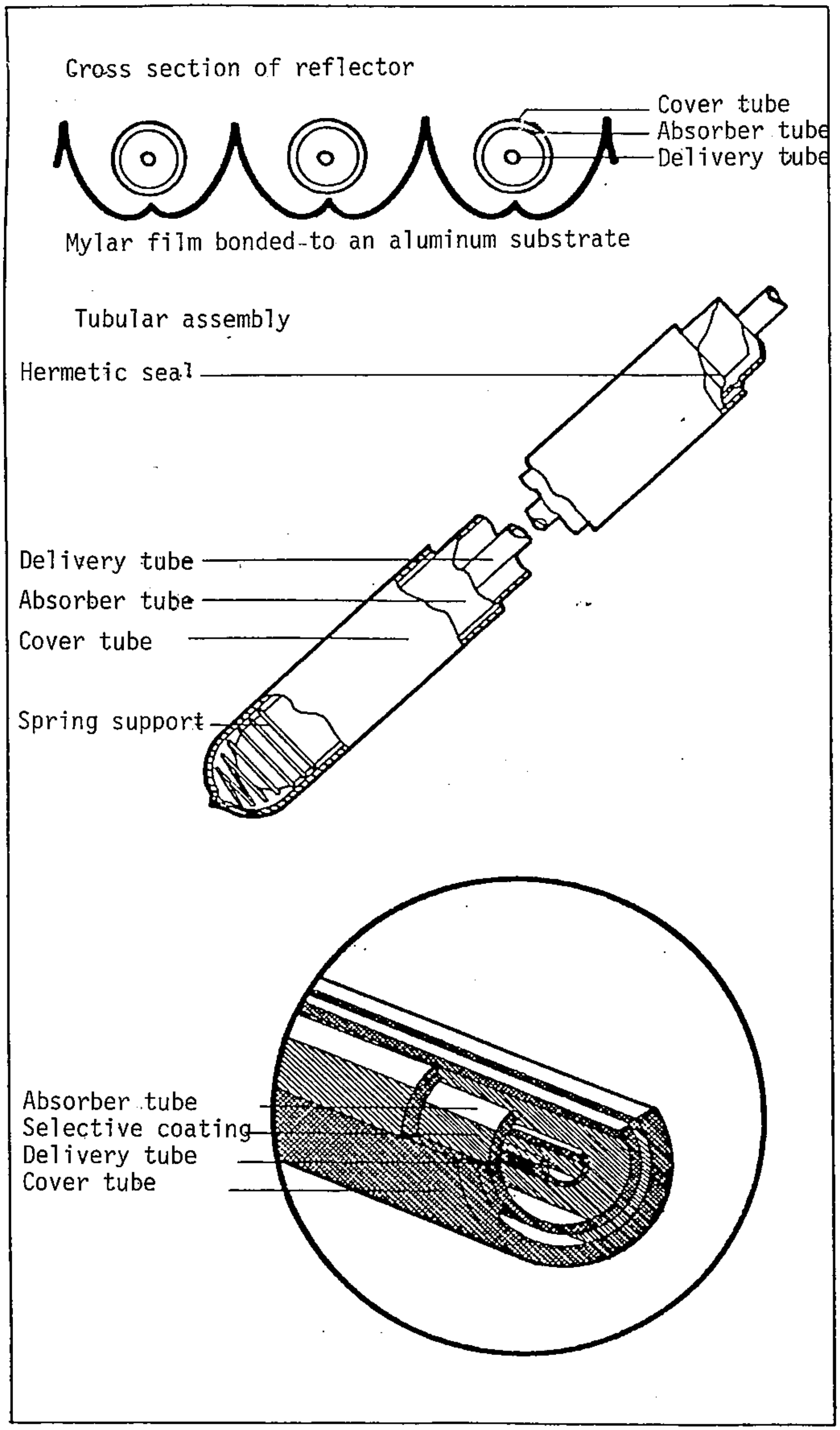


Figure 4-14. Solartec collector.

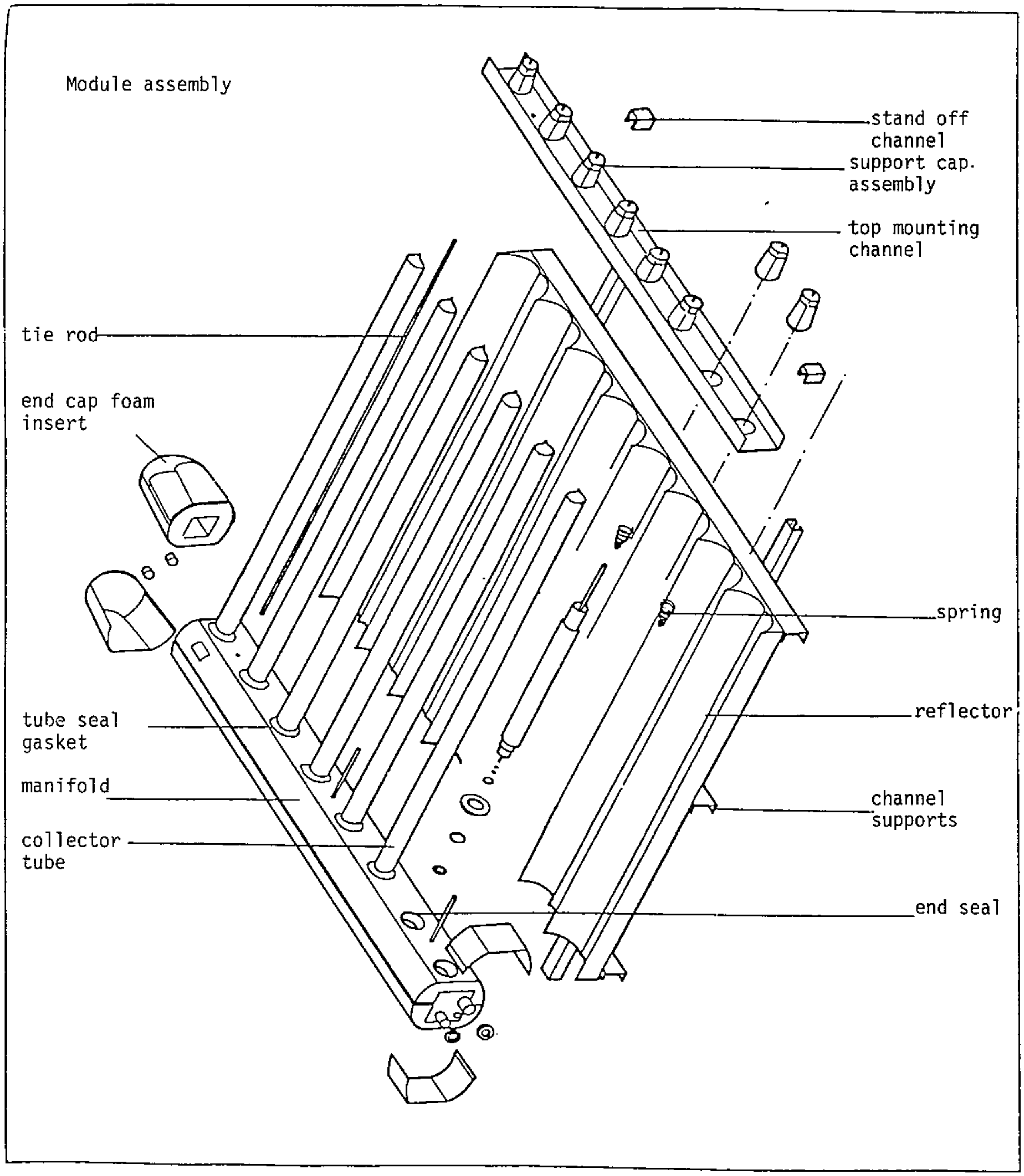


Figure 4-15. Solartec collector.

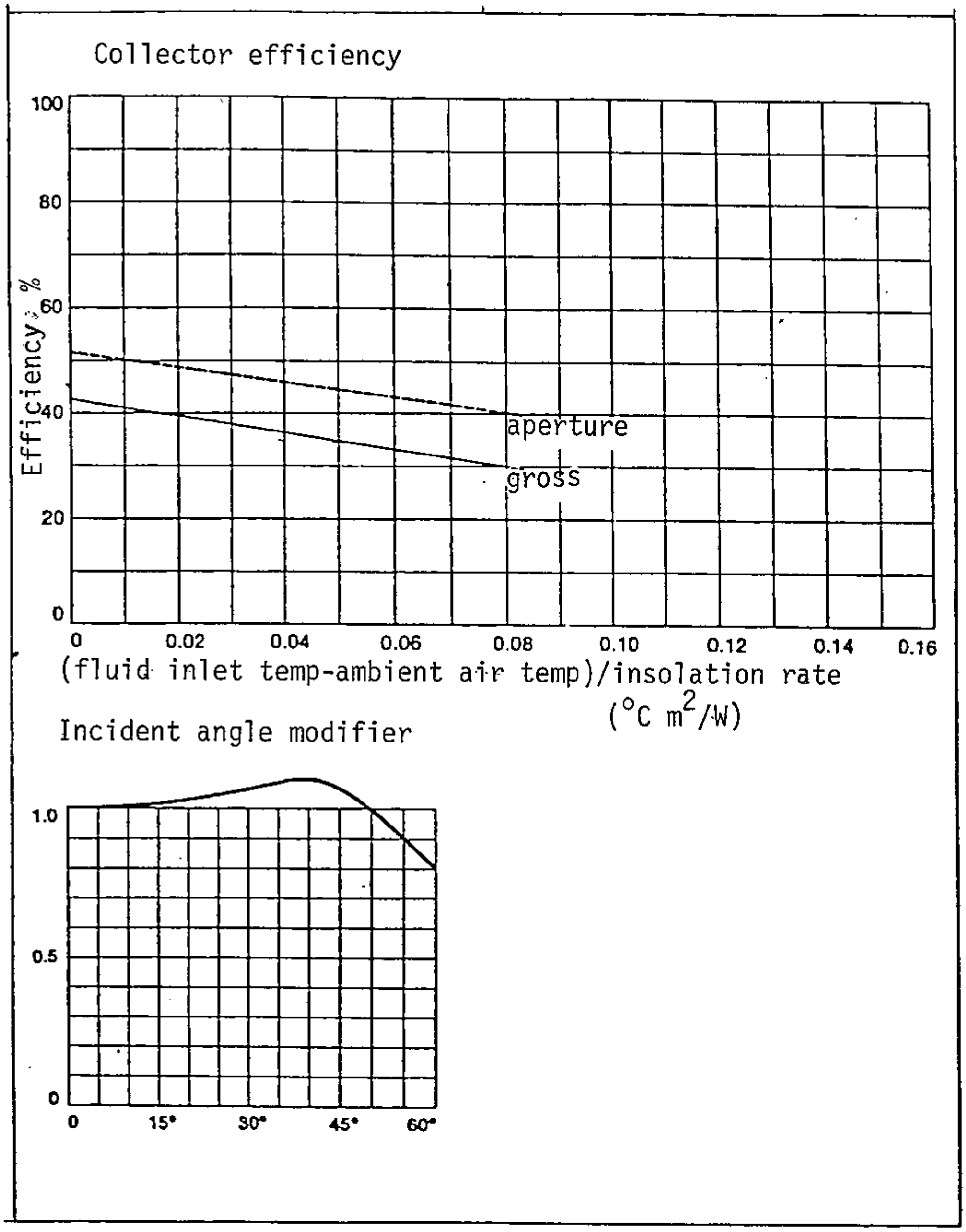


Figure 4-16. Performance of Solartec collector.

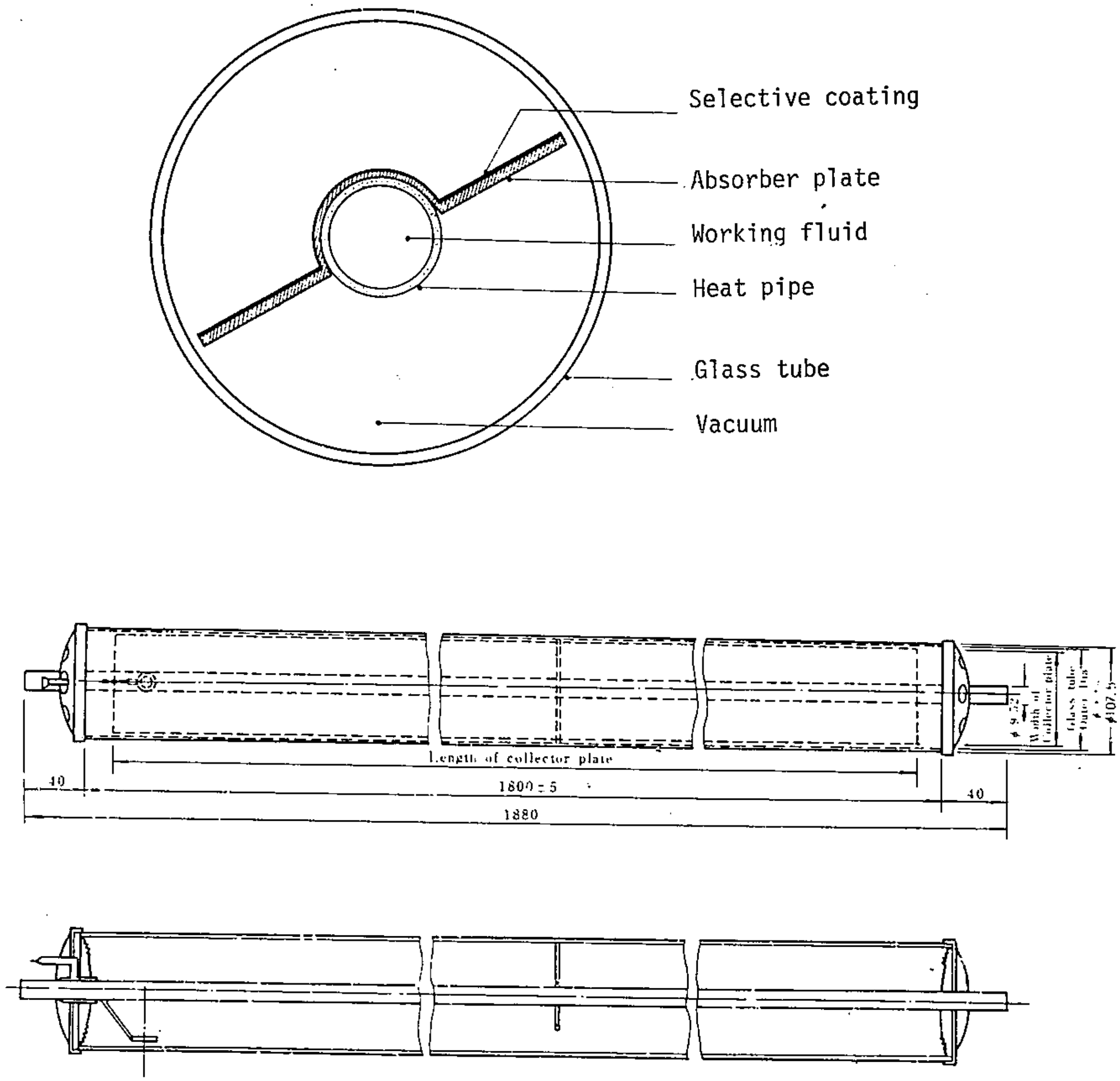
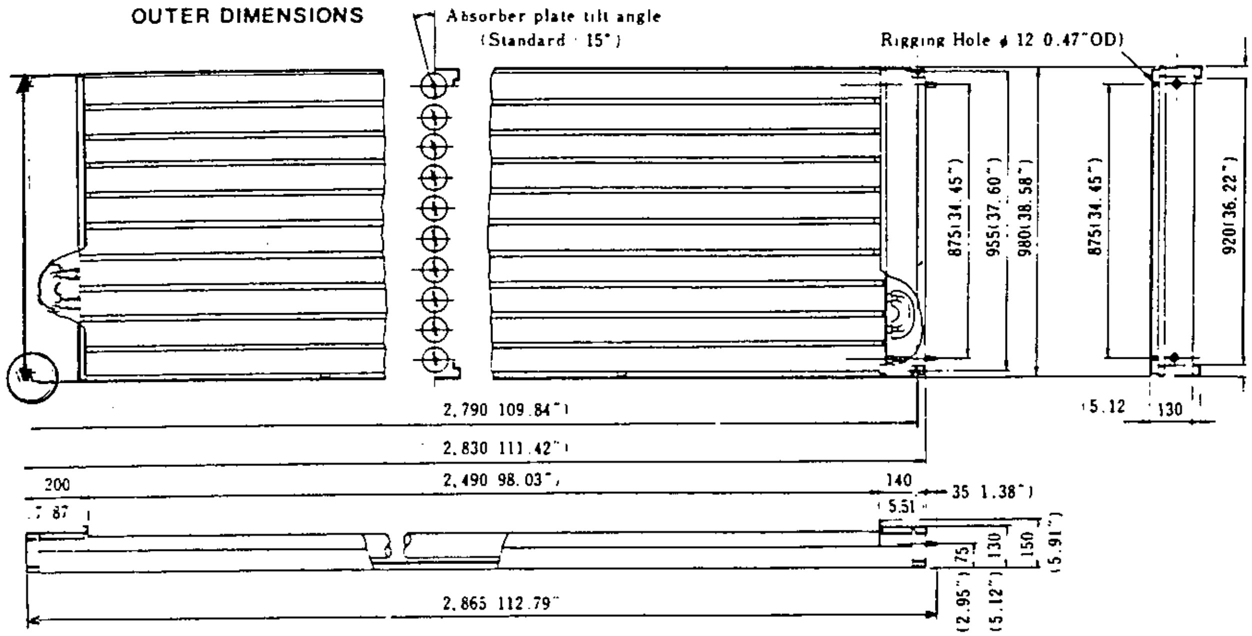


Figure 4-17. Structure of the Sanyo collector.

OUTER DIMENSIONS



SPECIFICATIONS

MODEL	STC-CU250L/STC-CU250R
TYPE	EVACUATED GLASS TUBE W/SELECTIVE COATING
SELECTIVE COATING	SOLAR ABSORPTIVITY 0.91, EMISSIVITY 0.12
ABSORBER AREA	1.75 m^2 (18.84 FT^2)
DIMENSIONS	2,830(+35)x980x150, 111.42"(+1.38")x38.58"x5.91"
OPERATING WEIGHT	72.3kg(160lb), 26.1kg/m^2(5.35lb/FT^2)Installation Area
FLOW RATE	50-300Lit/Hr (0.22-132GPM)
MAXIMUM OPERATING PRESSURE	5kg/cm^2(71.2PSI) BRAZED CONNECTION OR 2kg/cm^2(28.5PSI) RUBBER HOSE CONNECTION
HOLDING WATER	2.3 Lit. (0.6 Gallons)
PLUMBING LOCATION	LEFT (Other side as shown)/RIGHT (Shown side)
INSULATION	FIBER GLASS 20mm(0.8") THICKNESS Around Return Bends

Aperture area: $(2.490) \times (0.875 \times \frac{10}{9}) = 2.42\ m^2$

Figure 4-18. Description and specifications of the SANYO STC-CU250 collector.

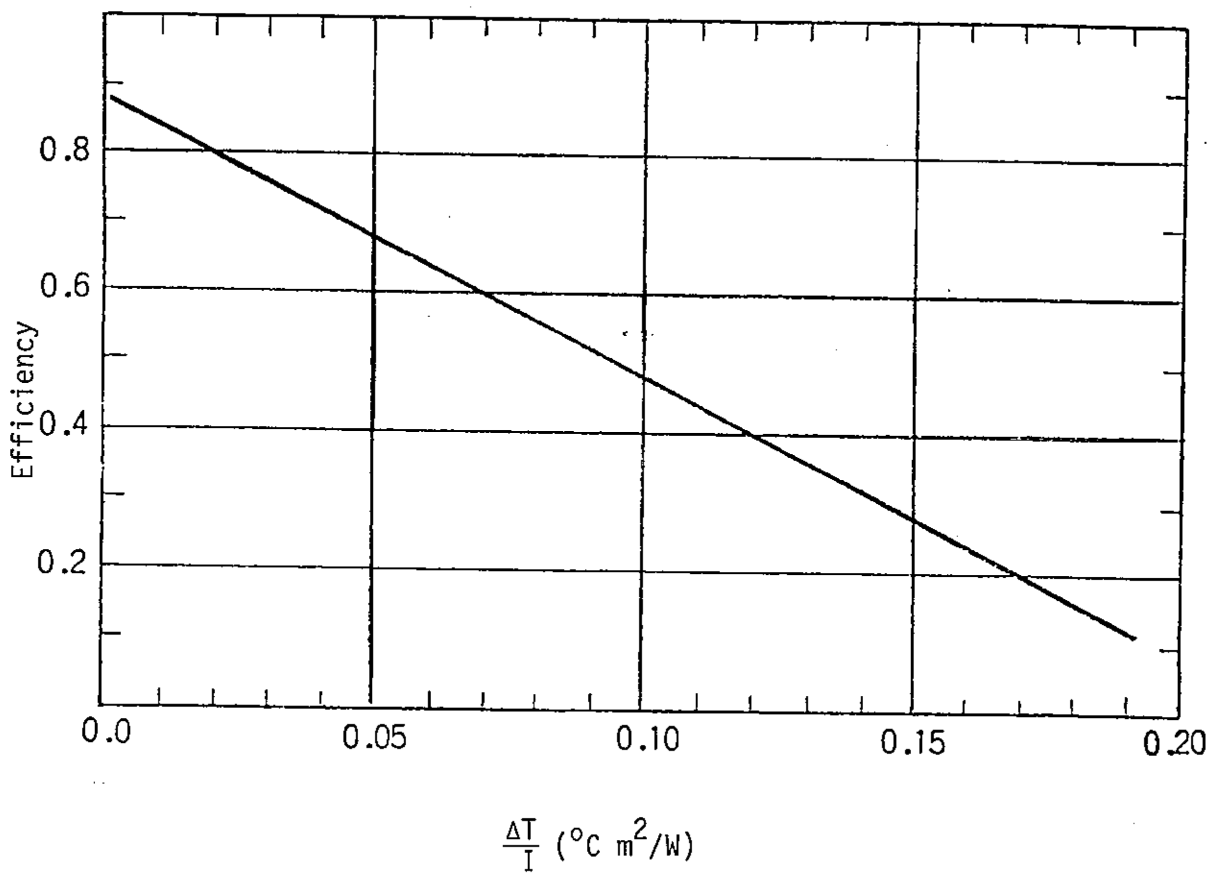


Figure 4-19. Efficiency based on absorber area of the Sanyo evacuated glass tube solar collector.

The collector characteristics are:

	On the roof	Vertical
Total absorber area	40.6 m^2	4.8 m^2
Total aperature area	52.8 m^2	6.9 m^2
F_R $(\tau\alpha)$	0.87	
$F_R U_L$	3.5 $W/m^2 \cdot K$	

IEA aperature area A100 = L x W x cos ∅
= L x n x p x cos ∅
= 1.75 x 7 x .124 x cos ∅
= 1.467 m^2

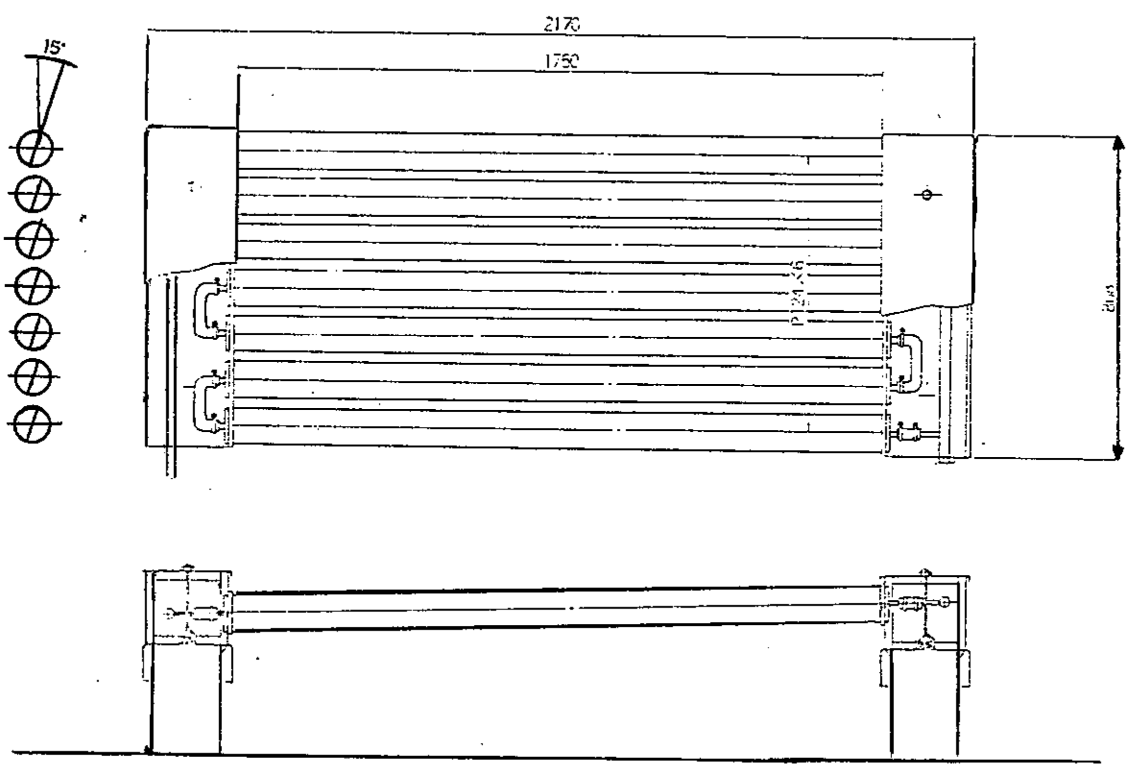


Figure 4-20. Sanyo Collector module and collector integration into base structure.

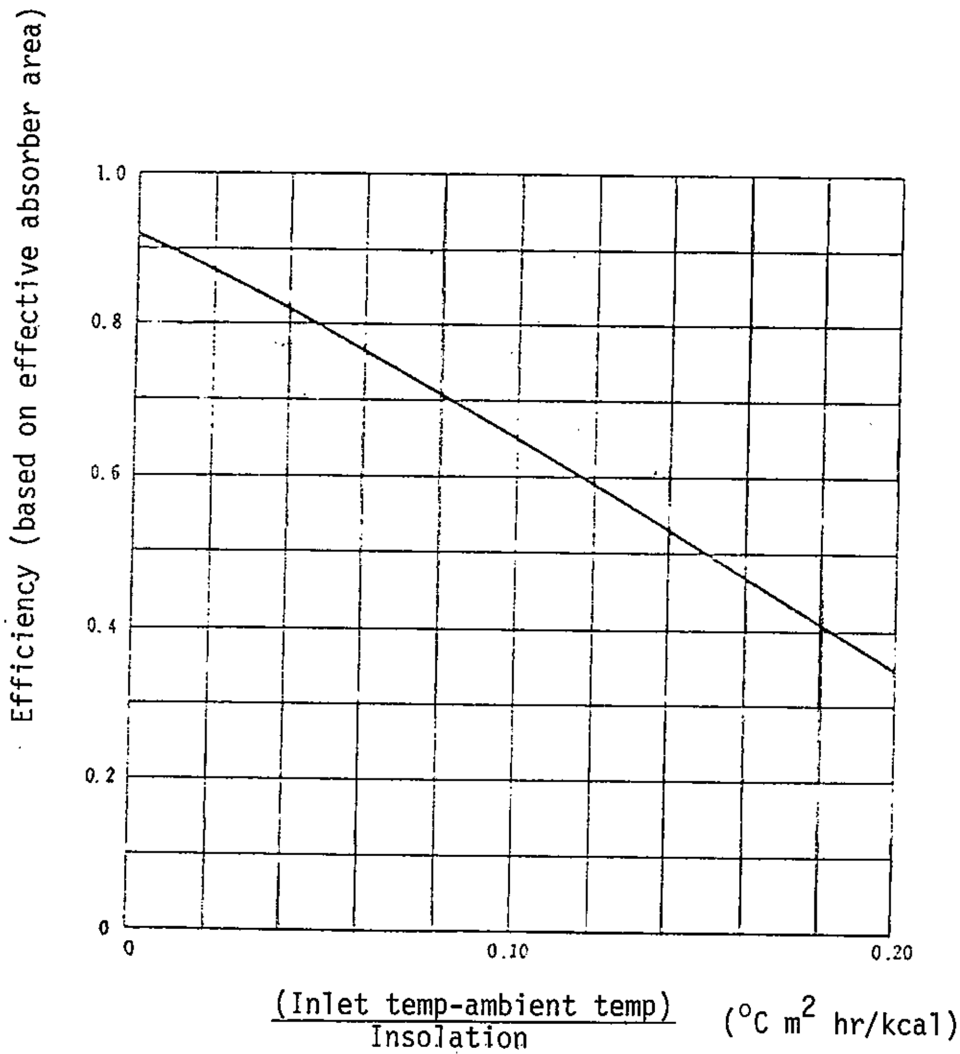


Figure 4-21. Collector Performance Chart (metric) for SANYO STC-250 collector.

TABLE 4-5. Storage Description

Mountain Springs Bottle Washing Facility Edmonton, Alberta, Canada	Due to the nature of this application in which the load occurred concurrently with available solar energy, a storage tank was not needed. Instead, an accumulator tank of 5.7 m^3 was utilized. The capacity of this tank was adequate to fill the entire collector loop and still have sufficient fluid inventory so that the heat exchanger circulating pump operated satisfactorily. During periods when the bottle washing facility was not operating, as on weekends, and solar energy was available, heat could be transferred from the accumulator tank to the soaker tank, effectively increasing the storage capacity of the system by 14 m^3. The accumulator tank is a steel tank lined with dense concrete, i.e. alcrete, precrete. Its gross volume is 7 m^3 with a working mass of 5700 kg. The heat capacity is 4200 J/kg°C with a maximum and minimum operating temperature of 93°C and 71°C respectively. The overall heat loss coefficient is 9.43 W/°C. Stratification is insignificant. All losses from the accumulator tank are non-useful.
Osaka Sanyo Solar House Osaka, Japan	In this system, two storage tanks are used. The first storage tank used until October 1979 was made of steel and insulated with 100 mm glass wool. The capacity of the tank was 1 m^3. In order to improve the insulation, the first storage tank was changed to one of FRP with 100 mm of urethane foam insulation. The capacity is 1 m^3. The overall heat loss factor of the first storage was 3.26 W/°C. The second storage tank was made of steel and insulated with 100 mm of glass wool. The overall heat loss of the second storage tank was UA = 11.4 W/°C for winter and UA = 13.7 W/°C for summer.
Eindhoven Technological University Solar House Eindhoven, Netherlands	The storage vessel has a gross volume of 10 m^3 with a working mass of 3700 kg. The heat capacity is 15.54 MJ/kg°C and the overall heat loss factor is 6.2 W/°C. Stratification is enhanced by a floating inlet, an amply dimensioned air-heat exchanger and bottom-to-top heating of domestic hot water. As a special feature there is a nitrogen-bubble in the top of the vessel, providing an expansion volume for the solar loop.
Knivsta District Heating Project Knivsta, Sweden	No storage is used. Heat is transferred through exchangers directly to the district heating system which plays the role of storage.
Solarcad District Heating Project Geneva, Switzerland	No storage is used. Heat is transferred through exchangers directly to the district heating system.
Evacuated Collector System Test Facility Bracknell, United Kingdom	The space heating storage consists of a vertical steel tank filled with water. It contains a helical copper coil the full height of the tank through which the hot fluid from the collectors is pumped. The coil has connections at top and bottom and also at the centre

to permit investigation of the effect of using only the lower part of the coil. The storage has connections at top and bottom for flow to and return from the space heating distribution subsystem. Expansion of the contents of the storage is accommodated by connecting it to an open expansion tank at high level. The storage has a height of 2.35 m, a dimater of 0.90 m and a volume of 1.40 m^3. The heat loss coefficient is about 10 W/°C. No losses are useful losses. The domestic hot water storage consists of a vertical copper cylinder, the lower half of which contains a copper heating coil through which the solar collector fluid is pumped. The cylinder is fed at the base with cold water from a storage cistern at high level and the preheated water is drawn off from the top. The cylinder has a height of 0.90 m, a diamter of 0.45 m amd a volume of 0.117 m^3. It has an overall heat loss coefficient of about 6 W/°C. No losses are useful losses.

Colorado State University
Solar House I
Fort Collins, Colorado USA

The Bally heat storage tank is designed on the principle of a walk-in refrigerator. The wall, floor and top sections are composed of two sheets of galvanized steel between which 10.2 cm of urethane foam insulation is integrally bonded. In May 1979, the rectangular Bally tank was augmented with two vertical baffles surrounding the return piping from collector and from the load to enhance stratification. Urethane foam insulation in the storage tank walls has a theoretical R factor of 6 m^2 -°C/W. The effective R value is only about 40 percent of this value, or 2.4 m^2 -°C/W. The result is a tank heat loss rate of 0.022 MJ/hr -°C. Thirteen pipe connections through the top of the tank, about double the number in a normal installation, contribute to a significant portion of the tank loss. However, these "losses" are contributions to the heating requirements of the building whenever heat is required, and are true losses only in mild spring and fall weather and, of course, in the summer.

A cylindrical steel glass-lined pressure vessel insulated with 6 inches of urethane foam was the main solar storage tank during the cooling season of 1981. It has dimensions of 2.4 m height, 1.7 m diameter and a total volume of 4.164 m^3 with a rated working pressure of 1,035 Mpa. Vertical baffles similar to those in the Bally tank are used to enhance temperature stratification.

Solarhaus Freiburg
Freiburg, West Germany

Domestic Hot Water Storage

The storage capacity of 2.5 m^3 of water has been determined as optimal by computer simulation runs. To increase system efficiency, this storage capacity has been separated into 1.5 m^3 of preheat storage and 1.0 m^3 of hot water storage. The storage tanks are connected in series to the cold water mains. Both are cylindrical, pressurized steel tanks with a height of about 2.0 m and a diamter of 1.1 and 0.9 m respectively. They are insulated with 20 cm of rockwool and covered with a thin galvanized sheet-steel envelope, given loss factors of 9.0 and 5.86 W/°C respectively. Delivery of solar energy occurs via immersed tubular heat-exchangers, which are located in the bottom of each tank. A 12 kW resistance electric heater, located in the upper half of the hot water tank, is used to supply electric auxiliary energy. It should be noted that solar energy is directly used in the drinking water system. There is no danger of contamination by the collector fluid because of the higher static pressure in the DHW system.

Solar Heating Storage

The storage capacity of the solar heating system is subdivided into two parts: a 15 m^3 of low temperature storage and 5 m^3 of conventional heating storage, as a buffer tank. There is storage for 7-10 days of heating when the average heating load is 100 kWh/day, which is typical for May or October.

The 15 m^3 storage tank is a cube of 2.5 m on a side, insulated with 10 cm of mineral wool and a loss coefficient of 25-35 W/°C, depending on storage tank temperature. Its time constant is about 25-30 days. The tank is made of welded 3 mm sheet-steel and withstands only the static pressure of its contents. Solar energy is delivered by two internal tubular heat exchangers at the bottom part of storage, and heating energy is withdrawn by another heat exchanger inside the top part of the storage.

The other heating storage tank of 5 m^3 capacity is designed for daily storage or direct use of solar energy. It is a cylindrical pressurized tank, insulated with 15 cm of mineral wool, has a loss coefficient of 15 W/°C and a time constant of about 15 days. Energy input is solar or thermal energy from the oil burner. The energy output is shared between heating and auxiliary energy for the DHW system.

Table 4.6. Summary description of components and subsystems.

<u>CANADA</u>-Mountain Springs Bottle Washing Facility

COLLECTION

The Solartec evacuated tube collector module is a drain back, liquid collector capable of delivering fluid at temperatures up to 97°C. The module consists of eight evacuated glass tubes operating in parallel with the supply and return headers located at the bottom of the module. Behind each of the tubes is a compound parabolic cusp reflector.

A modification has been made to the collector tubes in each bank. The pressure drop orifice was removed from the copper cup in which the evacuated tube was seated and a stainless steel vent tube was installed to produce the required pressure drop across the orifice at the top of the vent tube. This modification was necessary as the orifices in an entire bank failed to clear when the system drained back and the drop of water retained in the orifices froze, causing a blockage. This modification alleviated the problem as the orifice on the vent tube was located in the hottest part of the collector and would thaw if a minimum of solar radiation was available.

Collector Type	Solartec
Number of Modules	216
Total Aperture Area	282 m^2
Collector Tilt	50°
Surface Azimuth	0°
Working Fluid	deionized boiler grade water
Flow Rate	0.79 l/min

CONTROLS

The main system differential controller is custom built for this particular solar installation. There were two types of inputs to the controller: Thermistors (30k@25°C) and bimetallic freeze sensor (N.O., closes at 2°C). There are two types of outputs: solid state relays for activating solenoid valves and electro-mechanical relays for pump control.

<u>JAPAN</u>-Osaka Sanyo Solar House

COLLECTION

Two different collectors were used during the report period. Initially collectors were located both on the vertical plane of the veranda (porch) as well as on the flat roof of the building. Capacitance effects are shown in the corrected efficiency graphs in the results section.

Collector Type	Sanyo	GE
Number of Modules	36	24
Total Aperture Area	52.8 m^2	33.12 m^2
Collector Tilt	15°	15°
Surface Azimuth	0°	0°
Working Fluid	water	water

HEATING

In the heating subsystem the hot water at temperatures higher than 45°C in the first storage tank is supplied to the second storage tank which supplies the fan coil units. For operation with auxiliary, the hot water temperature from the auxiliary heater (3Ø, 200v, 12kw) to the second storage tank is controlled at 45°C by a three way valve.

COOLING

Hot water from the first storage tank is supplied to the generator of the absorption chiller. When the temperature in the first storage is too low, the auxiliary boiler starts and chilled water (10°C) produced in the chiller is supplied to the second storage tank.

The forced circulation absorption chiller uses as the absorption agent, an aqueous solution of lithium bromide and sodium chloride with a weight ratio of 4:1. The capacity of the chiller is 2RT and operates with design inlet and outlet temperatures of 15°C and 10°C respectively at a flow rate of 20 l/min. The cooling water temperature is 31°C (inlet) and 35°C (outlet) at a flow rate of 63.5 l/min. The heat source design temperature is 85°C at a flow rate of 30.8 l/min with return to storage at 80°C.

DOMESTIC HOT WATER HEATING

The domestic hot water supply subsystem consists of the hot water supply coil located in the first storage tank and an auxiliary heater (5.4 kw) built into the domestic hot water storage tank (500 liters). If the temperature of this tank falls below 50°C the auxiliary heater turns on.

CONTROLS

A general purpose microprocessor F8-SDS developed by Sanyo is used to control the system. There are 28 points for the sensors and 27 objects to control. For the temperature sensors copper-constantan thermocouples are used. There are four proportionally controlled motorized valves. There are also pumps, auxiliary boilers and chiller on-off controls. The status signals of the pumps, fans, valves, and the chiller are monitored.

NETHERLANDS-Eindhoven Technological University Solar House

COLLECTION

The 23 modules are mounted on a support-structure and are not integrated with the roof.

Collector Type	Phillips VTR 261
Number of Modules	23
Aperture Area	47.15 m^2
Collector Tilt	48°
Surface Azimuth	+7°(west)
Working Fluid	water
Module Connections	all in series

HEATING

Energy is transferred from the storage vessel to a water-to-air heat exchanger (Holland Heating), heat transfer capacity is 1500 W/°C. This heat exchanger heats the air up to 50°C from an outdoor temperature of -15°C. Heating of the garage takes place by use of waste ventilating air.

DOMESTIC HOT WATER

The heat exchanger in the storage vessel consists of 11.5 m of finned copper tube: (Trufin, type W/H 35-11-14 100 01). External heat exchanging surface is 2.42 m^2.

CONTROLS

Signals are fed to a central desk top HP-87A computer that contains the system's control strategy.

The variable collector flow (200-1200 l/m) is controlled by means of a frequency controller, an Electroproject EPFC-1.5kW unit, a Wilo type RS 25/70 V pump. Pt-100 sensors (0-20 mA) send signals to Witromat signallers (9404.420.20011). Aquametro Sin 111 flow meters are used. Motorized valves are made by Landis and Gyr.

SWEDEN-Knivsta District Heating Project

COLLECTION

Three types of collectors are installed on the roof of the district heating plant. The solar collector system for each type is a closed system with expansion tanks and circulation pumps. The heat from the solar collectors is transferred to the return pipes of the district heating system by means of a flat plate heat exchanger. Separate systems are used for each of the solar collector types. Circulation in the district heating system is powered by the main pump in the district heating network. A rough estimate of the heat capacity including array piping gives about 35 $kJ/m^2 °C$ for the GE collectors, 70 $kJ/m^2 °C$ for the O-I collectors and 25 kJ/m^2 for the Philips.

Collector Type	GE	O-I	Philips
Number of Modules	28	14	18
Total Aperture Area	38.36 m^2	35.64 m^2	24.62 m^2
Collector Tilt	45°	45°	60°
Surface Azimuth	0°	0°	0°
Working fluid	30% ethylene glycol	water	30% ethylene glycol
Fluid Flow Rate	27 l/min	22 l/min	10 l/min
Module Connections	2 rows of 14 modules	2 rows of 7 modules	3 rows of 6 modules

CONTROLS

The control equipment is made by GE. It consists of a radiation sensor and an electronic unit that integrates the intensity over a period of time. This implies that the pump does not stop during short durations of cloudiness. The pumps originally were designed to operate continuously whereas the flow on the district heating side is regulated by a motor valve which opens or closes at 4°C difference between the solar and district heating circuits. Other control strategies are possible, such as pump starts and stops dependent upon solar intensity or by a time clock. In the Philips solar circuit the pump can be started and stopped at an adjusted temperature difference between the solar collector and district heating temperature. The temperature sensors are of type Pt-100 with 1/3 DIN normal accuracy corresponding to max ±0.1°C deviation, including the linearization conversion from the Acurex system. The flow meters are of wing wheel (solar system) and turbine (district heating system) types. The calibration of the flow meters is within ±2 percent for the wing wheel and ±0.5 percent for turbines. Solar radiation is measured by means of calibrated Kipp & Zonen solarimeters.

SWITZERLAND-Solarcad District Heating Project

COLLECTION

The collectors are mounted on a flat roof with the absorber plates parallel to the collector plane. Each row shadow slightly part of the next one. Three separate loops for the Corning 'A' and 'B' and Sanyo collectors allow for separate performance measurements.

Collector Type	Corning Cortec 'A & B'	Sanyo
Number of Modules	12	8
Total Aperture Area	17.5 m^2	19.4 m^2
Collector Tilt	30°	30°
Surface Azimuth	0°	0°
Module Connections	2 rows of 6 modules	2 rows of 4 modules
Working fluid	30% antifreeze (Glycolen) & water	30% antifreeze (Glycolen) & water

CONTROLS

The solar radiation level controls collector circulation pumps. The heat exchanger pump on the district network side runs continuously. Three-way valves allow for the preheating of the closed collector loop until the temperature is higher than the return line. Preset times prevent fast system oscillations. Microcomputer controls will be employed later on.

UNITED KINGDOM-Evacuated Collector System Test Facility

COLLECTION

The solar circuit subsystem has a common return from all the collectors to the plant area. The flow can be directed just through or past the heating coil in the space heating storage, then through or past the coil in the domestic hot water storage. There are two separate flow pipes from the plant area to the collectors, each serving ten collector modules.

Collector Type	Philips VTR 141 (15 tube)
Number of Modules	20
Total Aperture Area	21.6 m^2
Collector Tilt	61.5°
Surface Azimuth	0°
Working fluid	30% propylene glycol-water
Fluid Flow Rate	6 l/min
Module Connections	2 rows of 10 modules

HEATING

The space heating load simulator subsystem draws off water from the space heating store at at a controlled temperature. It is controlled by the system computer, according to the prevailing weather conditions.

Heat is rejected to ambient through a series of heat exchangers. The present configuration of the system has a maximum water flow rate to and from the space heating store of 0.06 l/sec and an overall effectiveness of 0.31.

DOMESTIC HOT WATER HEATING

The domestic hot water subsystem draws off water at either 0.15 or 0.30 l/sec for a variable length of time. The flow rate and length of each draw off are selected by the computer according to the time of day. At present the total domestic hot water load is 90 l/day.

CONTROLS

The solar system is controlled by a collector thermostat, two differential thermostats, two high-limit thermostats and a fixed logic control unit.

USA-Colorado State University Solar House I

COLLECTION

Two types of collectors were used during the report period. The Miromit drain-back flat plate collector and the Philips VTR 141 Heat Pipe evacuated tube collector. The Miromit was used in the first two systems in both cooling and heating seasons. The Philips collector was used in systems three through eight.

Collector Type	MIROMIT	PHILIPS
Number of Modules/Collectors	26	52
Total Aperture Area	56 m^2	59.6 m^2
Collector Tilt	45°	45°
Surface Azimuth	0°	0°
Working Fluid	water	50% ethylene glycol & water
Fluid Flow Rate		42 l/min
Module/Collector Connections	13 vertical pairs	4 rows of 13 modules

HEATING

Space heating is accomplished via the main load pump circulating water from storage through an air heating coil, back to the bottom of the storage tank. Simultaneously, the blower in the duct is activated, thereby drawing air through the coil and delivering it via duct work to the rooms. Auxiliary heating is provided either by an electric boiler or an off-peak electric thermal energy storage unit.

OFF-PEAK ELECTRIC HEAT STORAGE UNIT

This device is an assembly of refractory bricks contained in a heavily insulated metal cabinet manufactured by the TPI Corporation. Electric heating elements supply heat to the bricks during the off-peak demand period at night. In normal operation, without auxiliary, air heated in the solar coil bypasses the off-peak electric unit. When auxiliary heat is needed, air leaving the solar heating coil is routed through the brick work by motorized dampers. During the night off-peak cycle, auxiliary space heating, if needed, is supplied to the air stream by direct resistance heating. The storage capacity is 200 kWh with 28.9 kW charging load at 240 volts, 121 amps.

COOLING

Two ARKLA chillers were used during the report period. The ARKLA model WF-36 lithium bromide absorption water chiller was used in systems two and three The chiller has a nominal rating of 10.5 kW cooling output (3 tons) at a chilled water outlet temperature of 7.2°C when supplied with 14.7 kW from hot water at 91°C and cooling water at 29°C. The resulting coefficient of performance (COP) is 0.72. Normal hot water supply temperatures to the chiller were 75 to 80°C and chilled water at a temperature of approximately 7°C was circulated from the unit through the direct coil from which it returned to the chiller at a temperature of 12°C.

The XWF-3600 is an advance in the state-of-the-art in residential size absorption chillers in that it accomplishes heat removal from the condenser and absorber by the direct evaporation of cooling water flowing over the external surfaces of the component parts, thus eliminating the need for a separate cooling tower. The entire unit is located outside the building.

The XWF-3600 was designed to have nominal thermal performance characteristics similar to those of the WF-36. However, some features of the prototype machine used at Solar House I are notably different. The minimum temperature of the hot water supply to the generator of the XWF-3600 is 80°C compared to the standard 70°C for the WF-36. This minimum is necessary to maintain an internal pressure difference adequate to force refrigerant to flow through a 30 cm gravity head. This height difference was not present in the WF-36. In addition, the direct evaporative cooling makes the performance of the XWF-3600 dependent on the limited wetted area exposed to water and air flow around condenser and absorber surfaces.

DOMESTIC HOT WATER HEATING

Three different arrangements were used during the report period. The first of these was a two-tank hot water system with an external heat exchanger. This hot water system has a completely separate circulation loop from storage through the exchanger, back to storage. Operation of the hot water system, with its two small pumps, is therefore independent of the space cooling system. The second was a one tank hot water system with external heat exchanger. During the winter of 1981 the two tank hot water system was converted to a single tank system by adding an electric heating element to the existing 300 liter preheat tank. The existing heat exchanger arrangement with its two pumps was retained. The third was a hot water tank with internal heat exchange. The hot water tank used in System 8 during the summer of 1981 was a 300 liter, stone lined tank with 5 cm of fiberglass bat insulation. Heat transfer to water in the tank is accomplished by means of a coil of finned copper tubing in the lower 30 cm of the vertical cylindrical tank. The tubing is double-walled to conform to codes that require positive separation of potable and nonpotable water. Auxiliary energy is provided to this tank by an electric heating element 30 cm from the top of the tank.

CONTROLS

System control was provided by use of a modular electronic control assembly (MECA II) manufactured by GTE Products Corporation. The MECA system consists of a MC-4A microcomputer module, an MB-1 motherboard, a CB-1 computer base and ten input/output modules. The MC-4A contains 4K bytes of memory. the MC-4A programmable plug-in chips (PROM) contain the nonvolatile memory which is programmed using the MECA Programming System. The MB-1 interfaces between the computer base and the input/output modules. The computer base is the mounting place for the microcomputer. Input/output modules each have four "ports." Three different types of modules were used: AI4 analog-to-digital converters were used for temperature inputs; SC (switch closure) input modules were used to activate or deactivate devices. All systems operations were controlled by a program (in the PROM chips) that included collector operation, DHW usage, house cooling and chiller operation.

To facilitage chiller performance testing, a tempering valve was installed to maintain a constant inlet fluid temperature to the chiller.

WEST GERMANY-Solarhause Freiburg

COLLECTION

Four different solar systems have been tested by the alternative coupling of the two collector systems (Corning and Philips), with two DHW and heating systems. As there is no principal change of the solar system design, the energy flows are affected by these experiments only in magnitude. The heat capacity of one Corning collector module has been estimated at about 5 kJ/K per module and 300 kJ/K for the entire array including piping etc. This is considered low as the collector reaches system temperature within a rather short time. The Philips collector field has a thermal capacity of 947 kJ/K, causing a pronounced heatup phase in the morning and a cooling-down phase in the afternoon.

Collector Type	Corning Cortec 'A'	Philips Mark IV
Number of Modules	24	4
Total Aperture Area	33.3 m^2	29.48 m^2
Collector Tilt	55°	55°
Surface Azimuth	12° west	12° west
Working Fluid	38% by volume propylene glycol-water solutions	
Fluid Flow Rate	32 l/min	32 l/min
Module Connections	4 rows of 6 modules	1 row of 4 modules

HEATING

The space heating system utilizes oversize radiators. This is because solar heating is usually at a lower temperature than conventional heating. For an external ambient temperature of -12°C, this system operates at 50°C rather than 90°C. The radiator operating temperature is centrally controlled so that it decreases linearly with rising ambient temperature. Additionally, all radiators are equipped with thermostatic valves to prevent overheating of the living space by external or internal loads.

DOMESTIC HOT WATER HEATING

The major component of the DHW system is the 1 m^3 hot water buffer tank.

A conventional circulation loop maintains most of the hot water distribution network at the design temperature for 16 hours of the day, even when there is no hot water consumption. The losses due to this circulation are approximately 20 percent of the net hot water load. The losses are outside the insulated enclosure in the house's attic, and so they are not useful.

Storage capacity is 2.5 m^3. This volume was determined to be the optimum for the system, from computer simulation. The storage consists of a 1.5 m^3 preheat tank and a 1 m^3 hot water storage tank. The purpose of dual storage vessels was to improve system efficiency. The preheat tank has the cold mains water inlet. Collector outlet water is returned into the preheat tank at the appropriate temperature level, between mains temperature and 60°C by a floating return pipe. The 1 m^3 hot water storage tank receives the solar preheated water in the lower half of the tank. The upper half of the hot water storage tank is constantly maintained in the design temperature range of 48-50°C, using auxiliary energy.

Solar energy may be delivered in both storage tanks via tubular heat exchangers built into the bottom of each tank. Actual solar energy delivery will depend on the control strategy of each experiment. Auxiliary energy is fed only into the hot water storage tank, either by a 12 kW electric resistance heater inside the tank, or by an external heat exchanger connected to the central heating system. It should be noted that solar energy is directly used in the drinking water system without any danger of contamination by the collector fluid. This is due to the higher static pressure in the DHW system. Both of the storage tanks are insulated all around with 20 cm of mineral wool.

CONTROLS

A microprocessor operated control system was installed in the Solarhaus Freiburg, with a conventional control system as standby. In order to investigate the influence of modified control on the dynamics and the energy consumption of the various systems, several control strategies for the solar, DHW, and the heating system have been developed and tested.

The collector pump is switched on for at least 10 minutes when the radiation level exceeds 130 W/m^2. Collector operation stops when the collector temperature rise falls below 0.5 K. Collected solar energy may be delivered to either the hot water or preheat storage tank, depending on their temperatures, and the insolation intensity. Any excess energy collected in the DHW system (i.e., storage tanks at maximum temperature) may be fed into the heating system storage, in parallel with the output from the heating system collectors.

For auxiliary control of DHW, a standard thermostat is used for the electric element in the 1 m^3 hot water storage tank.

5. SYSTEMS EXPERIMENTS

Most of the Task VI installations run multiple experiments or experiment with multiple systems. CSU Solar House I, for example, sequentially tested eight different systems during the two year period of this report and the Knivsta District Heating Project simultaneously tested three different collector systems.

Even with multiple experiments or experiments with multiple systems, an experimental project can only directly produce results for a very limited number of design points. This limitation is due to the expense of altering the design, to the weeks or months required to thoroughly debug an altered operating and data acquisition system, and to the need for a minimum of a few weeks or perhaps a season of data from one design to achieve a significant confidence level in the results. The task is currently developing specialized simulation models and carefully validating these models against data so that results may be extended to other design points and climates. Such extensions will be included in subsequent task reports.

The system experiments of this task provide not only validation data sets for the eventual generalization of results but, more importantly, operating experience and data that can only be gained from a real system. Many real problems in system and subsystem design, in component selection and matching, in reliability and longevity and in controls and operating strategies can only be discovered by actual system operation. In addition, simulations of complex systems, such as those in this task, inevitably have numerous serious deficiencies prior to validation against real data. Thus, the systems described in this section are providing important initial results for the overall Task VI programme.

In this section a brief alphanumeric descriptor designed to aid the reader in readily identifying the individual systems and experiments is introduced. The descriptor, which reads "country-function-sequential experiment/system number", is used in the tables and graphs for the remainder of the report. For example, J-HTG-1 is the first heating experiment for the Japanese Sanyo Osaka Solar House. Table 5-1 cross references the experiment descriptors with dates, operation modes, and major components.

Actual climate data for the experimental period for each of the installations which have reportable data is provided in Table 5-2. These data may be compared with the long term average climate information given in Table 3-1. The individual experiment descriptions also note whether or not the experiment period was typical.

Table 5-3 summarizes load information for each installation. Average daily loads range from 74 MJ for cooling the Sanyo Osaka Solar House in 1981 to the 200,000 MJ 1981 load of the Swiss district heating project. Further details of individual experiments and systems follow Table 5-3.

TABLE 5-1. Experiment Descriptors, Modes, Components and Operating Dates

Experiment	Mode	Dates	Collector	Chiller	Auxiliary	Main Tank	DHW	Controls
Canada								
C-IPH-1	industrial water heating	winter [illegible] to summer [illegible]	Solartec	NA	gas-fired burner	5 7 m^3 concrete lined steel tank	NA	conventional
Japan								
J-HTG-1	space and DHW heating	1 DEC 79 to 29 MAR 80	Sanyo	NA	electric water boiler	1 m^3 fiberglass tank inside heated space	0.5 m^3 external HX single tank electric auxiliary	F8-SDS Sanyo micropro-cessor
J-CLG-1	space cooling and DHW heating	1 JUL 80 to 30 SEP 80	Sanyo	Sanyo lithium bromide absorption	electric water boiler	1 m^3 fiberglass tank inside cooled space	0.5 m^3 external HX single tank electric auxiliary	F8-SDS Sanyo micropro-cessor
J-HTG-2	space and DHW heating	1 DEC 80 to 31 MAR 81	General Electric	NA	electric water boiler	1 m^3 fiberglass tank inside heated space	0.5 m^3 external HX single tank electric auxiliary	F8-SDS Sanyo micropro-cessor
J-CLG-2	space cooling and DHW	7 JUL 81 17 SEP 81	General Electric	Sanyo lithium bromide absorption	electric water boiler	1 m^3 fiberglass tank inside cooled space	0.5 m^3 external HX single tank electric auxiliary	conventional
Netherlands								
N-HTG-1	space and DHW heating	planned	Philips VTR 261	NA	gas-fired burner	4.0 m^3 multi-featured tank inside heated space	no DHW storage HX in main tank	HP-87A microcomputer
Sweden								
S-HTG-1	district space and DHW heating	AUG 81 to NOV 81	General Electric	NA	biomass fired plant	NA	NA	conventional with radiation integrators
S-HTG-2	district space and DHW heating	AUG 81 to NOV 81	Owens-Illinois	NA	biomass fired plant	NA	NA	conventional with radiation integrators
S-HTG-3	district space and DHW heating	AUG 81 to NOV 81	Philips VTR 141	NA	biomass fired plant	NA	NA	conventional with radiation integrators
Switzerland								
CH-HTG-1	District space and DHW Heating	Planned	Sanyo Corning	NA	gas-fired plant	NA	NA	micropro-cessor with conventional

Experiment	Mode	Dates	Collector	Chiller	Auxiliary	Main Tank	DHW	Controls
United Kingdom								
UK-HTG-1	space and DHW simulated heating	SEP 81 to MAY 82	Philips VTR 141	NA	NA	1.4 m^3 vertical cylindrical steel tank	0.12 m^3 internal HX cylindrical copper tank	computer control
USA								
USA-HTG-1	space and DHW heating	5 FEB 80 to 8 MAR 80	Miromit	NA	electric off-peak thermal storage	4.4 m^3 rectangular steel tank inside heated space	external HX two tank elec. aux.	ATOP, MECA I & conventional
USA-CLG-1	space cooling and DHW heating	10 JUNE 80 to 30 JUL 80	Miromit	Arkla WF36 lithium bromide absorption	electric boiler	4.4 m^3 rectangular steel tank inside cooled space	external HX two tank elec. aux.	conventional
USA-CLG-2	space cooling and DHW heating	11 AUG 80 to 8 SEP 80	Philips VTR 141	Arkla WF36 lithium bromide absorption	electric boiler	4.4 m^3 rectangular steel tank inside cooled space	external HX two tank elec. aux.	conventional
USA-CLG-3	space cooling and DHW heating	18 SEP 80 to 30 SEP 80	Philips VTR 141	Arkla XWF3600 lithium bromide absorption	electric boiler	4.4 m^3 rectangular steel tank inside cooled space	external HX two tank elec. aux.	conventional
USA-HTG-2	space and DHW heating	8 NOV 80 to 14 JAN 81	Philips VTR 141	NA	electric boiler	4.4 m^3 rectangular steel tank inside heated space	external HX two tank elec. aux.	conventional
USA-HTG-3	space and DHW heating	14 JAN 81 to 1 FEB 81	Philips VTR 141	NA	electric boiler	4.4 m^3 rectangular steel tank inside heated space	external HX single tank elec. aux.	conventional
USA-HTG-4	space and DHW heating	12 FEB 81 to 31 MAR 81	Philips VTR 141	NA	electric off-peak thermal storage	4.4m^3 rectangular steel tank inside heated space	external HX single tank elec. aux.	ATOP, MECA I
USA-CLG-4	space cooling and DWH heating	1 JUL 81 to 17 SEP 81	Philips VTR 141	Arkla XWF3600 lithium bromide absorption	electric boiler	4.2 m^3 cylindrical steel pressurized vessel outside cooled space	internal HX single tank elec. aux.	MECA II
West Germany								
WG-DHW-1C	DHW heating	MAR-MAY and AUG 79	Corning	NA	elec. and/or central heating storage	1.5 m^3 cylindrical tank outside heated space	internal HX two tank	micropro-cessor with conventional back-up
WG-HTG-1P	space heating	MAR-MAY and AUG 79	Philips MK IV	NA	oil burner	15.0 m^3 cylin-drical tank outside heated space	NA	micropro-cessor with conventional back-up

Experiment	Mode	Dates	Collector	Chiller	Auxiliary	Main Tank	DHW	Controls
WG-DHW-2P	DHW heating	JUN, JUL and SEP-DEC 79	Philips MK IV	NA	elec. and/or central heating storage	1.5 m^3 cylindrical tank outside heated space	internal HX two tank	micropro-cessor with conventional back-up
WG-HTG-2C	space heating	JUN, JUL and SEP-DEC 79	Corning	NA	oil burner	15.0 m^3 cylin-drical tank out-side heated space	NA	micropro-cessor with conventional back-up
WG-DHW-3P	DHW heating	JAN to MAY 80	Philips MK IV	NA	elec. and/or central heating storage	1.5 m^3 cylindrical tank outside heated space	internal HX two tank	micropro-cessor with conventional back-up
WG-HTG-3C	space heating	JAN to MAY 80	Corning	NA	oil burner	15.0 m^3 cylin-drical tank out-side heated space	NA	micropro-cessor with conventional back-up
WG-DHW-4C	DHW heating	JUN to DEC 80	Corning	NA	elec. and/or central heating storage	1.5 m^3 cylindrical tank outside heated space	internal HX two tank	micropro-cessor with conventional back-up
WG-HTG-4P	space heating	JUN to DEC 80	Philips MK IV	NA	oil burner	15.0 m^3 cylin-drical tank out-side heated space	NA	micropro-cessor with conventional back-up
WG-DHW-5C	DHW heating	JAN to DEC 81	Corning	NA	elec. and/or central heating storage	1.5 m^3 cylindrical tank outside heated space	internal HX two tank	micropro-cessor with conventional back-up
WG-HTG-5P	space heating	JAN to Dec 81	Philips MK IV	NA	oil burner	15.0 m^3 cylin-drical tank out-side heated space	NA	micropro-cessor with conventional back-up

Table 5-2. Climate Data for the Experimental Periods

Experiment	Dates	Degree Days[1] (°C days)	Average Daily Insolation (MJ/m^2)	Average Daily Ambient Temperature (°C)	Average Daily Temperature (°C) max	min
Japan						
J-HTG-1	1 DEC 79 to 29 MAR 80	1549	9.2	5.5	21.4	-3.9
J-HTG-2	1 DEC 80 to 31 MAR 81	1694	11.8	4.3	19.0	-7.2
J-CLG-1	1 JUL 80 to 30 SEP 80	163	13.1	24.6	34.4	13.9
J-CLG-2	7 JUL 81 to 17 SEP 81	227	17.3	26.7	35.2	13.2
Sweden						
S-HTG-1	AUG 81 to NOV 81	1041	8.5	8.0	26.0	-11.0
S-HTG-2	AUG 81 to NOV 81	1041	8.5	8.0	26.0	-11.0
S-HTG-3	AUG 81 to NOV 81	1041	8.5	8.0	26.0	-11.0
USA						
USA-HTG-1	5 FEB 80 to 8 MAR 80	1082	17.5	-1.5	7.4	-6.7
USA-CLG-1	10 JUN 80 to 30 JUL 80	360	21.0	21.7	30.6	13.5
USA-CLG-2	11 AUG 80 to 8 SEP 80	111	19.8	20.4	27.8	11.5
USA-CLG-3	18 SEP 80 to 30 SEP 80	13	25.7	16.7	26.0	8.2
USA-HTG-2	8 NOV 80 to 14 JAN 81	1813	14.2	3.1	11.0	-4.7
USA-HTG-3	14 JAN 81 to 1 FEB 81	568	17.5	0.9	8.9	-7.7
USA-HTG-4	12 FEB 81 to 31 MAR 81	1245	18.9	3.2	10.8	-3.8
USA-CLG-4	1 JUL 81 to 17 SEP 81	382	19.0	20.8	28.3	12.9
West Germany						
WG-DHW-1C	MAR-MAY & AUG 79	NA	12.5	12.9	NA	
WG-DHW-2P	JUN, JUL & SEP-DEC 79	NA	11.2	12.5	NA	
WG-HTG-1P	MAR-MAY & AUG 79	NA	12.5	12.9	NA	
WG-HTG-2C	JUN, JUL & SEP-DEC 79	NA	11.2	12.5	NA	
WG-DHW-3P	JAN-MAY 80	NA	9.4	6.2	NA	
WG-DHW-4C	JUN-DEC 80	NA	11.9	11.7	NA	
WG-HTG-3C	JAN-MAY 80	*3333	9.9	6.2	NA	
WG-HTG-4P	JUN-DEC 80		11.2	11.7	NA	
WG-DHW-5C	JAN-DEC 81	NA	10.7	9.8	NA	
WG-HTG-5P	JUN-DEC 81	2989	10.7	9.8	NA	

[1]Heating Degree Days based on 18°C; Cooling Degree Days based on 23.9°C.

TABLE 5-3. ACTUAL AVERAGE DAILY LOADS FOR TEST PERIOD

	Osaka Sanyo Solar House Japan	Knivsta District Heat. Proj. Sweden	Solarcad District Heat. Proj. Switzerland	Colorado State Univ. Solar House I USA	Solarhaus Freiburg West Germany
Actual Average Daily Heating Load (MJ/day)					
January 1980	75	NA	[2]270,000	[3]297	1861
January 1981	155	[2]630,000	300,000	292	1881
Actual Average Daily Cooling Load (MJ/day)					
July 1980	44	NA	NA	587	NA
July 1981	74	NA	NA	481	NA
Actual Average Daily Domestic Hot Water Load (MJ/day)					
January 1980	52	NA	NA	[3]66.7	187
July 1980	25	NA	37,000	19.9	144
January 1981	45	NA	NA	108.7	230
July 1981	17	90,000	34,000	8.3	126
Total Actual Average[1] Daily Loads (MJ/day)					
1979-80 heating season	130	NA	180,000	331	[4]1215
number of days of data	113	NA	243	43	304
1980-81 heating season	163	NA	200,000	359	[4]1111
number of days of data	72	NA	243	151	290
1980 cooling season	77	NA	NA	573	NA
number of days of data	71	NA	NA	107	NA
1981 cooling season	74	NA	NA	359	NA
number of days of data	69	NA	NA	77	NA

NA - not applicable; [1]includes DHW loads; [2]all Sweden and Switzerland's loads include DHW; [3]load is for February 1980; [4]heating seasons are based on calendar year Jan - Dec which includes summer storage losses.

5.1 MOUNTAIN SPRINGS BOTTLE WASHING FACILITY - CANADA

The objective is to determine via replacement or upgrading, where practical, or via simulation, subsystem components in an effort to maximize system performance and determine areas in which costs in future installations may be reduced or eliminated. The system is shown in Figure 5-1.

5.1.1 Experiment C-IPH-1 (winter 1979 - summer 1980)

The collector loop has two temperature sensors to monitor and control the system. One is mounted in a wall near the bottom of the solar tank and the other is located inside a specially equipped control solar collector. The collector operates in two modes. Normal operation: collector turns on at a ΔT of 17°C with a minimum run time of 30 minutes; collector turns off at a ΔT of 4°C. Overtemperature: If the solar tank temperature is greater than 90°C, the solar collection loop shuts off. If the collector control temperature becomes greater than 150°C the operation of the collection loop ceases. This is to prevent the breakage of hot tubes by thermal shock. There are two modes of operation for the heat transfer loop. First, if heat is demanded by the soaker tank and the accumulator temperature is 10°C greater than the inlet temperature to the heat exchanger (ΔT = 10°C), the circulation pump between the accumulator and the heat exchanger is activated, thus initiating heat transfer; the system turns off at ΔT of 2°C. Second, if the accumulator temperature reaches 90.5°C and if no heat is demanded by the soaker tank (i.e. weekends), both the soaker tank pump and the heat exchanger circulation pump are activated in order to dump heat into the 14000 liter soaker tank. This effectively increases the storage capacity of the system by 14000 liters.

5.2 OSAKA SANYO SOLAR HOUSE - JAPAN

System experiments in the Osaka Sanyo Solar House have been conducted for space heating, space cooling, and domestic hot water supply with loads generated by a family living there throughout a year. The life pattern of the family was not restricted to the heating and cooling time schedule prepared for the design load calculation, rather the period and duration of heating or cooling of the house were left to their demands.

The solar system can be divided into three major systems depending upon corresponding experiments, that is, a space heating and DHW supply system, space cooling and DHW supply system and DHW supply system. The solar system is shown in Figure 5-2.

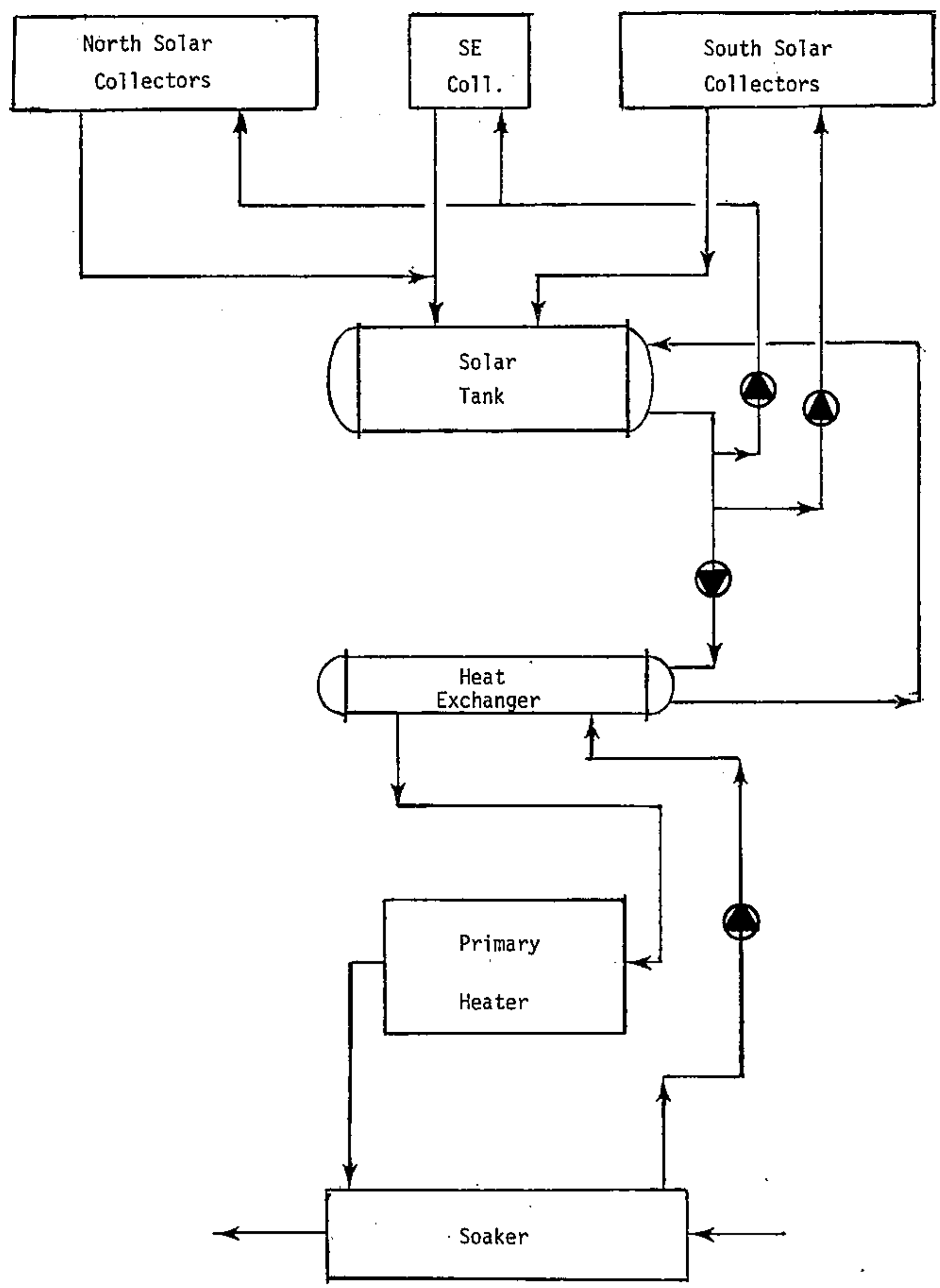


Figure 5-1. Solar System Schematic - Canada

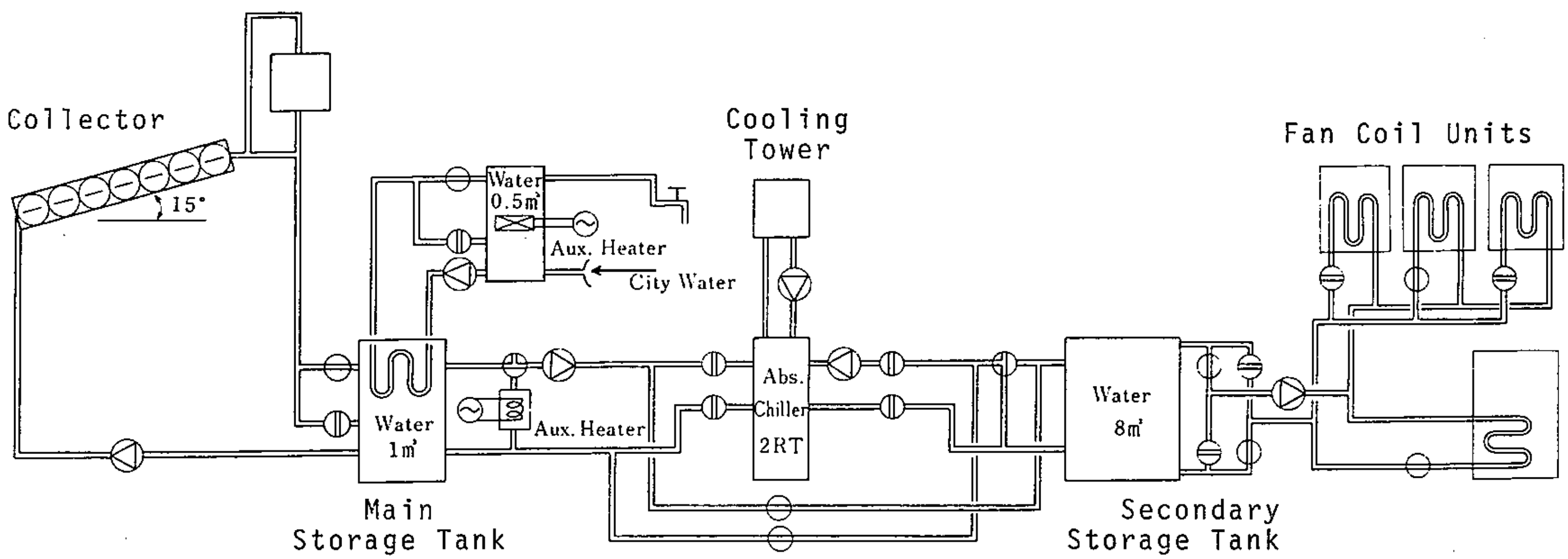


Figure 5-2. Solar System Schematic - Japan

The objectives of the space heating and DHW experiments are to provide sufficient data under real loads of the solar house under Osaka weather conditions, to evaluate the system components for the winter season and to develop an optimum control system for the solar house.

The operating modes in the space heating and DHW supply system experiments are considered to be combinations of basic modes for solar collection, space heating and DHW supply subsystems. Basic modes in the solar energy collection subsystem are a solar energy collecting mode and freeze protection mode. Basic modes in the space heating subsystem are a solar energy storing mode, energy storing mode, stored energy heating mode, solar energy heating modes and auxiliary heating mode. There are two stored energy heating modes. One is the mode in which energy is only transported from the second storage tank to the fan coil units and the other is the mode in which energy is transported from the first storage tank to the second storage tank and then from the second storage to a fan coil unit.

There are two distinct heating experiments, designated by J-HTG-1 and J-HTG-2, which use two different evacuated collectors.

The objectives of the space cooling and DHW experiments were almost the same as the space heating and DHW supplying system. In these experiments the absorption chiller of 7 KW was used for obtaining chilled water and the chiller performance was carefully examined.

There are also two distinct cooling experiments, designated by J-CLG-1 and J-CLG-2, which again use two different evacuated collectors.

Basic operational modes in these experiments can be considered in the same way as in the space heating and DHW supplying system. Basic modes in the space cooling subsystems are solar energy storing, energy storing, two stored energy cooling modes, solar energy cooling and auxiliary cooling modes. Basic modes in other subsystems are the same as in the space heating system except for the freeze protection mode which did not occur in these experiments. Among these modes the auxiliary cooling mode is operated only when cooling demands exist.

The system was controlled by a microprocessor. The additional controlled elements were the chilled water circulation pump, cooling tower, cooling water pump, and absorption chiller. The control strategies for solar energy collection in these experiments are the same as those in the space heating and DHW supply system. The solar energy collection was terminated even when solar incident energy is available, when stored energy is sufficient and the temperature of the first storage tank is greater than 95°C. When the temperature of the first storage tank becomes higher than 80°C, the chiller starts working, and the chilled water of 10°C is stored in the second storage tank. When the temperature of the second storage tank falls below 10°C, the chiller is terminated. When the temperature of the second storage tank is higher than 15°C, while the first storage tank is lower than 75°C, and space cooling is required, the chiller is then supplied by the auxiliary boiler.

5.2.1 Experiment J-HTG-1 (1 December 1979 - 29 March 1980)

Sanyo collectors were used during this first test period. The control strategy was changed on 11 January 1980 when a microprocessor was introduced in the control system.

The climate for this period was colder than the average year since the average temperature for this period is lower than for the thirty years average by 1.4°C. As for the insolation, this year can be considered typical.

Solar energy collection occurs when the temperature difference between the collector array outlet and the top of the first storage tank is greater than 3°C. Whether the valves are open or closed depends upon the temperature difference between the top and bottom of the storage tank. Freeze protection is operated when at least one of the temperatures in the collector arrays is less than 2°C and the ambient temperature is less than 0°C. The collector pump is then operated for four minutes. Freeze protection is not utilized within one hour after the last freeze protection operation even when the signal for freeze protection stands.

The DHW supply heat exchange occurs when the temperature difference between the first storage and the DHW storage tank is greater than 5°C and the pump stops when the temperature in the DHW storage tank reaches 50°C. When the temperature goes below 50°C, the DHW auxiliary heater in the DHW storage tank operates if time is between 16 to 19 hours.

For space heating, hot water from the second storage tank is sent to the fan coil units when at least one of the units is switched on. When the temperature in the first storage tank is higher than 45°C and also it is higher than the temperature in the second storage tank, heat is transferred from the first to the second storage tank until the temperature in the second storage tank is raised to 50°C.

The auxiliary boiler operates when the temperature in the second storage tank is lower than 40°C and also higher than that in the first storage tank and when a heating load exists.

5.2.2 Experiment J-HTG-2 (1 December 1980 - 31 March 1981)

For this period, the solar collectors used were GE collectors. The control strategy was the same as the experiment J-HTG-1. Because of a monitoring system failure and of a trouble in the power supply to the collector pump, the measurements could not be made until 7 January 1981.

The climate was cooler than the average year by 2.3°C. The insolation was, however, greater than the average year by 2.6 MJ/m^2 day.

5.2.3 Experiment J-CLG-1 (1 July - 30 September 1980)

In this operation only Sanyo collector arrays on the roof were employed and the effective collector area and their aperture area were 40.6 and 52.8 m^2, respectively.

The long term average ambient temperature and daily insolation for three months from July to September was 26.2°C and 16.3 MJ/m^2 day and, therefore, this summer period can be considered not typical.

From 11 to 17 August, the solar house was vacant, but the fan coil unit in the living room was still operated. From 21 August to 11 September, the measured data was difficult to process because of noises on the magnetic tape.

5.2.4 Experiment J-CLG-2 (7 July - 17 September 1981)

In this experiment, the evacuated collector used was the GE collector and the aperture of the collector arrays was 33.1 m^2.

This season was considered typical as the insolation and average ambient temperature were typical for the summer.

During this experiment there was a problem in the microprocessor.

5.3 EINDHOVEN TECHNOLOGICAL UNIVERSITY SOLAR HOUSE - NETHERLANDS

The objective of the basic experiment was to study the performance of evacuated tubular collectors in an optimally controlled up-to-date system under Dutch climatic conditions, to determine the influence on performance of the special features in the storage vessel, to find the optimal control strategy and to investigate simple technical solutions for safety measures such as freeze protection, boiling protection and expansion problems. See Figure 5-3.

5.3.1 Experiment N-HTG-1 (planned)

The collector loop can be divided into three operations. In the first, labelled normal operation, energy is transferred from collectors to storage tank, flow is controlled by the radiation intensity, the daily heat demand and ambient temperature. The pump in the collector loop starts at minimum-flow and has maximum-flow when temperature difference between collector outlet and storage bottom temperature is about 25°C. The mass flow is basically proportional to the square root of the solar radiation intensity beyond the threshold value dependent on earlier mentioned circumstances. The control strategy is carried out by a microcomputer.

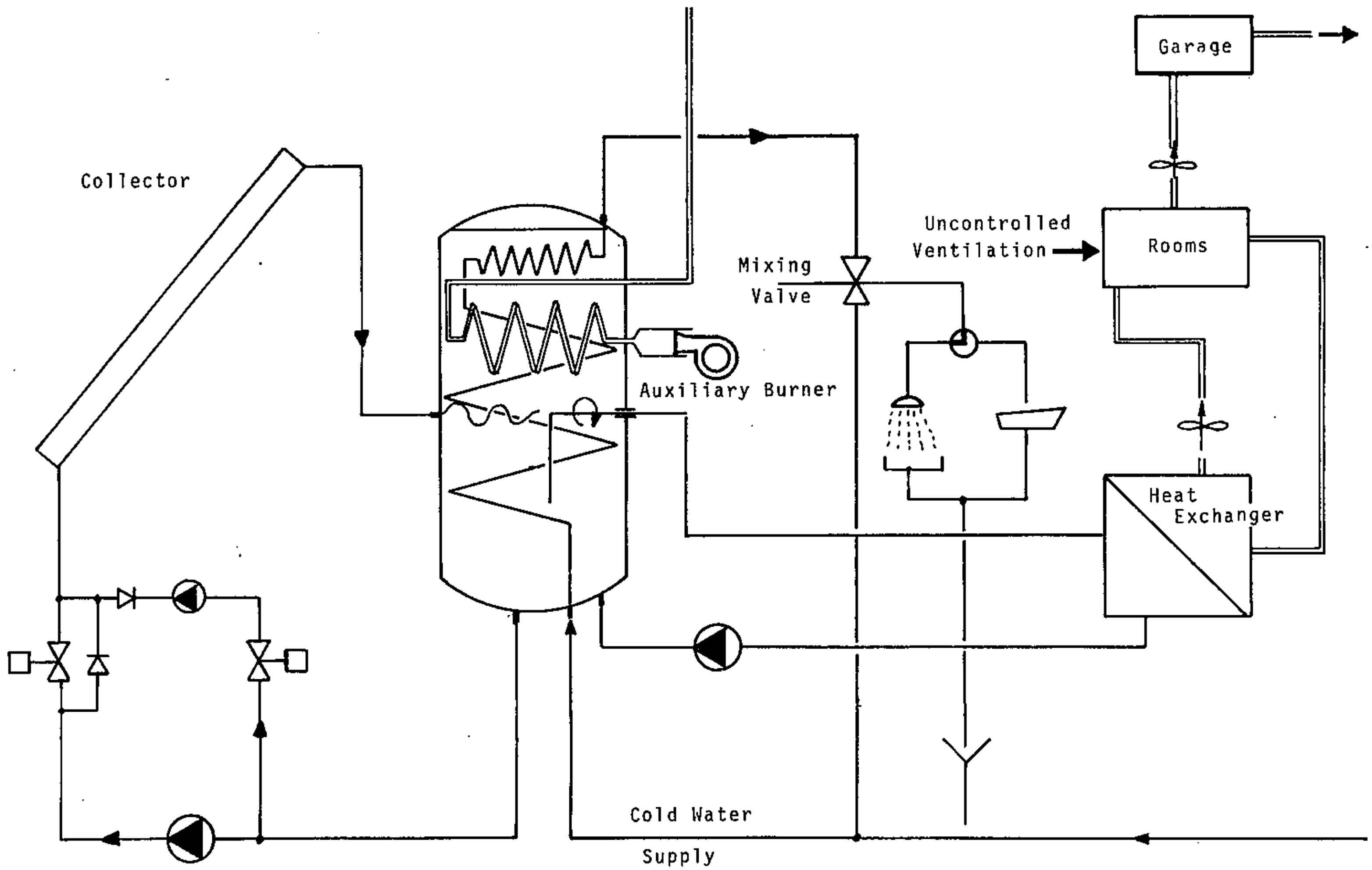


Figure 5-3. Solar System Schematic - Netherlands

In the high-temperature operation, if the temperature in the top of the storage vessel rises above 80°C, the pump in the collector loop stops, water in the collectors starts boiling and steam expels the remaining water to the storage vessel.

In the third anti-freeze operation if the temperature at the coldest spot of the collector loop drops below 5°C, collector pump will operate for 10 minutes, thus protecting the collector loop from freezing.

There are two operating modes for the storage vessel. First, storing energy from the collectors takes place as long as the temperature of 80°C has not been reached in the top of the vessel, and the difference between collector outlet and storage bottom temperature exceeds 2-10°C (adjustable). Second, when the temperature in the top of the vessel drops below 45-60°C (adjustable) storing from auxiliary continues until the top-temperature has increased 5-10°C (adjustable).

The domestic hot water system has only one operating mode: taking energy from the storage vessel via finned copper tube heat exchanger.

The heat distribution system also has only one mode of operation: taking energy from the storage vessel via a water-to-air heat exchanger. If the temperature in the living area drops below the set-point the heating system pump and air fan turn on. The swing arm outlet in the storage vessel, which is controlled by a servo motor, selects an adequate temperature level to meet the demand. These temperatures are 50°C when outside temperature is -15°C and 25°C when outside temperature is 16°C and above. Linear interpolation occurs for intermediate temperatures.

5.4 KNIVSTA DISTRICT HEATING PROJECT - SWEDEN

The long term goal of the solar energy activities of UKAB is to reduce oil dependence. The main purpose of the Knivsta project is to gain experience in handling this new technology and to find out how the collector systems work outside the laboratories. The three solar systems will all be operated in the same way. One of the technical experiments to be carried out is the investigation of heat capacity effects. The Knivsta installation comprises systems with both high and low heat capacity and hence its role and impact on energy production in large collector fields can be easily studied. See Figure 5-4 for systems diagram.

From a climatic point of view, this experimental period is representative for all countries with a Northern moderate climte extending from a warm August period to a very unproductive cloudy November. The total measured irradiated energy during the test period was about 972 MJ/m^2, which has to be compared with the expected 4,320 MJ/m^2 yearly irradiation on an inclined surface of 45°. Hence the system performance is expected to be below the average expected for a whole year.

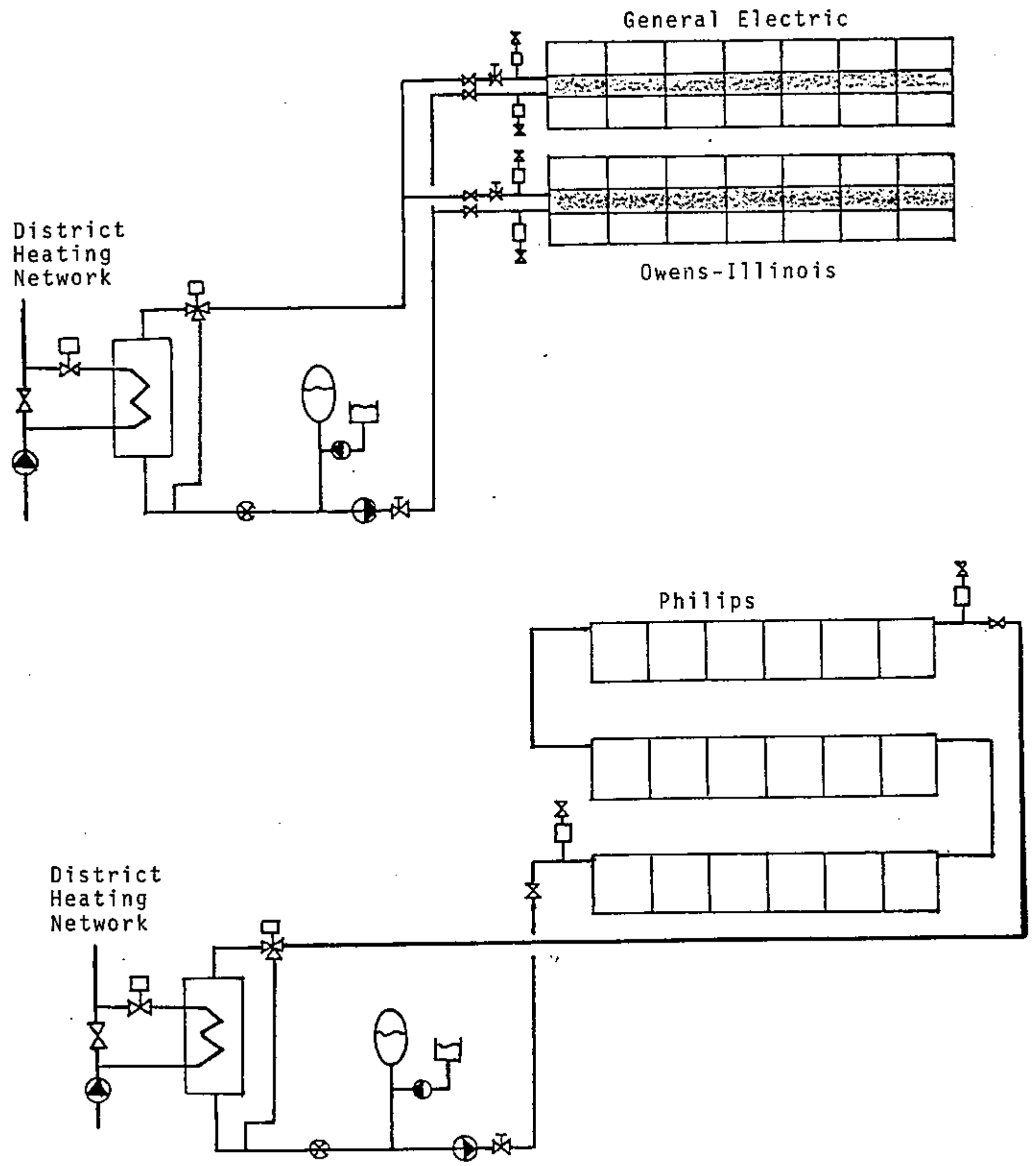


Figure 5-4. Solar System Schematic - Sweden

Several mistakes were made when the system was designed. Three exactly similar systems were installed in order that the measurements could be done under conditions that were as similar as possible. This resulted, for example, in pump capacity and expansion volume not sized correctly for all three systems.

The main reason behind all problems was that the static pressure in the solar circuits was often too low. On some occasions the static pressure in the highest point was lower than atmospheric pressure. This contributed, for example, to serious problems with air leakage into the system.

The pumps in the GE and OI systems were replaced. The first pumps were only about 50 W and could only manage about 75 percent of the nominal flow. Those pumps have been replaced by larger (1 kW) pumps. However, this is a disadvantage from the measurements viewpoint as a large quantity of energy is introduced to the system in the form of work done by the pumps. The smaller pump was sufficient for the Philips system. Other problems include: tube blocking within the GE and OI collector modules occurred requiring cleaning that was often difficult to do. Boiling problems also occurred which required the stopping of the pumps. Often the system would then require bleeding and the addition of make up water. All three of the experiments listed below use the same measurement system and were operated during the same report period but have separate collector subsystems.

5.4.1 Experiment S-HTG-1 (August - November 1981)

This experiment uses General Electric collectors.

5.4.2 Experiment S-HTG-2 (August - November 1981)

This experiment uses Owens-Illinois collectors.

5.4.3 Experiment S-HTG-3 (August - November 1981)

This experiment uses Philips VTR141 collectors.

5.5 SOLARCAD DISTRICT HEATING PROJECT - SWITZERLAND

5.5.1 CH-HTG-1 (planned)

The current main objective for the experiment is to evaluate performances with respect to all energy flows for the Sanyo and Corning collector systems. This will involve precise measurements for at least one year, calibrations, data analysis, study of capacity effects and heat losses, varying control parameters, modelling, simulation and validation. The final goal is to understand the system and its dynamics in order to design properly the final 1000 m^2 system and to evaluate the potential use of evacuated collectors in the Swiss climate. See Figure 5-5 for systems diagram.

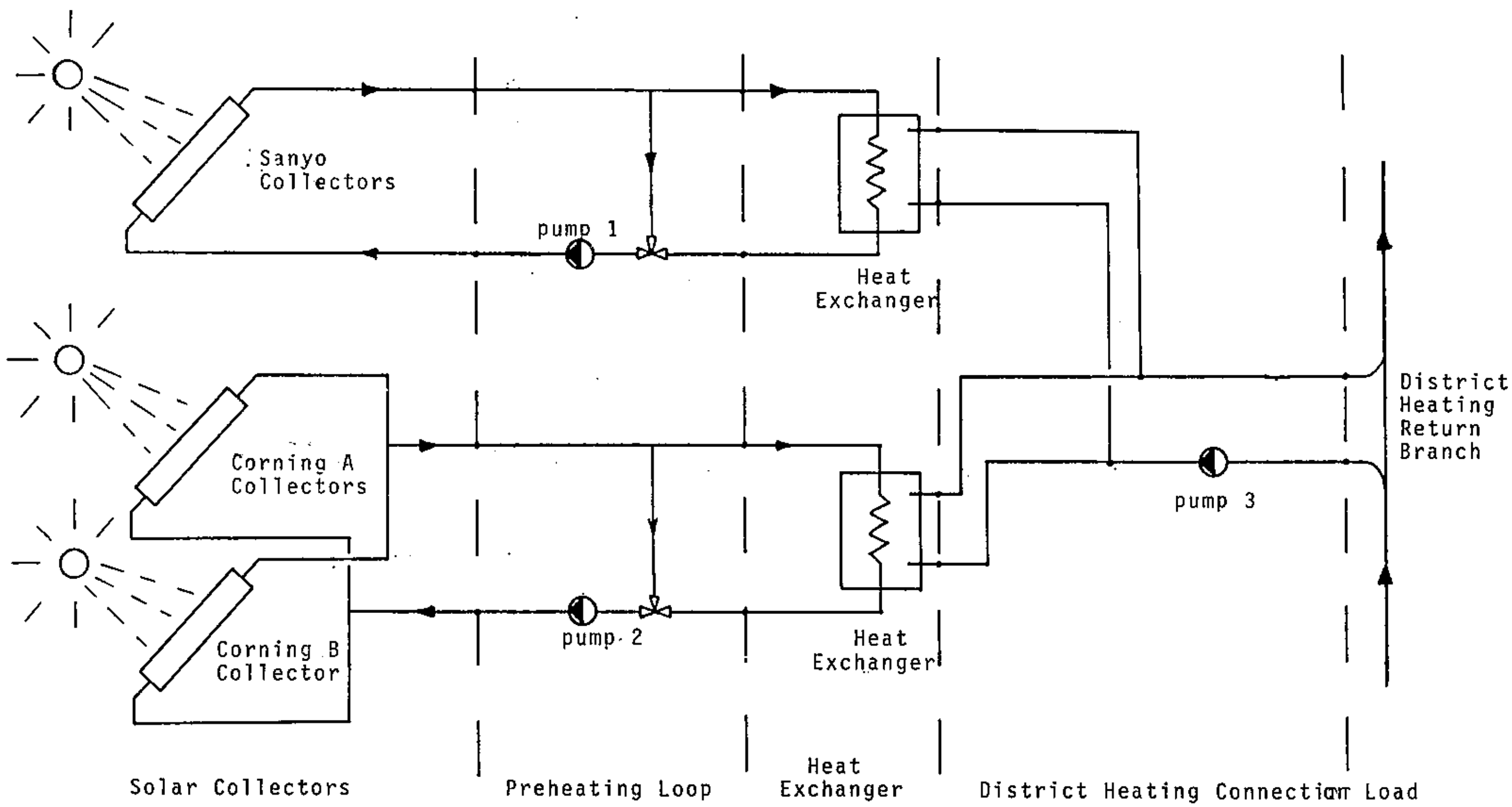


Figure 5-5. Solar System Schematic - Switzerland

5.6 EVACUATED COLLECTOR SYSTEM TEST FACILITY - UNITED KINGDOM

The analysis of the 1981-82 season results will proceed through the summer of 1982 to produce collector efficiency curves under operating conditions, system efficiencies, solar fractions and energy input/output data for major subsystems. This information will be used to validate the system model for operation with simulated loads. See Figure 5-6 for systems diagram.

5.6.1 Experiment UK-HTG-1 (September 1981 - May 1982)

The operating modes of the system are designed so that when the collector temperature reaches the setting of the collector thermostat (60°C), the solar circuit pump is turned on and the fluid bypasses the heating coils in the storage tank. After a delay (3 minutes) the differential thermostats are interrogated. Each of these senses the temperature of the circulating fluid immediately before the branch to one of the storage tanks and the temperature of water in that tank. If the differential exceeds the on differential (5°C) the circulating fluid is directed through the coil in the storage. When the differential drops below the off differential (2°C), the fluid is directed past the coil in the storage. If the temperature in either storage exceeds the high limit (90°C for the space heating store and 55°C for the domestic hot water store), the fluid is directed past the appropriate coil. If the collector fluid bypasses both coils the pump is stopped and restarting is inhibited for eleven minutes.

5.7 COLORADO STATE UNIVERSITY SOLAR HOUSE I - USA

The major components in a series of solar heating, cooling and hot water systems have been installed, evaluated, and replaced at approximately one-year intervals. The extensive results of these investigations have provided information for evaluating a wide variety of solar heating and cooling systems. In the two-year period between October 1979 and September 1981, shorter performance measurements were made on a total of eight different systems employing two types of solar collectors.

A flat plate collector in a drain back design was used in a space heating system and in a cooling system with a conventional absorption chiller. Space heating was also provided by three slightly different systems in which an evacuated heat pipe collector was used. This same collector was also used in three cooling systems, one with the commercial chiller and two with an experimental lithium bromide absorption chiller employing internal evaporative cooling.

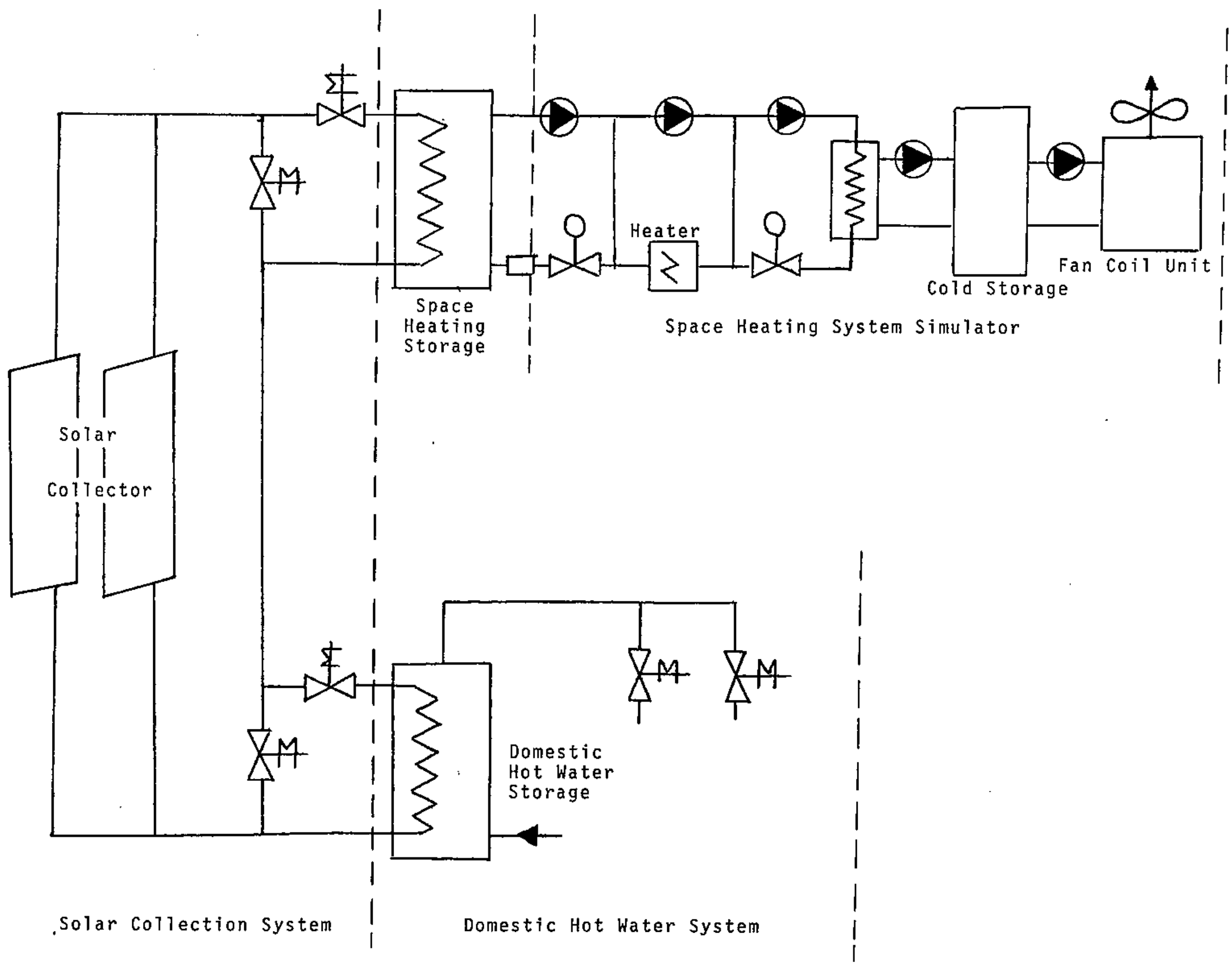


Figure 5-6. Solar System Schematic - United Kingdom

5.7.1 System USA-HTG-1 (5 February - 8 March 1980)

The Miromit collector, Bally tank, off-peak auxiliary, external heat exchanger two tank service hot water system and MECA I controls were used. The objectives of the experiment were: 1) to test the off-peak electric heat storage auxiliary with predictive type controller; and 2) to test a drain back arrangement for freeze protection.

In the solar collection and storage mode the collector pump turns on whenever the collector temperature exceeds the bottom of the storage tank temperature by 10°C and remains on until a temperature difference of 2°C occurs. Space heating occurs when the room thermostat signals a demand for heat and if the temperature at the top of the tank exceeds 25°C, the main load pump is actuated and water from storage is circulated through the air heating coil. If the room temperature falls yet another 1°C then the solar heat is stopped and the air passes through the off-peak auxiliary unit.

The service hot water system provides for a direct exchange from main storage to service hot water via two small pumps and a heat exchanger. When the main storage exceeds the temperature in the bottom of the service hot water preheat tank by 10°C, the two pumps are actuated and heat is transferred to the service hot water. When this temperature difference falls below 2°C, the pumps are shut off. If the temperature in the preheat tank exceeds 60°C no further energy is supplied from the main tank to the auxiliary electric hot water heater. If the temperature falls below the setting in that tank, heat is electrically supplied to raise the temperature of the water to the thermostat setting.

Electric heat is supplied to the off-peak heat storage unit between 10:00 pm and 6:00 am during each night when sensors indicate insufficient solar heat in storage for supplying all space heating requirements the following day (until 10:00 pm), assuming no solar energy is received during that period. An electric duct heater is also provided in the off-peak unit to provide resistance heating if needed. See Figure 5-7 for the system diagram.

5.7.2 System USA-CLG-1 (10 June - 30 July 1980)

Space cooling with drain back flat plate collector, separate cooling tower, absorption water chiller and external heat exchanger two tank service hot water system was used. This system is similar to USA-HTG-1 except the WF36 Arkla chiller with outside cooling tower and electric auxiliary is used in place of the heating components. The objective of the experiment was to test the drain down collection system used during the previous heating season in a cooling system and to compare this cooling system with other Solar House I cooling systems. The same cooling system had been used with two different evacuated tubular collectors in previous seasons and will be used with the heat pipe

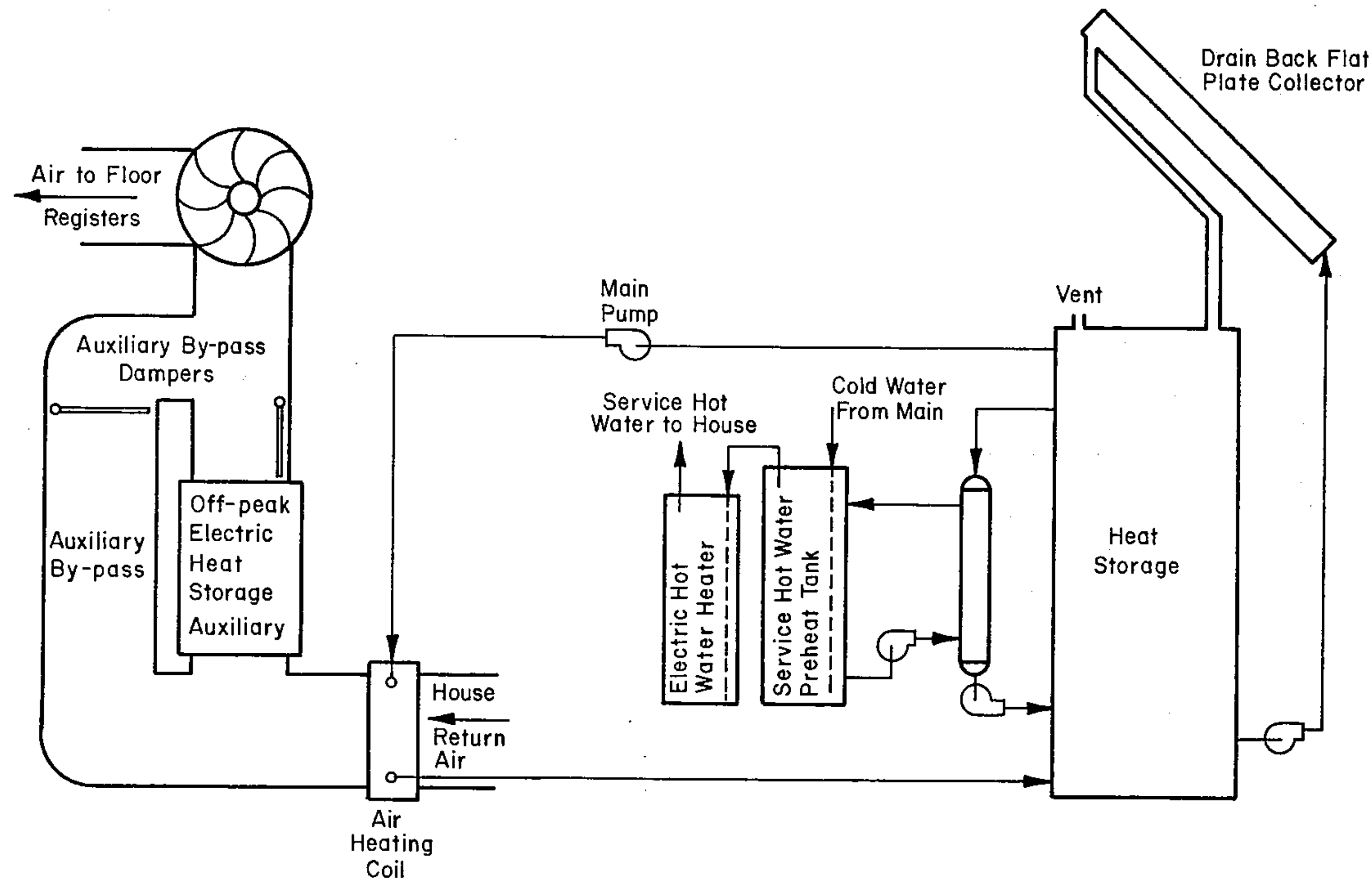


Figure 5-7. USA-HTG-1, Space Heating with Drain Back Flat PLate Collector, Electric Off-Peak Auxiliary and Double Tank Service Hot Water System with External Heat Exchanger.

evacuated tubular collector. When the system was in the solar mode, the solar auxiliary valve was in a position such that water was drawn from solar storage through the pump and returned from the absorption chiller to the bottom of the storage tank. When the room temperature rose above the thermostat set point, the main circulating pump was actuated, the chilled water pump and the cooling tower pump started, and the main system blower circulating air through the cooling coil and house was turned on. If the temperature at the top of the storage tank was greater than 70°C, the solar/auxiliary valve position remained unchanged, and the chiller generator was supplied with hot water from solar storage. However, if the temperature at the top of the solar storage tank was below 70°C, the valve moved to the auxiliary position, and the chiller generator was supplied with water from the hot water boiler, to which electricity was simultaneously supplied. Operation of the chiller, either from main solar storage or from the auxiliary boiler, continued until the temperature in the living space fell below the thermostat setting, where upon the heat supply to the chiller was terminated. However, the other chiller operations continued for several minutes in order that the cooling capability stored in the chiller could be fully utilized. See Figure 5-8 for system diagram.

5.7.3 System USA-CLG-2 (11 August - 8 September 1980)

Space cooling with single loop Philips VTR141 evacuated tubular collector, Arkla WF36 chiller and two tank external heat exchanger service hot water system was used. This system differs from System USA-CLG-1 in that the evacuated tubular collector replaces the flat plate collector and that the collector is not drained. The objective of this experiment was to test the new Philips heat pipe evacuated tubular collection systems with the Arkla WF36 chiller system and to compare this system with previous Solar House I cooling systems. The same cooling system had been used with three previous collectors. The solar collection and storage mode operated whenever a heat exchanger block of the Philips heat pipe evacuated tubular collector exceeded the temperature near the bottom of storage by more than 8°C, the collector pump was actuated and water from the bottom of the tank circulated to the vertical manifolds on the right and left sides of the collector. The water then circulates in parallel through the four horizontal rows of manifolds on which the collector tubes and heat exchange blocks are mounted and culminates where it is returned to the top of the storage stratification manifold. When the temperature at the exit of the collector in the same heat exchanger block used for turn-on fell to a level within 1°C of the temperature at the bottom of storage, the pump was shut off. The flow rate was .7 liters per second in the collector loop. See Figure 5-9 for system diagram.

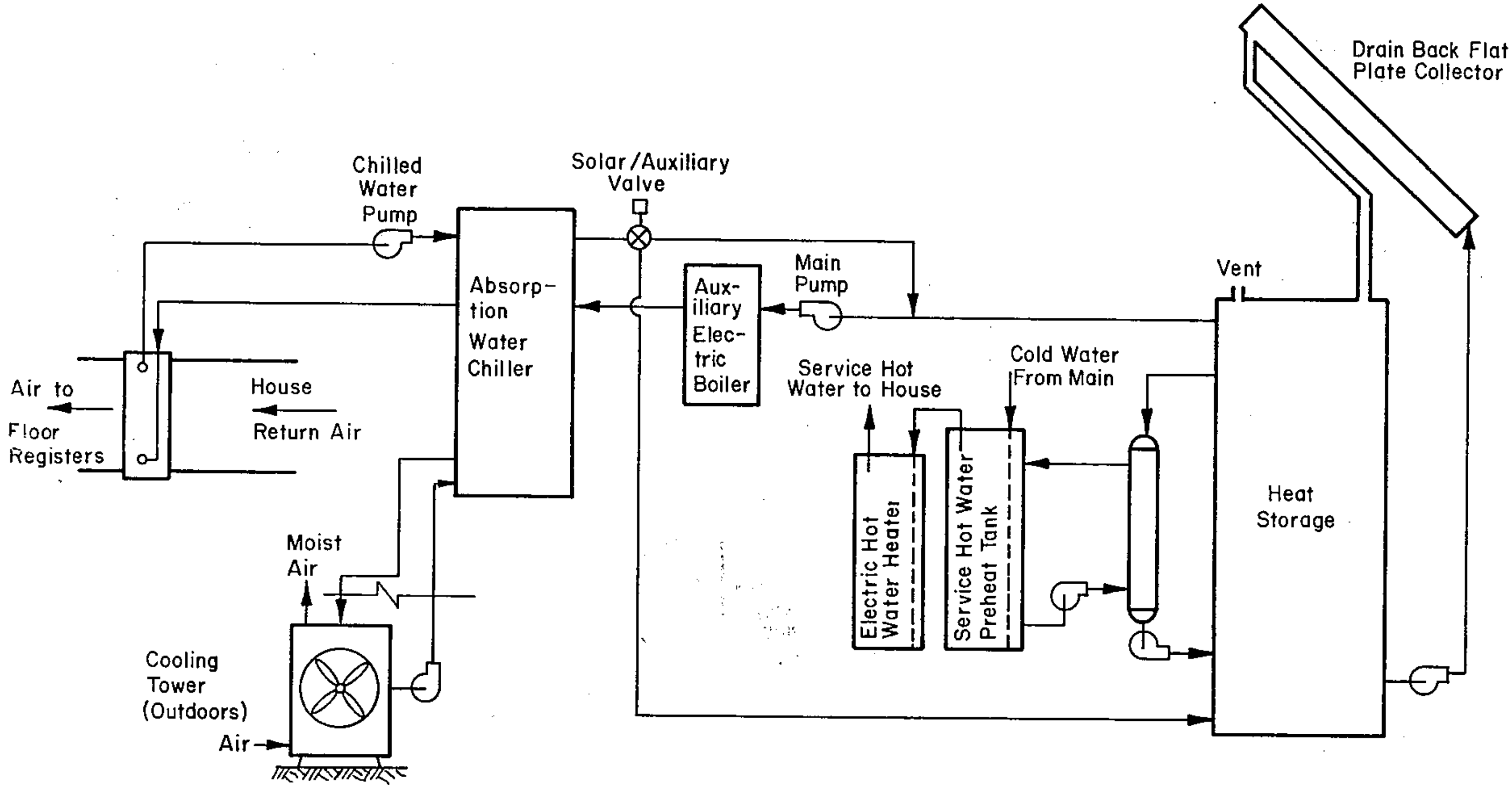


Figure 5-8. USA-CLG-1, Space Cooling with Drain Back Flat Plate Collector, Seperate Cooling Tower Absorption Water Chiller and External Heat Exchanger Two Tank Service Hot Water System.

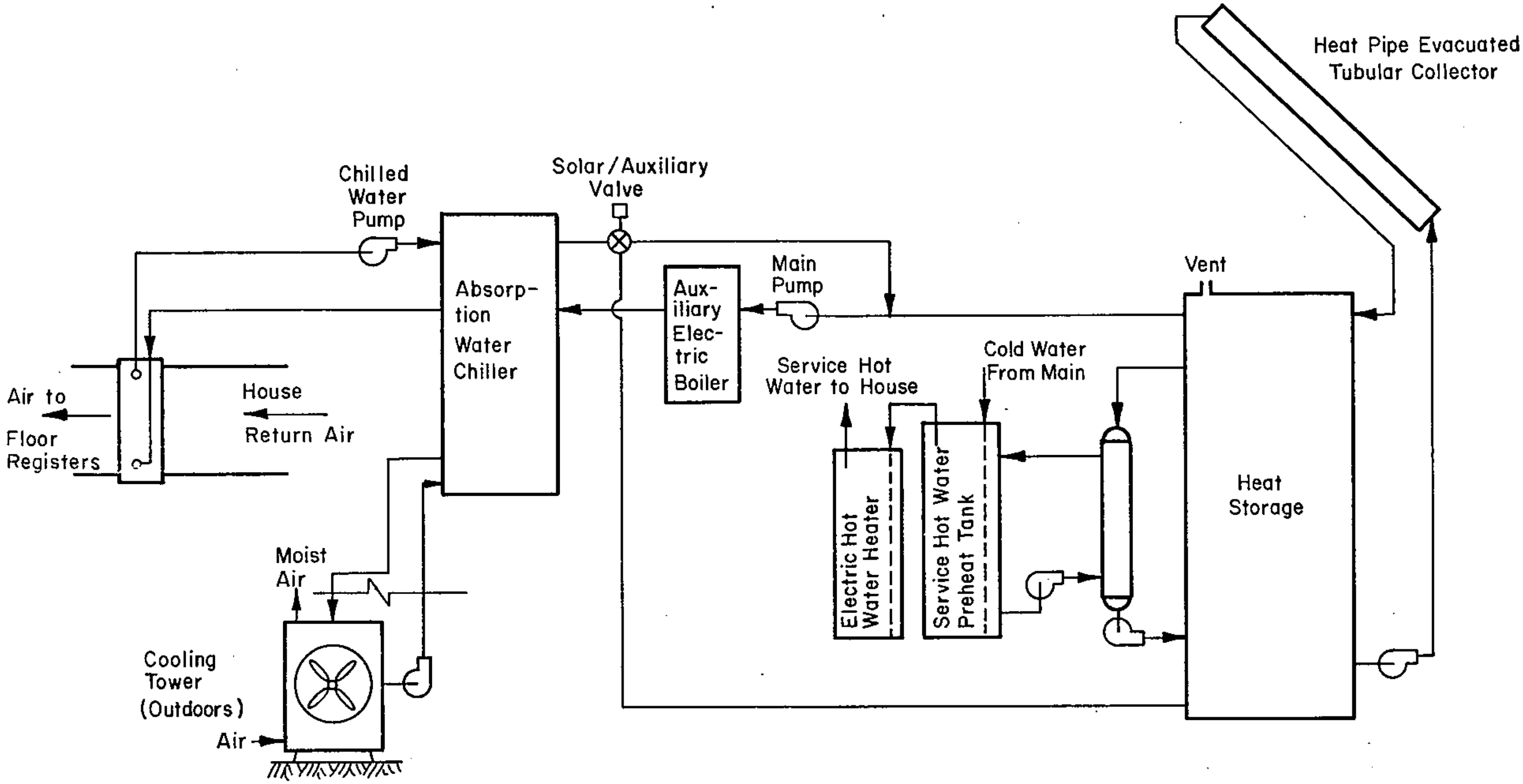


Figure 5-9. USA-CLG-2, Space Cooling with Single Loop Heat Pipe Evacuated Tubular Collector, Seperate Cooling Tower Absorption Water Chiller and External Heat Exchanger Two Tank Service Hot Water System.

5.7.4 System USA-CLG-3 (18 September -30 September 1980)

Space cooling with single loop Philips VTR141 evacuated tubular collector, Arkla XWF3600 chiller and two tank external heat exchanger service hot water system was used. This system differs from the previous one in that the Arkla WF36 chiller is replaced by the Arkla XWF3600 chiller. The objective of this experiment was to test the Philips VTR141 evacuated tubular collector and third generation Arkla prototype and compare the results with previous systems.

The operation of this system is essentially similar to that for USA-CLG-2. Operation of the Arkla XWF3600 is essentially the same as the Arkla WF36 except that the minimum storage tank temperatures are higher (80°C versus 70°C) and the auxiliary shut off temperature is also 10° higher (85°C versus 75°C). Chiller operations were still delayed for three and one-half minutes after the heat supply was shut off to chiller to fully utilize the cooling capability stored in the chiller. Various controls in the absorption chiller itself regulate the temperature of cooling water supplied to the condenser, the temperature of hot water supply to the generator, the operation of the small solution pump which circulates the absorbent liquid, and the cooling tower operation. See Figure 5-10 for system diagram.

5.7.5 System USA-HTG-2 (8 November 1980 - 14 January 1981)

Space heating with double loop Philips VTR141 evacuated tubular collectors, electric auxiliary boiler and two tank external heat exchanger service hot water system was used. In this system components from system USA-CLG-3 are replaced by a solar coil for heating air and an electric auxiliary boiler. The purpose of the experiment was to test the cooling season system as a heating system.

A 50 percent solution of water and ethylene glycol was used as the collector fluid and heat was transferred to the solar storage tank by means of two model 503 Young Radiator tube and shell heat exchangers in series. Solar energy was delivered to space heating and service hot water using the same controls as for USA-HTG-1 in the previous heating season. The electric boiler and later the off-peak electric thermal storage unit, which had been previously used, were employed. The hot water subsystem was arranged as a two tank system until January 15, and as a single tank system thereafter. The solar collection and storage mode operated whenever the temperature of the control heat exchanger block exceeded the temperature near the bottom of storage by more than 8°C, the two collector pumps were activated. Water from near the bottom of storage was pumped through the counterflow heat exchanger to transfer heat from the collector loop and was returned to the top of the stratification manifold inside the storage tank. All other characteristics are the same as described previously. Energy delivered to the building to meet space heating requirements was controlled by a two stage thermostat.

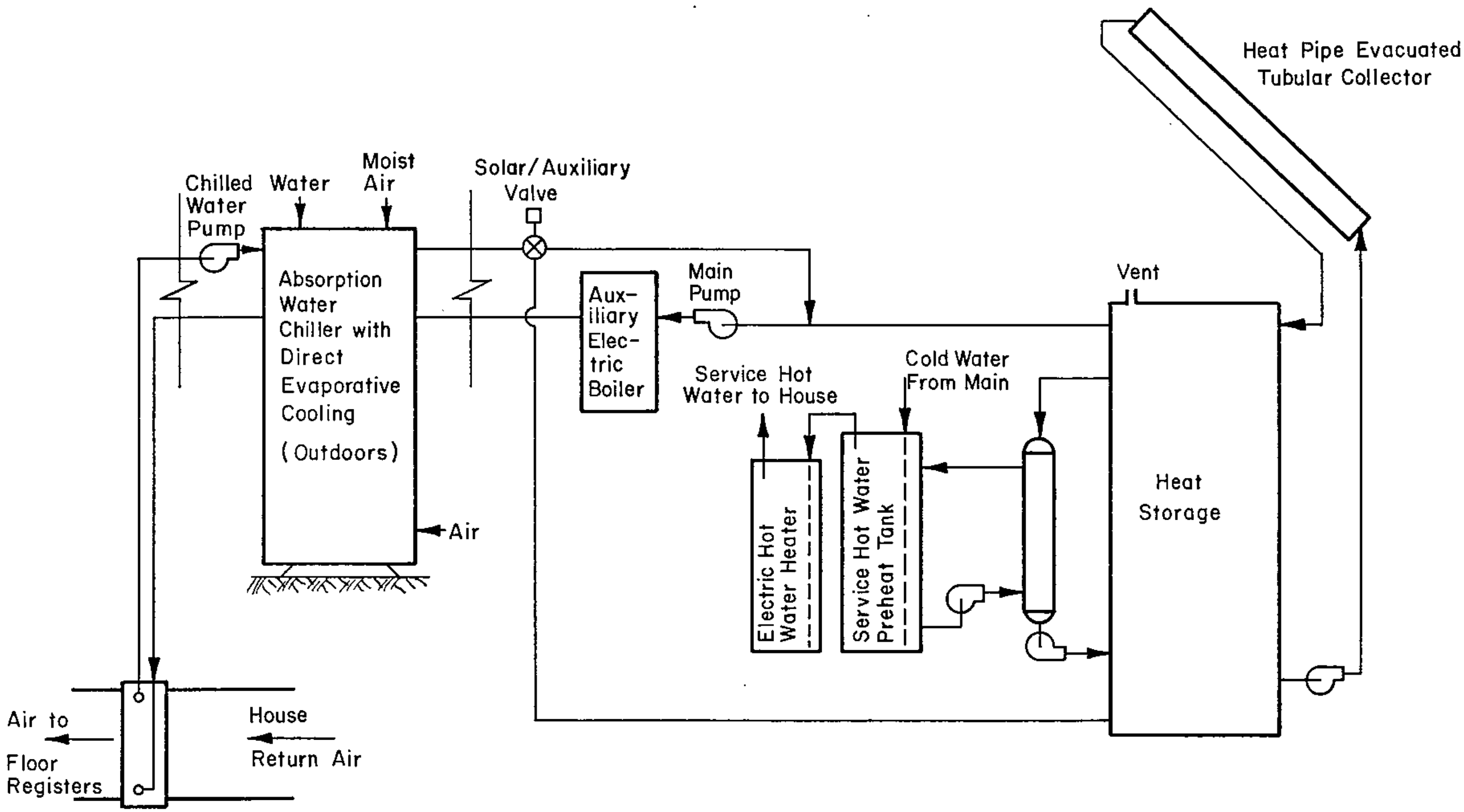


Figure 5-10. USA-CLG-3, Space Cooling with Single Loop Heat Pipe Evacuated Collector, Direct Evaporative Cooling Absorption Water Chiller and External Heat Exchanger Two Tank Hot Water System.

When room temperature dropped below the thermostat set point, the first stage switch closed turning on the blower and pump and placing the solar/auxilairy switch in the solar position so that solar heated water from the main storage tank circulated through the duct coil. A minimum temperature limitation of 30°C was imposed on the main storage tank so that first stage solar heating was bypassed if storage was less than this temperature. If solar heating provided in this mode caused the room temperature to rise above the set point, the first stage thermostat switch opened turning off the fan and load pump. If the room temperature continued to fall because the rate of solar energy delivery was less than the rate of energy loss from the building, the second stage thermostat switch closed activating the auxilairy heating subsystem. From November through January, auxiliary energy was provided by an electric boiler heating water circulating in a closed loop through the heating coil. This auxiliary mode is similar to auxiliary supply to chillers in systems USA-CLG-1, 2, and 3. During February and March, auxiliary energy was provided by the off peak electric thermal storage unit in a manner similar to that described for system USA-HTG-1. Solar and auxiliary energy could not be simultaneously delivered while using the electric boiler, although simultaneous delivery had been possible with the off-peak unit. See Figure 5-11 for system diagram.

5.7.6 System USA-HTG-3 (14 January - 1 February 1981)

Space heating with double loop Philips VTR141 evacuated tubular collectors, electric auxiliary boiler and single tank external heat exchanger service hot water was used. The only component changed from system USA-HTG-2 was the service hot water system. The two tank system was changed to a single tank system. The objective of this experiment was to examine the performance of the single hot water system version of the previous system. This change consisted of using an electric heating element in the top section of what was formerly the preheat tank to provide auxiliary energy rather than using a separate tank to provide auxiliary. A minor plumbing change was required in the preheat tank to prevent water in the top segment from mixing with the rest of the water while solar energy was being delivered. All other components and operating modes remained the same. See Figure 5-12 for system diagram.

5.7.7 System USA-HTG-4 (12 February - 31 March 1981)

Space heating with the double loop Philips VTR141 evacuated tubular collectors, off-peak electric auxiliary and single external heat exchanger service hot water was used. Beginning February 12, 1981, auxiliary space heating was provided by stored off-peak electric thermal energy rather than by the electric boiler of the previous two systems. All load management hardware and control strategies were the same as described for system USA-HTG-1. All other components and controls remained the same as for system USA-HTG-3. See Figure 5-13 for system diagram.

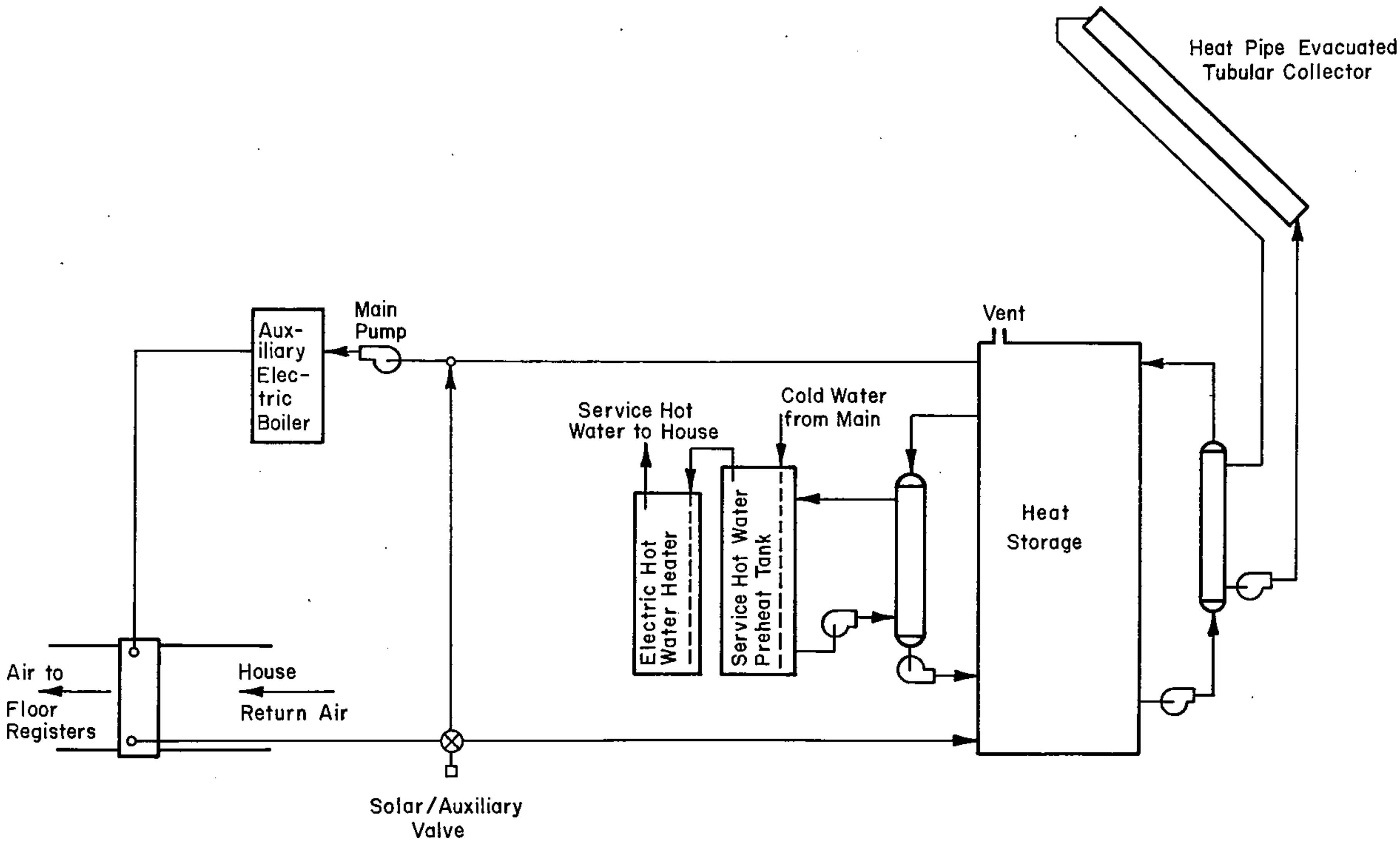


Figure 5-11. USA-HTG-2, Space Heating with Double Loop Heat Pipe Evacuated Tubular Collector, Electric Auxiliary Boiler and External Heat Exchanger Two Tank Service Hot Water System.

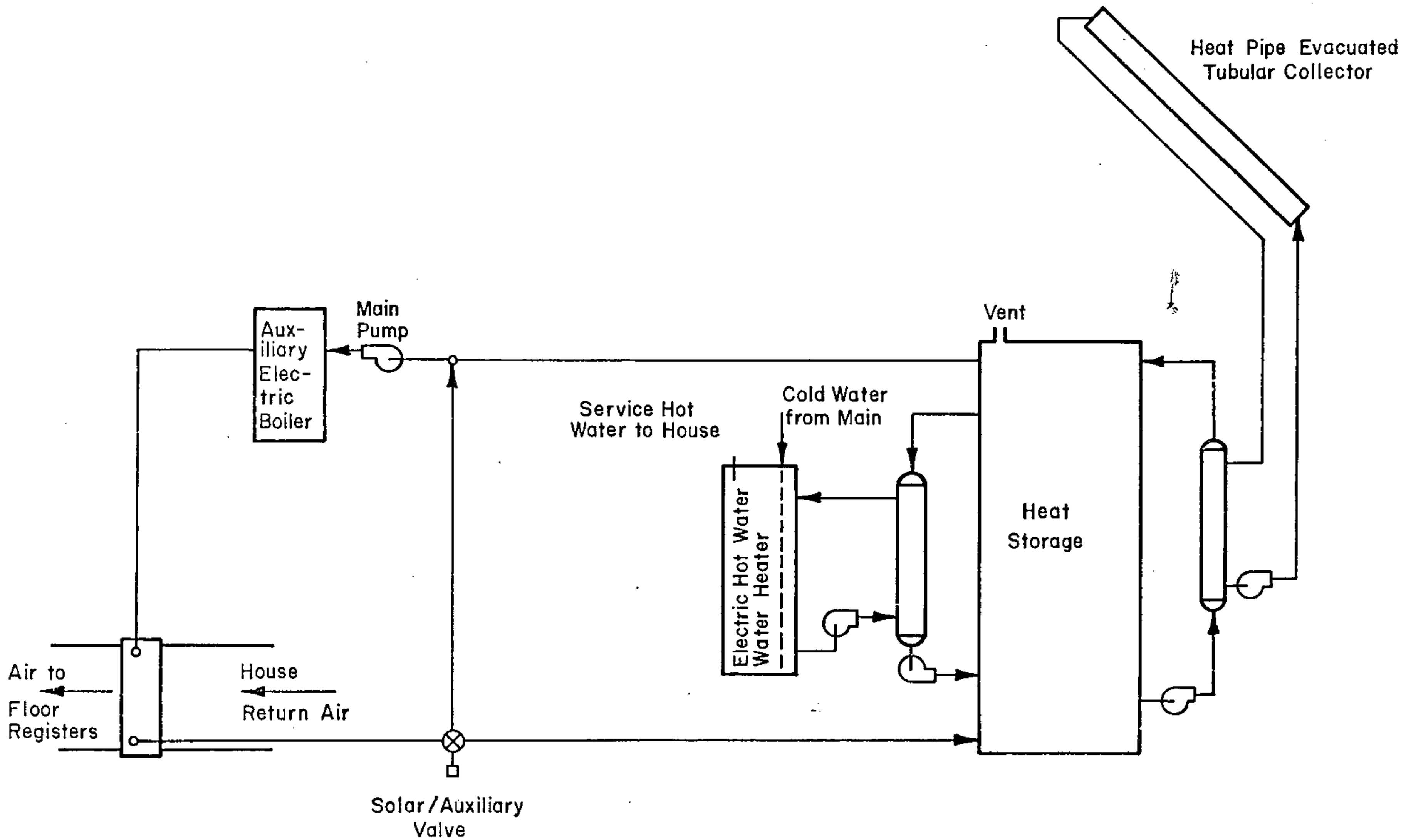


Figure 5-12. USA-HTG-3, Space Heating with Double Loop Heat Pipe Evacuated Collector, Electric Auxiliary Boiler and External Heat Exchanger Single Tank Hot Water System.

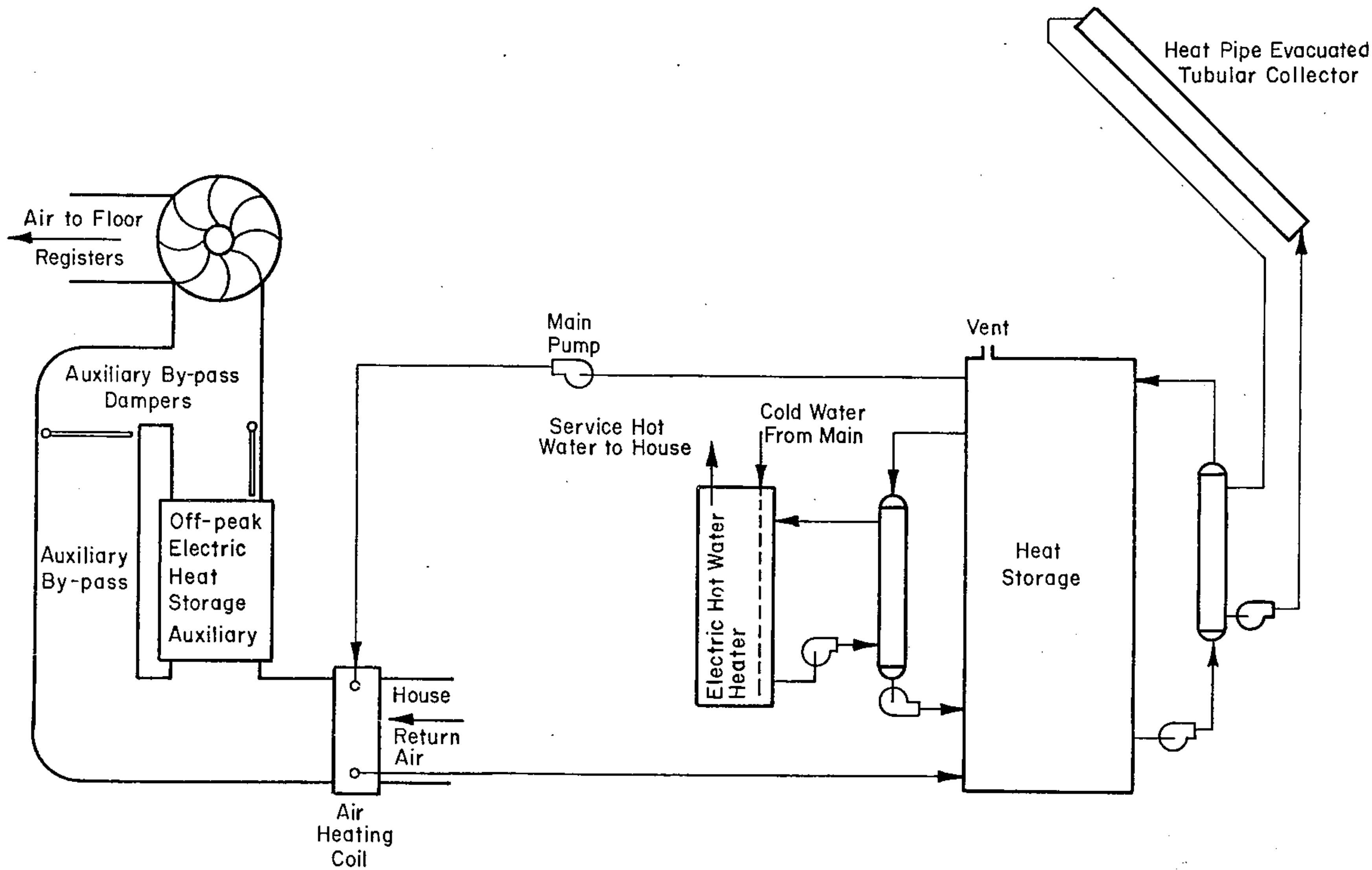


Figure 5-13. USA-HTG-4, Space Heating with Double Loop Heat Pipe Evacuated Collector, Off-Peak Electric Auxiliary and External Heat Exchanger Single Tank Hot Water System.

5.7.8 System USA-CLG-4 (1 July - 17 September 1981)

Space cooling with single loop Philips VTR141 evacuated tubular collectors, Arkla XWF3600 chiller and one tank internal heat exchanger hot water system was used. The cooling system tested during the summer of 1981 used the same collector and chiller that had been in use in system USA-CLG-3 at the end of the 1980 cooling season. The major changes were to replace the Bally storage tank with a steel pressure vessel located outside of the conditioned space and to use a single tank for domestic hot water. The objectives of this experiment were further testing of the Philips VTR-261, XWF3600 components of system USA-CLG-3 and higher temperature testing of both the collector and chiller. Operation of the solar collection and storage was the same as described in system USA-CLG-3. Note that the pressurized storage tank temperature could exceed 96°C. See Figure 5-14 for system diagram.

5.8 SOLARHAUS FREIBURG - WEST GERMANY

Four solar systems have been realized by the alternative coupling of the two collector systems CORNING and PHILIPS with the DHW and heating (HTG) systems.

CORNING coupled with DHW	(1)
PHILIPS coupled with HTG	(2)
PHILIPS coupled with DHW	(3)
COENING coupled with HTG	(4)

These collector exchange experiments affect the solar system energy flows only in magnitude.

A change of energy flows occurs in the solar systems when they are operated in different experiments either with the "preheat storage control" or with the improved "two-storage control" strategy. In the preheat storage control mode, solar energy is delivered only to the preheat tanks of the DHW and heating systems, and the hot storage tanks are not supplied with solar energy.

In contrast to this simple strategy, "two storage control strategy" defines a priority for collected solar energy to be delivered either to the hot water storage tank or to the preheat storage tank. It depends on the level of radiation as well as on the storage tank temperatures and on the collector load temperatures.

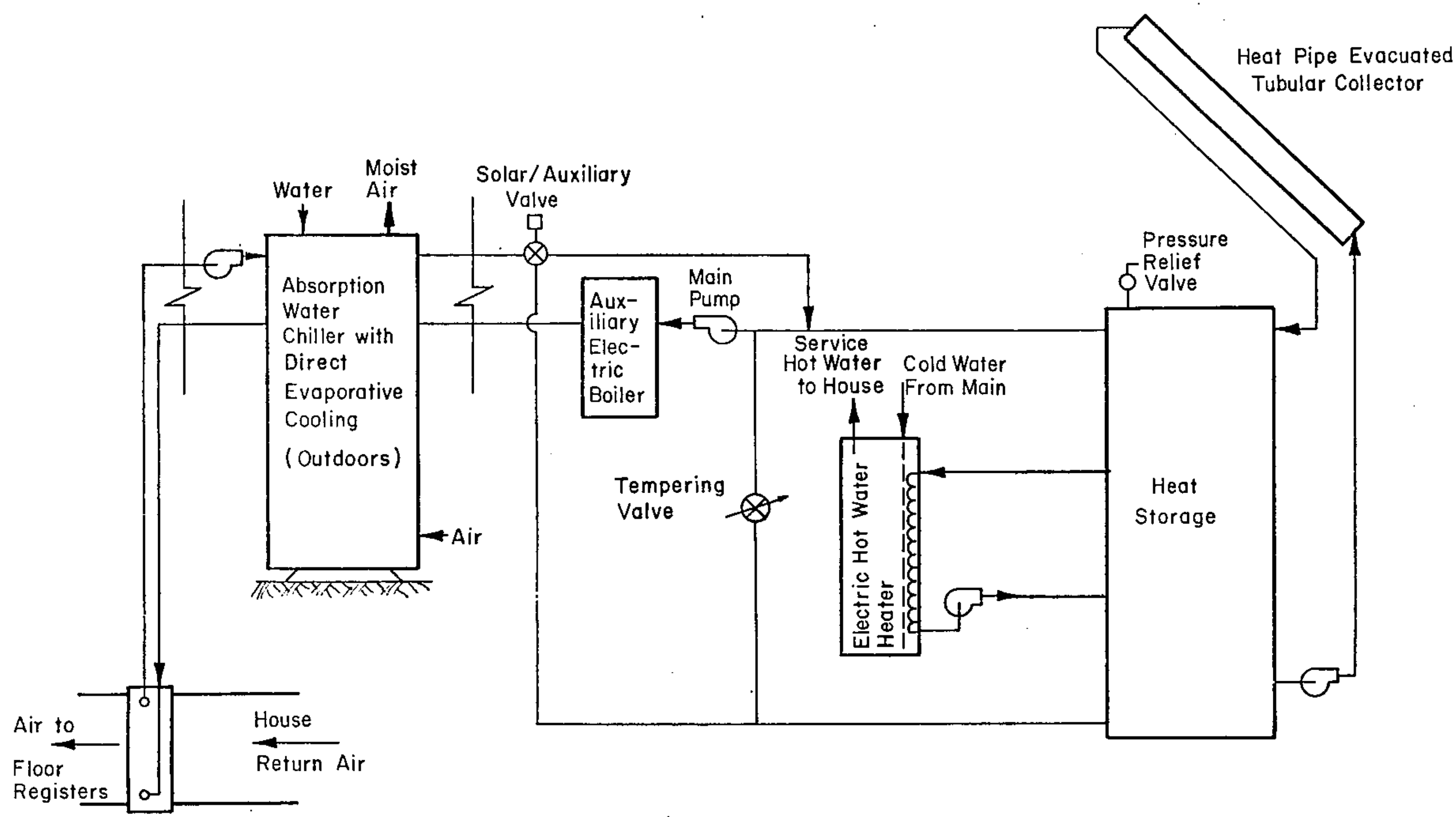


Figure 5-14. USA-CLG-4, Space Cooling with Single Loop Heat Pipe Evacuated Collector, Direct Evaporative Cooling Absorption Water Chiller and Internal Heat Exchanger One Tank Hot Water System.

Solar energy collected from high level of incident radiation is delivered with priority directly into the hot water storage tank on a temperature level close to the design temperature, until it reaches its maximum temperature. This procedure reduces consumption of auxiliary energy when solar energy is simultaneously available. Collected solar energy of low radiation density is always delivered into the preheat storage with lower temperatures in order to operate the collector with higher efficiency. These experiments have been investigated since May 1980 and have been interrupted several times for modification. An essential system difference exists in the DHW system between the delivery of auxiliary energy either by electricity or thermal energy, which is provided from the hot storage tank of the heating system either by solar energy or fossil thermal energy. The experiment specifics have been described together with the DHW system in section 4.6. Since November 1980, the electric DHW auxiliary system has been replaced by the thermal DHW auxiliary experiment. There were no basic problems with the operation of the energy systems or control. Troubles occurred with flow meters in the DHW consumer circuits, caused by lime deposits until a complete replacement by another type of flow meter, which has operated perfectly since January 1980. Furthermore there was no measurement of heating oil consumption in 1979. Instead of reporting the meteorological conditions for all mutually overlapping experiment periods, those are given in the results section together with the seasonal or yearly results. See Figure 5-15 for system diagram.

5.8.1 Experiment WG-DHW-1C (March-May and August 1979)

Domestic hot water supplied by Corning collector.

5.8.2 Experiment WG-HTG-1P (March-May and August 1979)

Space heating supplied by Philips collector.

5.8.3 Experiment WG-DHW-2P (June, July and September-December 1979)

Domestic hot water supplied by Philips collector.

5.8.4 Experiment WG-HTG-2C (June, July and September-December 1979)

Space heating supplied by Corning collector.

5.8.5 Experiment WG-DHW-3P (January-May 1980)

Domestic hot water supplied by Philips collector.

5.8.6 Experiment WG-HTG-3C (January-May 1980)

Space heating supplied by Corning collector.

5.8.7 Experiment WG-DHW-4C (June-December 1980)

Domestic hot water supplied by Corning collector.

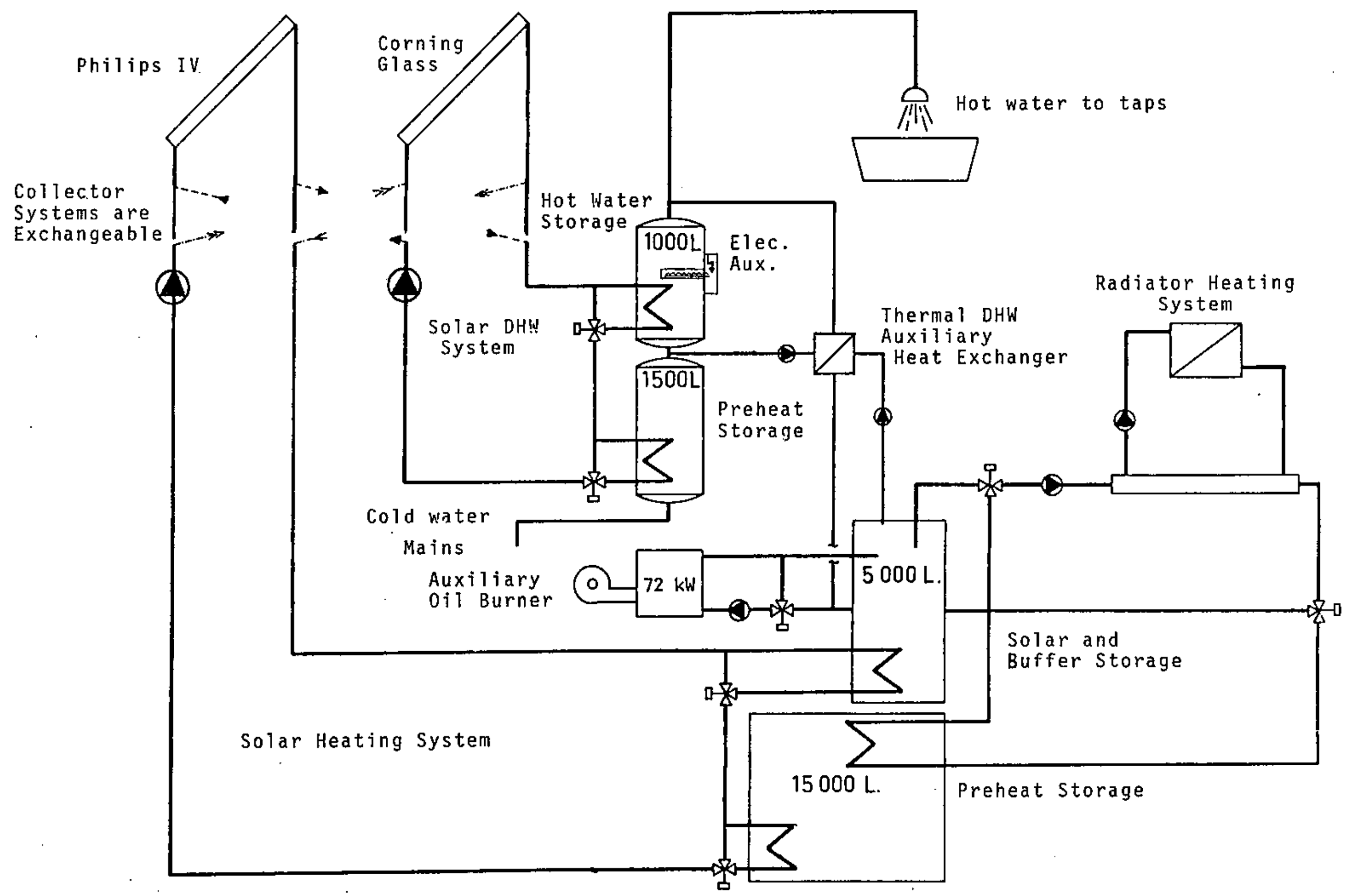


Figure 5-15. Solar System Schematic - West Germany

5.8.8 Experiment WG-HTG-4P (June-December 1980)

Space heating supplied by Philips collector.

5.8.9. Experiment WG-DHW-5C (January - December 1981)

Domestic hot water supplied by Corning collector.

5.8.10 Experiment WG-HTG-5P (January- December 1981)

Space heating supplied by Philips collector.

6. RESULTS

Five different types of graphic material are presented in this section. Formats follow the IEA Task VI format of Appendix B. These formats have been further standardized so that one installation's results may be readily compared with those of another. Axes on plots are identically dimensioned and labelled so that overlays of several installation's plots can be made. Comparisons and evaluations of the results are made in the last part of this section.

Results are reported for the three installations which were operating and had thoroughly tested data acquisitions systems at the beginning of the reporting period: Japan, the U.S. and West Germany. Partial results are reported by Sweden. The other installations were in varying stages of operational or reporting readiness. Since achieving a thoroughly tested and reliable data acquisition system for systems of such complexity typically requires about two years of professional and technical effort, the availability of Sweden's results is fortuitous.

6.1 EFFICIENCY PLOTS

Normally there is one efficiency plot for each experimental period. However, if appropriate, several experimental periods are combined for these plots. The abscissa in these figures is the temperature difference between the average collector fluid temperature and the average ambient temperature divided by the solar incident energy on the aperture plane per unit aperture area of the collector (T100-T001)/G100*. The ordinate is the solar energy collected, corrected for capacitance effects, divided by the incident solar energy on the aperture plane, (Q112 + Q105)/H100. Performance is shown in the form of the regression lines which are based on more than 80 data points per experiment. The data points are divided into four groups with regard to four ranges of (T100-T001)/G100. A vertical bar and dot is drawn for each range. The location of the dot provides the mean value of the group and the length of the bar shows one standard deviation on either side of the mean. So that reasonably steady state conditions are represented, data within one hour before and two hours after solar noon were selected.

6.1.1 Osaka Sanyo Solar House - Japan

Efficiency plots are shown in Figures 6-1 through 6-4. The points have been corrected to eliminate the capacitance effect of the collectors using a multiple regression technique. The regression lines for experiments J-HTG-1 and J-CLG-1 have some uncertainty since the deviations are large for large values of the abscissa. The intercepts of the regression lines on the ordinate in the experiments, J-HTG-1 and J-CLG-1, are a little greater than in the experiments, J-HTG-2 and J-CLG-2. However, the performances of the two kinds of collectors are considered to be similar.

*Definitions for the IEA Task VI nomenclature used in this section are provided in Appendix B. Also, see references [33] and [34].

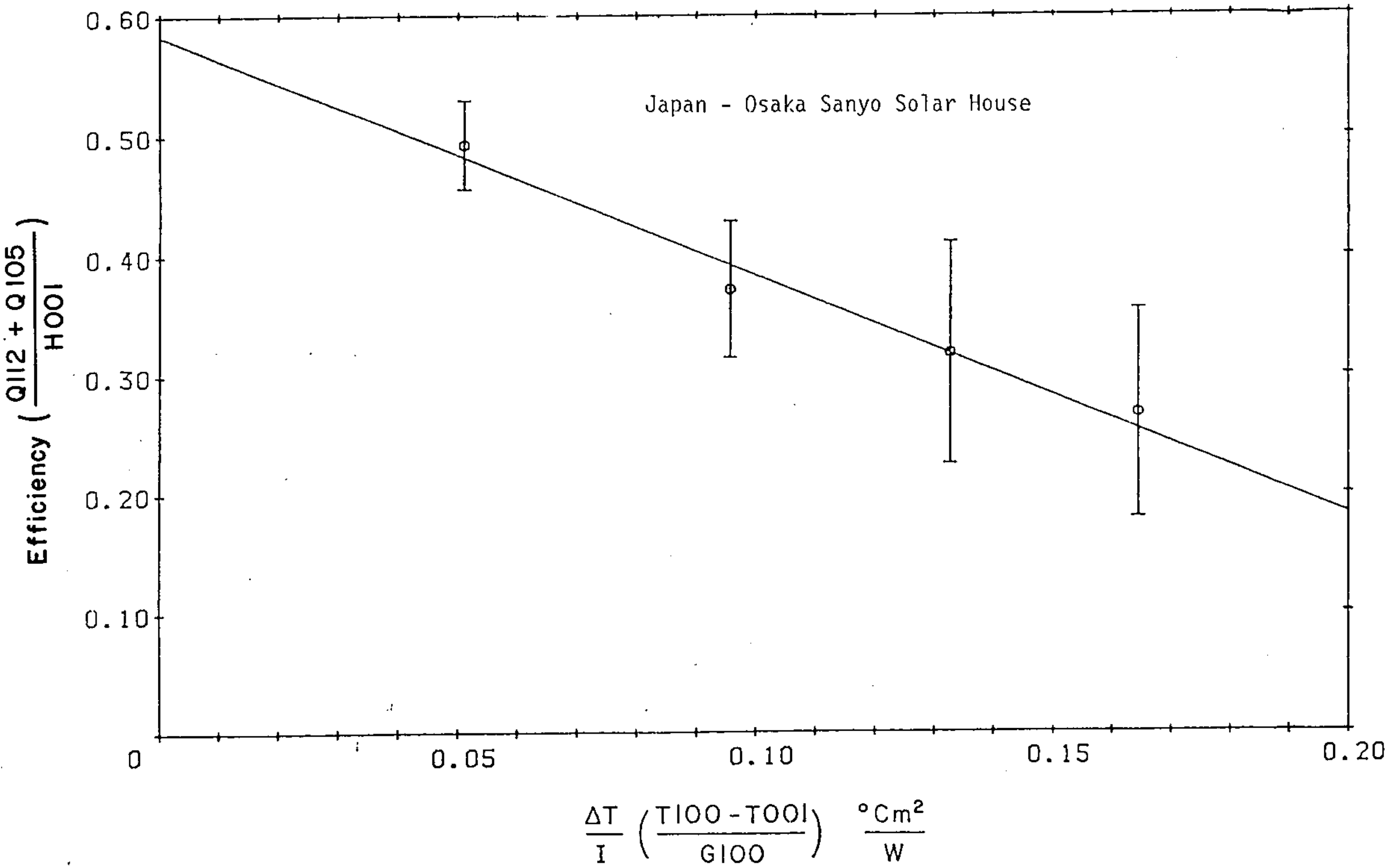


Figure 6-1. J-HTG-1, Array Efficiency for Sanyo Collectors

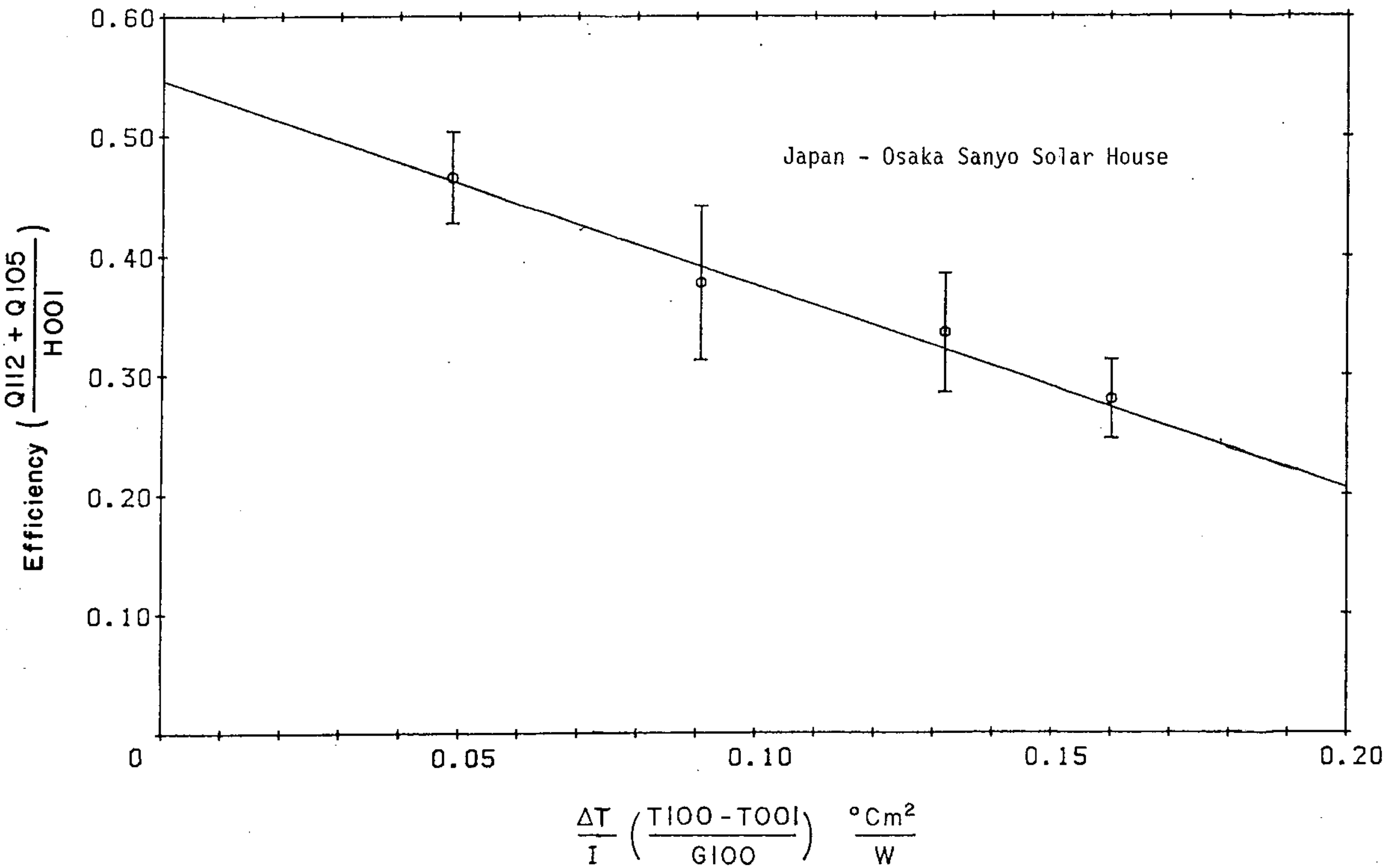


Figure 6-2. J-HTG-2, Array Efficiency for General Electric Collectors

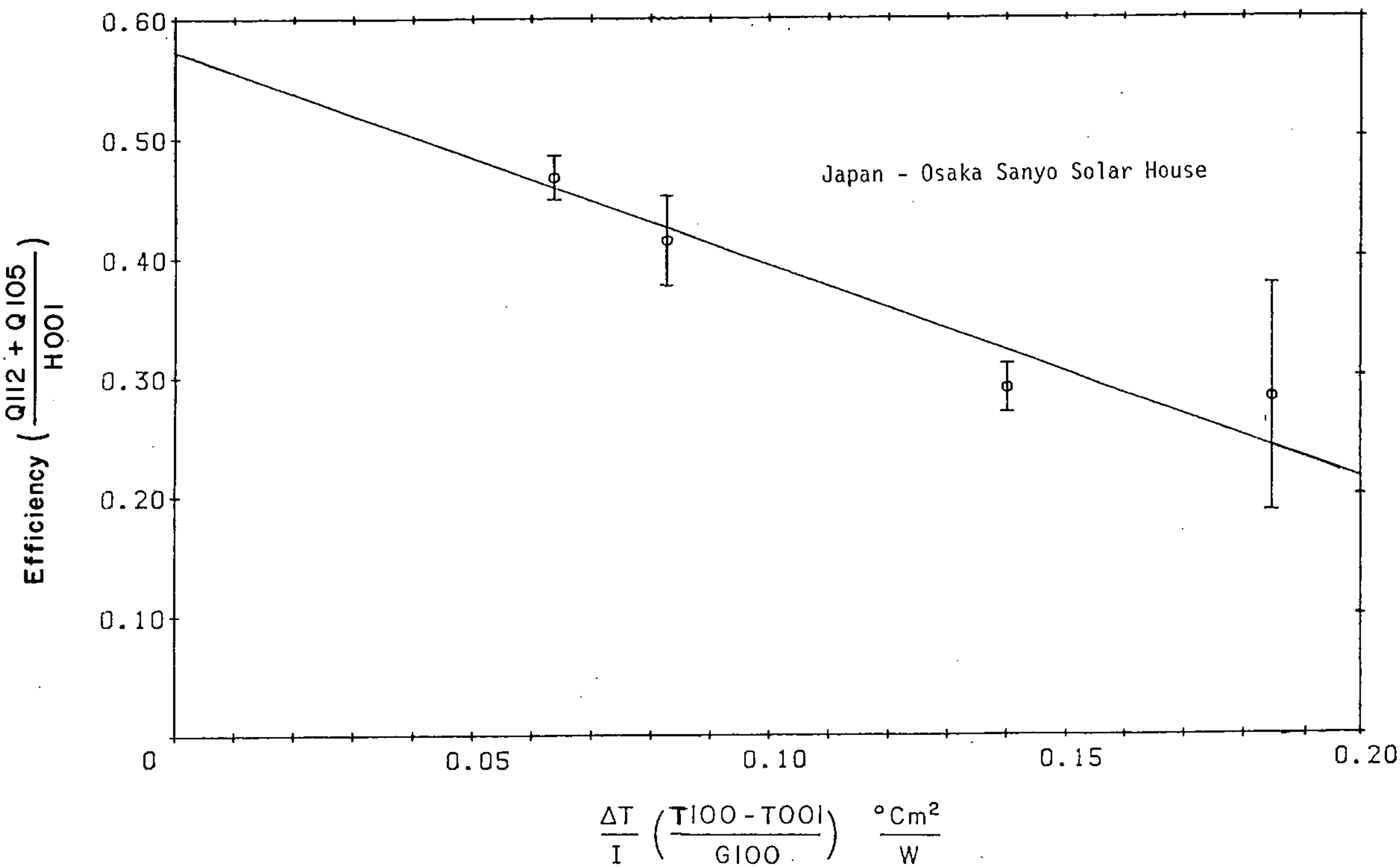


Figure 6-3. J-CLG-1, Array Efficiency for Sanyo Collectors

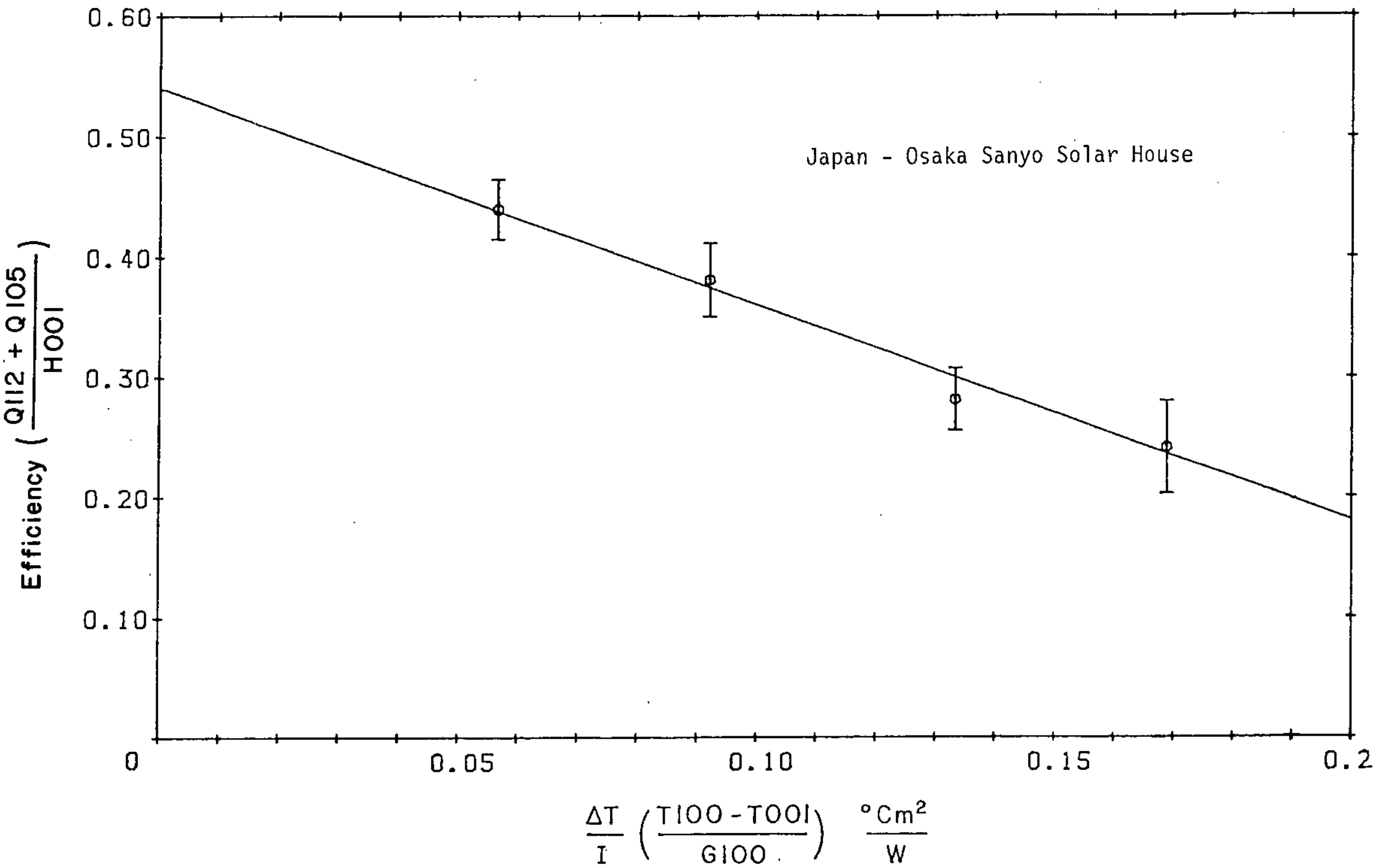


Figure 6-4. J-CLG-2, Array Efficiency for General Electric Collectors

6.1.2 Knivsta District Heating Project - Sweden

The collector efficiency was evaluated similarly to the instantaneous efficiency definition for standard tests. However, in this case hourly mean values for the total array including some shorter interconnection piping are used. Only selected noon data (between 11:00 and 13:00 hrs) on clear days have been chosen. Even so, a considerable deviation from both manufacturers information and measured instantaneous efficiency on a single collector can be observed, as shown in Figures 6-5, 6-6 and 6-7. The greatest deviation is found for OI collectors. Although heat capacitance effects may have some influence, they cannot be solely responsible for the array efficiencies found. Array efficiency for the GE collector also lies below the single collector results. Recent changes in the GE system have given an increased efficiency. Philips collectors, however, fit very well to the efficiency curve provided by the manufacturers. In this case the contribution of the reflected light to the back surface is not measured and hence causes an uncontrolled addition to the energy irradiated on the collector.

It is interesting to note that OI collectors show the best hourly array efficiency of all 3 collector types tested (related to aperture area).

6.1.3 Colorado State University Solar House I - USA

In Figure 6-8, the efficiency of the Miromit flat plate collector used in heating experiment USA-HTG-1 and cooling experiment USA-CLG-1 was correlated with the usual operating parameter (T100-T001)/G100. The efficiency correlation reported by the collector manufacturer is shown for comparison. As seen in Figure 6-8, under good solar conditions, and at moderate temperature levels, collector efficiency was substantially below the manufacturer's rating. Deterioration of the selective surface may have occurred during prolonged stagnation when this system was not being used for heat supply. Other possible reasons for reduced efficiency may be the accumulation of dust beneath the glass cover and on the absorber plate, unequal flow through multiple collectors in parallel, and separation of water tubes from absorber plate because of bond failure.

Performance at lower radiation levels and higher system temperatures appears to have been higher than the rating, but data in this operating range are sparse and in doubt. As expected, the efficiency of the Miromit collector was higher than the earlier site-built collector, but it was not as efficient as the Chamberlain flat plate collector used in CSU House III. The completely wetted absorber plate and the black chrome selective surface in the latter unit were responsible for the higher efficiency.

The flat plate collector used in CSU Solar House I is no longer in production, steel having been replaced with copper and the black nickel absorber surface having been replaced with black chrome.

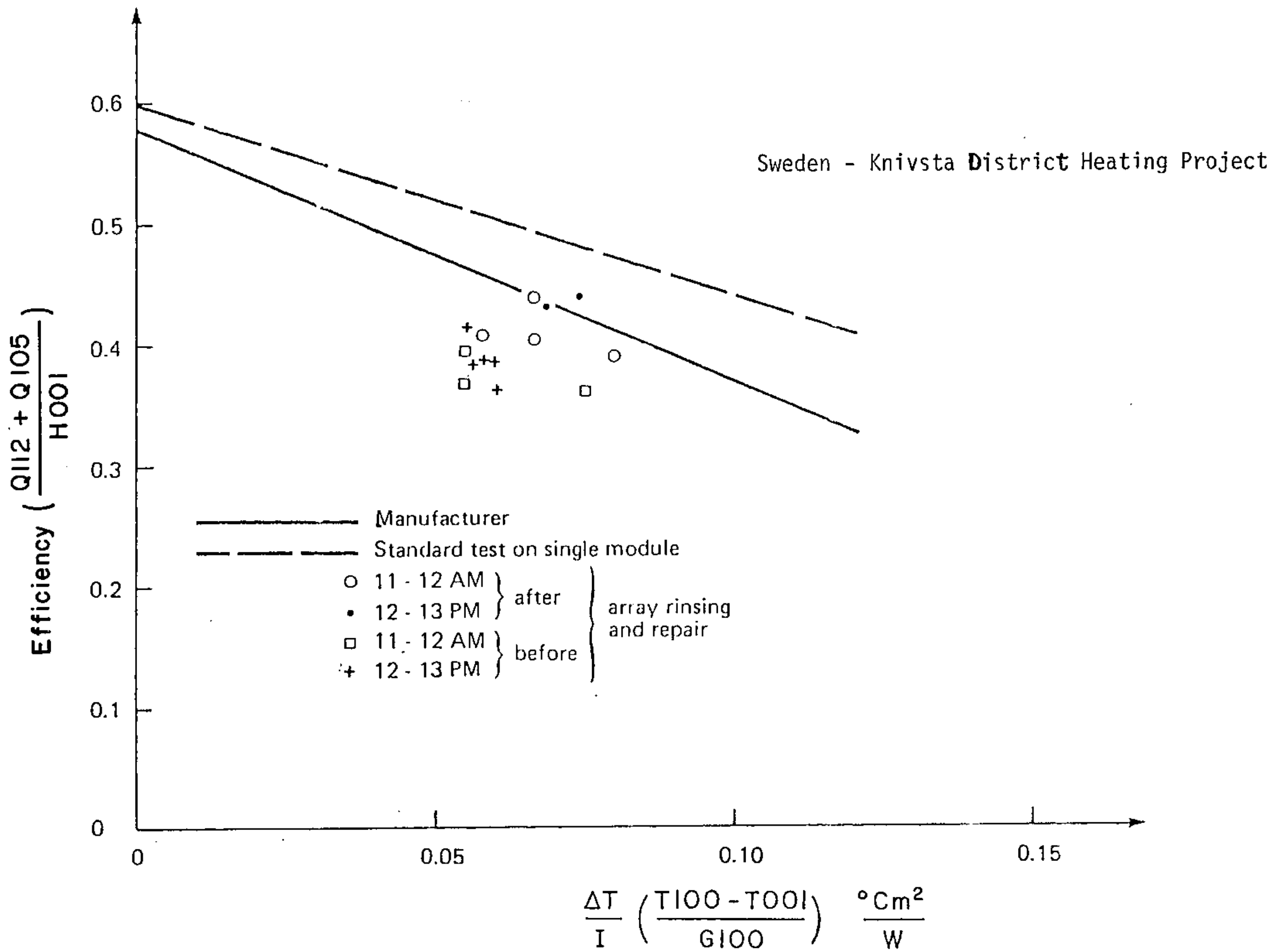


Figure 6-5. S-HTG-1, Array Efficiency for General Electric Collectors

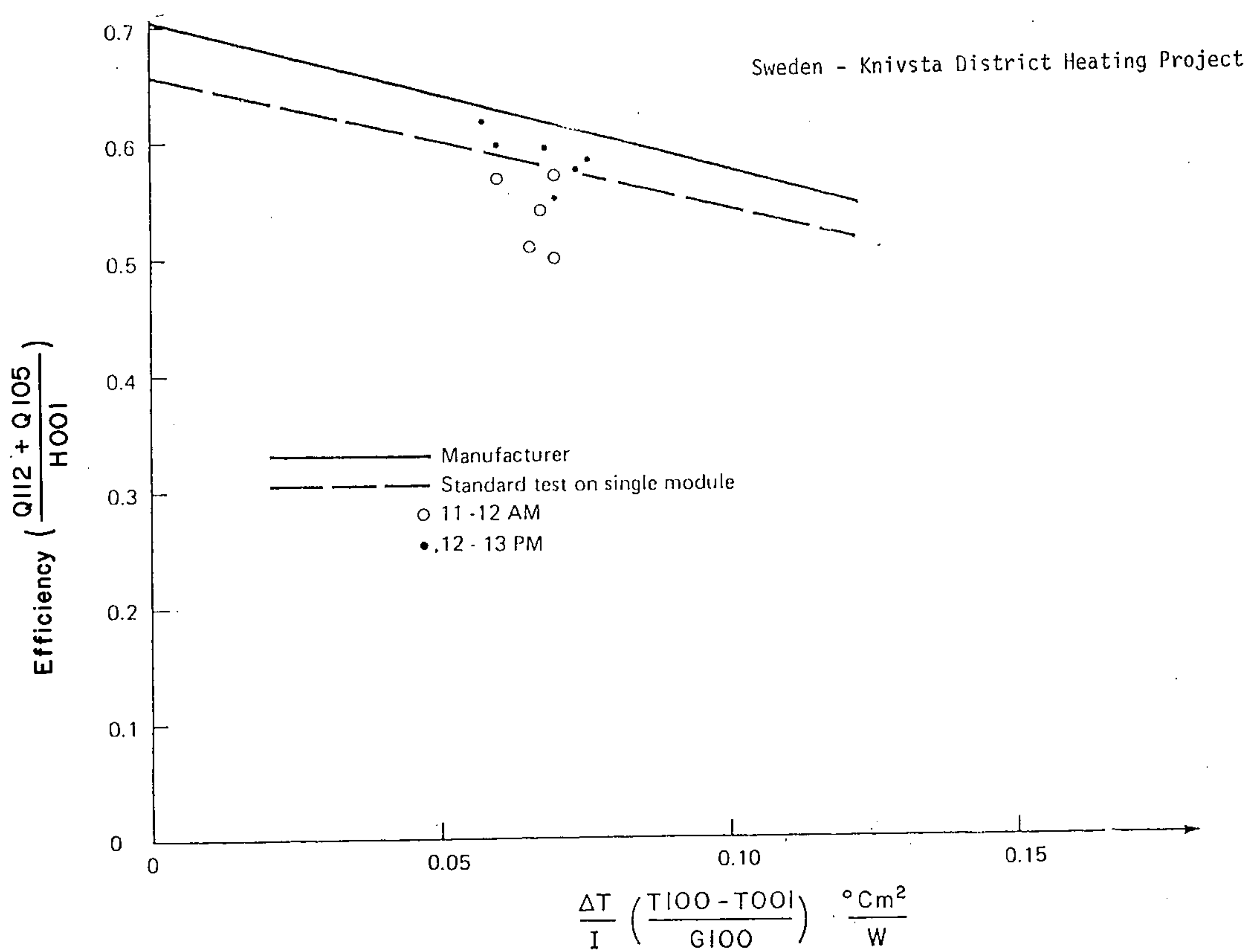


Figure 6-6. S-HTG-2, Array Efficiency for Owens-Illinois Collectors

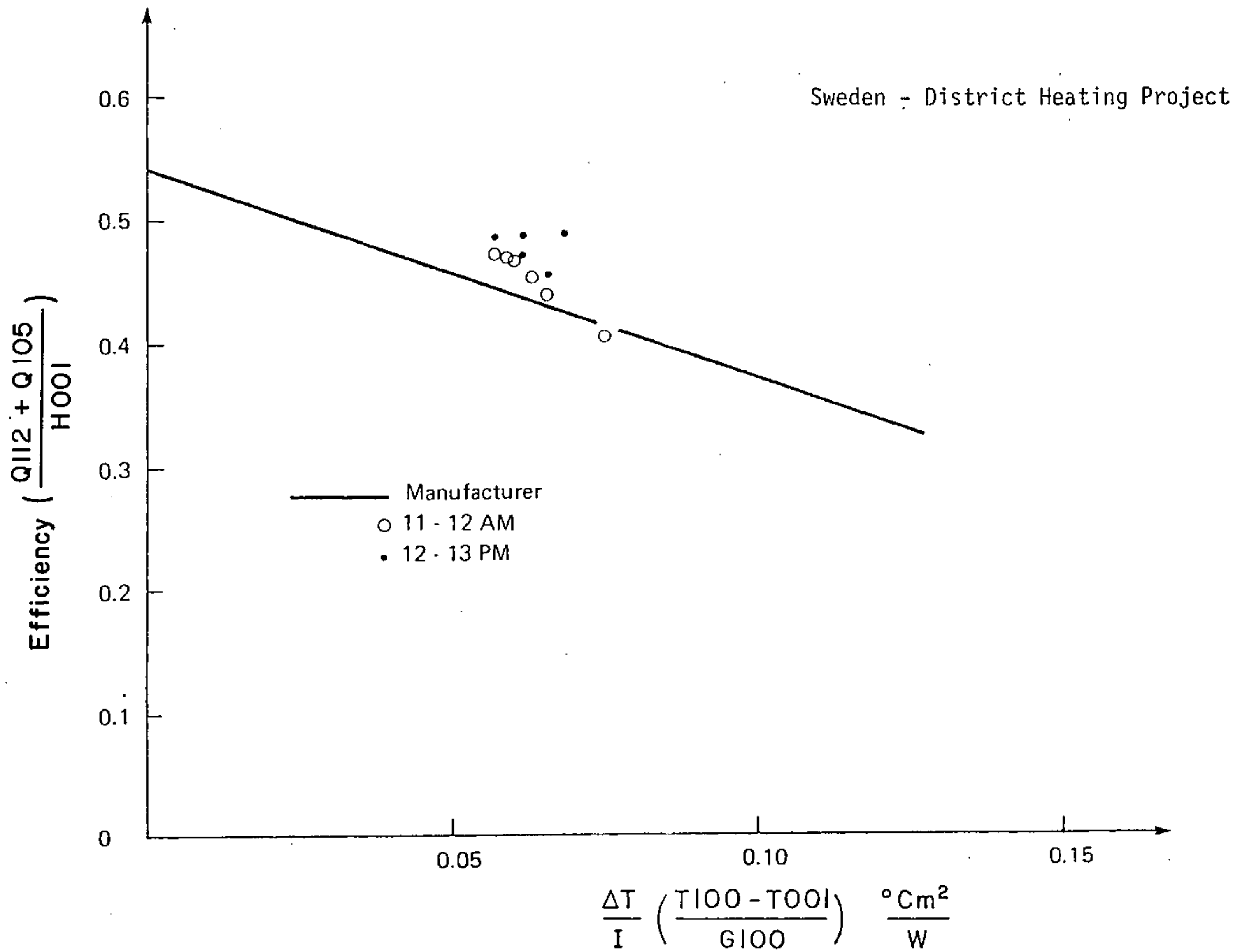


Figure 6-7. S-HTG-3, Array Efficiency for Philips VTR 141 Collectors

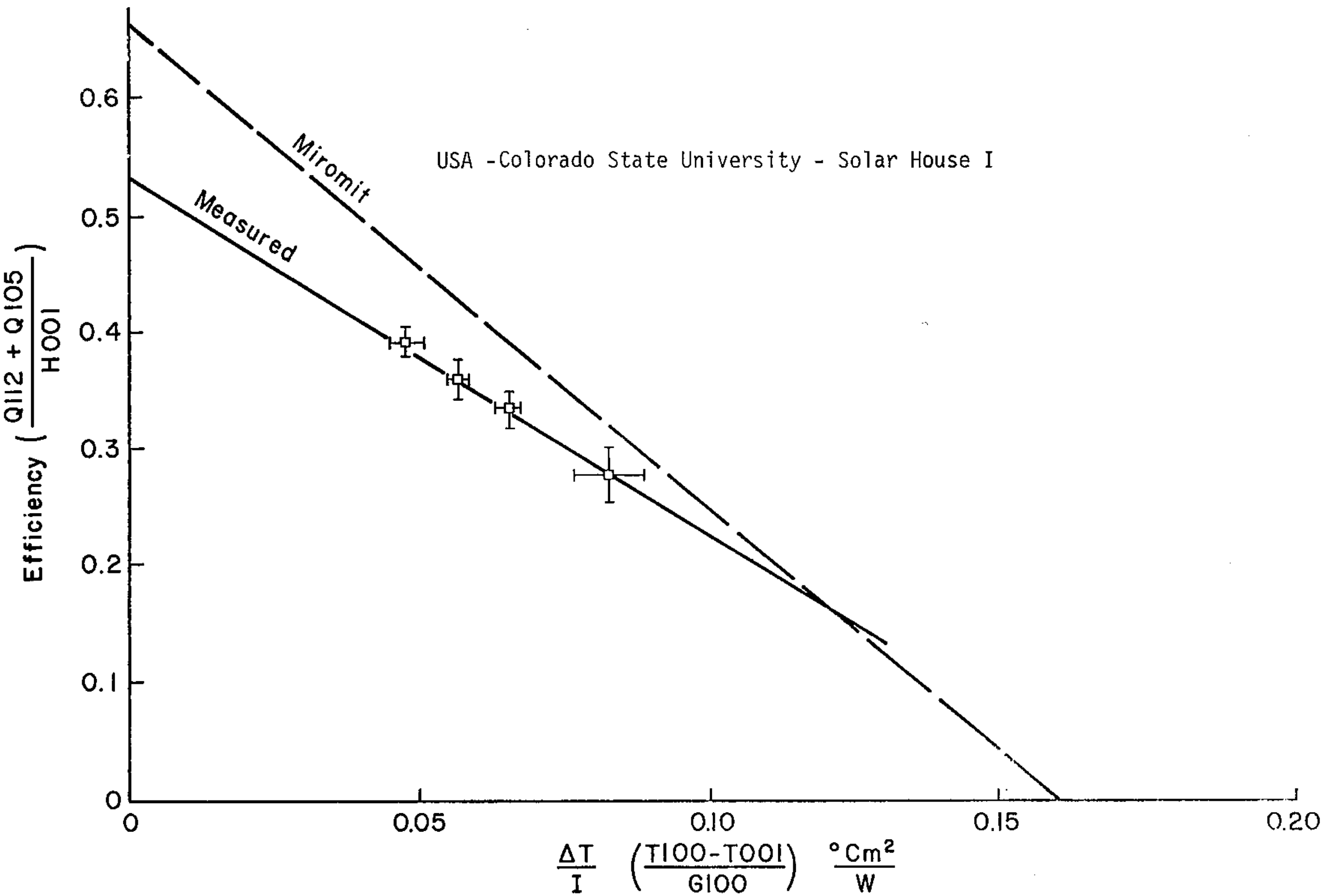


Figure 6-8. USA-HTG-1 and CLG-1, Array Efficiency for Miromit Flat Plate Collectors

Figure 6-9 is a similar correlation for the evacuated tube collector operating in heating experiments USA-HTG-2, USA-HTG-3, and USA-HTG-4, with heat exchange to storage, (the "winter" line), and in cooling experiments USA-CLG-2, USA-CLG-3, and USA-CLG-4 in a single loop design (the "summer" line). The manufactuer's correlation was derived from the performance curves.

There were no substantial mechanical or operational problems with the Philips VTR141 evacuated tube collector. Solar collection efficiency was significantly higher than with the flat plate type, and higher than in the Philips Mark IV evacuated tube collector previously used. Efficiency was not as high, however, as that of the Corning evacuated tube collecter used in CSU Solar House I during 1977-78.

As indicated in Figure 6-9, Philips VTR141 collection efficiency in the several systems tested agreed satisfactorily with manufacturer's specifications and with anticipated performance estimates. The lower efficiency in summer is due to the effects of high operating temperatures on the vapor transfer process in the heat pipe, as explained below.

There is a self limiting temperature above which heat cannot be transferred by the heat pipe in the Philips VTR141 collector. If operating at temperatures approaching that limit, there is a greater decrease in collector efficiency with increase in temperature than with other types of evacuated tube collectors. As the critical temperature of the isobutane working fluid in the heat pipe collector is approached (134°C), collector efficiency decreases because of increased heat loss rates. The heat of vaporization decreases toward zero as temperatures approach the critical, so the rate of vaporization and condensation must rise in order that energy transfer from absorber to condenser can continue. It is probable that the resulting increase in evaporation rate and vapor velocity causes increased hold-up of liquid in the condenser section of the heat pipe. Return flow of liquid to the evaporator section may then be irregular or interrupted so that the heat pipe is only partially wetted. Rise in absorber plate temperature and increased thermal loss then occurs. Considerably reduced efficiency was usually observed when collector delivery temperatures exceeded about 105°C. Sharp decreases in collector array efficiency at these elevated delivery temperatures are probably due to some of the tubes becoming "vapor locked" in this manner, particularly the hotter ones near the exit end of the water flow path. Use of a working fluid with a higher critical temperature will result in improved efficiency at collector temperatures needed for absorption chiller operation.

6.1.4 Solarhaus Freiburg - West Germany

The efficiency plots shown in Figures 6-10 through 6-16 were constructed following the stated IEA format. The data points have been corrected for capacity related effects and have been separated into four groups between 0.0 and 0.2 with an increment of 0.05°Cm^2/W and then represented in the plot by an average point.

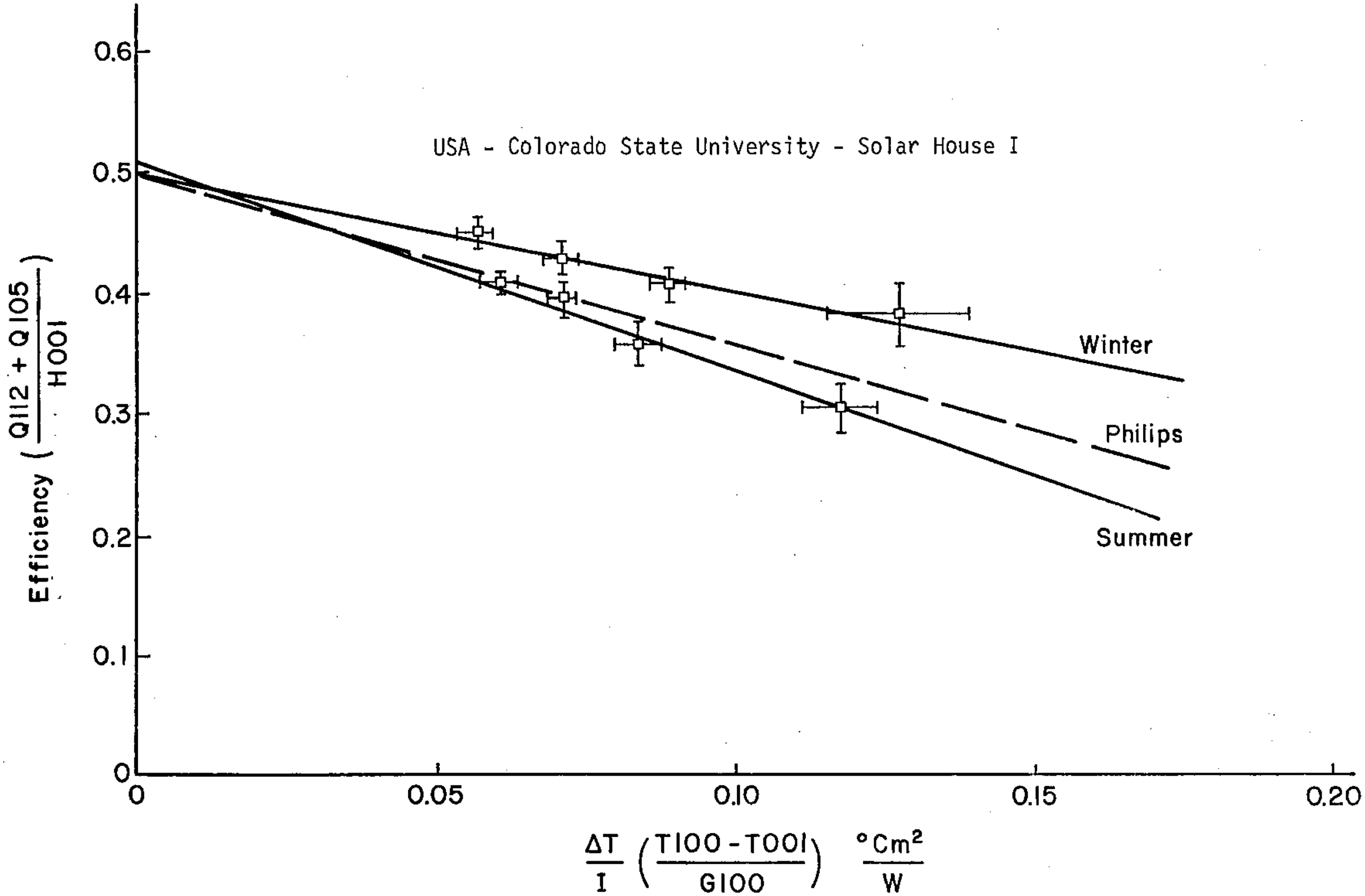
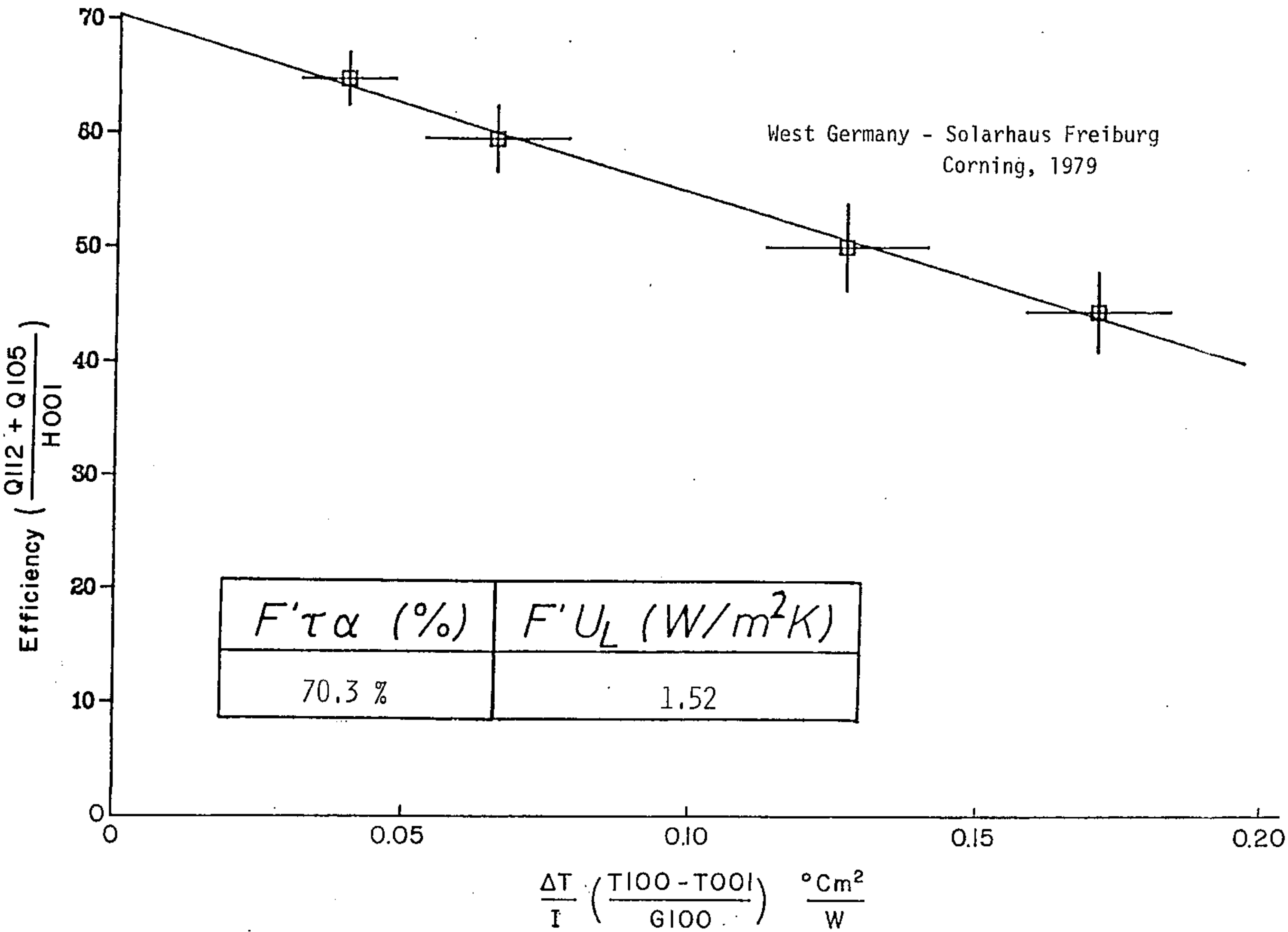


Figure 6-9. USA-HTG-2, 3, and 4 and CLG-2, 3, and 4, Array Efficiency for Philips VTR 141 Collectors



$F'\tau\alpha$ (%)	$F'U_L$ (W/m^2K)
70.3 %	1.52

Figure 6-10. WG-DHW-1C and HTG-2C, Array Efficiency for Corning Glass Collectors

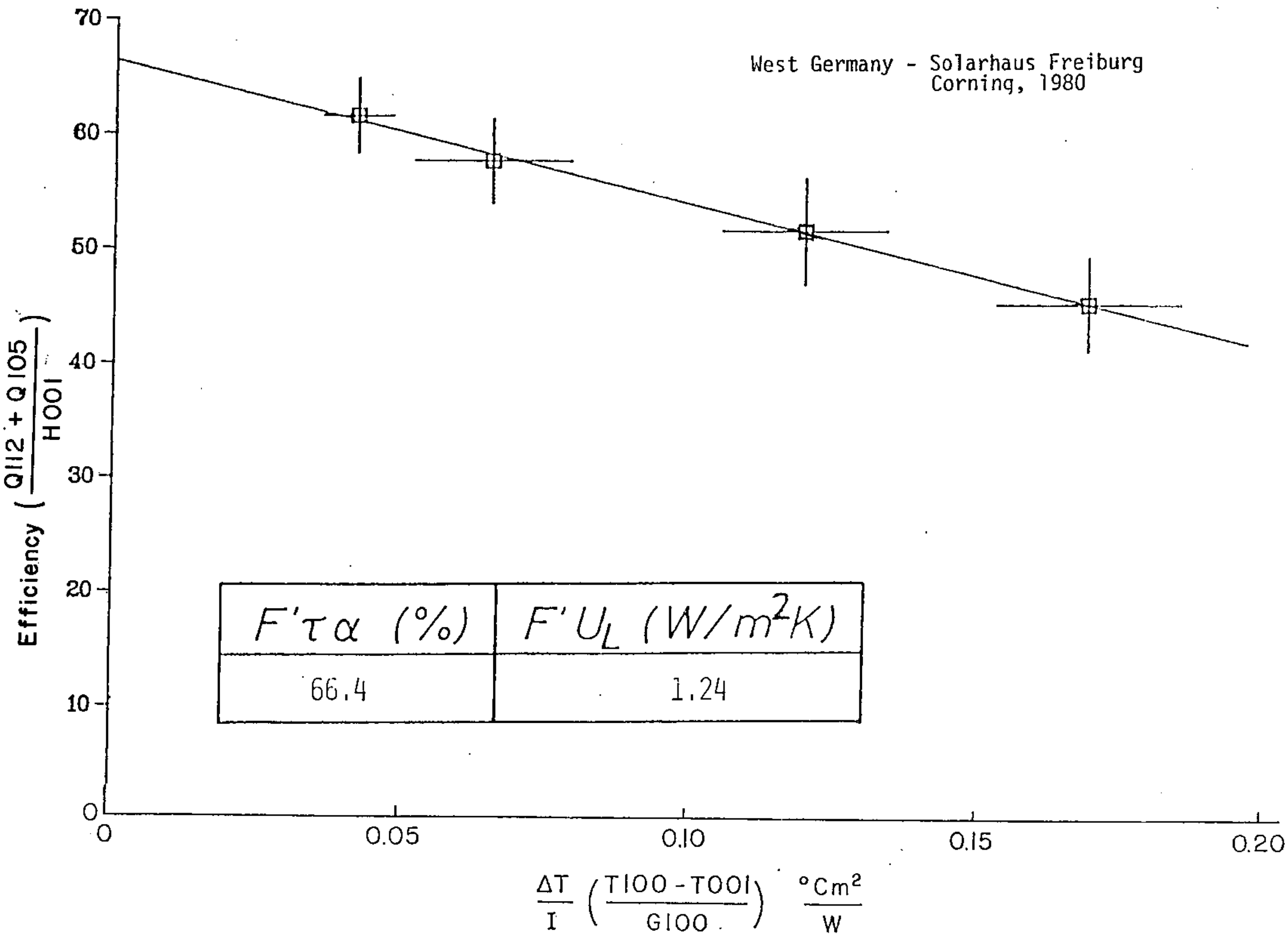


Figure 6-11. WG-DHW-4C and HTG-3C, Array Efficiency for Corning Glass Collectors

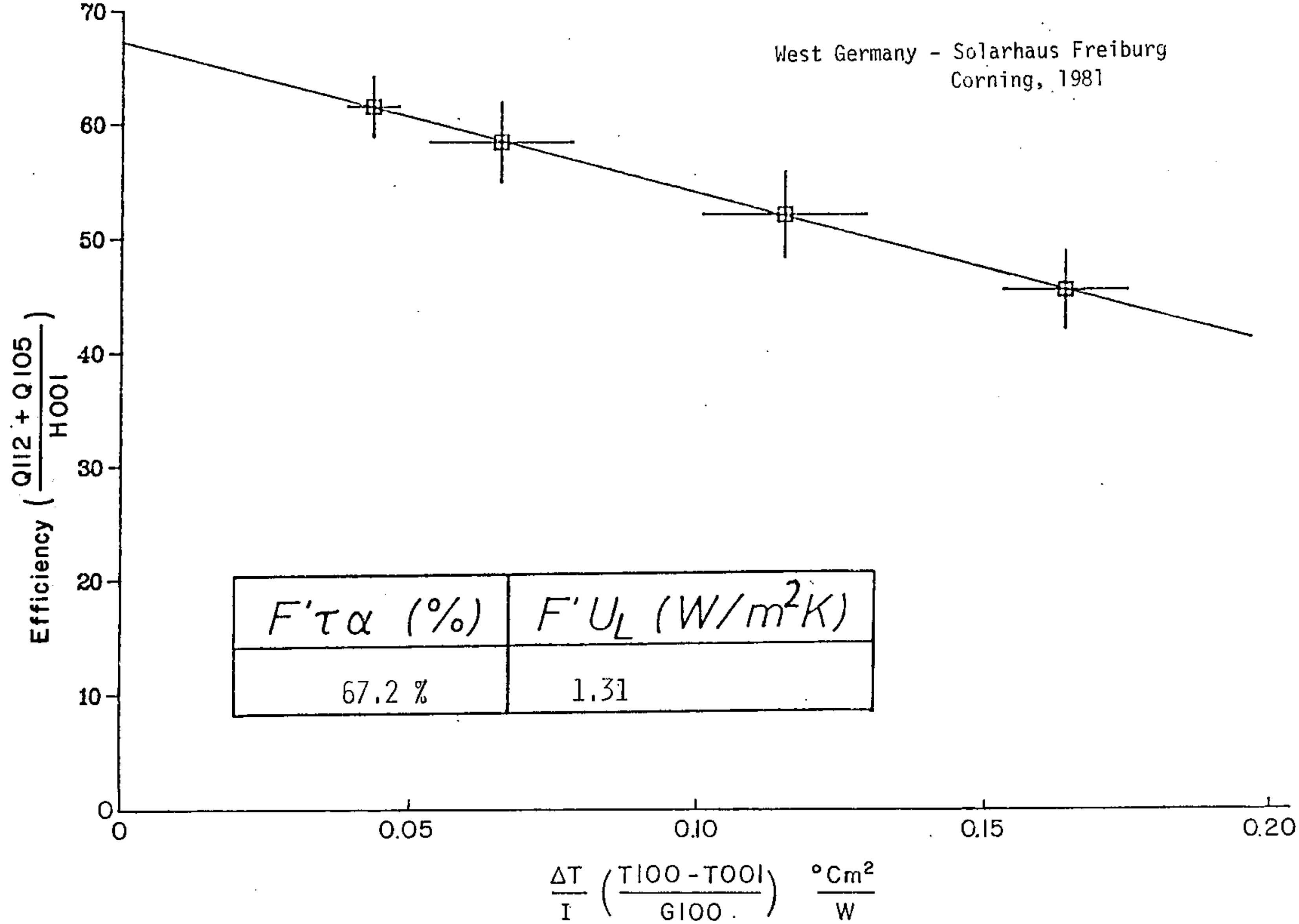


Figure 6-12. WG-DHW-5C, Array Efficiency for Corning Glass Collectors

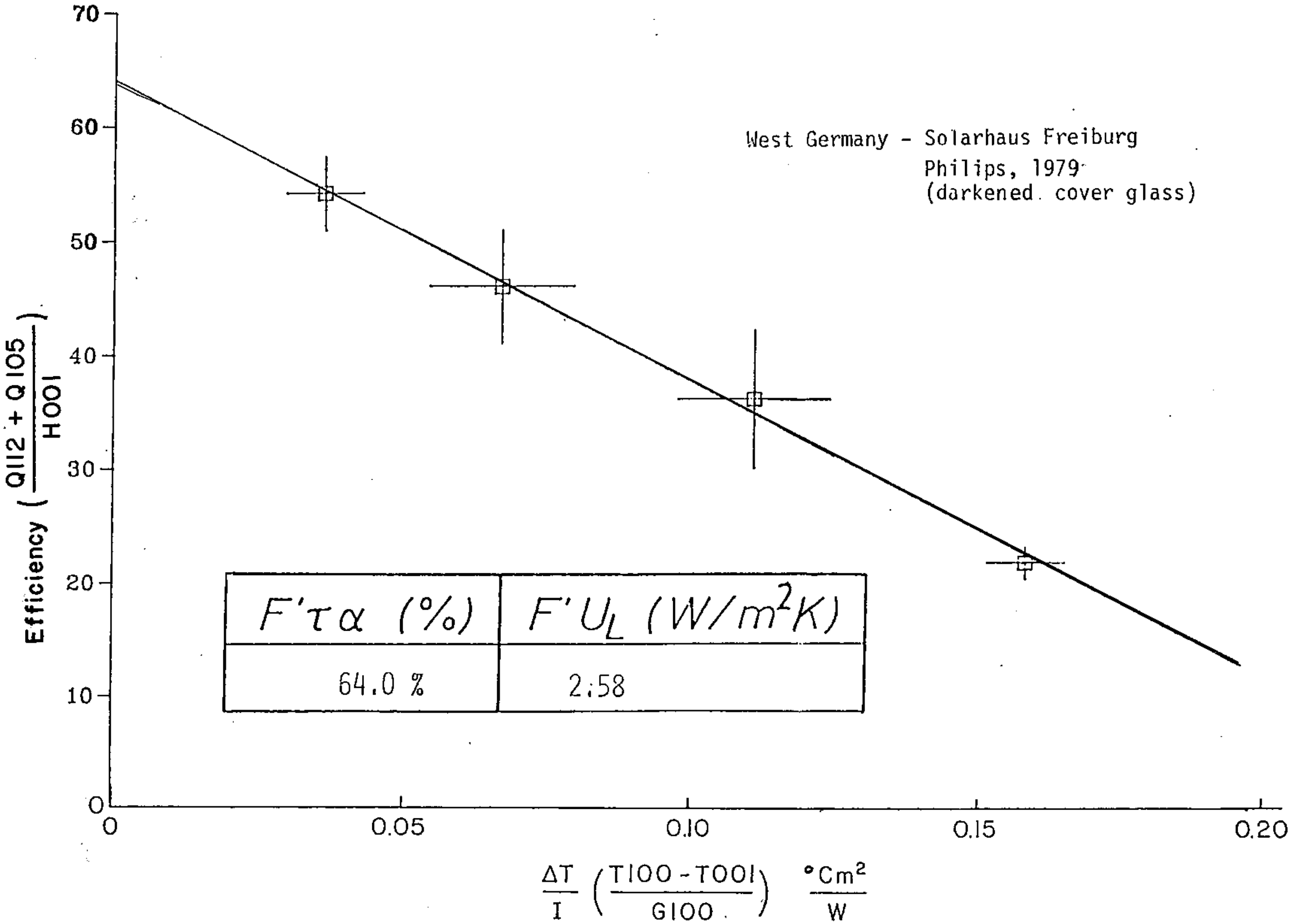


Figure 6-13. WG-HTG-1P, Array Efficiency for Philips MK IV Collectors

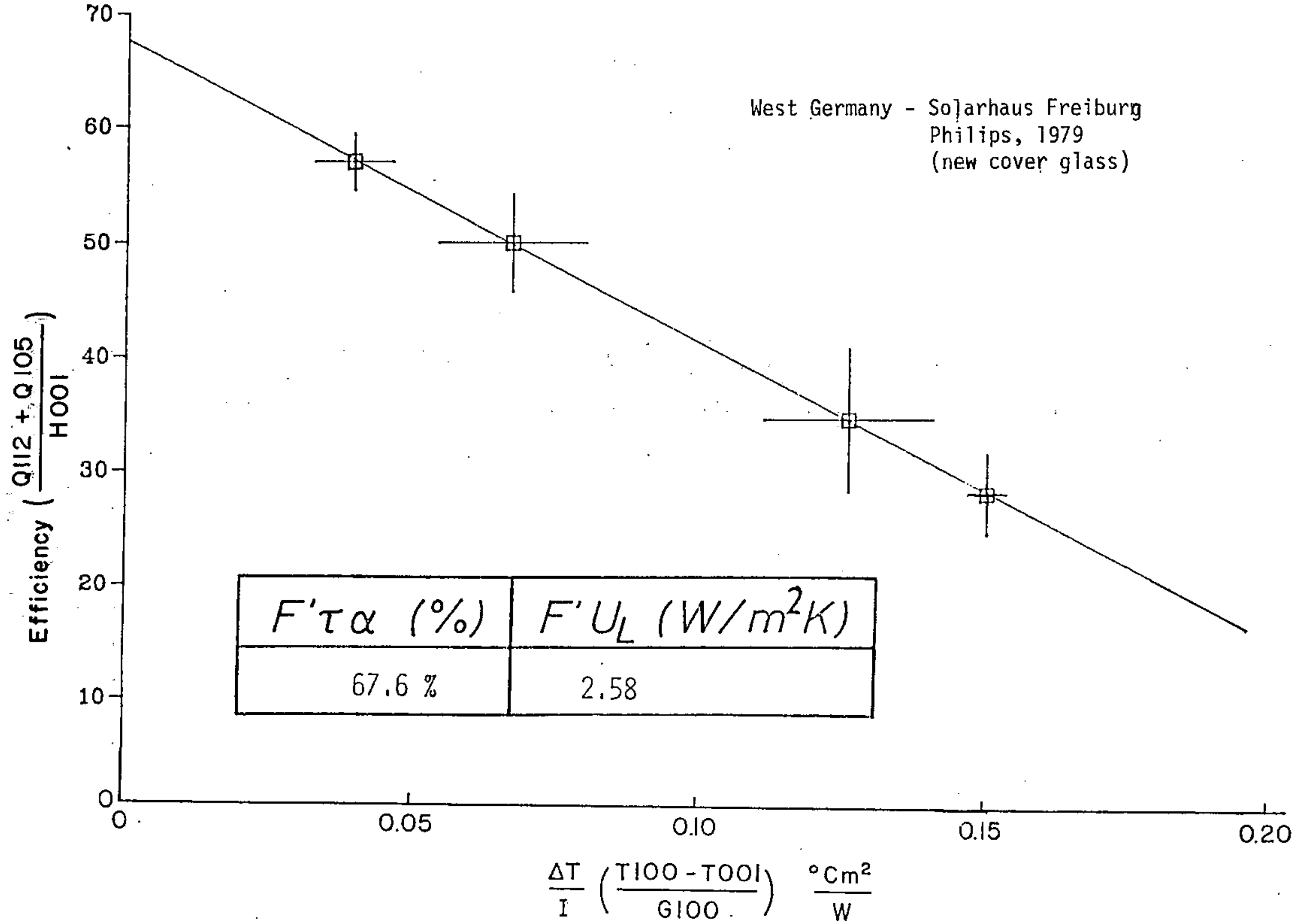


Figure 6-14. WG-DHW-2P, Array Efficiency for Philips MK IV Collectors

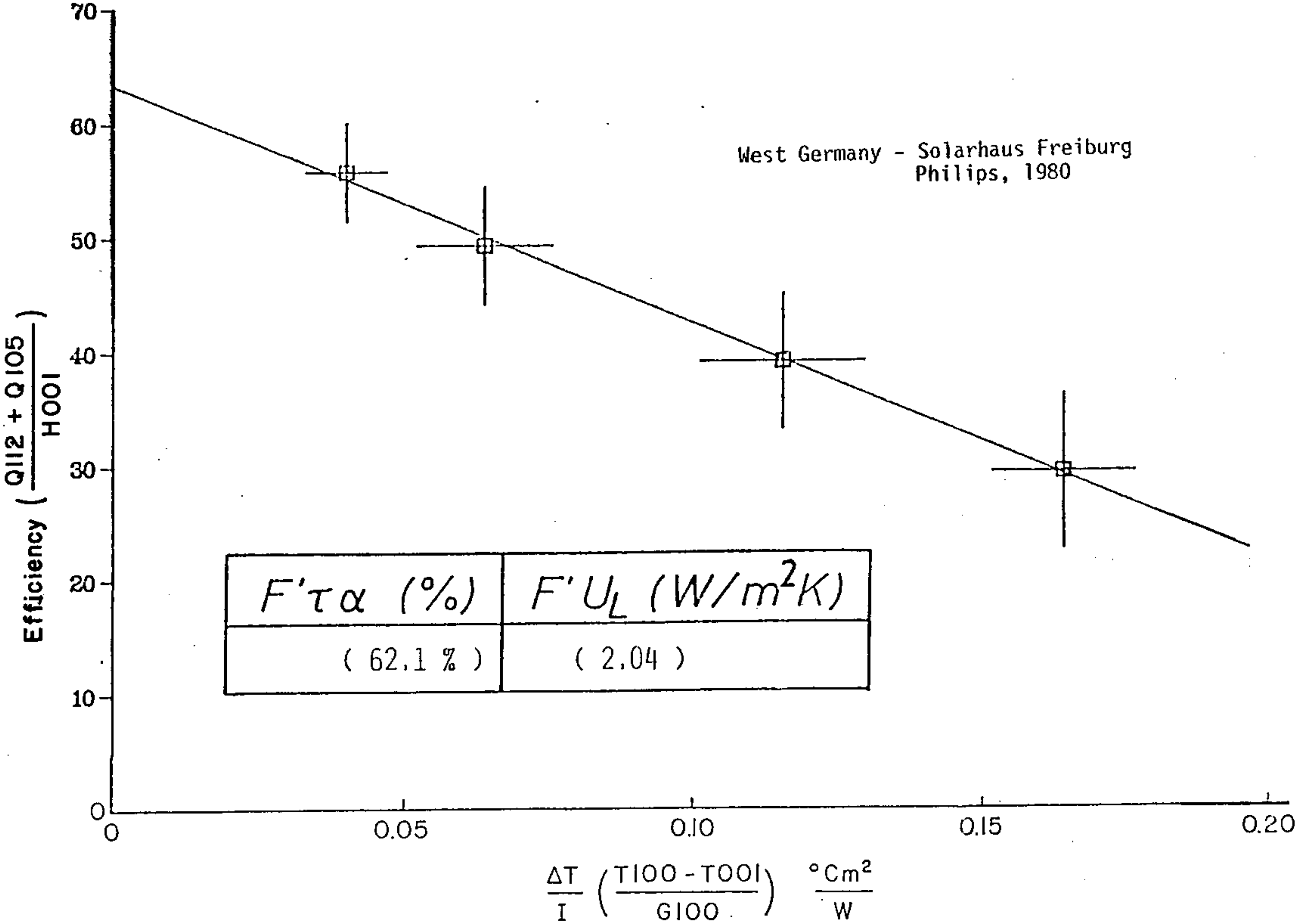


Figure 6-15. WG-DHW-3P and HTG-4P, Array Efficiency for Philips MK IV Collectors

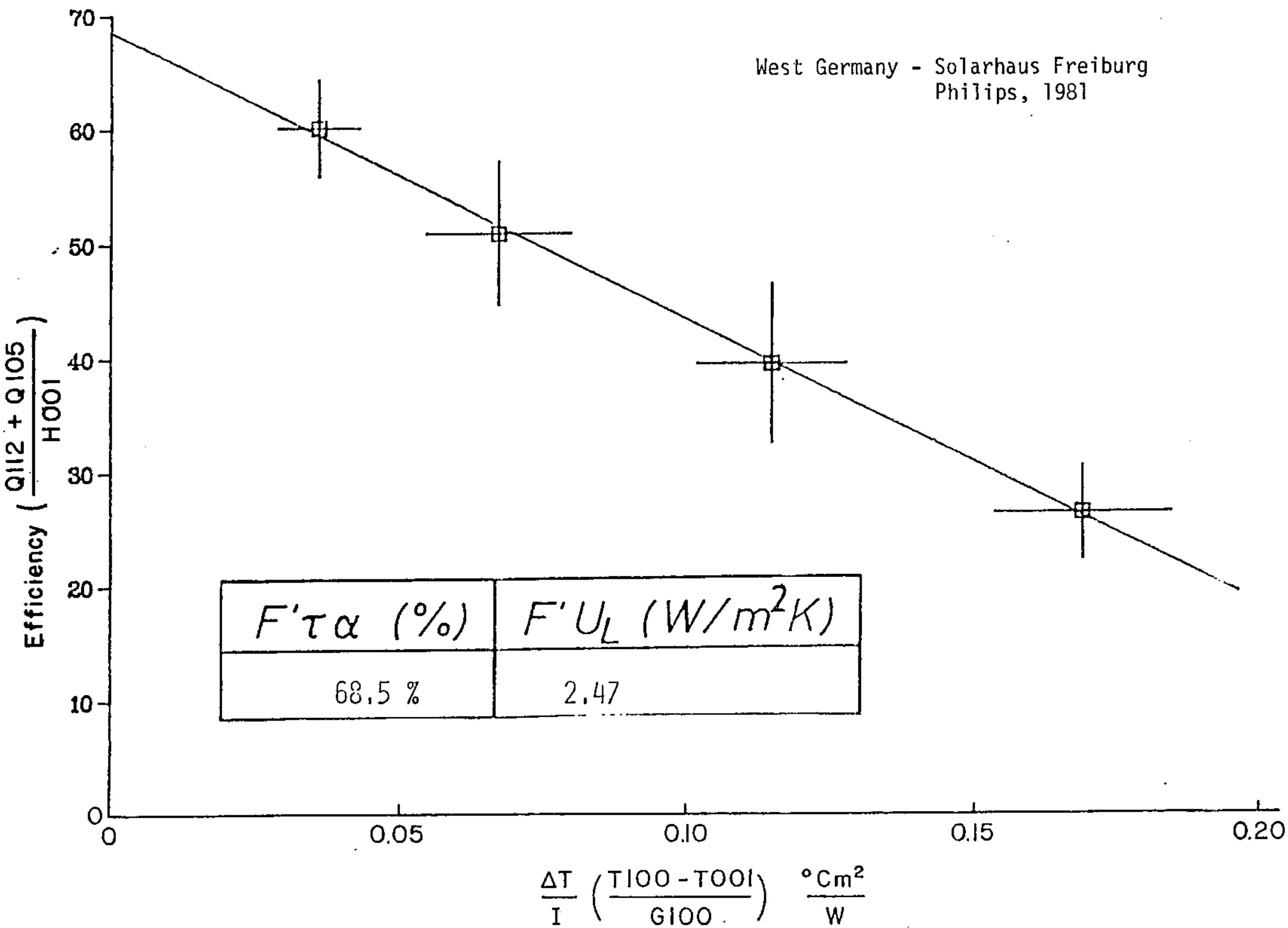


Figure 6-16. WG-HTG-5P, Array Efficiency for Philips MK IV Collectors

Three years of measuring collection system efficiencies found the typical low heat loss parameters of evacuated tubular collectors unchanged during four years of operation and agree quite well with expectations of manufacturer's test data. Except for the replacement of the darkened cover glass of Philips MK IV collector (August 1, 1979), the parameter values of the optical efficiency showed less variation than measurement accuracy and agree with the expected test values. The effect of solarization of the Philips MK IV cover pane glass is shown in Figures 6-13 and 6-14.

Solar radiation onto the collector plane (55° tilt) has been measured in 1979 by means of an EPPLEY Black and White Pyranometer, the readings of which had to be corrected because of a strong non-linearity (-10% reading at 1 kW/m^2). Although the correction procedure had been established by correlation against an EPPLEY PSP Pyranometer, the overall correction error is certainly higher ($\pm$ 2%) than the precision of the PSP itself ($\pm$1.0%). All radiation measurements in 1980 and 1981 have been carried out with an EPPLEY PSP, individually calibrated against an international standard (EPPLEY HF Cavity Self-calibrating Pyranometer).

During 1980, construction of a residence south of the Solarhaus Freiburg required the use of a crane, which shaded the Philips collector during selected hours of efficiency measurement. It was removed in January 1981.

The procedure of capacity correction has been successfully applied to efficiency measurements under transient collector system conditions. Nevertheless, there remains a considerable amount of scatter in hourly mid-day measurements, which is about twice as high as the overall measurement accuracy. This scatter may depend on several factors, e.g. on seasonal dependence of incidence angle, remaining effects of "lumped-capacity" or non-linearity of the thermal loss coefficient. The scatter is less important in the efficiency plots of the Corning collector (low capacity collector) and increases from 1979 to 1980 due to more frequent variations in system temperature (change in control strategy). More investigations should be carried out in this field in order to apply collector efficiency parameters to longterm quality control and in order to use these parameters in simulation studies under off-normal incidence angles.

6.2 ENERGY INPUT/OUTPUT PLOTS

Energy input/output plots are generated by fitting a least squares regression line to daily collection performance data. The points, when aggregated into average collector to average ambient temperature difference ranges, clearly closely fit a linear curve as can be seen in Figures 6-17 and 6-18. The ordinate in these plots is the daily total solar energy collected per unit collector aperture area, Q112/A100. The abscissa is the

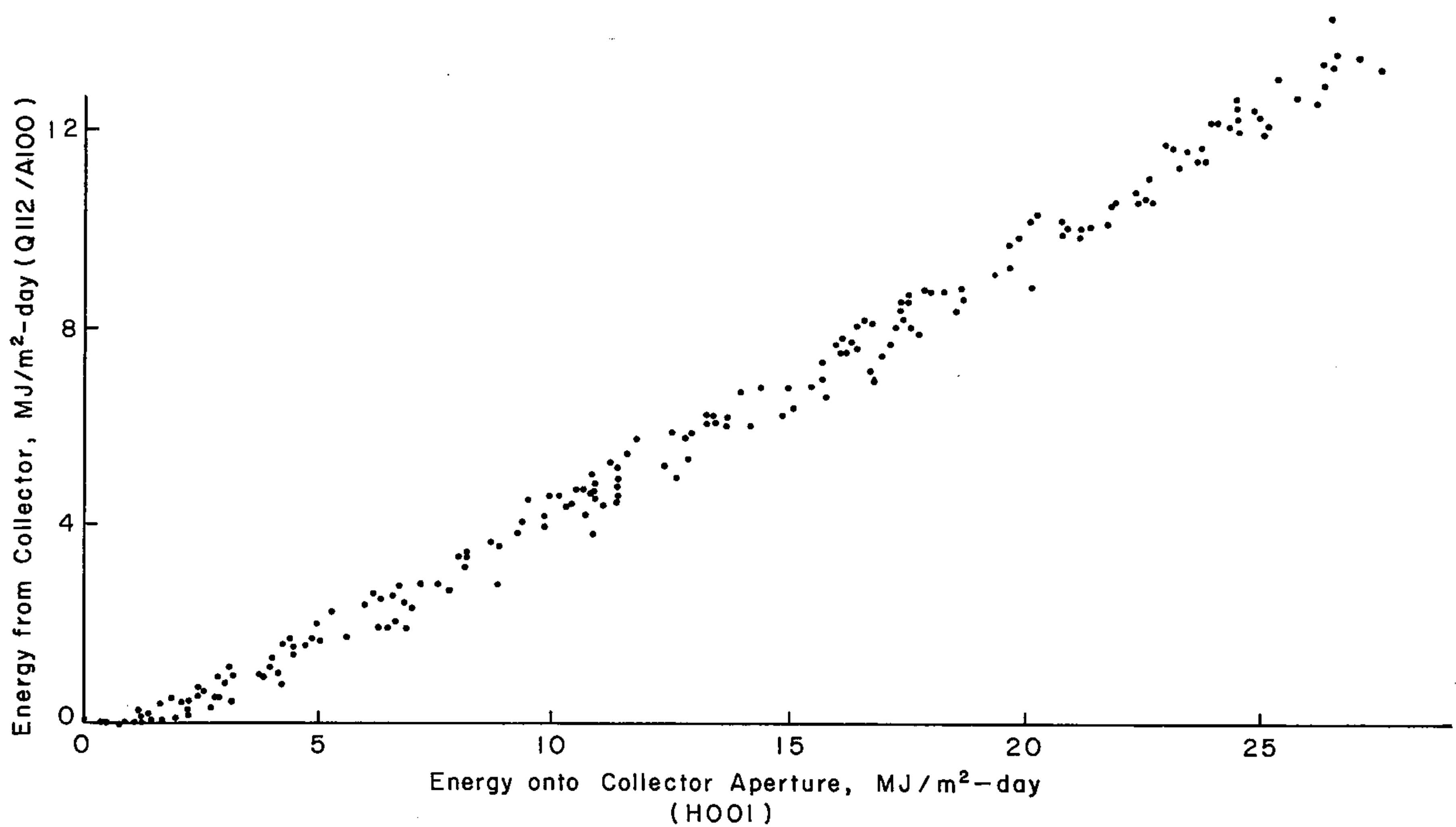


Figure 6-17. Daily Energy Input/Output for the Solarhaus Freiburg Corning Collector During 1980

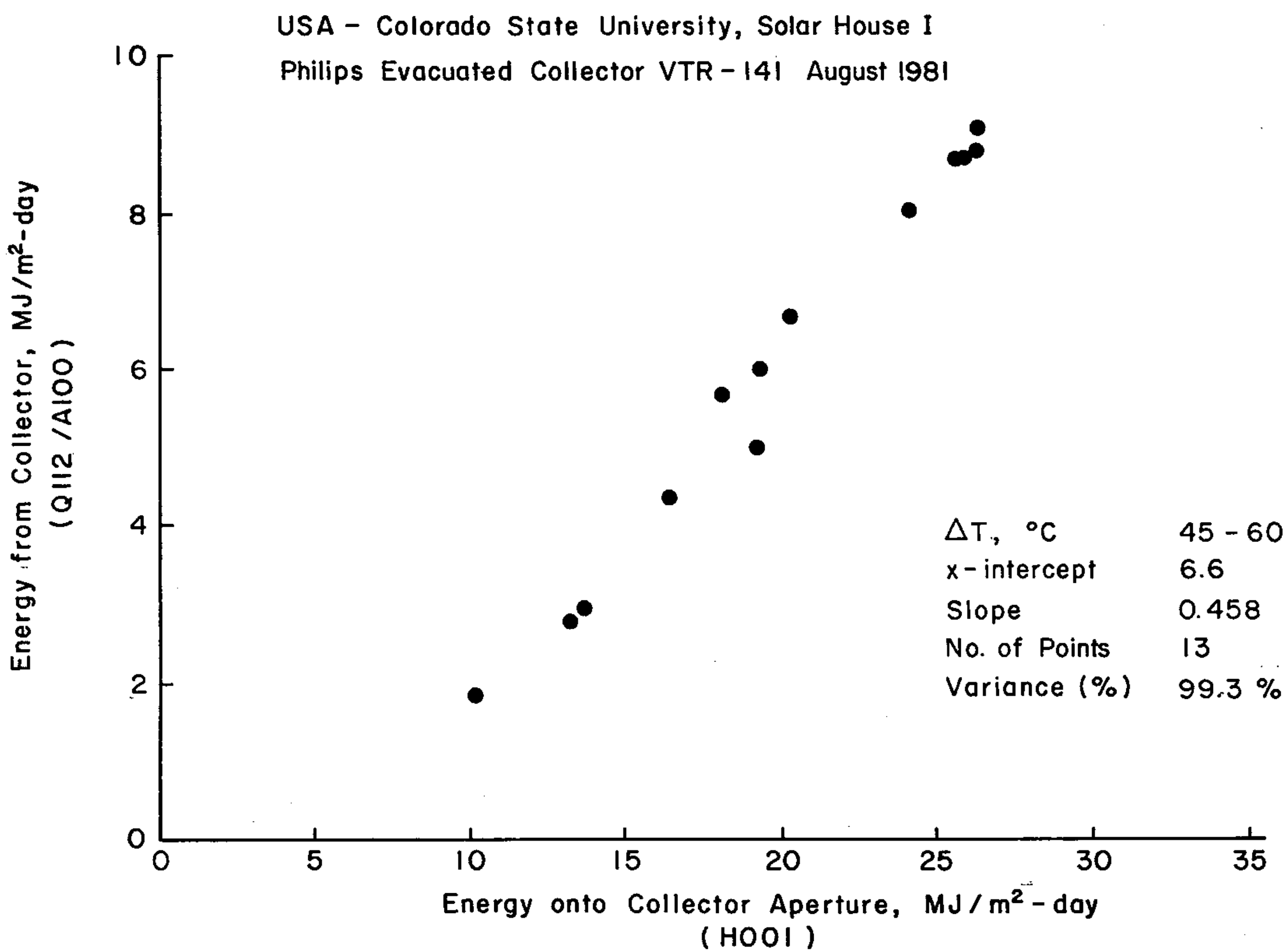


Figure 6-18. Daily Energy Input/Output for CSU Solar House I During August 1981

daily total solar incident on the aperture plane per collector aperture area, H100/A100. Normally one energy input/output plot is included for each experimental period. If appropriate, however, several experimental periods are combined. Only monthly regression lines are shown for the various temperature difference ranges in order that differences among systems and operating conditions can be clearly seen. The number of points used in the regression and the variance, or coefficient of determination, are also shown.

6.2.1 Osaka Sanyo Solar House - Japan

The regression lines for daily solar incident energy versus the daily total solar energy collected for the SANYO collector in heating and cooling seasons J-HTG-1 and J-CLG-1 are shown in Figures 6-19 and 6-20, respectively.

Figures 6-21 and 6-22 show the regression lines for the GE collector for the winter experiment, J-HTG-2, and the summer experiment, J-CLG-2.

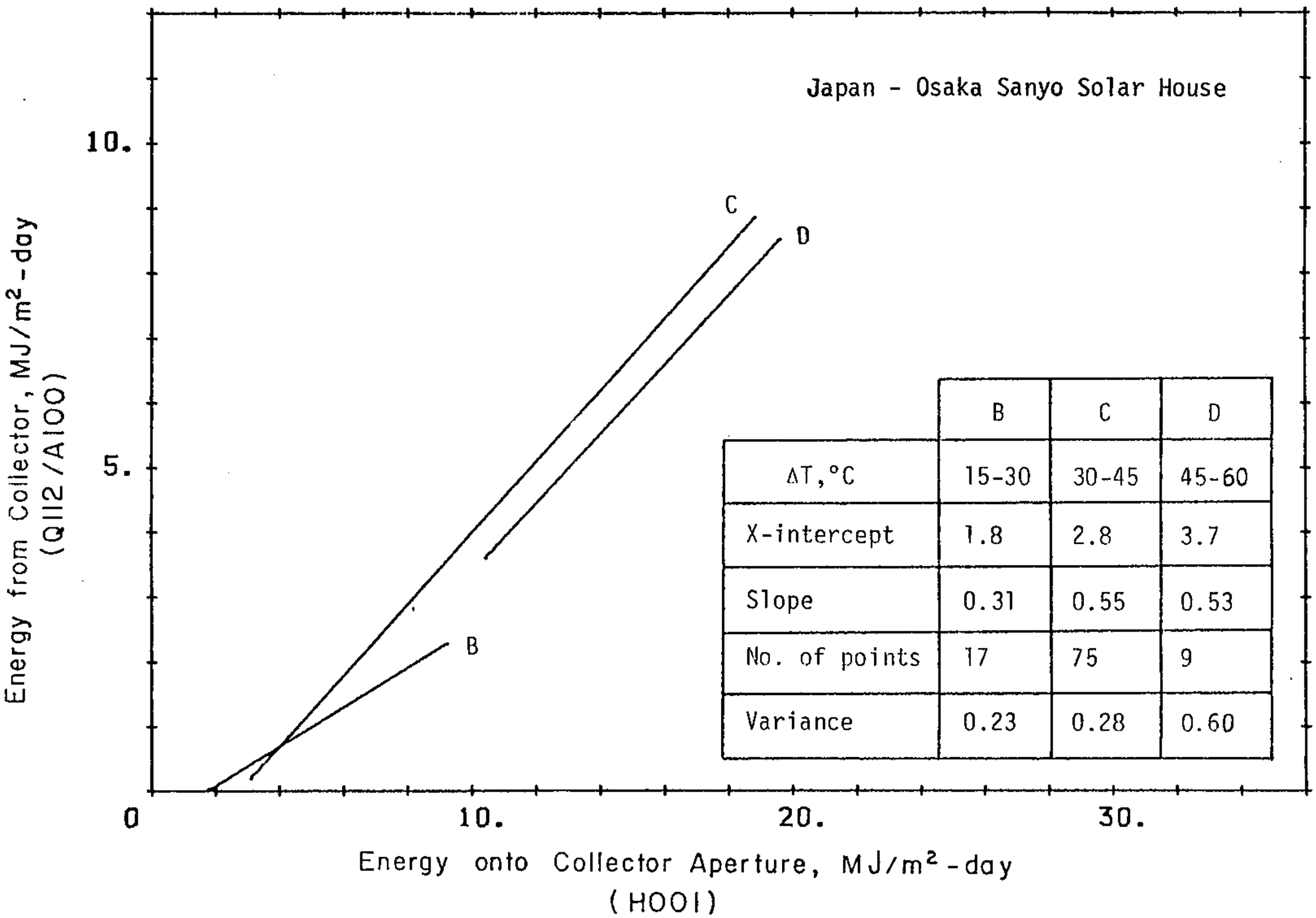
6.2.2 Knivsta District Heating Project - Sweden

The daily energy input/ouput (Q112/H100) is depicted in Figures 6-23, 6-24 and 6-25. Here a very surprising result was received for September when the system operation was changed from differential temperature control to continuous operation after September 18. In the first (normal) case the system has to be warmed up in the morning when the collector sensor indicates a stagnation temperature suitable for start-up. In the "continuous operation case", which was chosen to avoid freezing problems during winter operation, the collectors are already warm and energy contribution is calculated whenever the temperature gain in the collector is positive.

The surprising result is that almost all daily energy input/output points fit a nearly straight line with a very sharp threshold limit. Two distinct lines were produced, one for the temperature-controlled operation, the other for the continuous operation. The curves are nearly parallel and indicate a constant energy gap for the two control strategies.

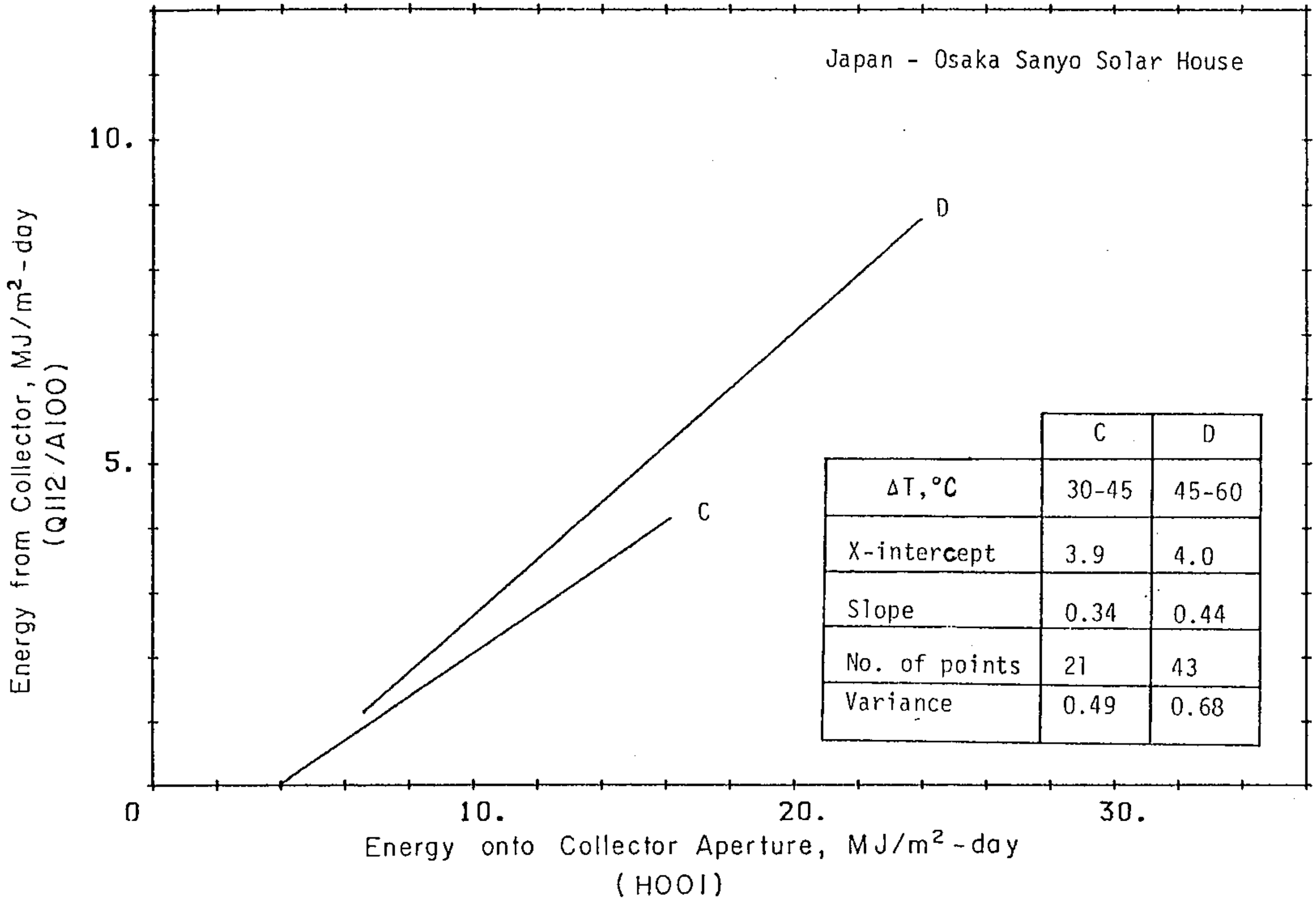
The explanation of the observed system behaviour can be found in the system application. The solar energy system is used with district heating at almost constant temperatures of about 60°C. This results in a relatively constant heat loss during the operation time and hence in the observed good fit of the average input/output line. Because of the heat capacity effects and the low heat loss coefficient, the evacuated tube collectors keep the operating temperatures constant under varying irradiation conditions during the day and the stochastic deviation from a linear fitting is very low.

The constant energy gap between temperature controlled and continuous operation can be explained by the heat capacity energy to be invested during the morning start-up. A one-time heating from ambient to operating temperature is all the energy needed to be invested in the system under



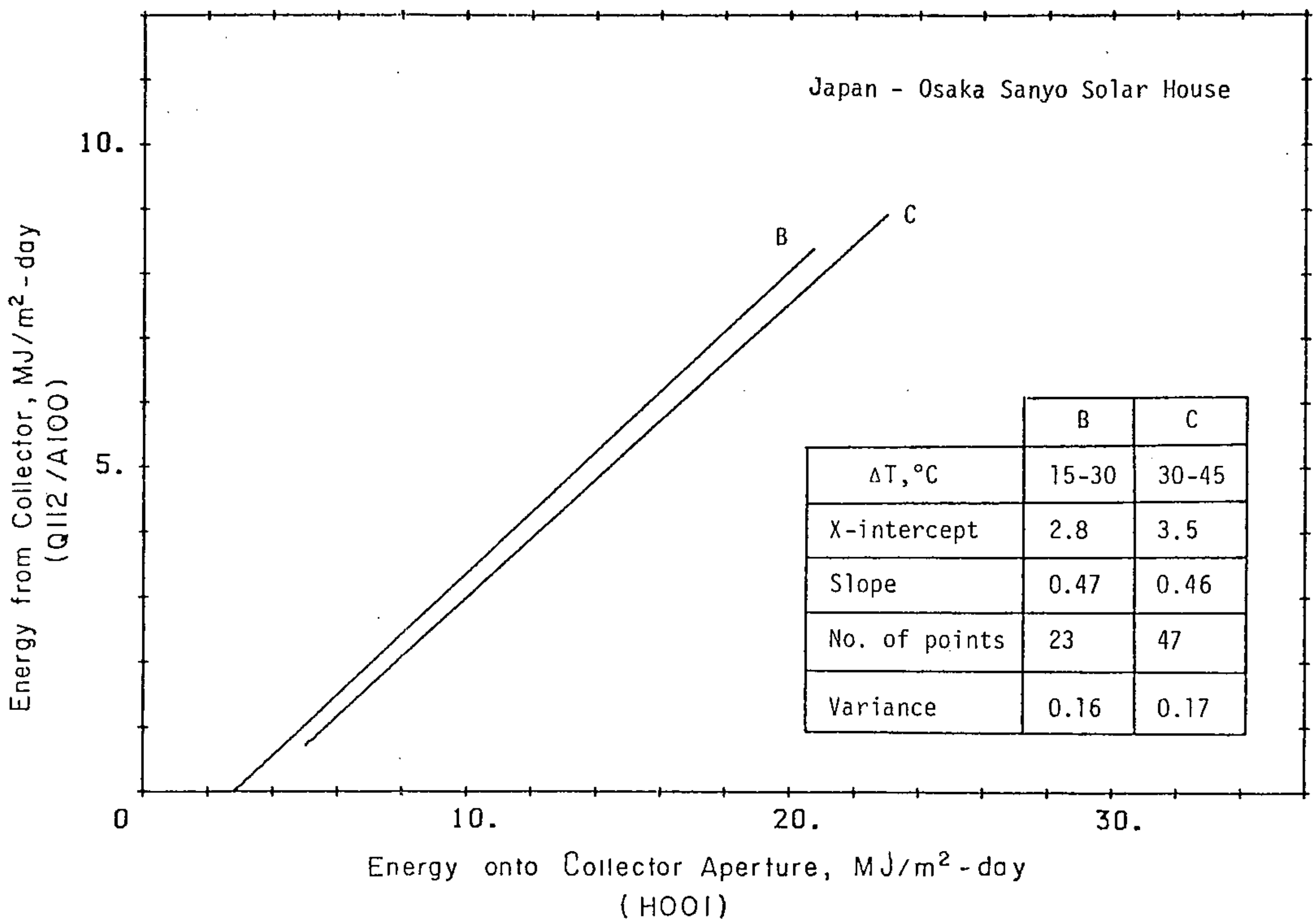
	B	C	D
ΔT,°C	15-30	30-45	45-60
X-intercept	1.8	2.8	3.7
Slope	0.31	0.55	0.53
No. of points	17	75	9
Variance	0.23	0.28	0.60

Figure 6-19. J-HTG-1, Daily Collection Performance for Sanyo Collectors



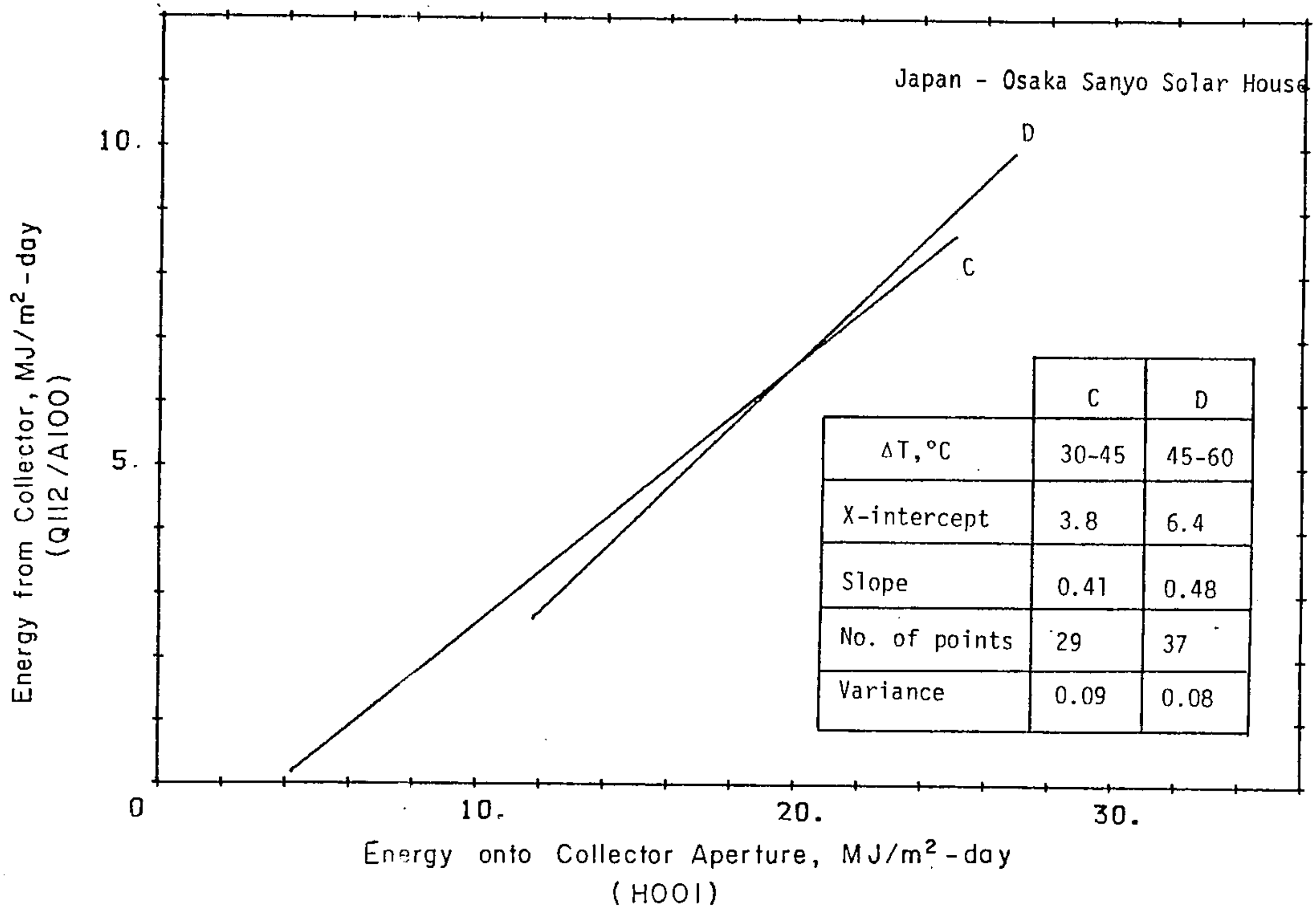
	C	D
ΔT, °C	30-45	45-60
X-intercept	3.9	4.0
Slope	0.34	0.44
No. of points	21	43
Variance	0.49	0.68

Figure 6-20. J-CLG-1, Daily Collection Performance for Sanyo Collectors



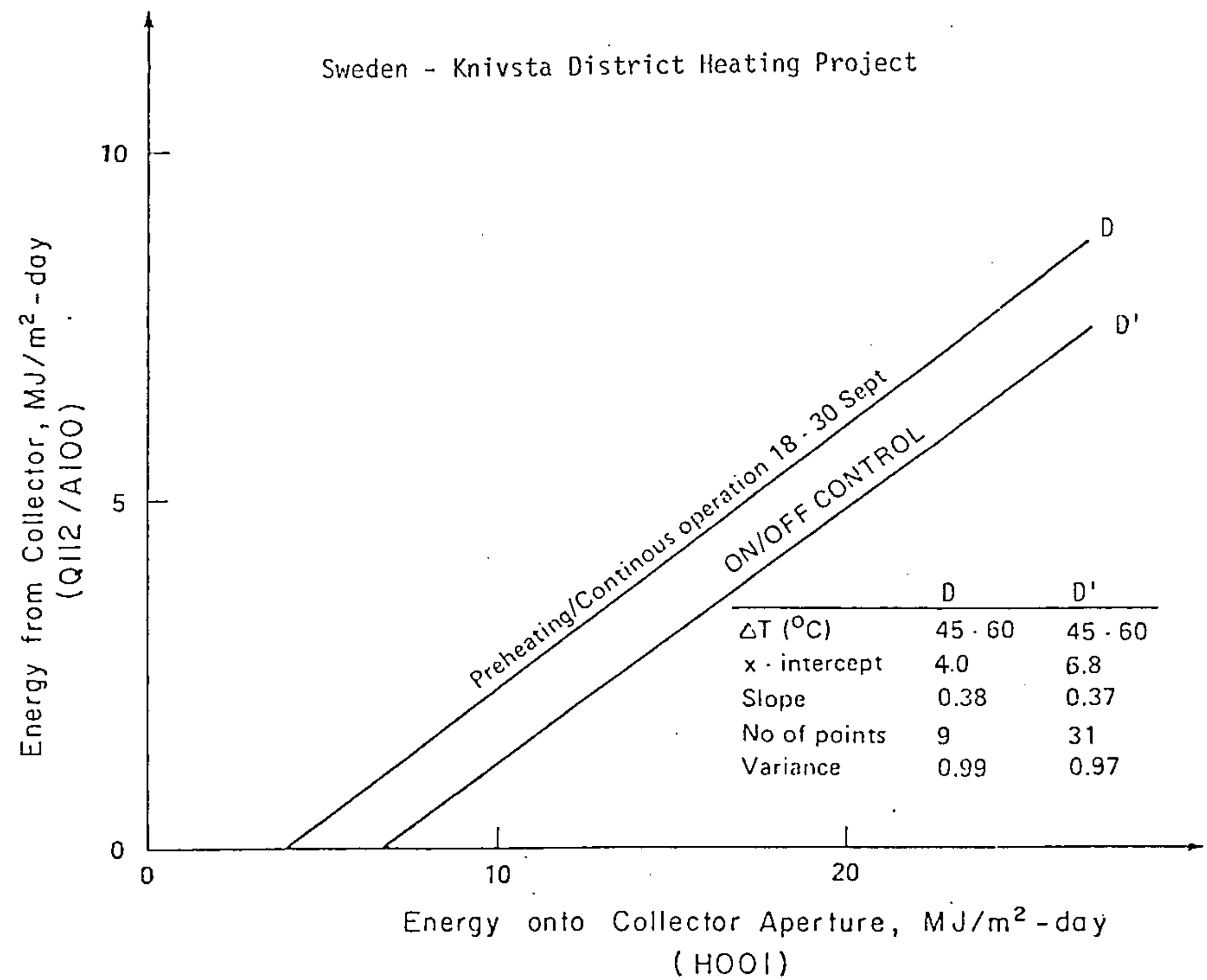
	B	C
ΔT,°C	15-30	30-45
X-intercept	2.8	3.5
Slope	0.47	0.46
No. of points	23	47
Variance	0.16	0.17

Figure 6-21. J-HTG-2, Daily Collection Performances for General Electric Collectors



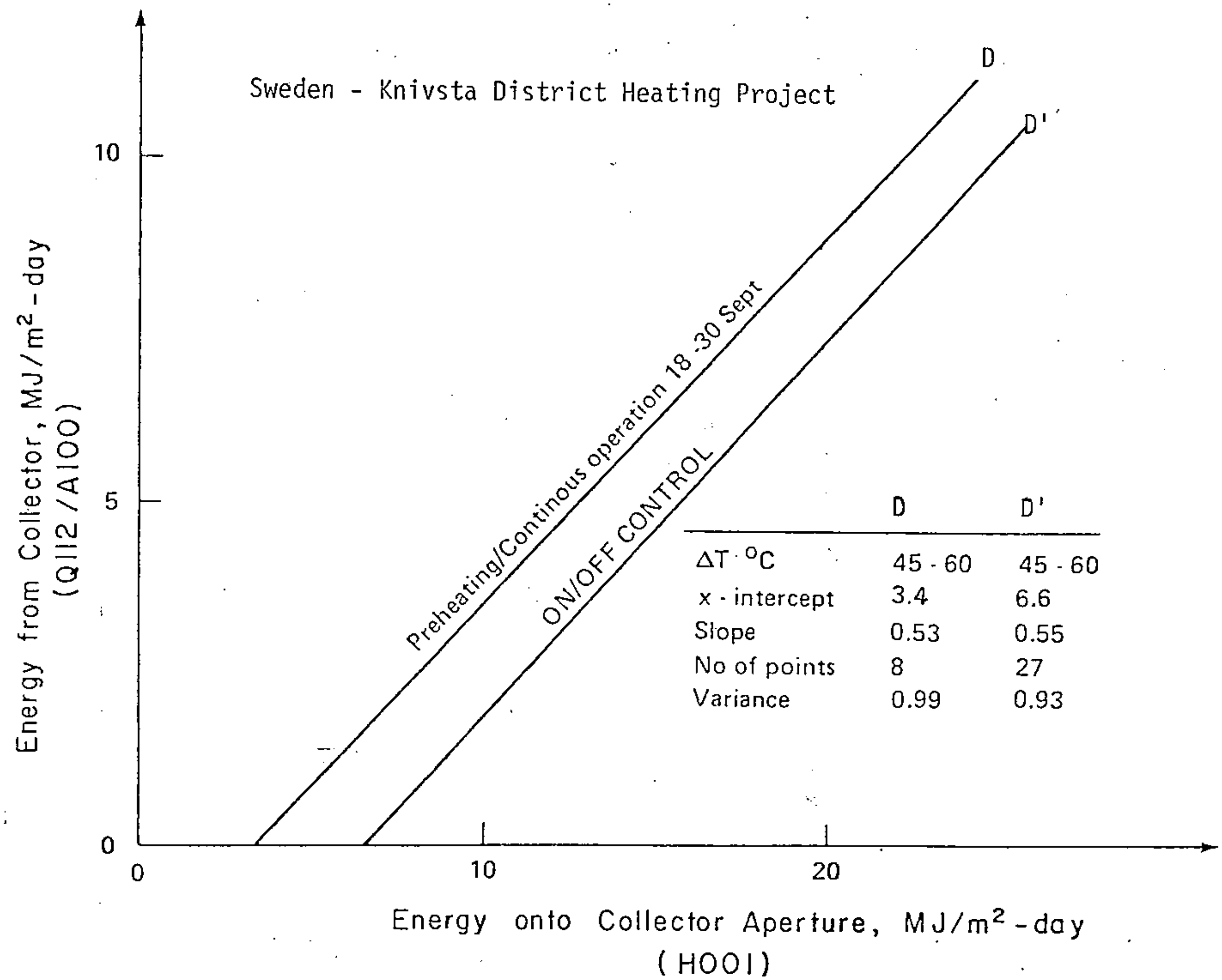
	C	D
ΔT, °C	30-45	45-60
X-intercept	3.8	6.4
Slope	0.41	0.48
No. of points	29	37
Variance	0.09	0.08

Figure 6-22. J-CLG-2, Daily Collection Performances for General Electric Collectors



	D	D'
ΔT (°C)	45 - 60	45 - 60
x - intercept	4.0	6.8
Slope	0.38	0.37
No of points	9	31
Variance	0.99	0.97

Figure 6-23. S-HTG-1, Daily Collection Performances for General Electric Collectors



	D	D'
ΔT · °C	45 - 60	45 - 60
x - intercept	3.4	6.6
Slope	0.53	0.55
No of points	8	27
Variance	0.99	0.93

Figure 6-24. S-HTG-2, Daily Collection Performances for Owens-Illinois Collectors

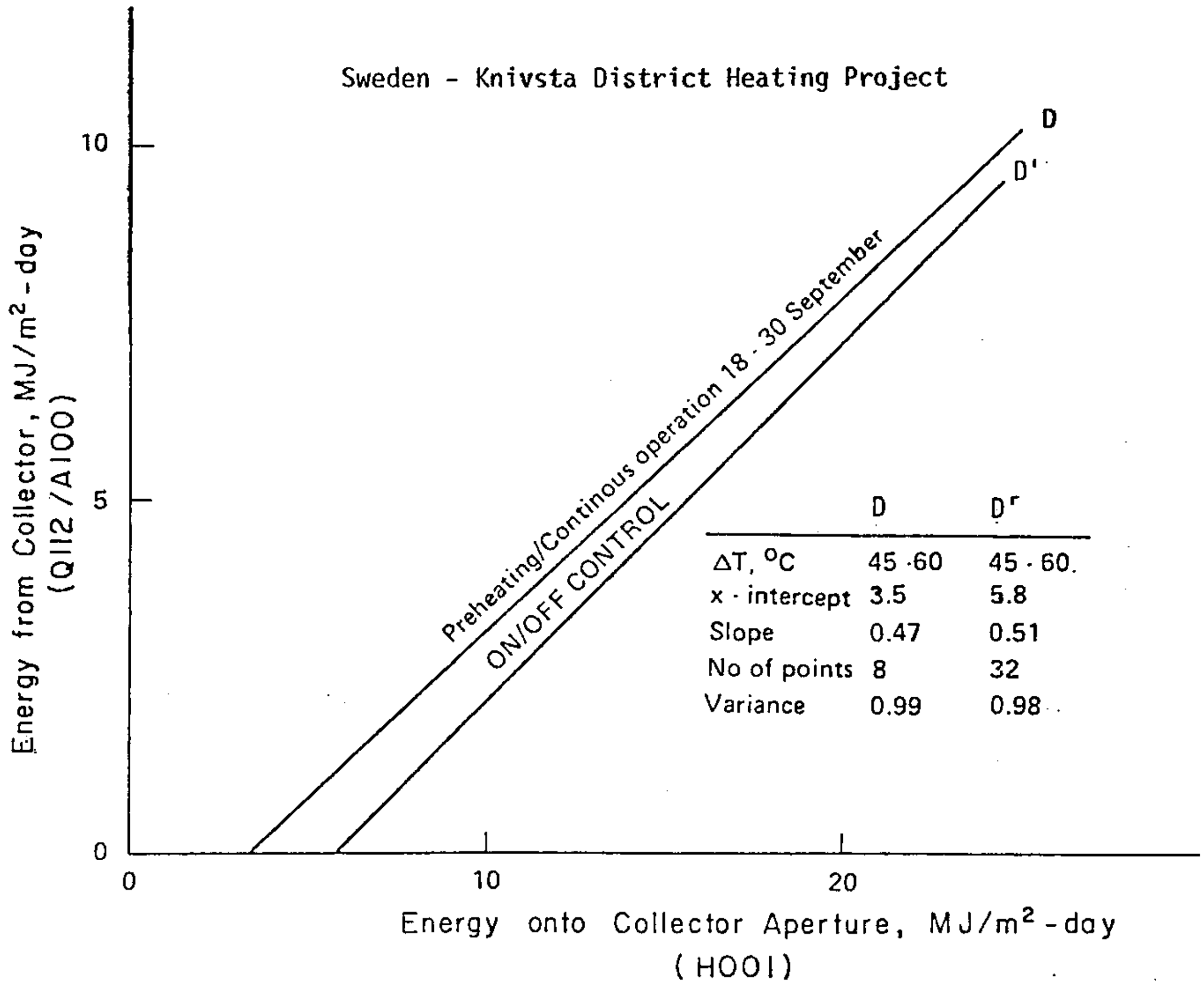


Figure 6-25. S-HTG-3, Daily Collection Performances for Philips VTR 141 Collectors

most of the summer operation conditions (no winter experience has been gained so far). From the energy gap we can therefore directly draw conclusions about the total heat capacity of the system. For example, if we relate to an average September morning temperature of 12°C, the heat capacity of the OI system is calculated to be 1.24 MJ/m^2 whereas for the Philips collectors the calculated heat capacity is 0.83 MJ/m^2. It is obvious that heat capacity effects between both systems are not as stringent as may be believed from the difference in construction in both types of collectors. However, the largest difference is seen in the starting and stopping behavior. The Philips system starts relatively early in the morning whereas the OI collectors start with a large delay, but run longer into the evening. On the other hand, on a sunny November day, we observed that both GE and Philips collectors were operating for 5 hours, whereas the OI system could never warm up to operating conditions.

6.2.3 Colorado State University Solar House I - USA

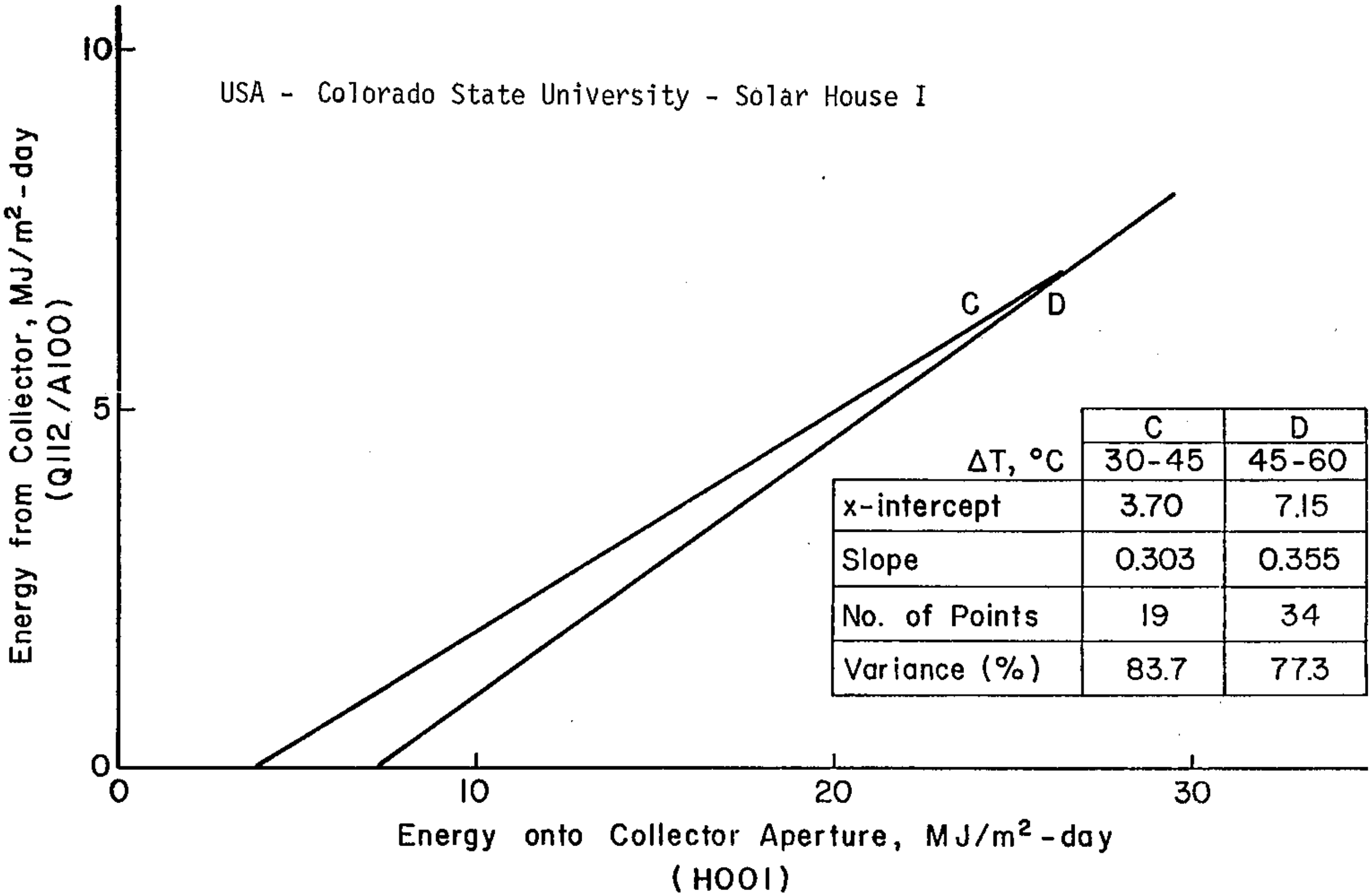
The energy input/output graphs were constructed following the stated IEA format. For experiments USA-HTG-1 and USA-CLG-1, Figure 6-26 shows the daily collected energy as a function of solar radiation, partially subdivided by average storage temperatures during collection. The variance ranges from 0.77 to 0.84.

In Figures 6-27 and 6-28, heat collection is correlated with solar radiation for the Philips VTR141 collector in the heating experiments USA-HTG-2, USA-HTG-3 and USA-HTG-4 and in the cooling experiments USA-CLG-2, 3, and 4 respectively. The variance is from 0.86 to 0.97.

6.2.4 Solarhaus Freiburg - West Germany

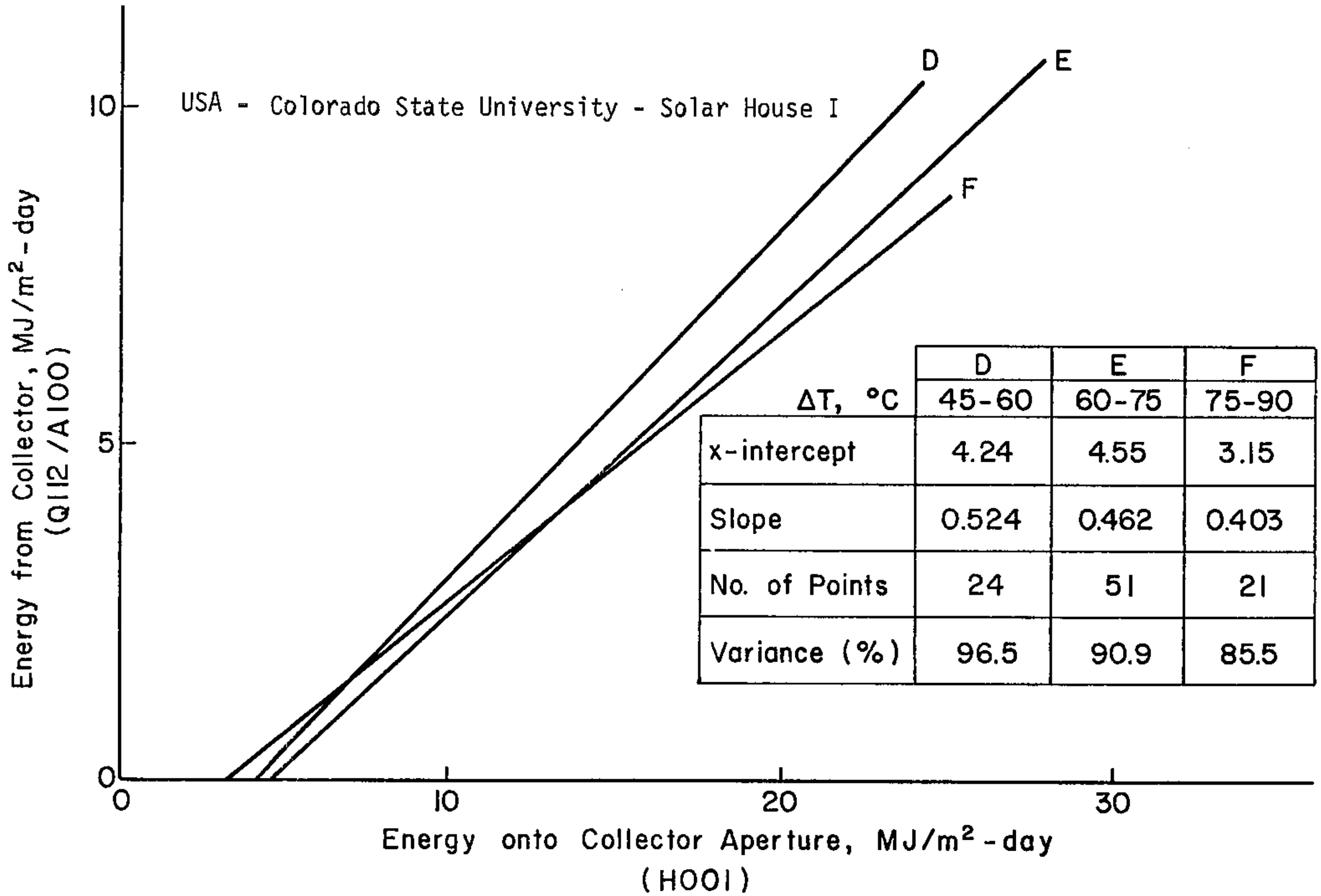
Daily integrals of solar energy collected Q112 are plotted against daily integrals of total incident solar radiation H001, as stated in the IEA format. In addition to the separation in three classes of temperature differences ΔT (average daily collector system temperature minus ambient temperature) has applied to the primary daily data points. This procedure yields several regression lines per year, the specification of which is compiled in a table on each Figure. Using multi-linear regression analysis, Solar Collected (Q112) has been expressed as a multi-linear function of total daily insolation and temperature difference Q112 = Q112 (H001, ΔT). The corresponding factors and statistics are included in each of the Figures. All regression lines of both collector systems show a significant linear correlation of collected solar energy with incident daily radiation. (Figures 6-29 to 6-35).

There are two plots for Philips MK IV collector used in 1979, one with the solarized glass cover and then after its replacement in order to demonstrate the influence of $F'\tau\alpha$ on the regression coefficient of the graph. Another interesting result is the difference of minimum daily radiation between the Corning and Philips MK IV collector systems. Because of its low capacity, the Corning system begins production of



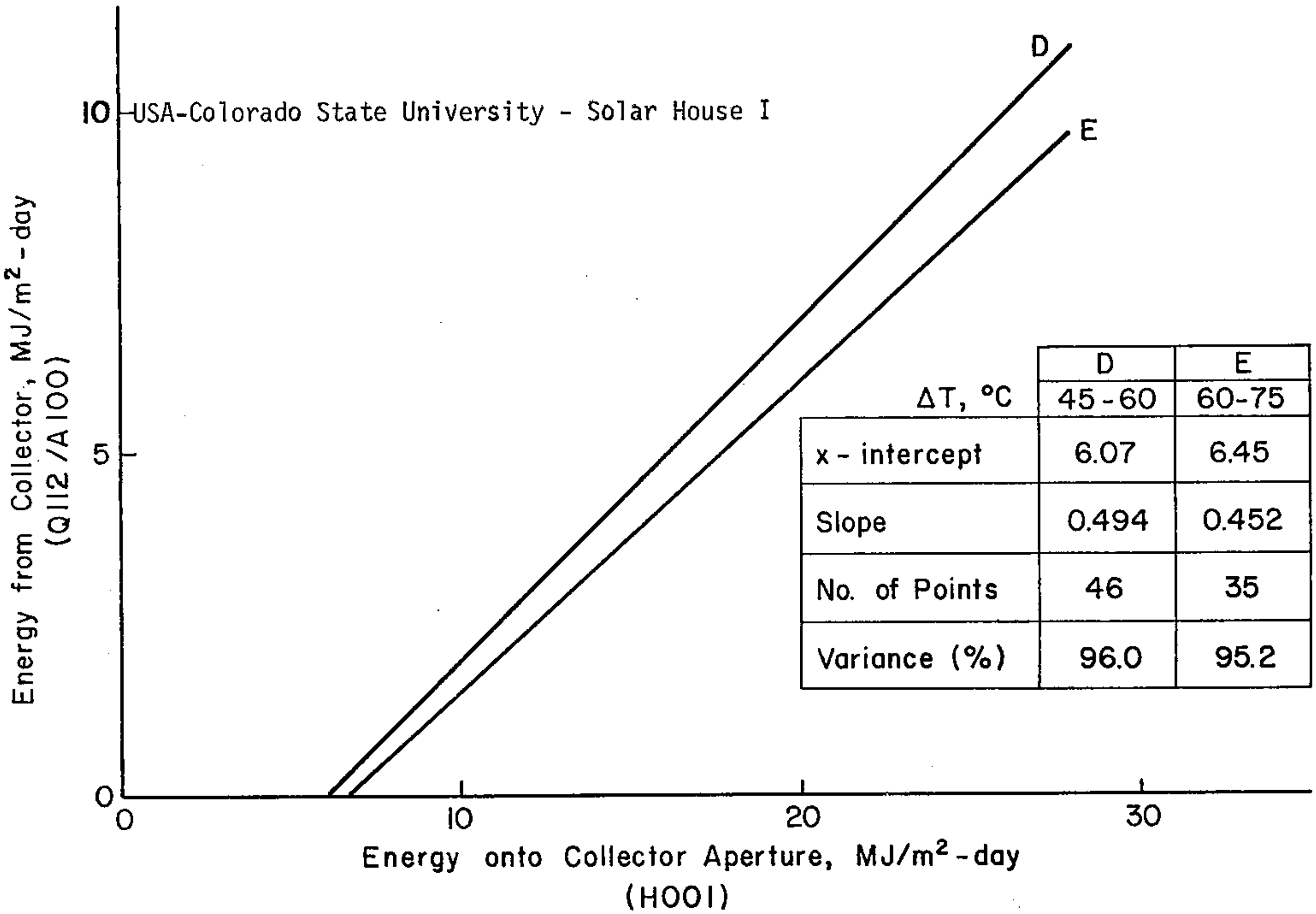
	C	D
ΔT, °C	30-45	45-60
x-intercept	3.70	7.15
Slope	0.303	0.355
No. of Points	19	34
Variance (%)	83.7	77.3

Figure 6-26. USA-HTG-1 and CLG-1, Daily Collection Performances for Miromit Flat Plate Collectors



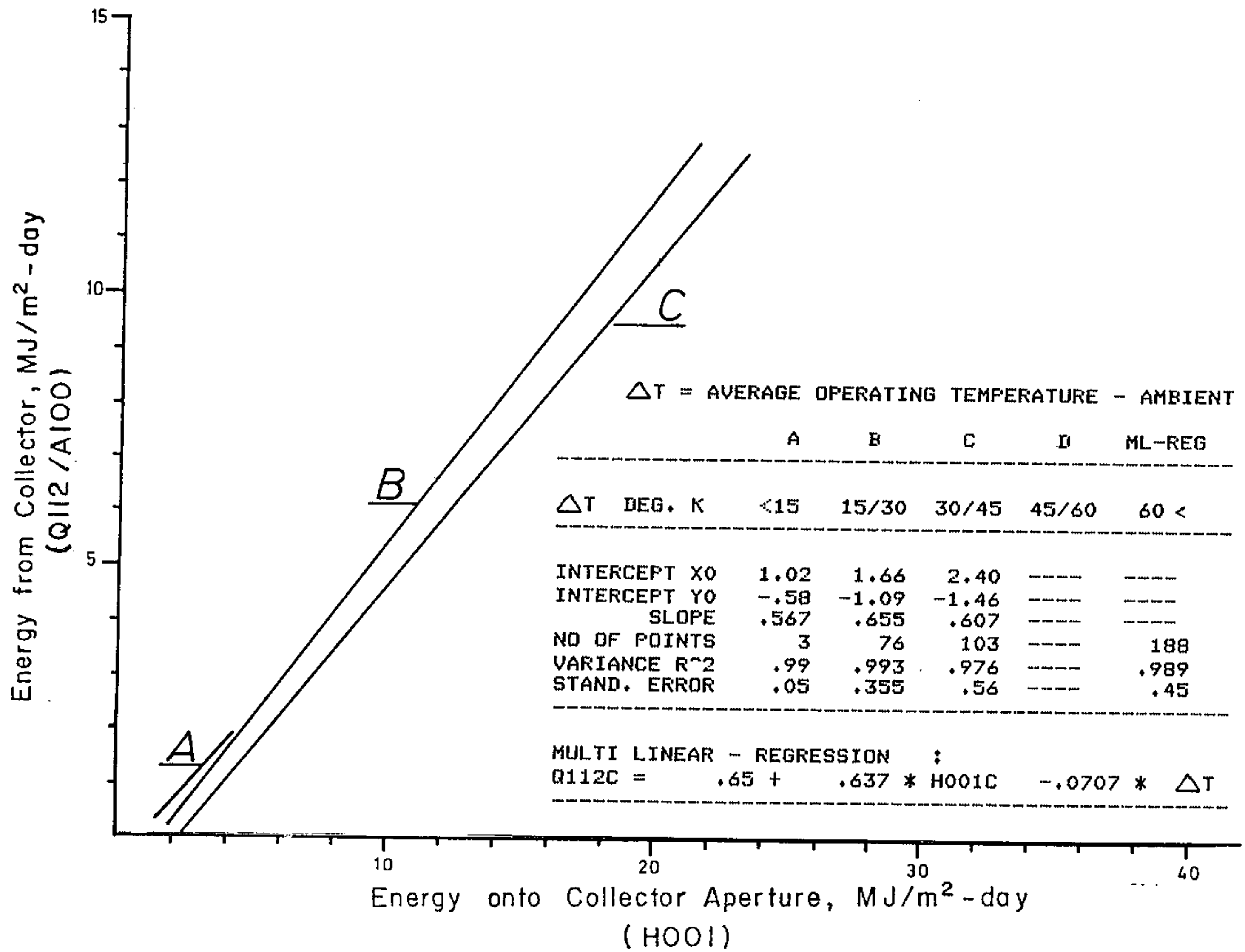
	D	E	F
ΔT, °C	45-60	60-75	75-90
x-intercept	4.24	4.55	3.15
Slope	0.524	0.462	0.403
No. of Points	24	51	21
Variance (%)	96.5	90.9	85.5

Figure 6-27. USA-HTG-2, 3, and 4, Daily Collection Performances for Philips VTR 141 Collectors



	D	E
ΔT, °C	45-60	60-75
x - intercept	6.07	6.45
Slope	0.494	0.452
No. of Points	46	35
Variance (%)	96.0	95.2

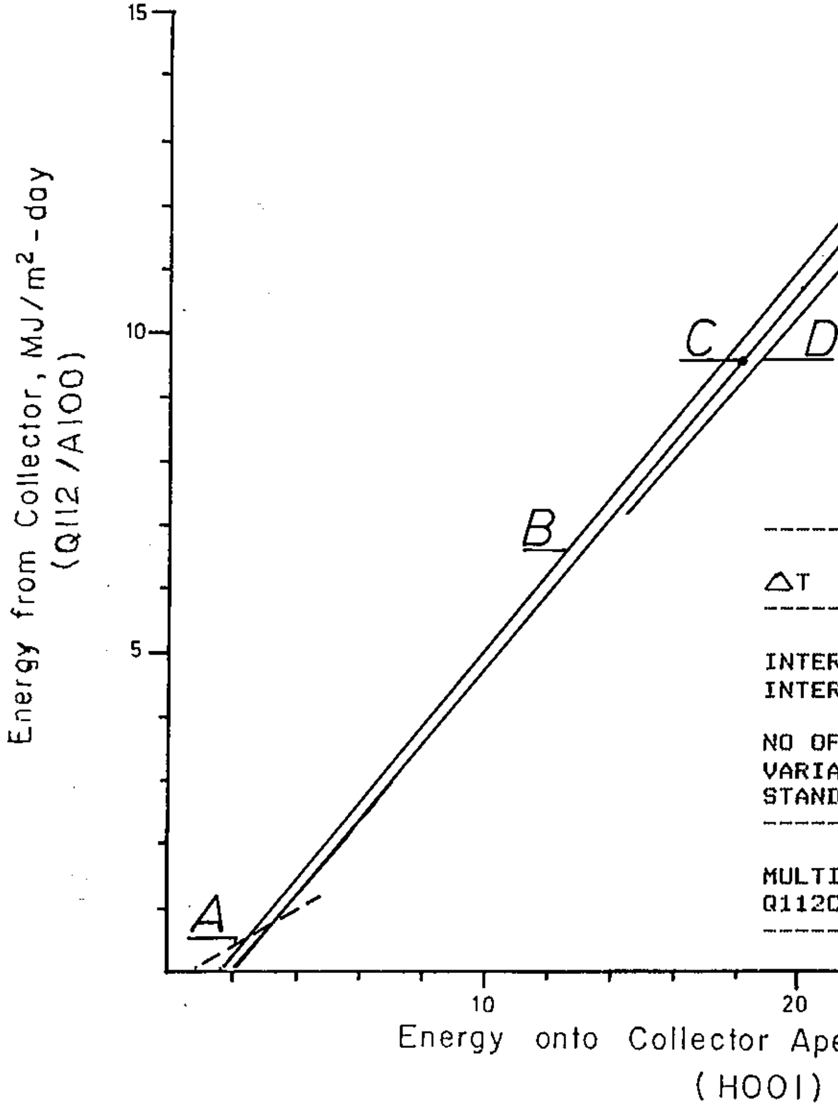
Figure 6-28. USA-CLG-2, 3, and 4, Daily Collection Performances for Philips VTR 141 Collectors



	A	B	C	D	ML-REG
ΔT DEG. K	<15	15/30	30/45	45/60	60 <
INTERCEPT X0	1.02	1.66	2.40	----	----
INTERCEPT Y0	-.58	-1.09	-1.46	----	----
SLOPE	.567	.655	.607	----	----
NO OF POINTS	3	76	103	----	188
VARIANCE R^2	.99	.993	.976	----	.989
STAND. ERROR	.05	.355	.56	----	.45

MULTI LINEAR - REGRESSION :
Q112C = .65 + .637 * H001C -.0707 * ΔT

Figure 6-29. WG-DHW-1C and HTG-2C, Daily Collection Performances for Corning Glass Collectors



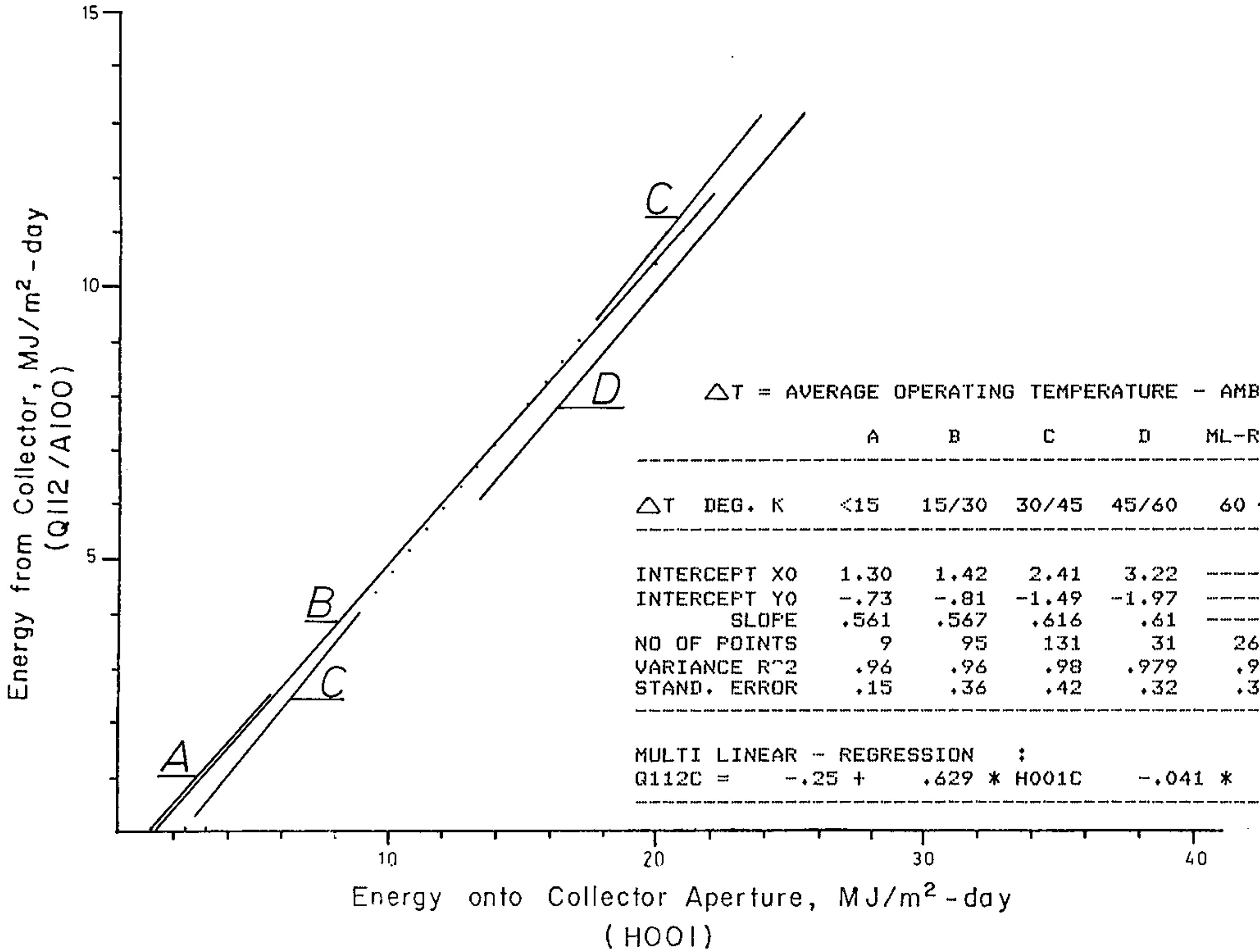
ΔT = AVERAGE OPERATING TEMPERATURE - AMBIENT TEMPERATURE

	A	B	C	D	ML-REG
ΔT DEG. K	<15	15/30	30/45	45/60	60 <
INTERCEPT X0	.357	1.64	1.95	1.90	----
INTERCEPT Y0	-.1	-1	-1.17	-1.1	----
SLOPE	.28	.607	.598	.576	----
NO OF POINTS	7	129	129	19	284
VARIANCE R^2	.44	.988	.982	.987	.99
STAND. ERROR	.23	.35	.51	.31	.42

MULTI LINEAR - REGRESSION :

Q112C = -.37 + .61 * H001C -.028 * ΔT

Figure 6-30. WG-DHW-4C and HTG-3C, Daily Collection Performances for Corning Glass Collectors



ΔT = AVERAGE OPERATING TEMPERATURE - AMBIENT TEMPERATURE

	A	B	C	D	ML-REG
ΔT DEG. K	<15	15/30	30/45	45/60	60 <
INTERCEPT XO	1.30	1.42	2.41	3.22	----
INTERCEPT YO	-.73	-.81	-1.49	-1.97	----
SLOPE	.561	.567	.616	.61	----
NO OF POINTS	9	95	131	31	266
VARIANCE R^2	.96	.96	.98	.979	.99
STAND. ERROR	.15	.36	.42	.32	.38

MULTI LINEAR - REGRESSION :

Q112C = -.25 + .629 * H001C -.041 * ΔT

Figure 6-31. WG-DHW-5C, Daily Collection Performances for Corning Glass Collectors

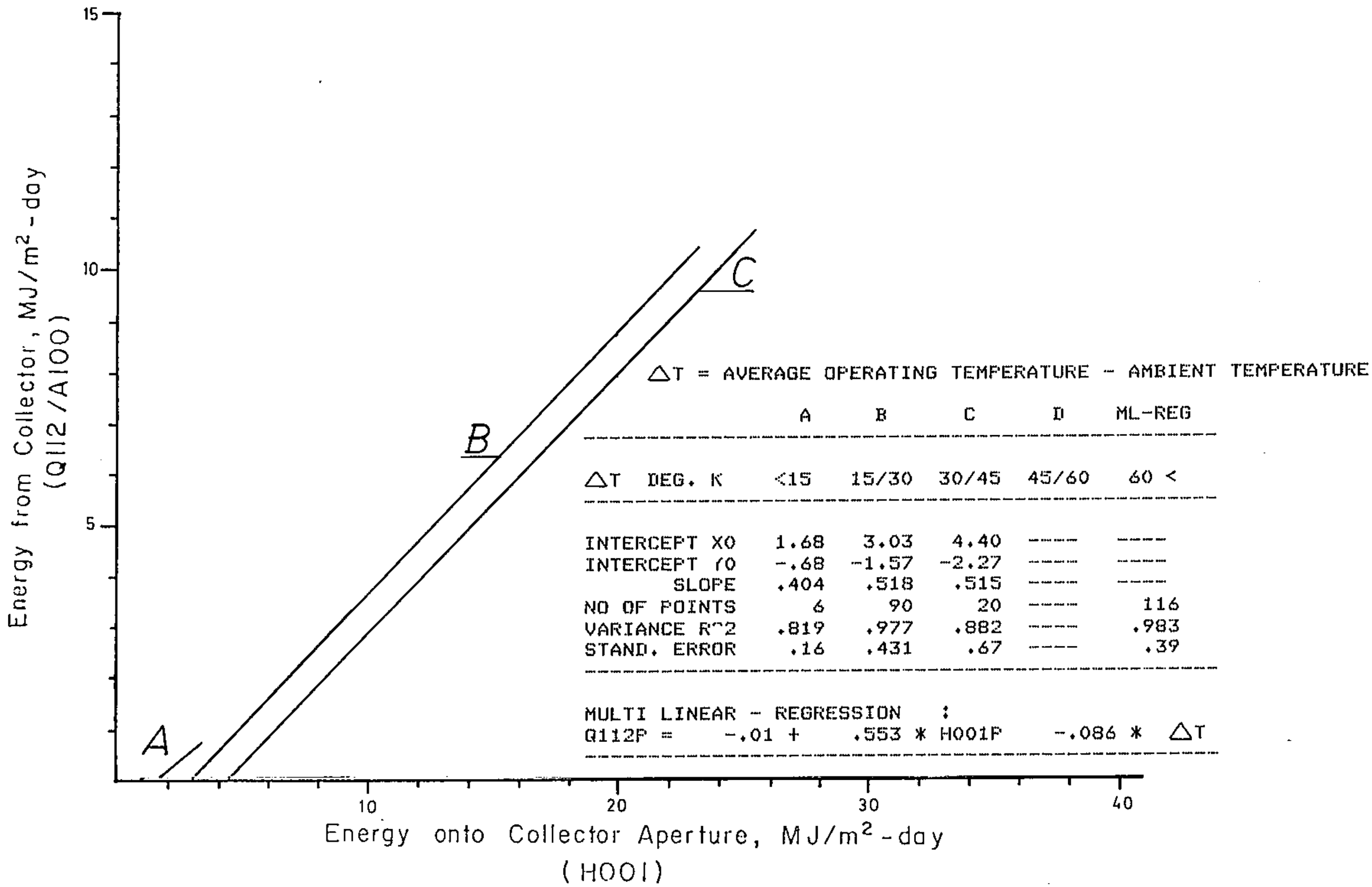
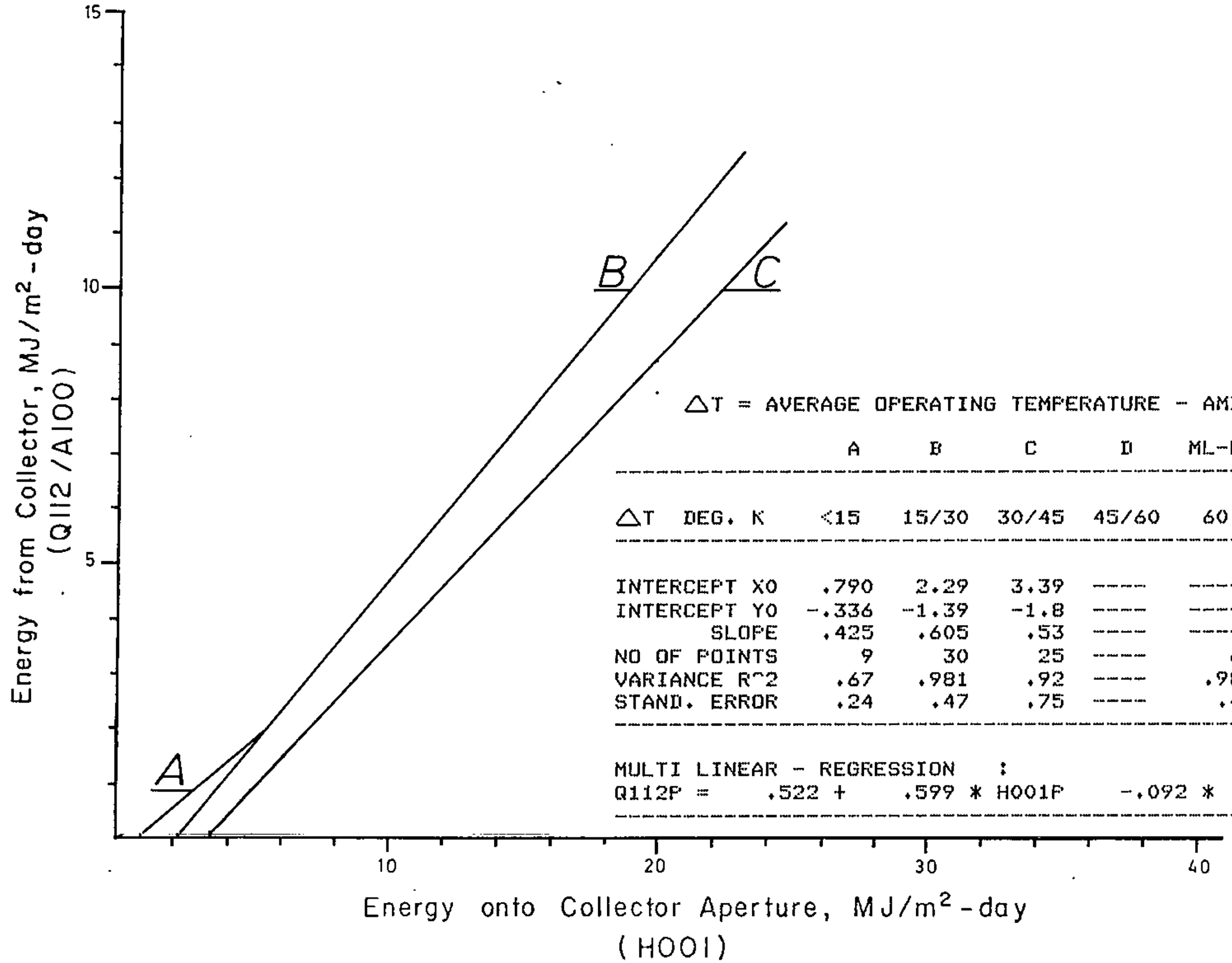


Figure 6-32. WG-HTG-1P and DHW-2P, Daily Collection Performances for Philips MK IV Collectors With Solarized Glass Panels



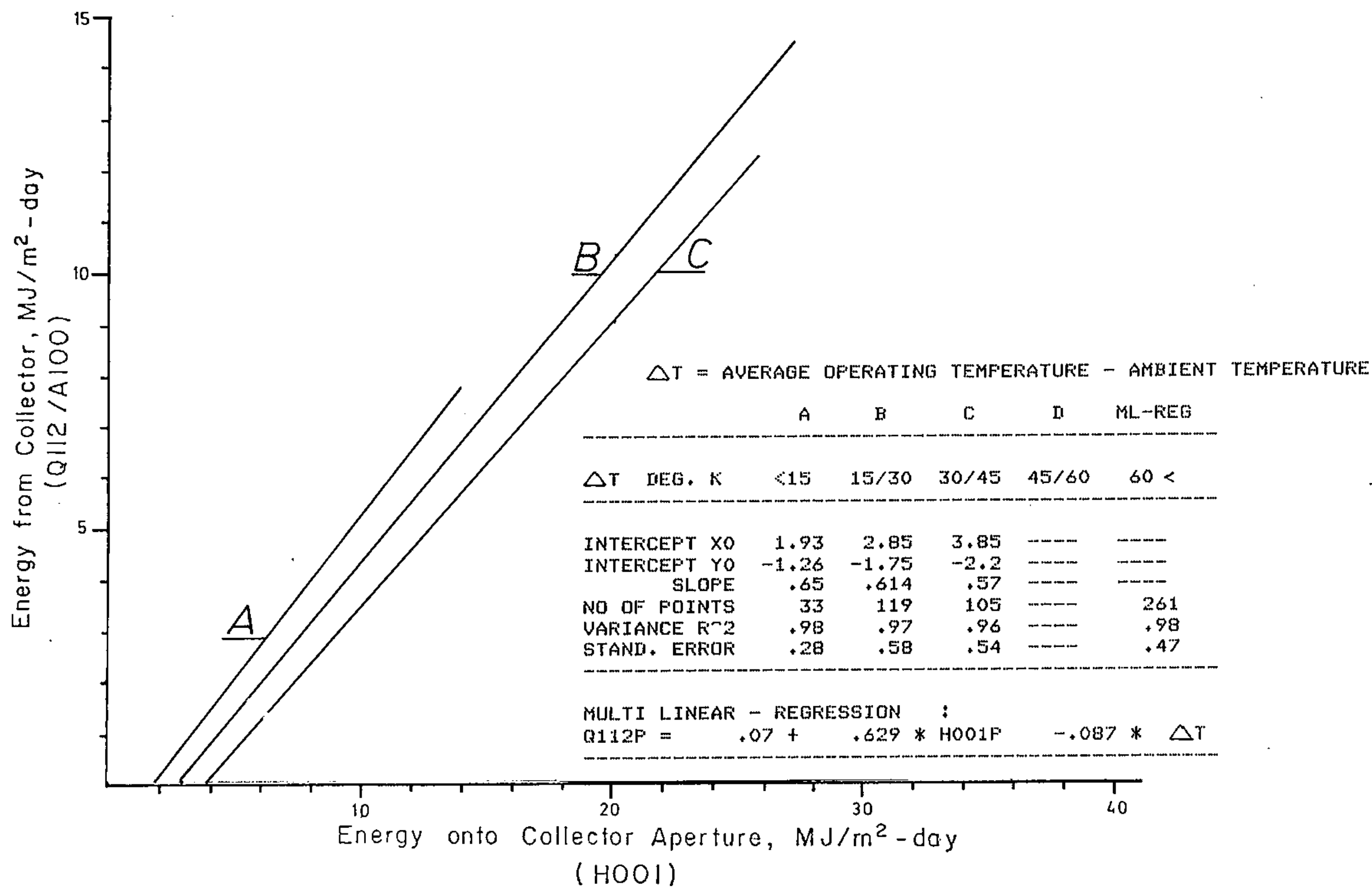
ΔT = AVERAGE OPERATING TEMPERATURE - AMBIENT TEMPERATURE

	A	B	C	D	ML-REG
ΔT DEG. K	<15	15/30	30/45	45/60	60 <
INTERCEPT XO	.790	2.29	3.39	----	----
INTERCEPT YO	-.336	-1.39	-1.8	----	----
SLOPE	.425	.605	.53	----	----
NO OF POINTS	9	30	25	----	66
VARIANCE R^2	.67	.981	.92	----	.986
STAND. ERROR	.24	.47	.75	----	.48

MULTI LINEAR - REGRESSION :

Q112P = .522 + .599 * H001P -.092 * ΔT

Figure 6-33. WG-DHW-2P, Daily Collection Performances for Philips MK IV Collectors With New Glass Panels



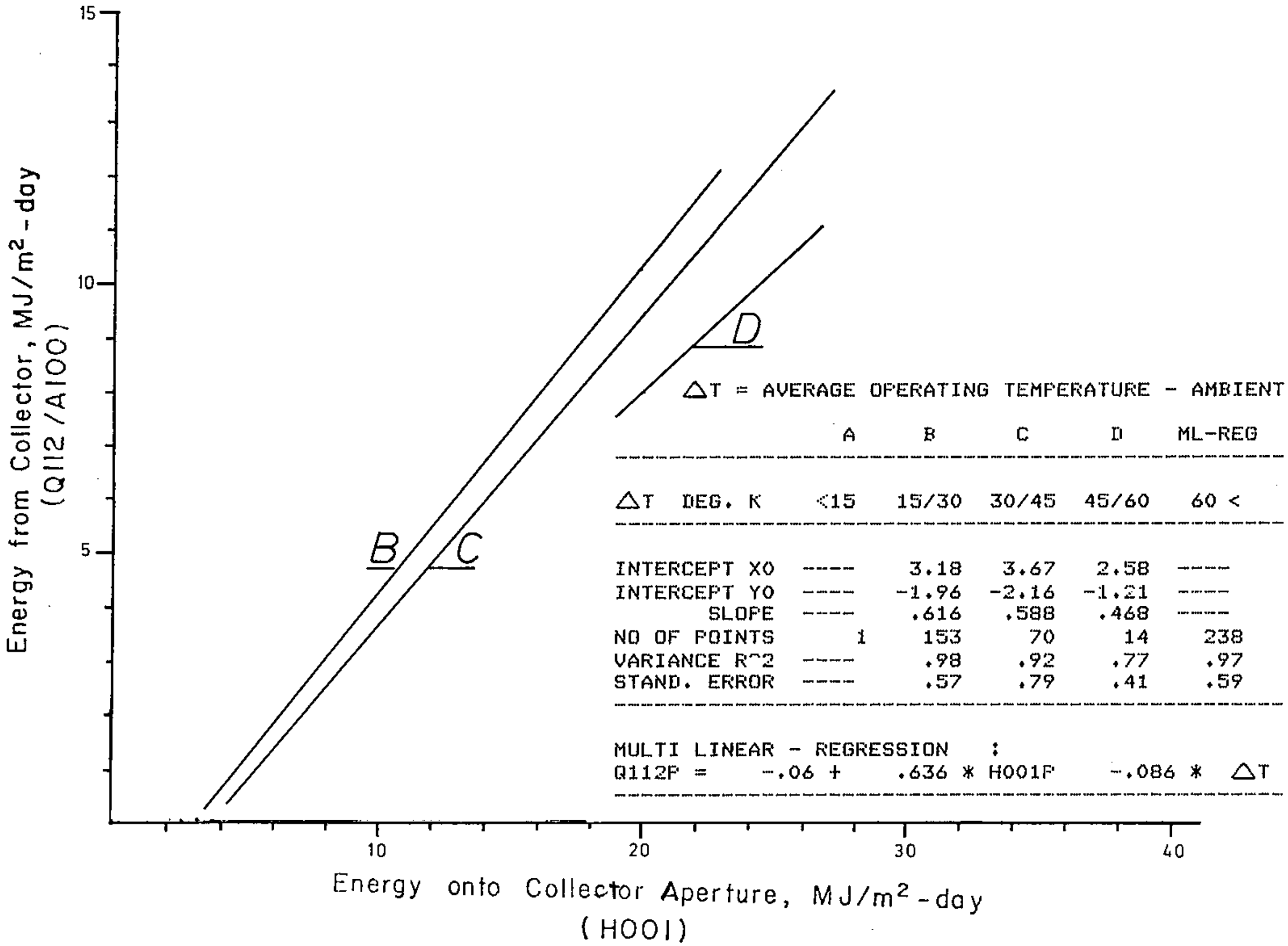
△T = AVERAGE OPERATING TEMPERATURE - AMBIENT TEMPERATURE

	A	B	C	D	ML-REG
△T DEG. K	<15	15/30	30/45	45/60	60 <
INTERCEPT XO	1.93	2.85	3.85	----	----
INTERCEPT YO	-1.26	-1.75	-2.2	----	----
SLOPE	.65	.614	.57	----	----
NO OF POINTS	33	119	105	----	261
VARIANCE R^2	.98	.97	.96	----	.98
STAND. ERROR	.28	.58	.54	----	.47

MULTI LINEAR - REGRESSION :

Q112P = .07 + .629 * H001P -.087 * △T

Figure 6-34. WG-DHW-3P and HTG-4P, Daily Collection Performances for Philips MK IV Collectors



ΔT = AVERAGE OPERATING TEMPERATURE - AMBIENT TEMPERATURE

	A	B	C	D	ML-REG
ΔT DEG. K	<15	15/30	30/45	45/60	60 <
INTERCEPT XO	----	3.18	3.67	2.58	----
INTERCEPT YO	----	-1.96	-2.16	-1.21	----
SLOPE	----	.616	.588	.468	----
NO OF POINTS	1	153	70	14	238
VARIANCE R^2	----	.98	.92	.77	.97
STAND. ERROR	----	.57	.79	.41	.59

MULTI LINEAR - REGRESSION :
Q112P = -.06 + .636 * H001P -.086 * ΔT

Figure 6-35. WG-HTG-5P, Daily Collection Performances for Philips MK IV Collectors useful thermal solar energy at a minimum of daily radiation which is about half of the value of the Philips collector system. This quality of a collector system becomes even more important when more frequent low radiation conditions exist.

6.3 ENERGY FLOW DIAGRAM

Energy flow diagrams combine the qualitative interaction of energy flows between different subsystems with the display of their quantitative value. Normally one energy flow diagram is included for each experiment. If appropriate, however, several experimental periods are combined.

6.3.1 Osaka Sanyo Solar House - Japan

Arrow diagrams of the energy flow for experiment J-HTG-1 is shown in Figure 6-36. All of the energy flows and their magnitudes are noted on the figure itself. One interesting energy requirement is the 1330 MJ drawn from the first storage tank used for freeze protection. Also the heat losses from the second storage were partly used to reduce heating load in the living room on the first floor. The solar fractions for the heating, the DHW, and the total loads were 0.89, 0.89 and 0.89, respectively. The total system COP was 0.79.

In the cooling season experiment J-CLG-1, Figure 6-37, the total collected energy was 15,417 MJ and the overall efficiency was 29.2% which was lower than in the heating season experiment J-HTG-1. This is due to the intentional control that the solar energy collection was forced to stop when the storage condition of the first storage tank was full even when solar energy was strong enough to be collected by the collector arrays. The cooling load was 3,704 MJ for this period, smaller than the design cooling load, since this summer was cool. The loss from the second storage tank was 2,038 MJ, excluding the part of the losses which was used to extract the load. The absorption chiller load was 5,820 MJ and its COP was 0.58, as expected. The solar fractions to the cooling, DHW supplying, and the total loads were 0.88, 0.99, and 0.90, and the values were better than designed. The total system COP was 0.37.

Figure 6-38 shows the arrow diagram of energy flow for the heating season experiment J-HTG-2. In this season, the overall collection efficiency was 33.1% and this value is lower than that in the experiment J-HTG-1. This is mainly due to the reduction of the collector area and to the colder weather in this season than in the previous season. The heating load in this season was 7,923 MJ (110 MJ/day) and larger than in the previous season (74.1 MJ/day). Due to the colder weather, freeze protection was often needed, resulting in large energy consumption for the protection. Since the control strategy for January resulted in providing the priority for the DHW supplying, the larger amount of

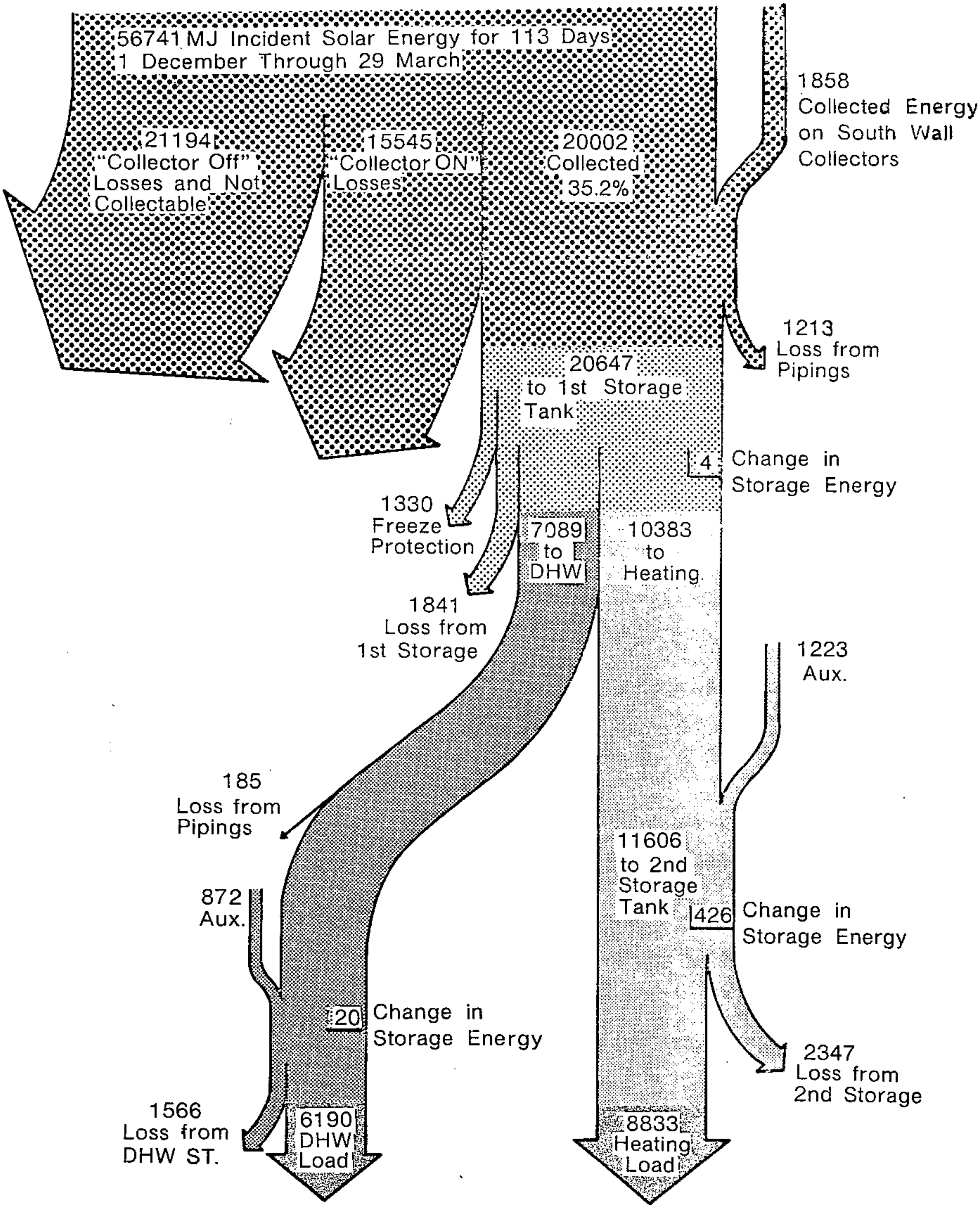


Figure 6-36. J-HTG-1, Energy Flow Diagram

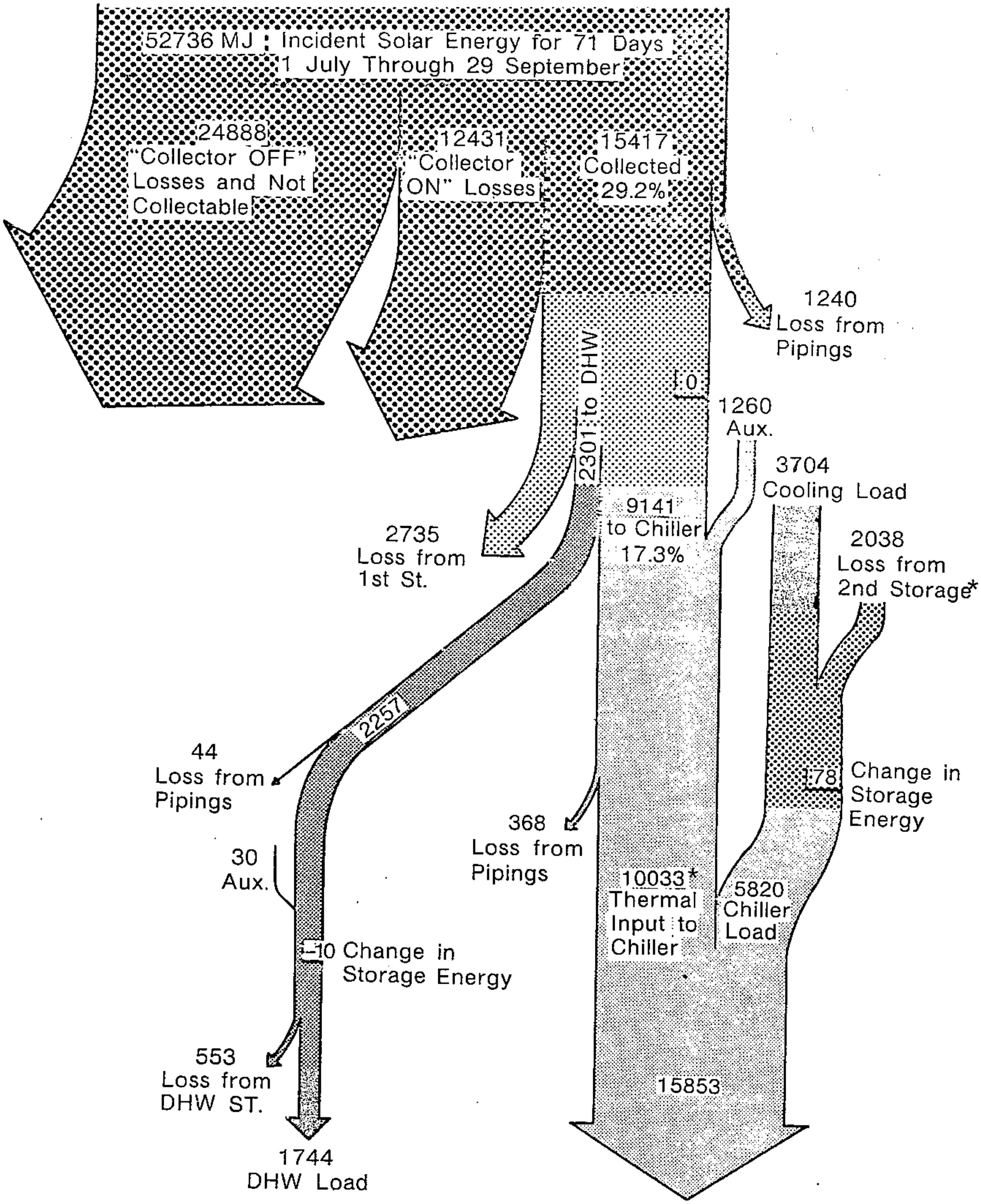


Figure 6-37. J-CLG-1, Energy Flow Diagram

*2038 should be subtracted from 10033.

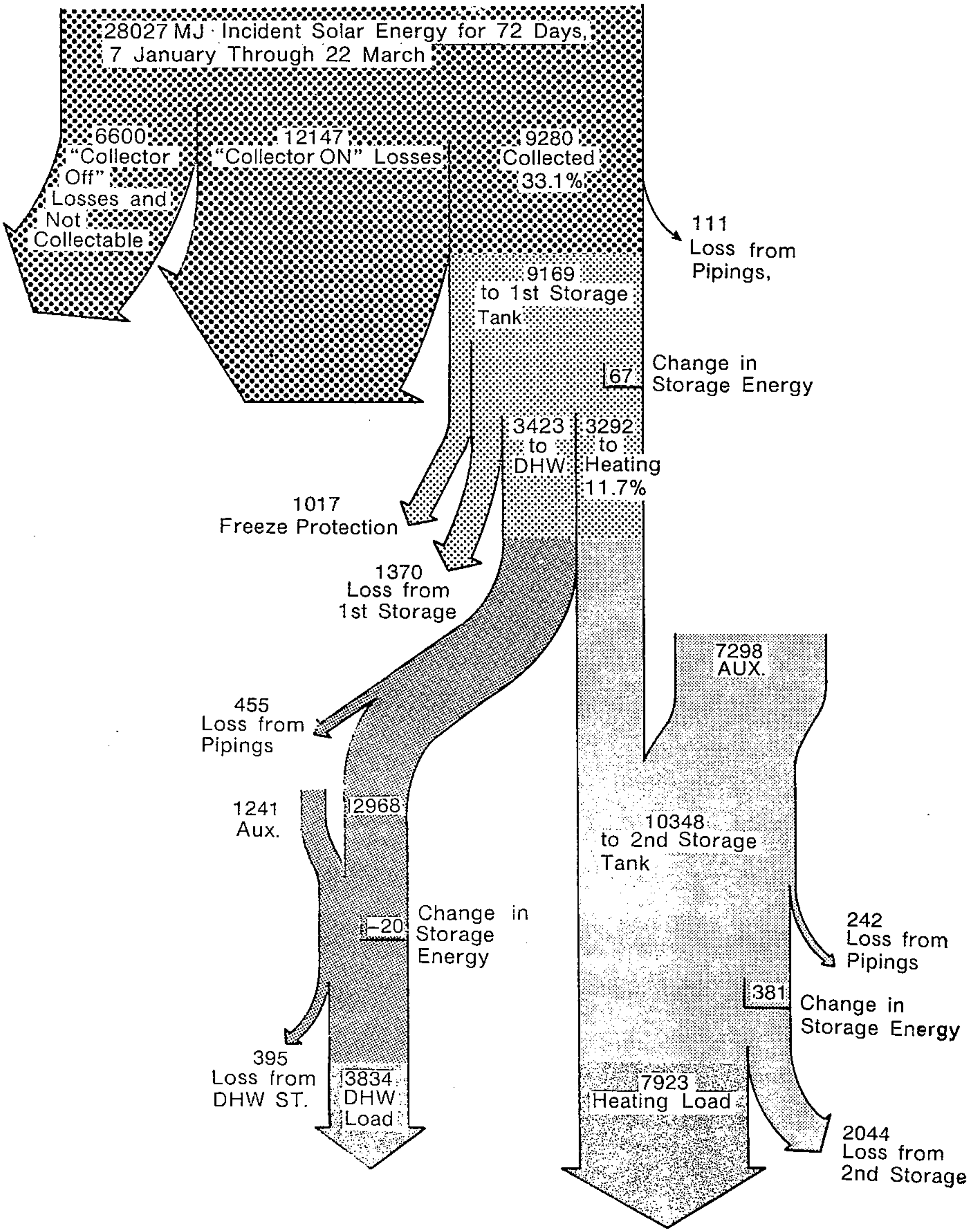


Figure 6-38. J-HTG-2, Energy Flow Diagram

heat was transferred form the first storage tank to the DHW storage tank then to the second storage tank, and therefore, a great amount of auxiliary energy had to be supplied for heating. The solar fractions to the heating, DHW supplying, and total loads were 0.31, 0.73, and 0.38, respectively. The total system COP was 0.34.

Figure 6-39 shows the results of the experiment J-CLG-2 for 69 days. The overall collection efficiency is due to the same reason as the experiment J-HTG-2. The solar fraction to the total loads was 0.72 and the total system COP was 0.19.

6.3.2 Knivsta District Heating Project - Sweden

There is no storage in the system and hence the energy balance to the district heating systems is easily established.

The results for the period August - November are summarized in Figures 6-40, 6-41, and 6-42. The breakdown period 11-17 September is not included in the presentation.

6.3.3 Colorado State University Solar House I - USA

For the total period of operation of each system, the energy flow charts in Figures 6-43 to 6-46 depict the sources, quantities and uses of solar and auxiliary energy.

For system USA-HTG-1, Figure 6-43, results show relative uniform solar collection efficiency averaging 24 percent of the total incident solar energy for the Miromit flat plate collector. Approximately 73 percent of the daily incident energy was received during collector pump operation. During collection, 33 percent of the incident solar radiation was delivered to storage. The system supplied 63 percent of the heating and hot water requirements in this period.

Figure 6-44 shows results for systems in operation in the summer of 1980. Results for these systems, USA-CLG-1,2,3, include data from both the Miromit flat plate collector and the Philips evacuated tubular collector. Figures 6-8, 6-9, 6-26, 6-27 and 6-28 show the performance differences in the two sets of collectors.

Figure 6-45 gives a summary of results for winter 1980-81. That winter was unusually warm, and little auxiliary heating and hot water energy was required. Solar energy provided about 90 percent of energy usage for the period.

Figure 6-46 shows results for the summer of 1981, System USA-CLG-4. Solar energy received during operation was 80 percent of the daily total. In July and August of that year, the main storage tank was vented at atmospheric pressure, but in September the vent was replaced with a pressure relief valve which permitted storage tank temperatures

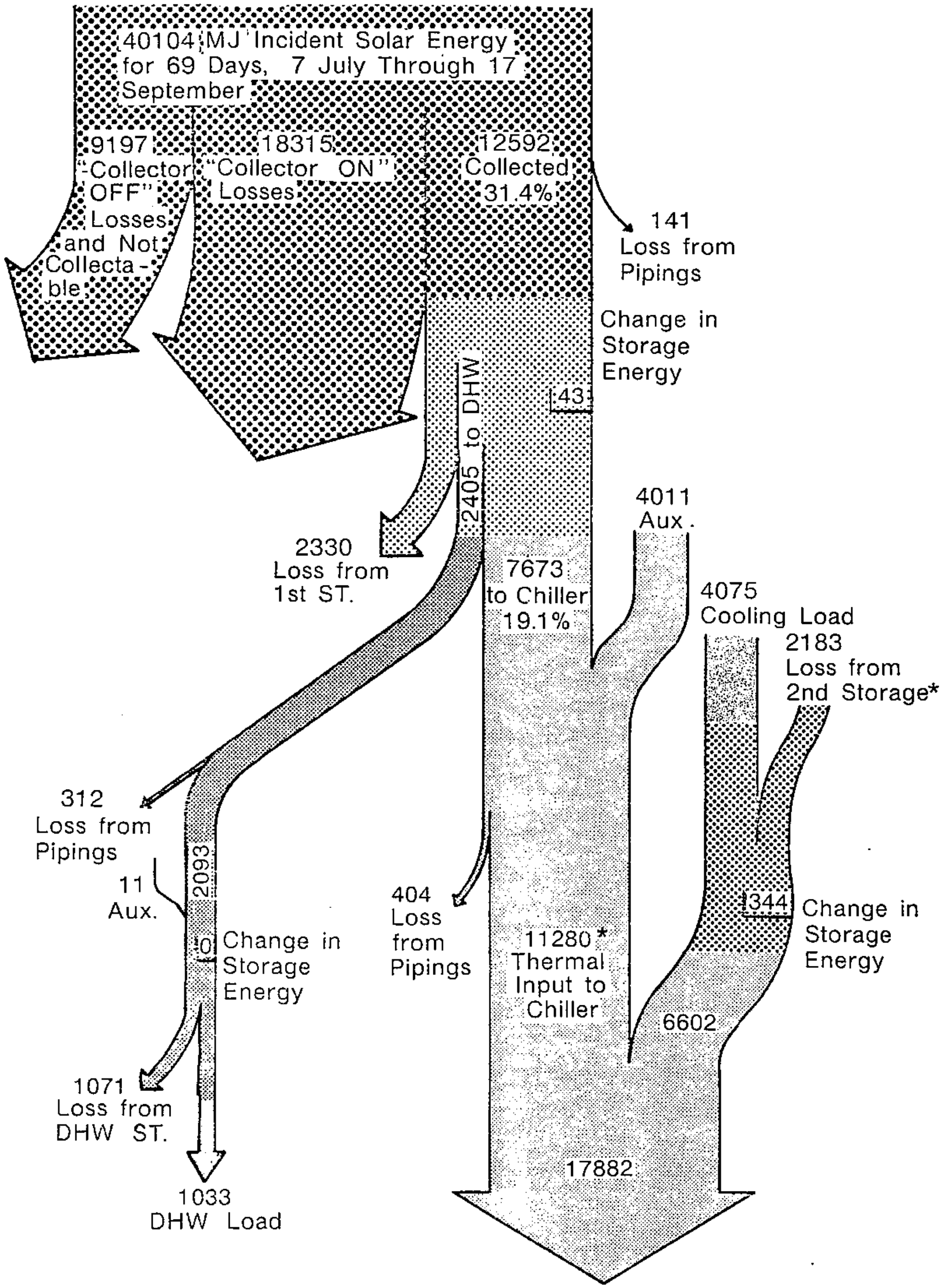


Figure 6-39. J-CLG-2, Energy Flow Diagram

*2183 should be substracted from 11280.

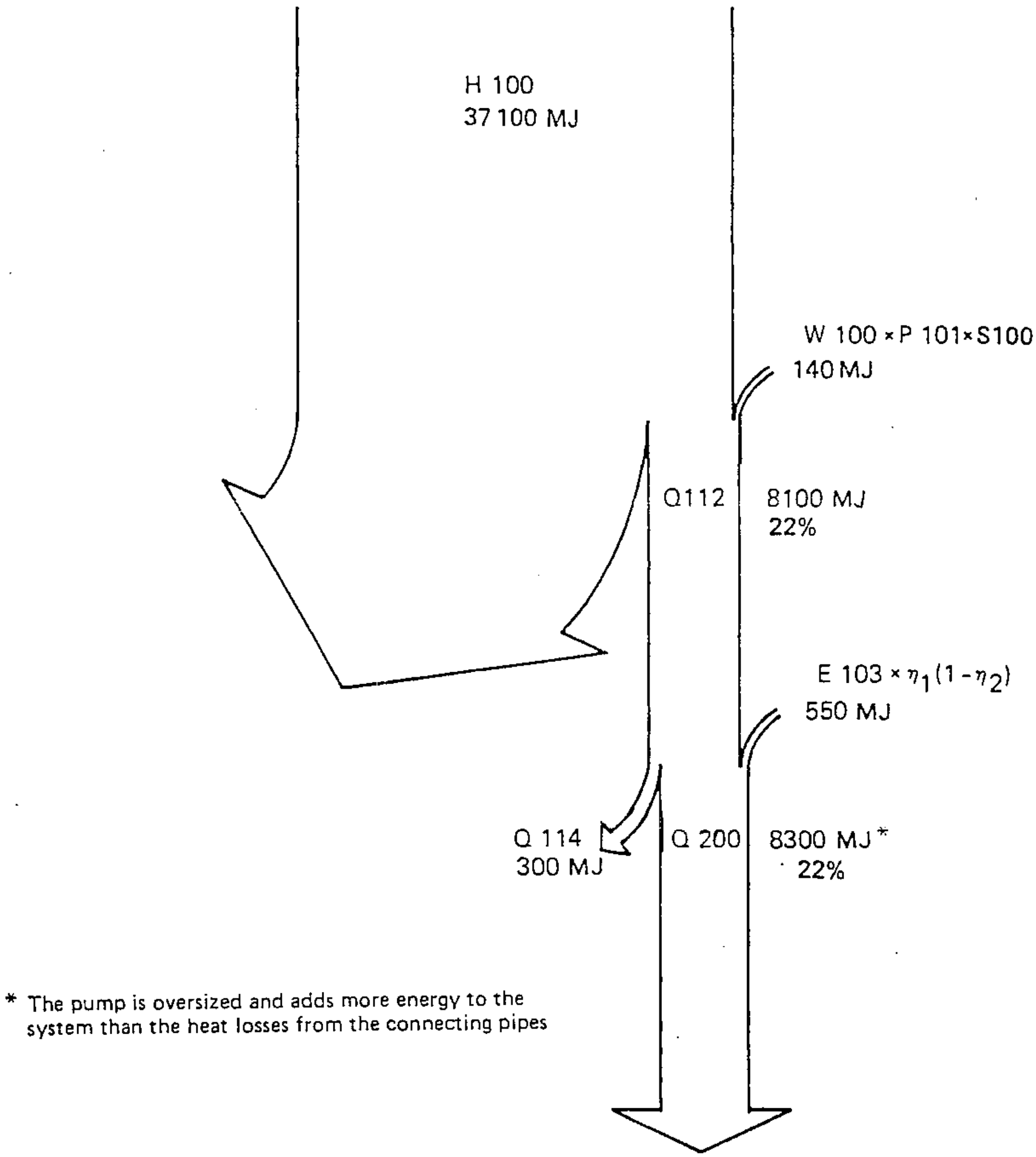


Figure 6-40. S-HTG-1, Energy Flow Diagram

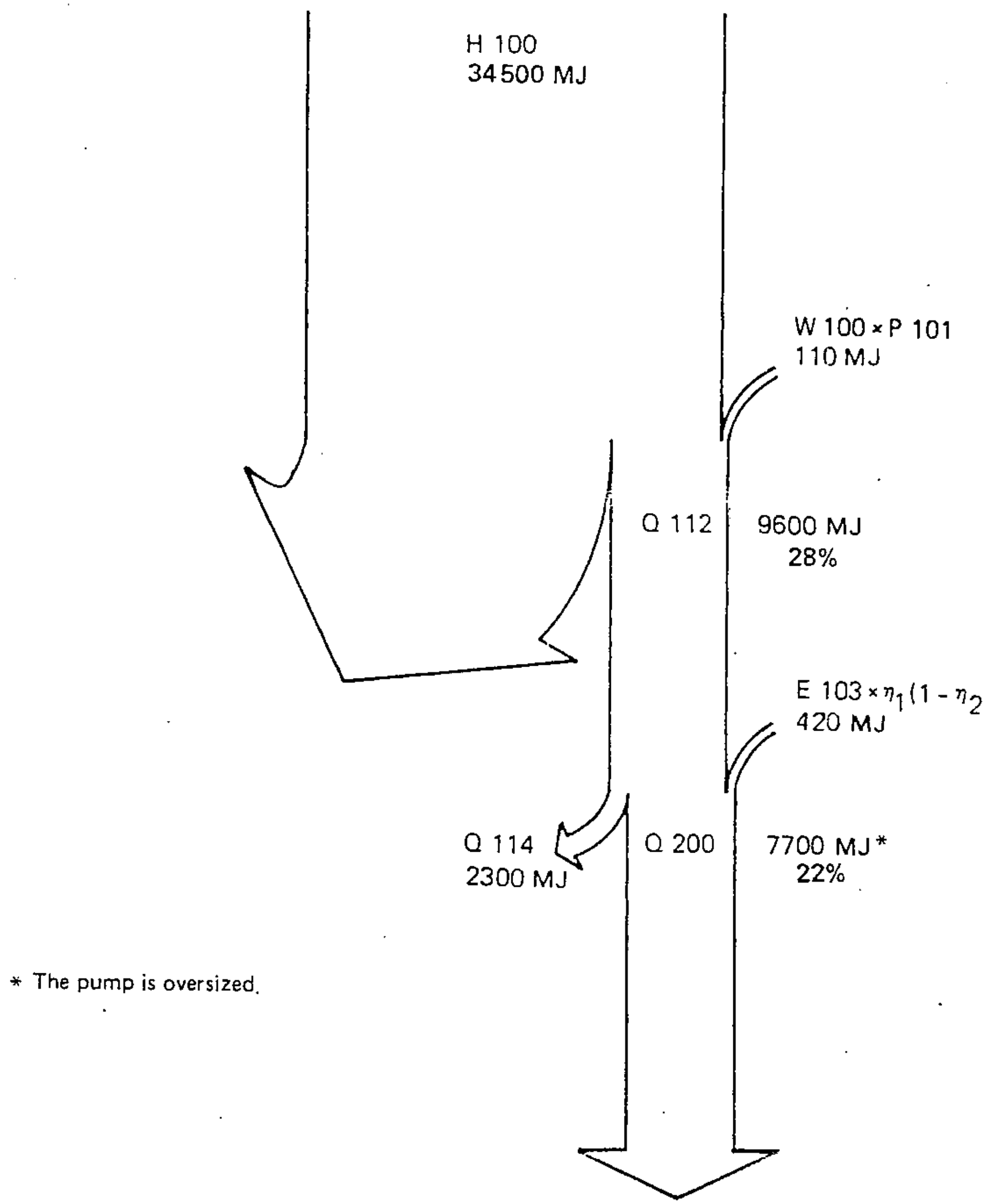


Figure 6-41. S-HTG-2, Energy Flow Diagram

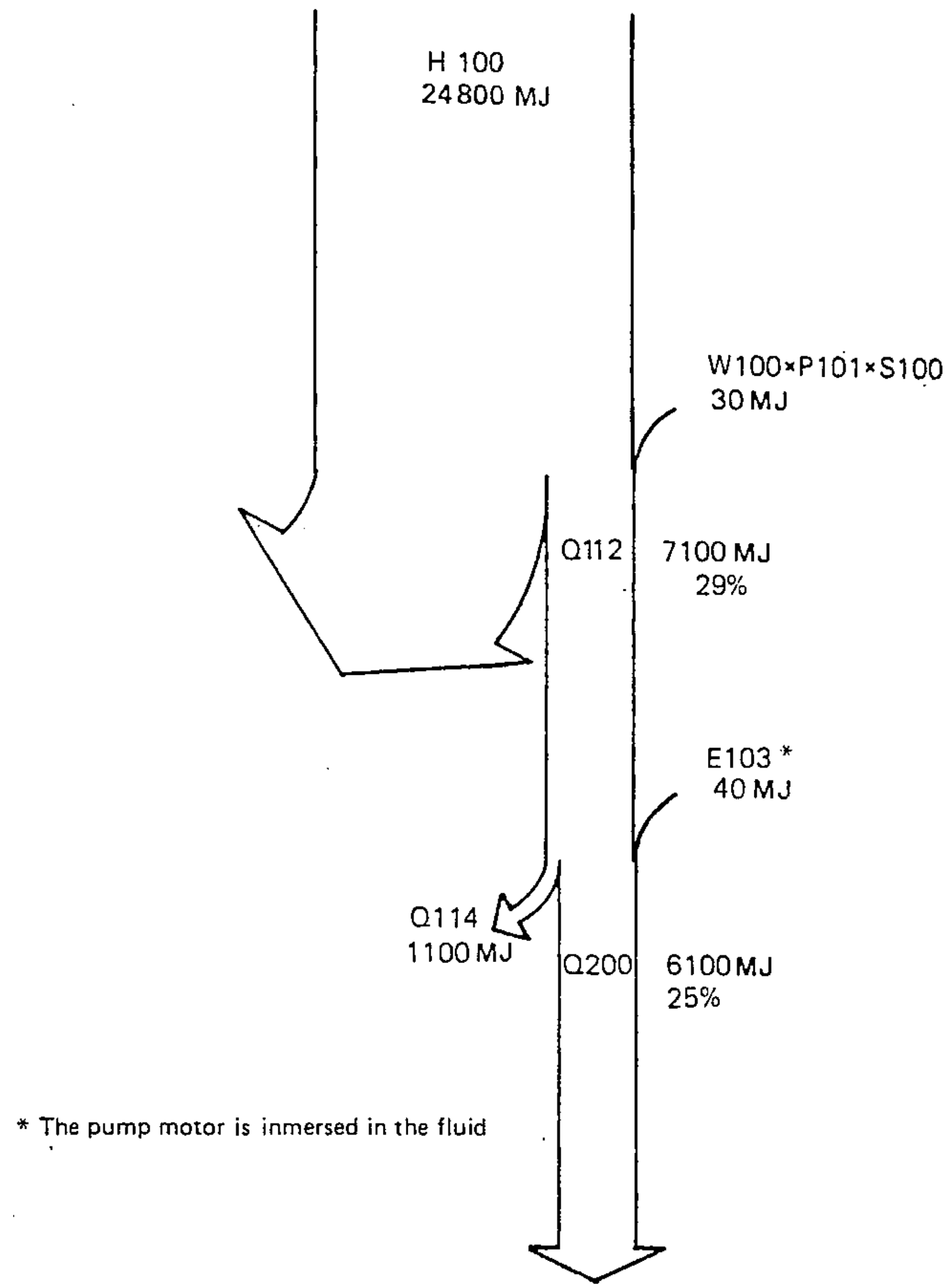


Figure 6-42. S-HTG-3, Energy Flow Diagram

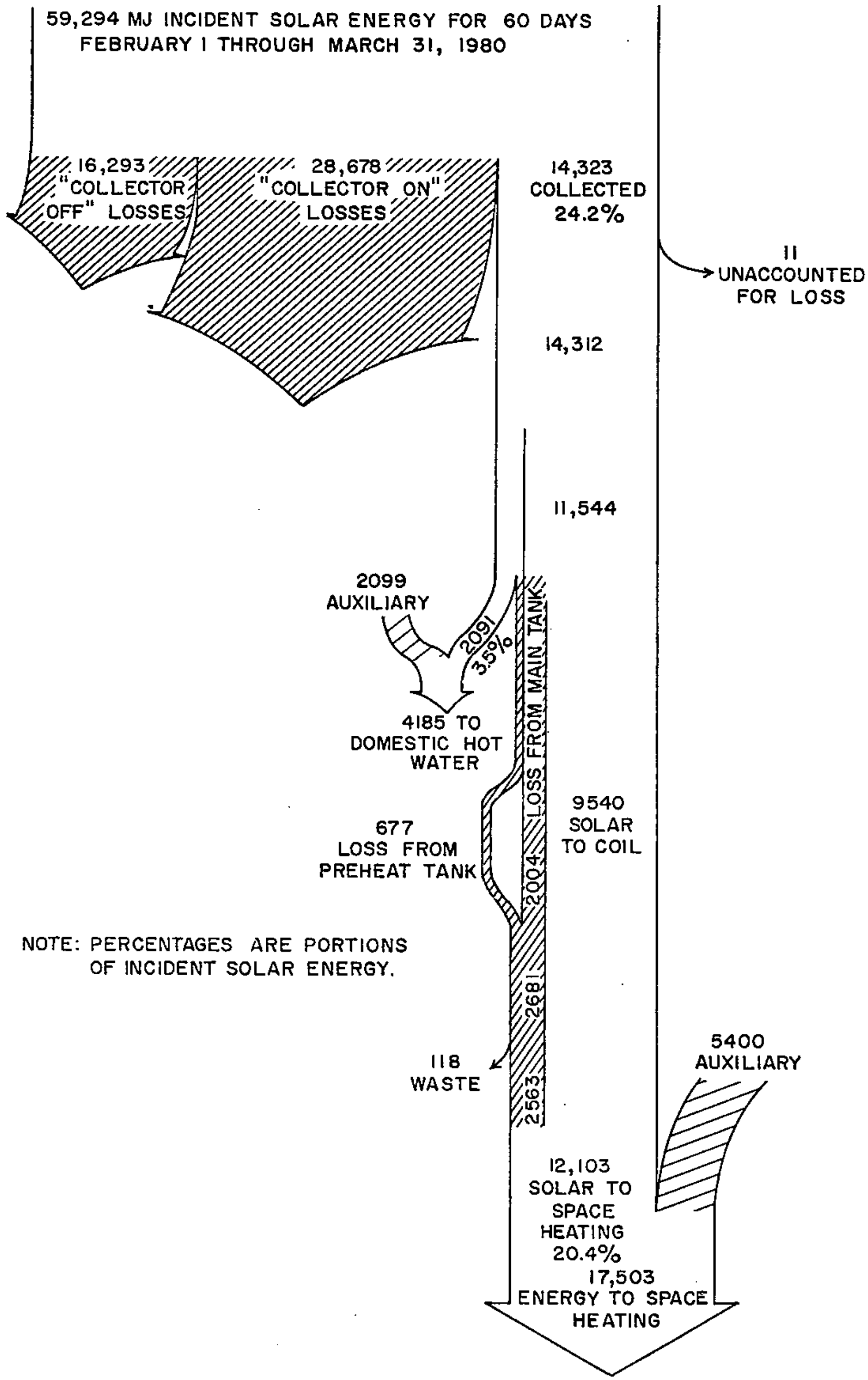


Figure 6-43. USA-HTG-1, Energy Flow Diagram

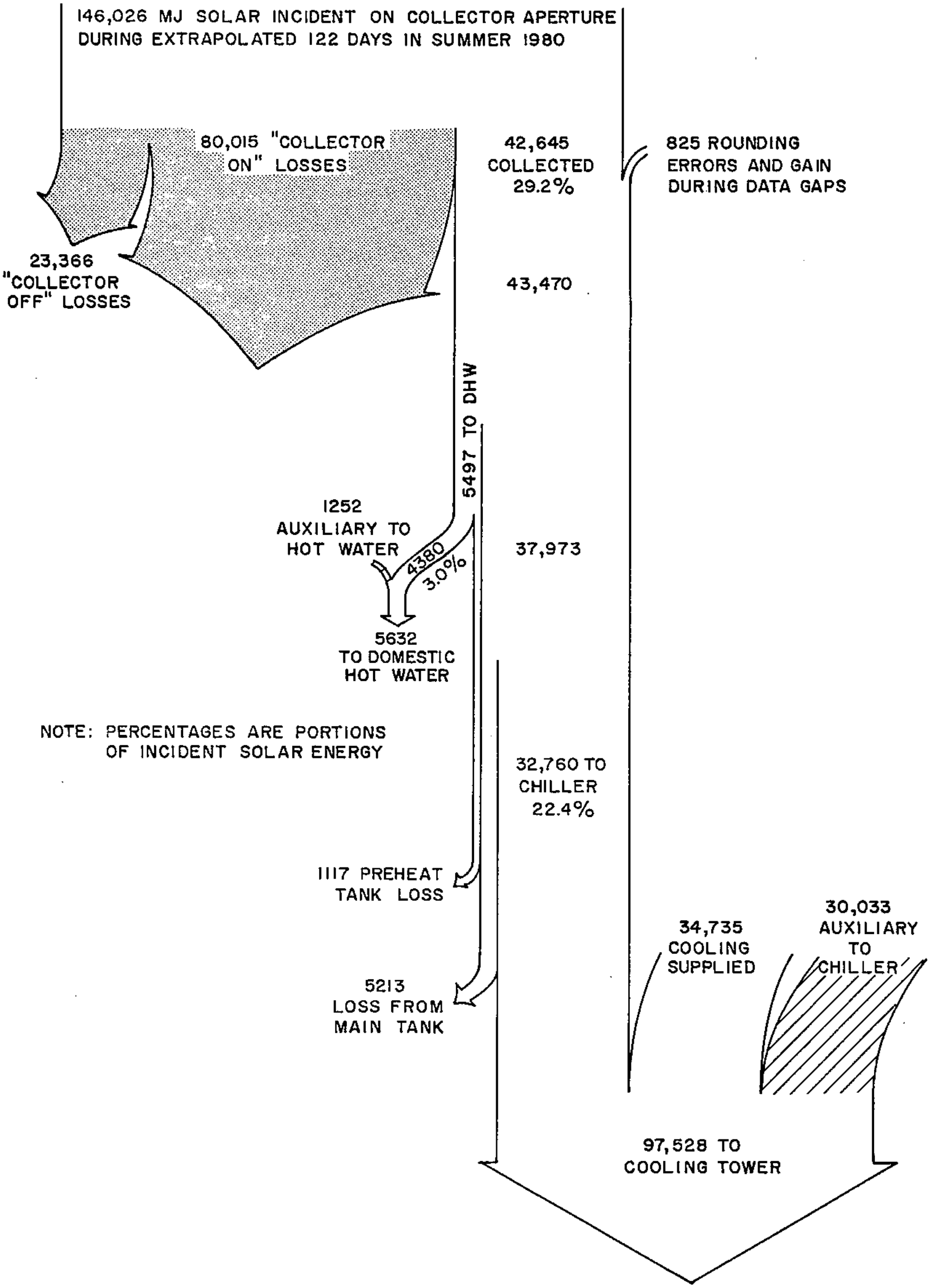


Figure 6-44. USA-CLG-1, 2, and 3, Energy Flow Diagram

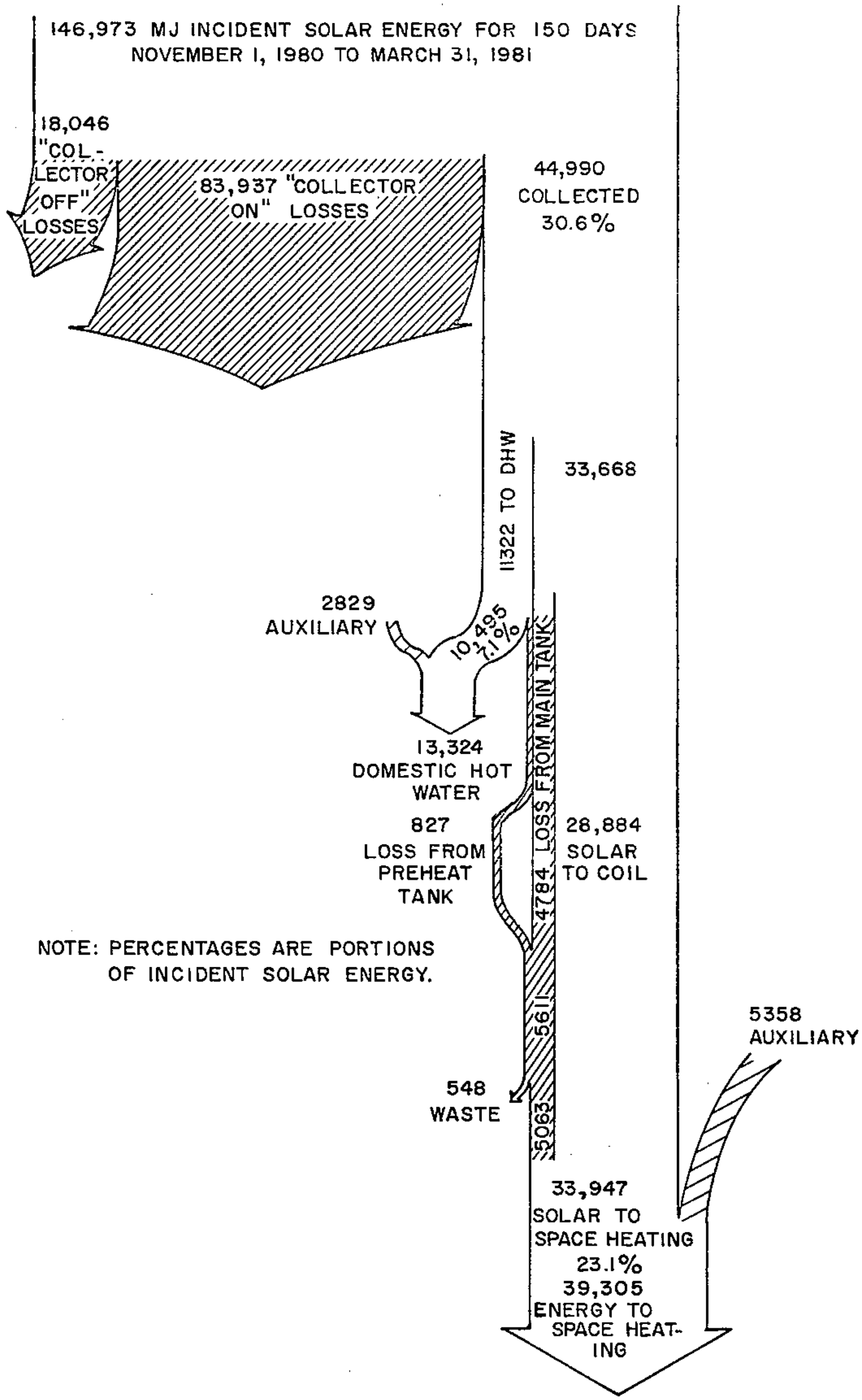


Figure 6-45. USA-HTG-2, 3, and 4, Energy Flow Diagram

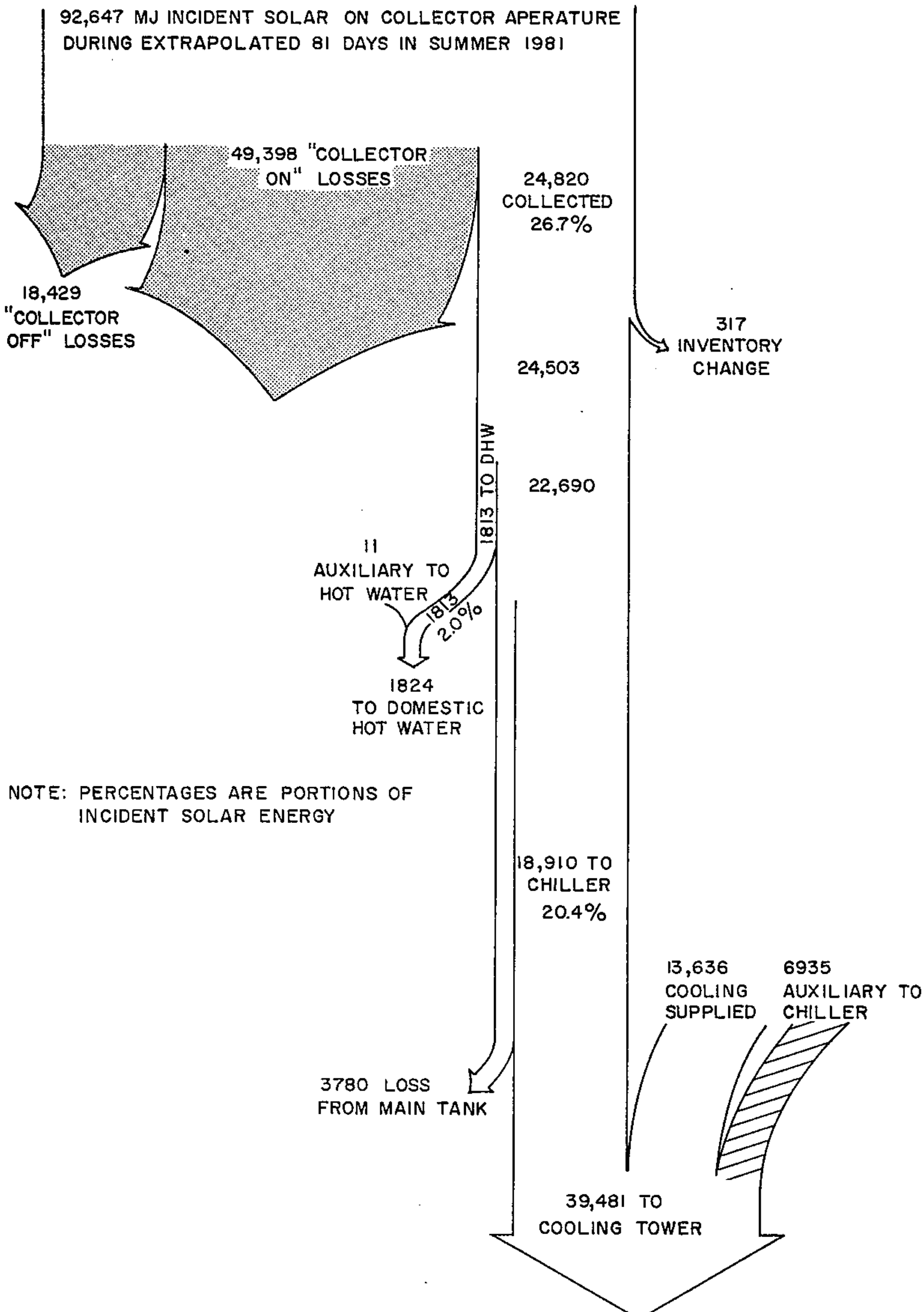


Figure 6-46. USA-CLG-4, Energy Flow Diagram

over 100°C. As a result average storage tank tempeatures were about 83°C with the vent, but reached 94°C in September. As a result, collection efficiency was reduced from 29 percent in July and August to 20 percent in September.

6.3.4 Solarhaus Freiburg - West Germany

Two versions of the energy flow diagrams have been constructed, one to show the energy flow of the solar DHW system as an individual system, and another to show the interaction between the two solar systems and the conventional parts of a heating system. In version one, the incident solar radiation, (on top of the diagram) is indicated both with respect to aperture and absorber area of the collector system or systems. (Weighted areas are specified in 1980 due to collector exchange). All figures appearing in the diagram are percentages based on net warm water load = 100%. Collected heat from the collector system passes through the distribution system to enter the two storage tanks, either in parallel or in series. Cold water supply of 10 - 12°C is preheated by a small amount as it passes through the building from the basement to the third floor. Auxiliary energy is directly delivered into the DHW storage tank. In version two, the energy flow of the two collector and solar distribution systems is nearly the same as used in the DHW diagram, which is displayed in this diagram on the right hand side. Solar excess energy from the DHW system enters into the solar distribution system of solar heating system at the left side of the diagram. All figures presented in this diagram are percentages based on the heating load = 100%. In order to permit direct comparison both diagrams of 1980 and 1981 are established on the same energy scale. DHW diagrams, Figures 6-47 and 6-48, show that the flow of solar thermal energy through the various distribution systems and components remains nearly unchanged within the years 1980 and 1981. This indicates a high level of reliable operation of the solar and DHW systems.

There is a slight improvement of collection system efficiency from 46.6% in 1980 to 50% in 1981 due to the exchange of the collector system in June 1980. This may explain part of the higher solar fraction of 62.3% of the gross DHW load, although an increase in the net DHW load of about 9% has been observed in 1981. Another reason for this variation could be the modified control strategies which have been tested since May 1980, but investigations in this field using validated computer models are not yet completed.

The combined energy flow diagrams, Figures 6-49 and 6-50 for 1980 and 1981, clearly show how solar energy is used together with auxiliary energy both in the DHW and heating systems. Although the investigation of the independent operation of the solar DHW system remains our primary objective, these diagrams suggest the definition of a global solar fraction of the entire heating and DHW load. This global solar fraction has been determined to 22% in 1980 and to 24% in 1981. These values correspond to an average amount of 1296 MJ/m^2 year (360 kWh/m^2 year) of used solar energy per m^2 of aperture area per year, corresponding to a global system efficiency of 33.5%.

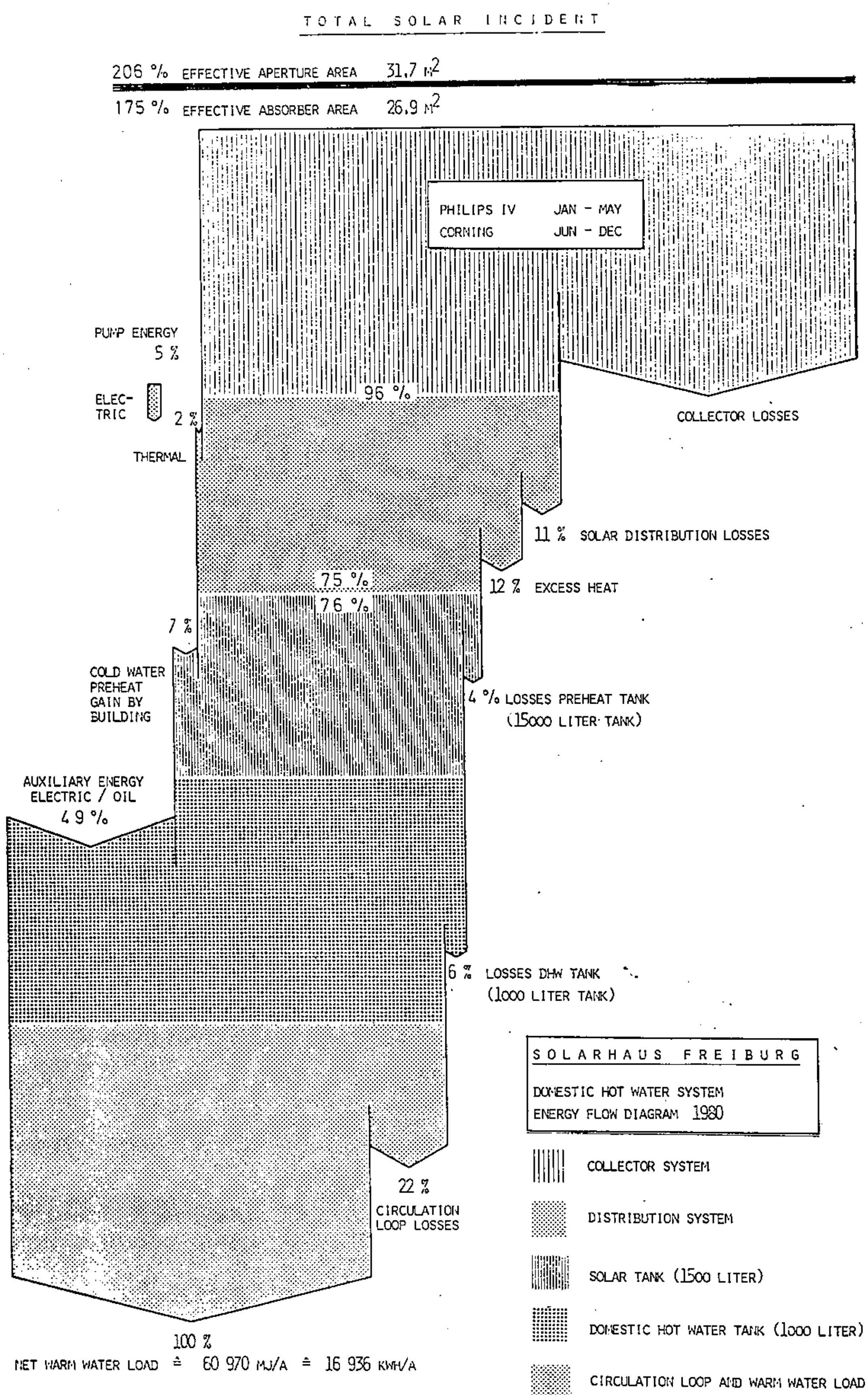


Figure 6-47. WG-DHW-1980, Energy Flow Diagram

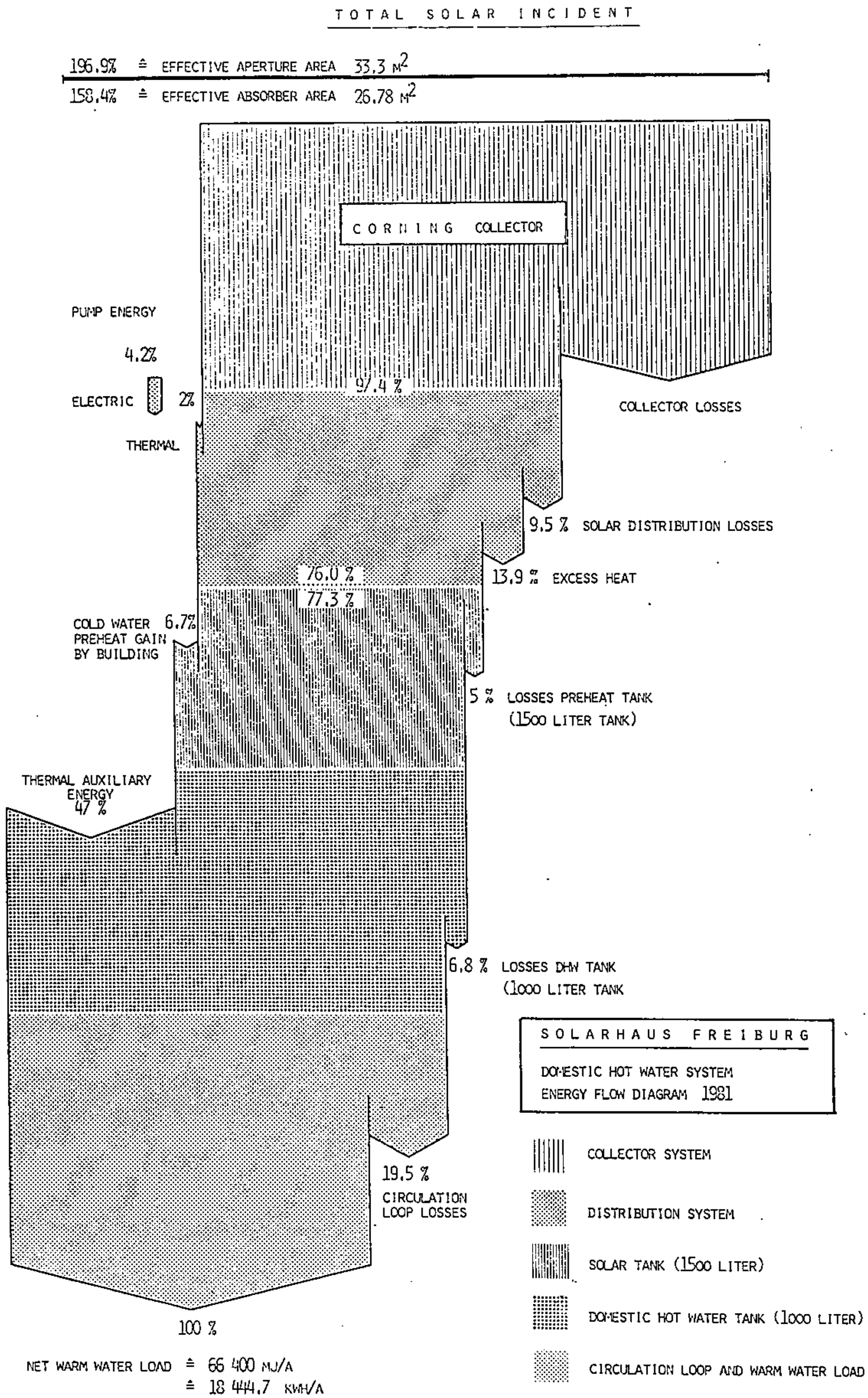


Figure 6-48. WG-DHW-1981, Energy Flow Diagram

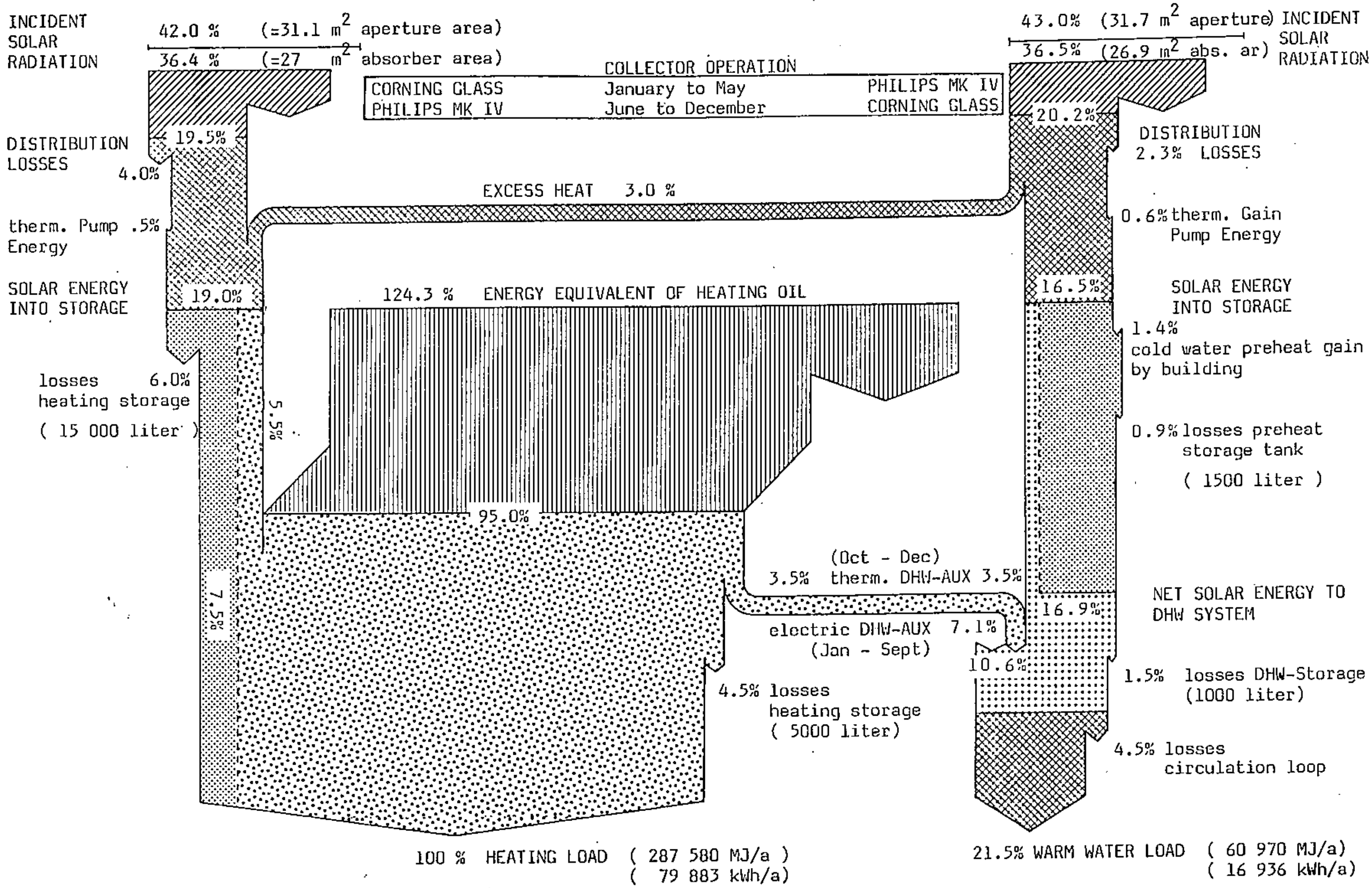


Figure 6-49. WG-1980, Energy Flow Diagram

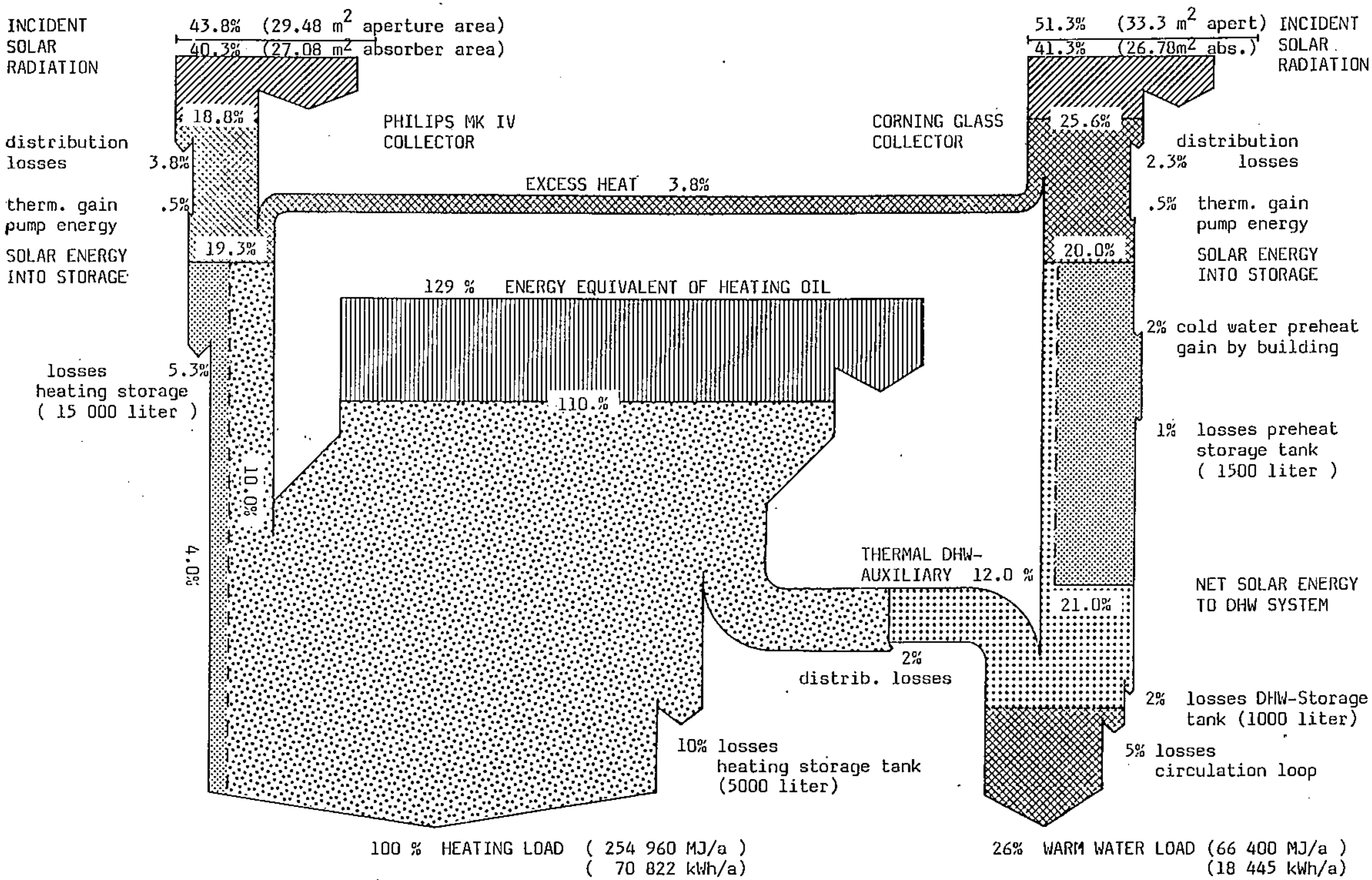


Figure 6-50. WG-1981, Energy Flow Diagram

Furthermore, comparison of these energy flow diagrams show three remarkable differences between 1980 and 1981:

1) Conversion efficiency of the auxiliary oil burner has been increased from 77% in 1980 to an annual value of 85% in 1981 by adjustment of the flue gas pressure and of the heating oil flow rate both with respect to the nominal values of the burner and to the actual load conditions.

2) Thermal DHW - auxiliary energy has been transported from the 5 m^3 buffer storage tank to the 1 m^3 DHW storage tank by means of the "energy hysteresis" control strategy. Together with the improvements of the oil burner, an overall conversion efficiency (useful thermal auxiliary vs. energy content of heating oil) of 76% has been measured in 1981. This value is about 2 - 3 times as high as in conventional systems. (This modification of control strategy caused the operation of the DHW system with thermal auxiliary to produce warm water at a price per m^3 of warm water about 36% lower than when operating with electric auxiliary energy). In order to reduce consumption of heating oil, a change of solar system control strategy caused most collected solar energy to be delivered to the 5 m^3 buffer storage tank in summertime. As the heating load and the expected DHW auxiliary load were much smaller at this time, considerable losses were produced in the 5 m^3 tank when the 15 m^3 tank was at lower temperatures.

3) Normalized to the number of degree-days (18.3°C) in the heating seasons of 1980 (3142) and 1981 (2990) there was a decrease in the overall annual heating load by 7.3% in 1981. This reduction was caused by a six week experiment beginning with November 1981, where the ventilation system was operated only 50% of the time of each day in order to reduce the ventilation load of the house.

6.4 ENERGY SUPPLY AND DELIVERY BAR CHART

The month-to-month system performance characteristics are easily seen on energy supply and delivery bar charts. These charts may be used to compare the effectiveness of different systems and to ascertain other system performance characteristics, such as the ability of the collection system to supply energy at low insolation levels.

6.4.1 Osaka Sanyo Solar House - Japan

The average energy supply and delivery rates for the solar collectors are shown in Figures 6-51 and 6-52. Figure 6-51 shows them monthly for the Sanyo collectors in the heating and cooling experiments, J-HTG-1 and J-CLG-1 and Figures 6-52 for the GE collectors in the experiments, J-HTG-2 and J-CLG-2.

The comparison between the experiments with the Sanyo and the GE collectors show that there are differences in the percentage of the solar while collecting. This is considered due to the difference in the collector aperture areas.

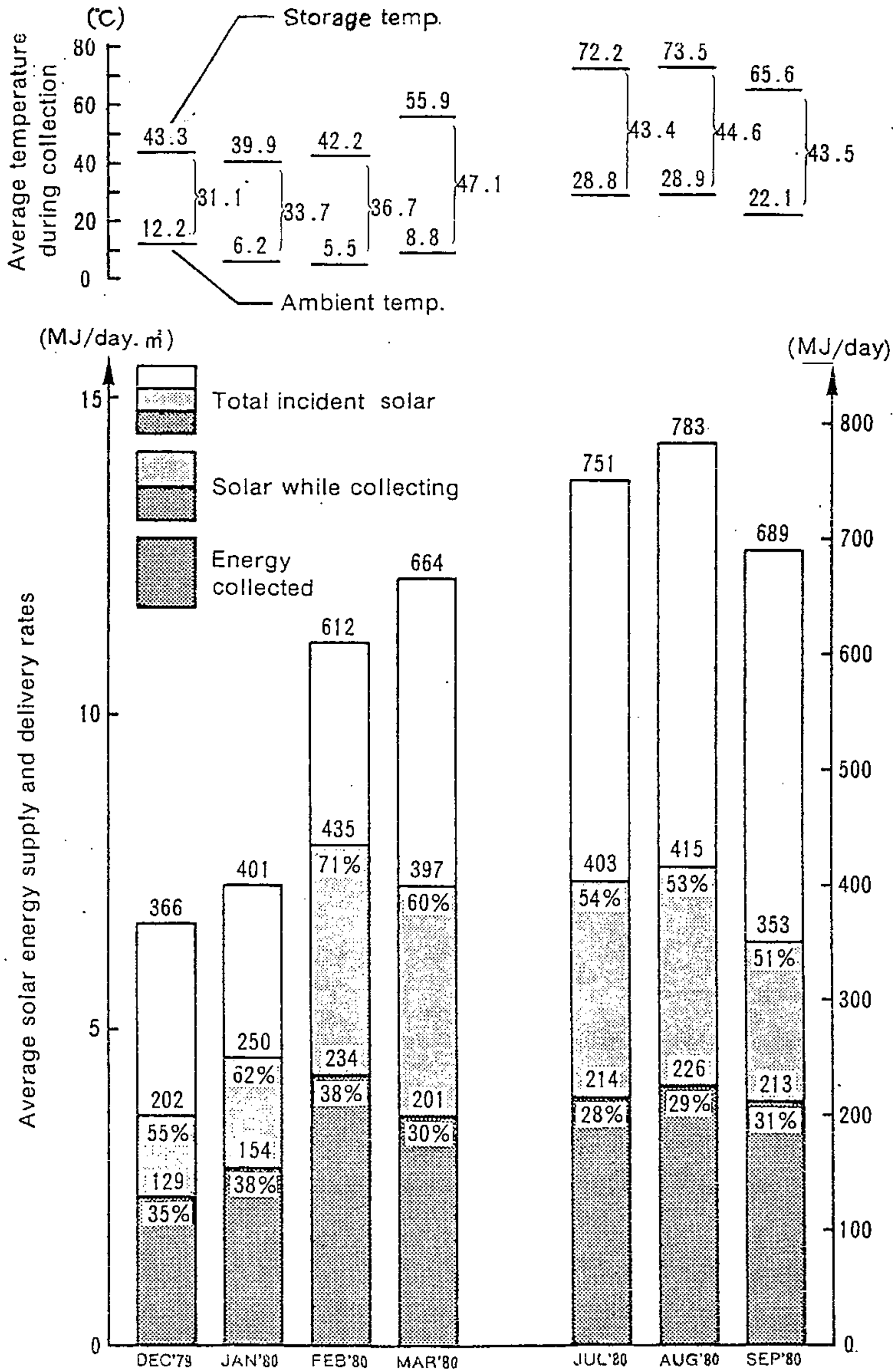


Figure 6-51. J-HTG-1 and CLG-1, Average Energy Supply and Delivery Rates

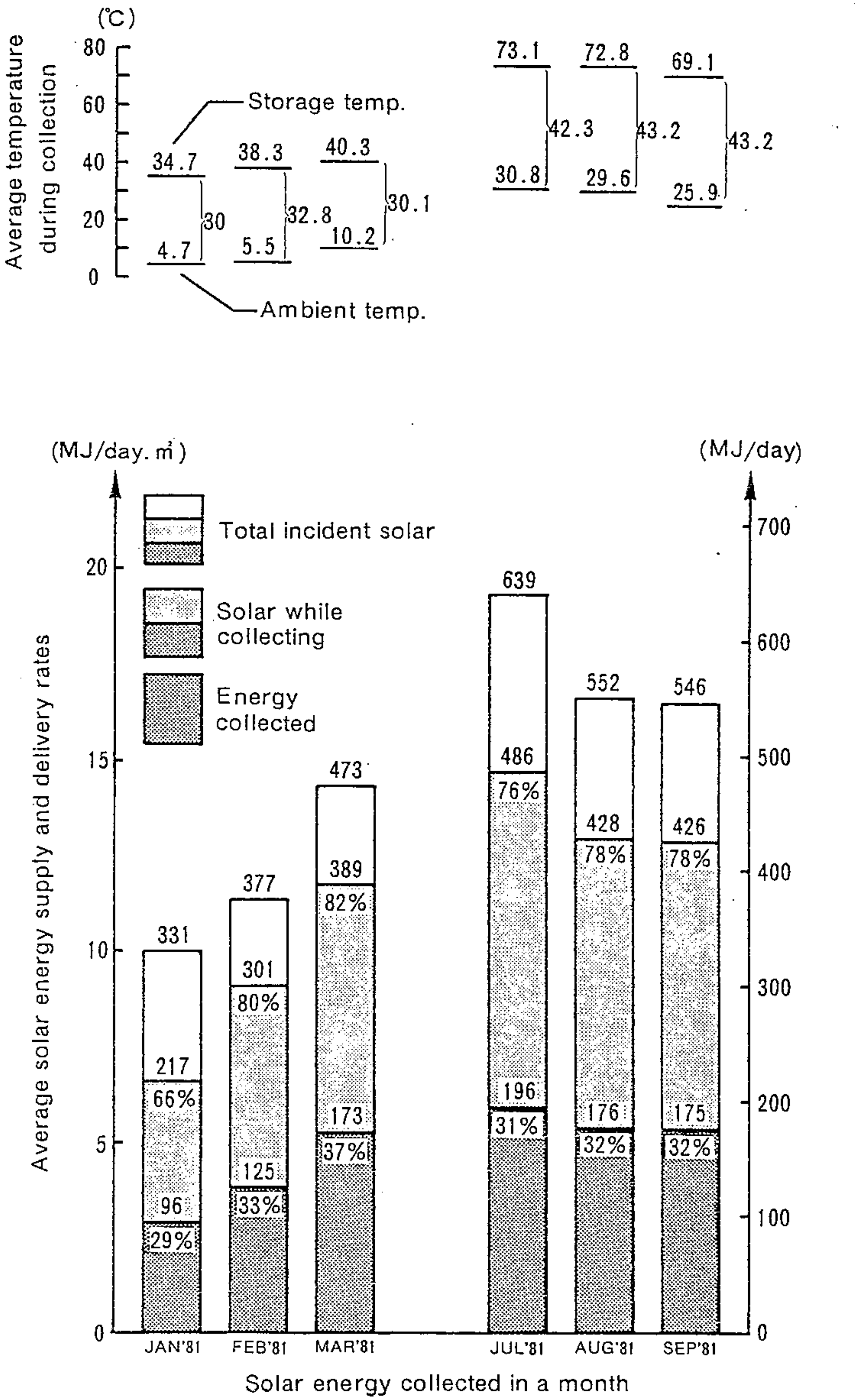


Figure 6-52. J-HTG-2 and CLG-2, Average Energy Supply and Delivery Rates

6.4.2 Knivsta District Heating Project - Sweden

The energy supply breakdown for all three systems is summarized in Figure 6-53. The energy bars indicate the daily average of irradiated or produced energy respectively per square meter of collector area of each system. The bars show 5 levels of energy. The highest one indicates the irradiated solar energy H100, and the one below represents the solar energy irradiated when the system could theoretically collect energy (H150). The third level shows the energy irradiated under the time the system is actually operating (H101). The fourth level from the top shows the energy collected by the solar collector array (Q112), and the bottom bar corresponds to the net energy delivered to the district heating system (Q200). Hence, efficiencies which can be derived from the relations of these bars correspond to system energy availability (N151), to array efficiency (N100, N101) and system efficiency (N102), respectively. It emerges from Figure 6-53 that the Philips system shows the best array efficiency and system efficiency when compared to the other collector systems. However, because of higher tilt angle, the Philips collectors exhibit similar or just slightly higher output per unit aperture area.

6.4.3 Colorado State University Solar House I - USA

The monthly solar energy supply and delivery for the eight USA experiments are separated into heating and cooling season bar charts. Figure 6-54 provides a comparison of performance of solar heating systems employing a drain back flat plate collector, system HTG-1 and an evacuated tube, double loop collector, system HTG-2. The evacuated tube collector system is seen to have substantially higher collection efficiency, about 31 percent compared to 24 percent, both based on aperture area. Although the two systems were not operated in corresponding months in the two years, average daily space heating demands were nearly the same, 226 MJ/day in February and March, 1980, and 264 MJ/day in the following November-January period. The two collectors had nearly equal aperture areas, 56 m^2 for the flat plate and 60 m^2 for the evacuated tube. Thus, the 62-63 percent solar portion of the total requirements met by the flat plate system may be directly compared with the 70-94% supplied by the evacuated tube double loop system. Both systems demonstrated satisfactory performance, but overall efficiency of system HTG-2 was clearly superior to that of system HTG-1.

Systems HTG-3 and HTG-4 differ from system HTG-2 only in the manner of supplying auxiliary heat for hot water and space heating, so solar collection and delivery in all three systems would not be expected to differ significantly. Figure 6-54 shows this to be the case. Monthly average collection efficiency in the six periods (5 months) was in the narrow range from 28.2 to 33.4 percent. Average space heating demands were also similar, 244 to 305 MJ/day, and hot water requirements ranged from 73 to 120 MJ/day.

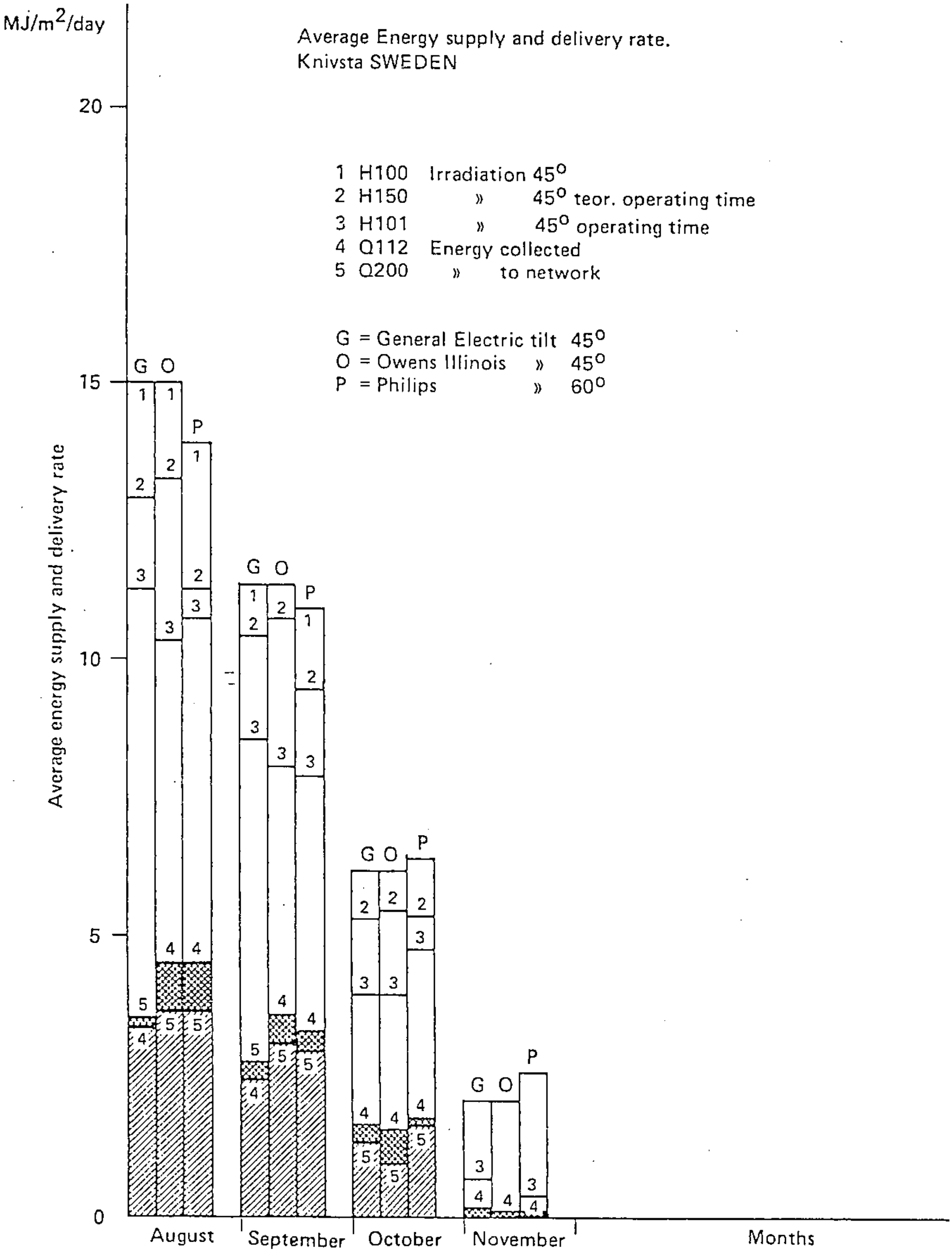


Figure 6-53. S-HTG-1, 2, and 3, Average Energy Supply Rates

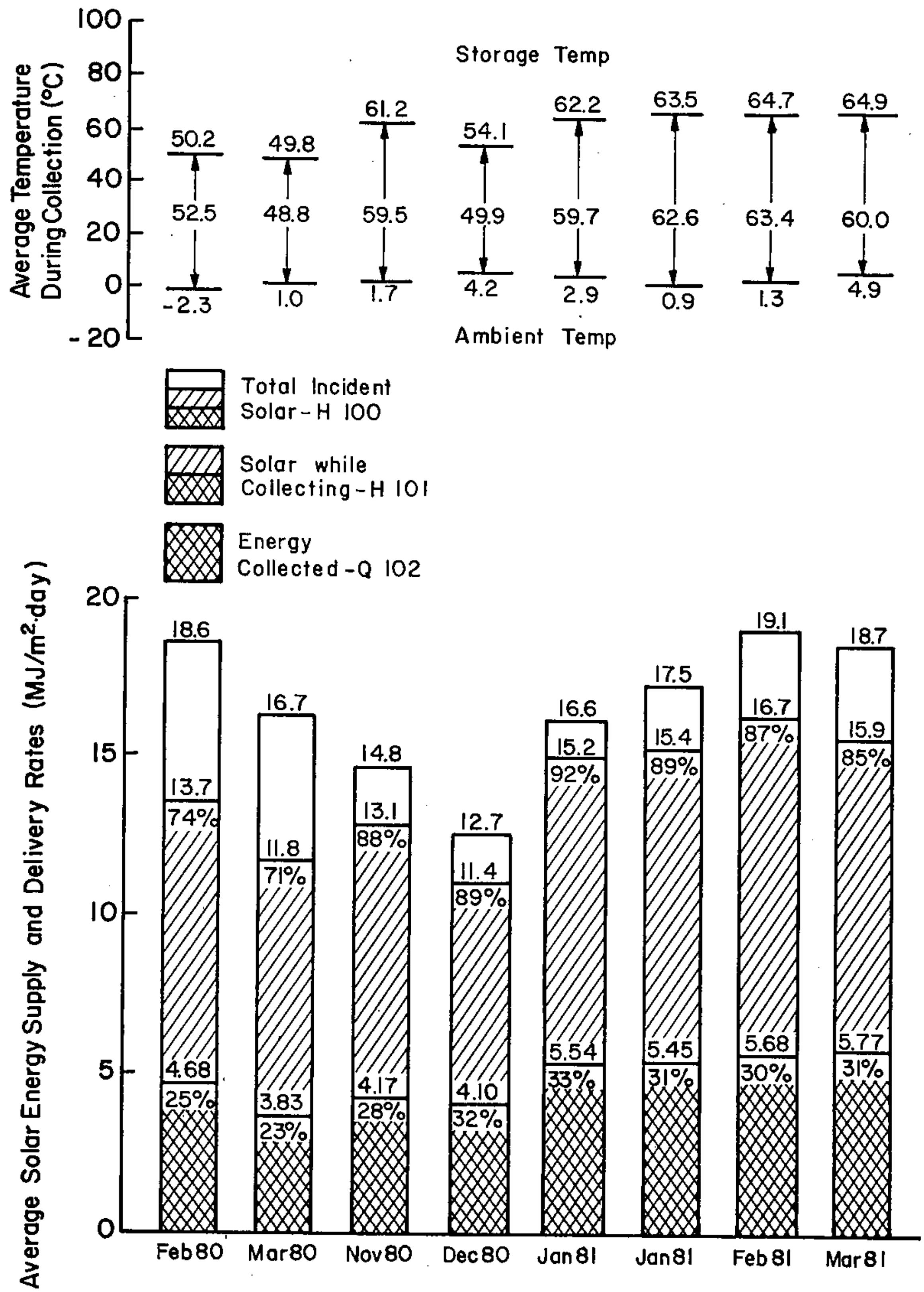


Figure 6-54. USA-HTG-1, 2, 3, and 4, Average Energy Supply Rates

The only significant difference in the performance of systems HTG-3 and HTG-4 was in the larger quantity of solar hot water provided by the single tank design in systems HTG-3 and HTG-4. However, the higher total hot water usage experienced with those systems would be expected to increase the solar supply also. The results clearly show that the single tank system is more effective than the two-tank design, mainly because of lower heat losses from smaller tank surfaces.

Similarity in design and performance of systems HTG-2, HTG-3 and HTG-4 permits comparison of all three with system HTG-1. Moreover, system HTG-1 and system HTG-4 were both operated in February and March, the former in 1980, the latter in 1981. Solar conditions and heat requirements are seen to be similar (See Figure 6-54). The 30 percent efficiency of system HTG-4 with the evacuated tube collector can therefore be directly compared with the 24 percent efficiency of system HTG-1 with a flat plate collector in a drain-back design. Total system efficiency was 28-29 percent in system HTG-4, 18-22 percent in system HTG-1. Besides lower collection, higher losses appear to have limited the net heat supplied by system HTG-1.

Figure 6-55 shows solar collection performance of the four systems used for cooling and hot water supply in the summers of 1980 and 1981. During the first two months of the 1980 summer, the flat plate, drain-back collector was used (System CLG-1), and for the other three periods in 1980 and 1981, the evacuated tube heat pipe collector was used in a single loop design (Systems CLG-2, CLG-3,4). The two systems used from June to mid-September, 1980 (Systems CLG-1 and CLG-2) included the WF36 with cooling tower, whereas the XWF3600 evaporatively cooled chiller was used in Systems CLG-3 and CLG-4 in late September 1980, and during the summer of 1981.

Comparison of Systems CLG-1 and CLG-2 shows that solar collection efficiency for cooling and hot water was 23 percent with the flat plate solar heat supply and 38 to 40 percent with the evacuated tube system. Cooling produced by the WF36 chiller averaged 118 and 142 MJ/day with the flat plate collector, 157 and 235 MJ/day with the evacuated tube collector. Respective system efficiencies (total solar heat used divided by solar radiation received) were 19 to 20 percent and 27 to 36 percent. The substantial superiority of the evacuated tube collector for use in a solar cooling system is evident.

Replacement of the WF36 chiller and cooling tower with the directly cooled XWF3600 chiller in Systems CLG-3 and CLG-4 resulted in reduced solar collection (comparing System CLG-4 with System CLG-2) because of the higher operating temperature requirement. Collection efficiency with the WF36 chiller (System CLG-2) averaged 35 percent and with the XWF3600 (System CLG-4) about 26 percent. Corresponding storage temperatures averaged 70.7° and 83.4°C. When storage was operated in a pressurized mode in September 1981, its temperature averaged 93.6°C and collection efficiency decreased to 21 percent.

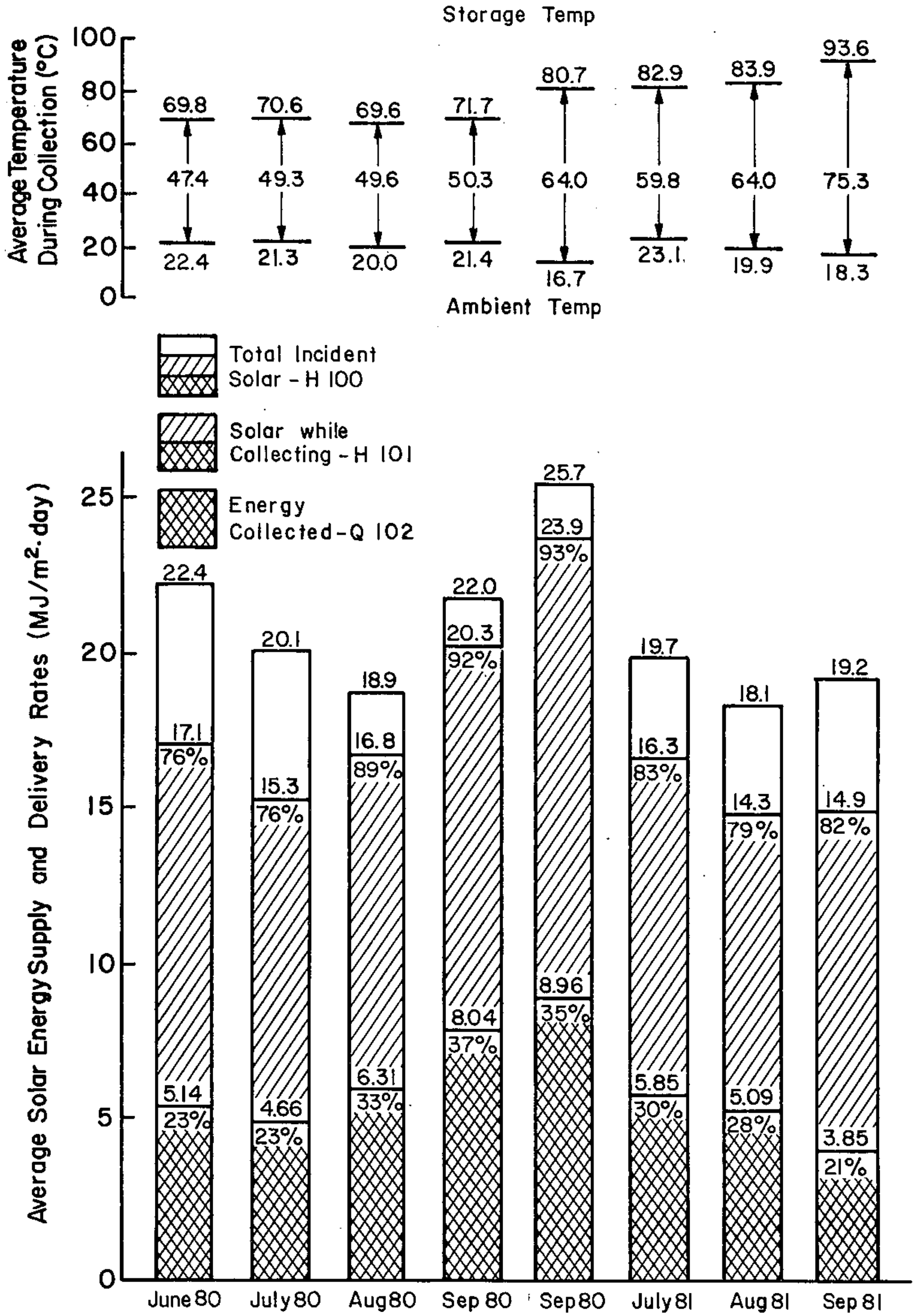


Figure 6-55. USA-CLG-1, 2, 3, and 4, Average Energy Supply Rates

Differences in collection efficiency at these several operating temperatures are partially due to differences in the intensity of solar radiation necessary for useful heat to be collected. Approximately 90 percent of the total daily radiation was received during operation of System CLG-2 (WF36 chiller), but only about 80 percent with System CLG-4 (XWF3600 chiller), decreasing to 77 percent when storage was pressurized. Higher storage temperatures required by the XWF3600 chiller result in a higher radiant energy threshold for net solar collection to occur and lower percentage of total solar that can be collected. Higher collector heat losses while operating at the higher temperatures required by the XWF3600 chiller decreased collector output. Solar cooling delivered by the XWF3600 chiller was also lower than that obtained with the WF36 unit, for similar reasons. Solar cooling of 157 and 235 MJ/day was obtained at a COP of 0.55 with the WF36 unit, and 145, 118 and 99 MJ/day at COP's of 0.44 and 0.56 with the XWF3600.

6.4.4 Solarhaus Freiburg - West Germany

These bar charts (Figures 6-56 through 6-61) show the daily average of total incident solar radiation H100, the radiation incident during operation of the collector pumps H101, as well as the collected thermal solar energy Q112 of the entire collector field. Monthly values of the years 79, 80, 81 of both collector systems Corning Glass and Philips IV are displayed together with the collection system efficiency N100.

Corning Glass Collector - In the years 1980 and 1981, an average yearly amount of 1952 MJ/m^{2}a (542 kWh/m^{2}a) of solar thermal energy has been delivered by the Corning Glass collector per m^2 of aperture area, corresponding to an average annual collector system efficiency of 50%. There was no variation of annual efficiency from 1979 - 1981. The collector system COP has been determined to 23, which includes the operating energy of the circulation pump.

Philips Mark IV Collector - An average annual output of the Philips Mark IV collector system of 1593 MJ/m^{2}a (443 kWh/m^{2}a) per m^2 of aperture area has been measured in 1980 and 1981, giving an average annual collector system efficiency of 42%. Solarization of the cover panes (which were replaced end of July 1979) caused the efficiency to decrease in 1979 by approximately 2% in the yearly average. It should be noted, that a shading of this collector by the neighboring roof reduces its yearly incident radiation by about 4%.

The annual variation of monthly efficiency within both collector systems may be explained by the annual distribution of incident radiation which is in January only about 1/4 of the summer maximum, causing the collection system to operate near the "point of minimum radiation", explained on the Input/Output Diagrams.

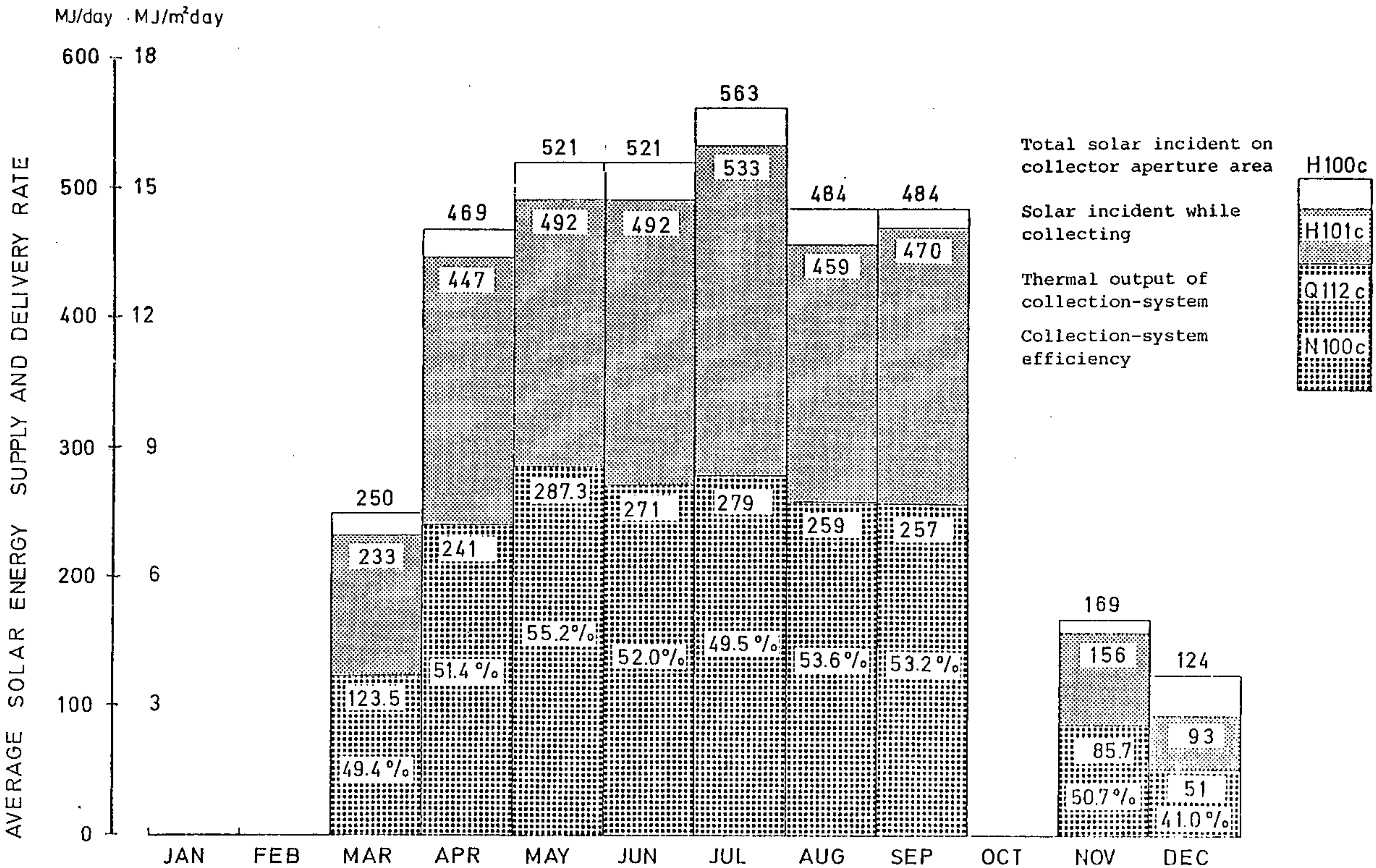


Figure 6-56. WG-Corning-1979, Average Energy Supply Rates

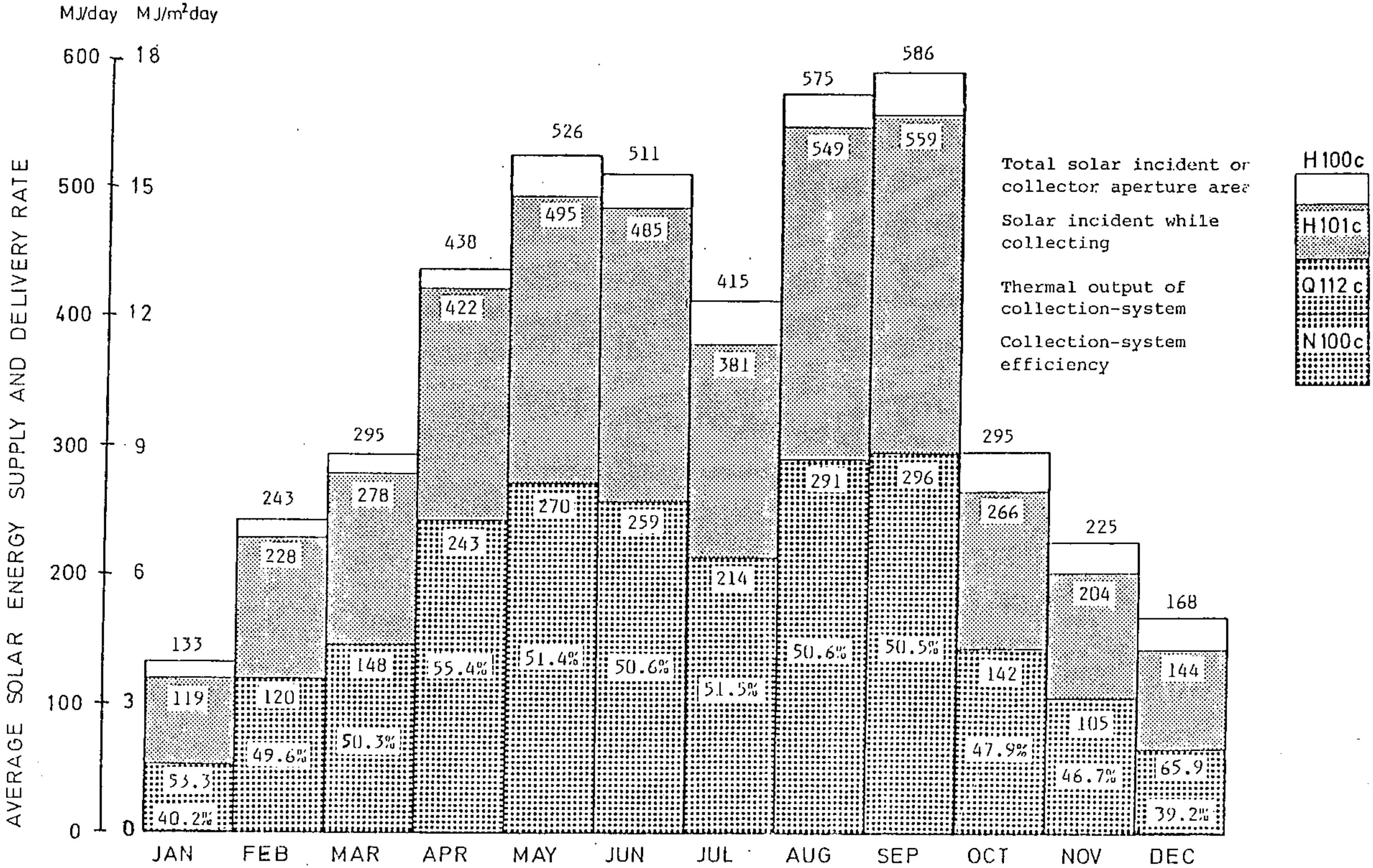


Figure 6-57. WG-Corning 1980, Average Energy Supply Rates

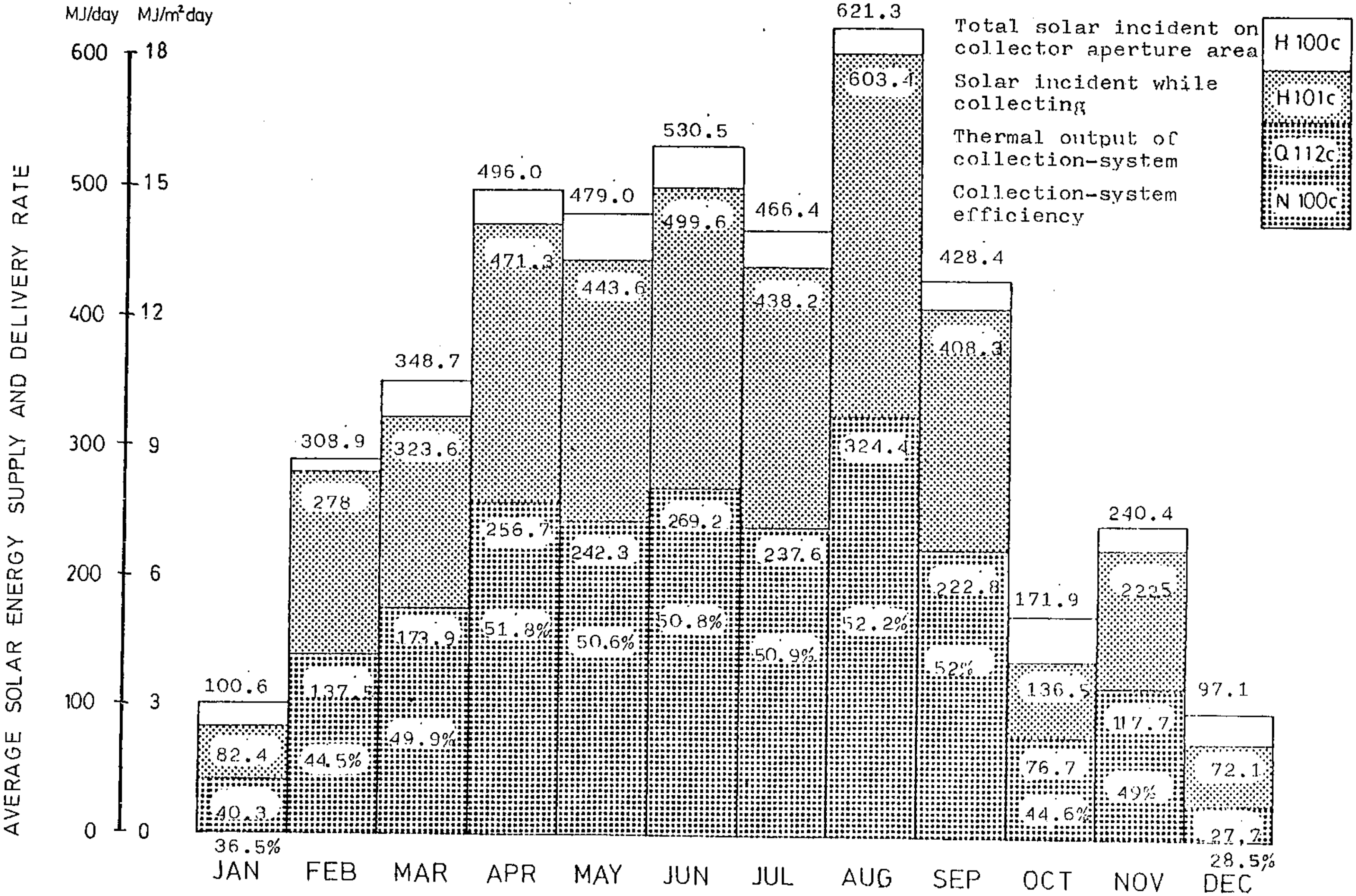


Figure 6-58. WG-Corning-1981, Average Energy Supply Rates

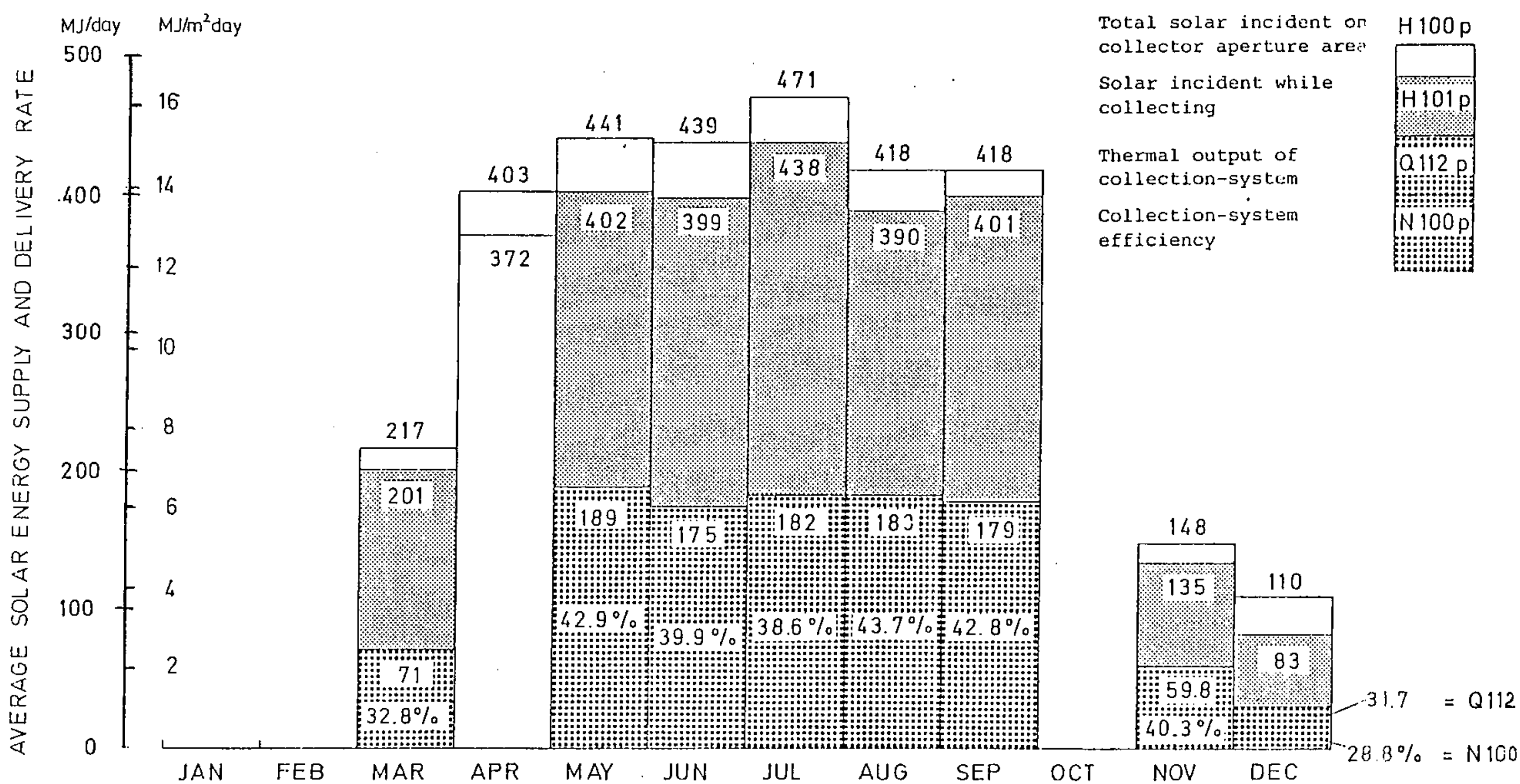


Figure 6-59. WG-Philips-1979, Average Energy Supply Rates

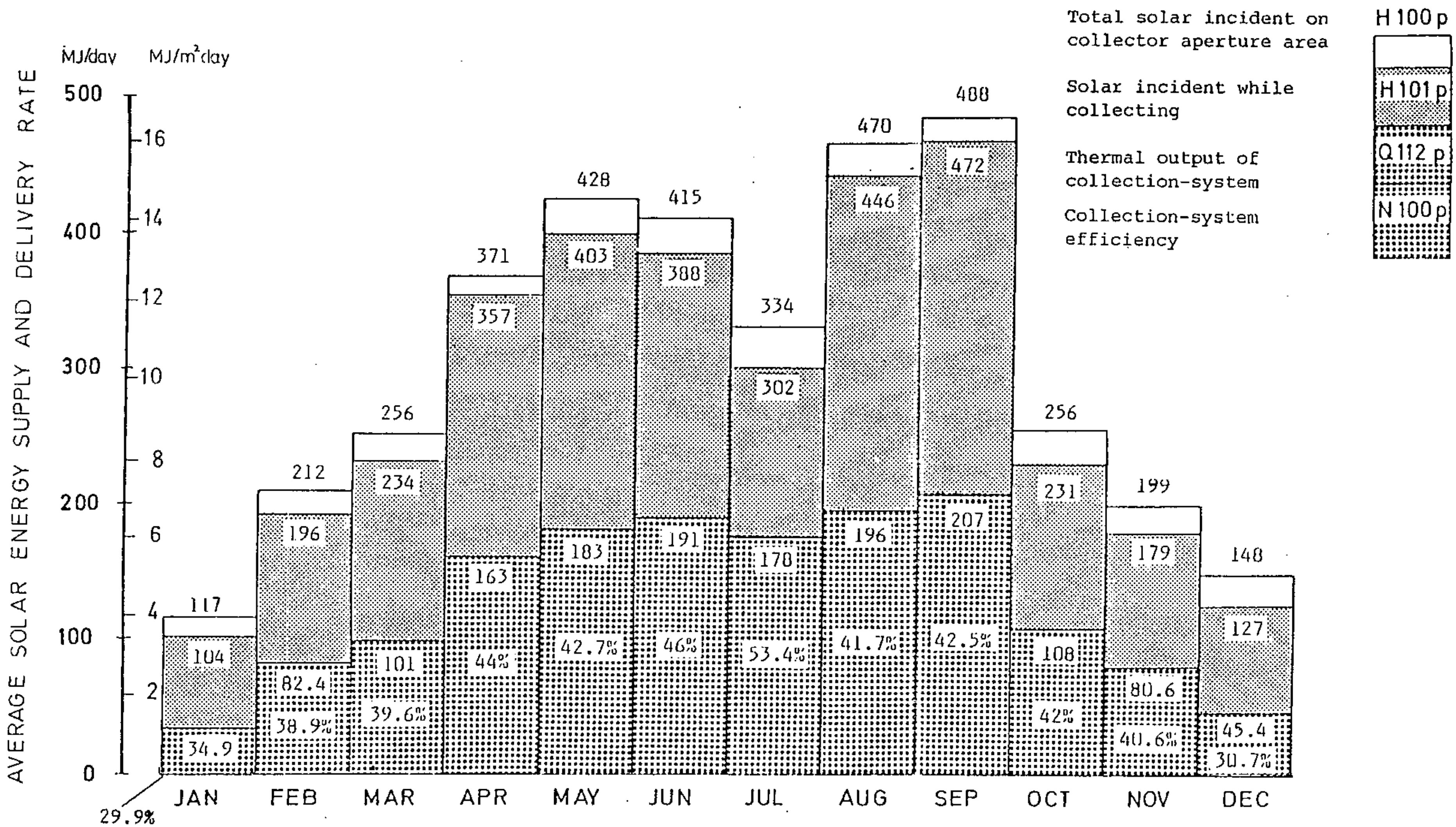


Figure 6-60. WG-Philips-1980, Average Energy Supply Rates

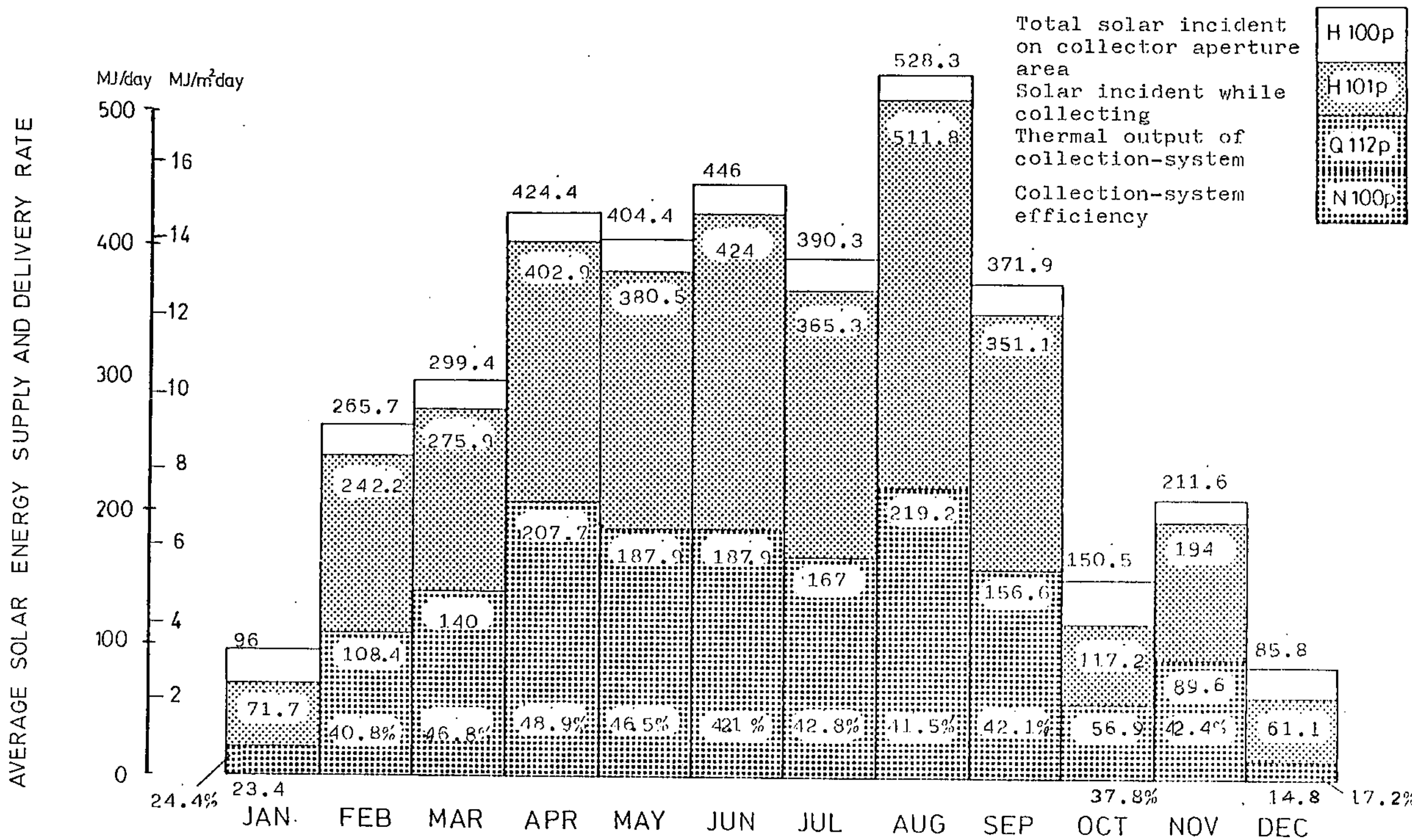


Figure 6-61. WG-Philips-1981, Average Energy Supply Rates

6.5 ENERGY USE BAR CHART

The energy use bar chart shows the solar and auxiliary energies which have met the space heating, cooling, and hot water demands.

6.5.1 Osaka Sanyo Solar House - Japan

The average energy supply rates for the heating season, J-HTG-1, and the cooling season, J-CLG-1, were shown in Figure 6-62. In this figure the average energy supply rates for each month in the experiments are shown. The solar fractions for the months shown in the figure were more than 80%, and the performances of the distribution system can be considered very satisfactory.

The same diagrams for the heating experiments, J-HTG-2, and the cooling experiment, J-CLG-2, are shown in Figure 6-63. This figure shows that the loads for the heating season were so large that much of the auxiliary energy was used to satisfy the load. However, the auxiliary energy used especially in January and February was much more than expected. This is considered to be due to the reduction of the collector area from 54.8 to 33.1 m^2 and to the fact that the conventional control had to be used since the microprocessor failed to work.

6.5.2 Colorado State University Solar House I - USA

The use of solar and auxiliary energy for meeting the heating, cooling and domestic hot water requirements of Solar House I are shown in Figures 6-64 and 6-65.

Figure 6-64 shows results for all the heating systems, USA-HTG-1, 2,3, and 4. The results show the improved performance of the evacuated tube collector in use from November 1980 over the flat-plate collector used in February and March of 1980.

Figure 6-65 shows results for all cooling systems, USA-CLG-1,2,3, and 4. Once again the advantages of the evacuated tubular collector may be seen, especially for the higher water temperatures required for absorption cooling.

6.5.3 Solarhaus Freiburg - West Germany

The energy use bar charts are separated into average DHW system use and solar space heating delivery and use. For the DHW chart, above the zero line, daily averages of collected solar energy delivered into the storage tanks (Q102W) plus auxiliary energy (Q301) are displayed in the sense of the positive y-axis. Auxiliary energy was supplied by electricity until October 1980, since then it is supplied by thermal energy from the oil burner. Below the zero line, in the sense of the negative y-axis.

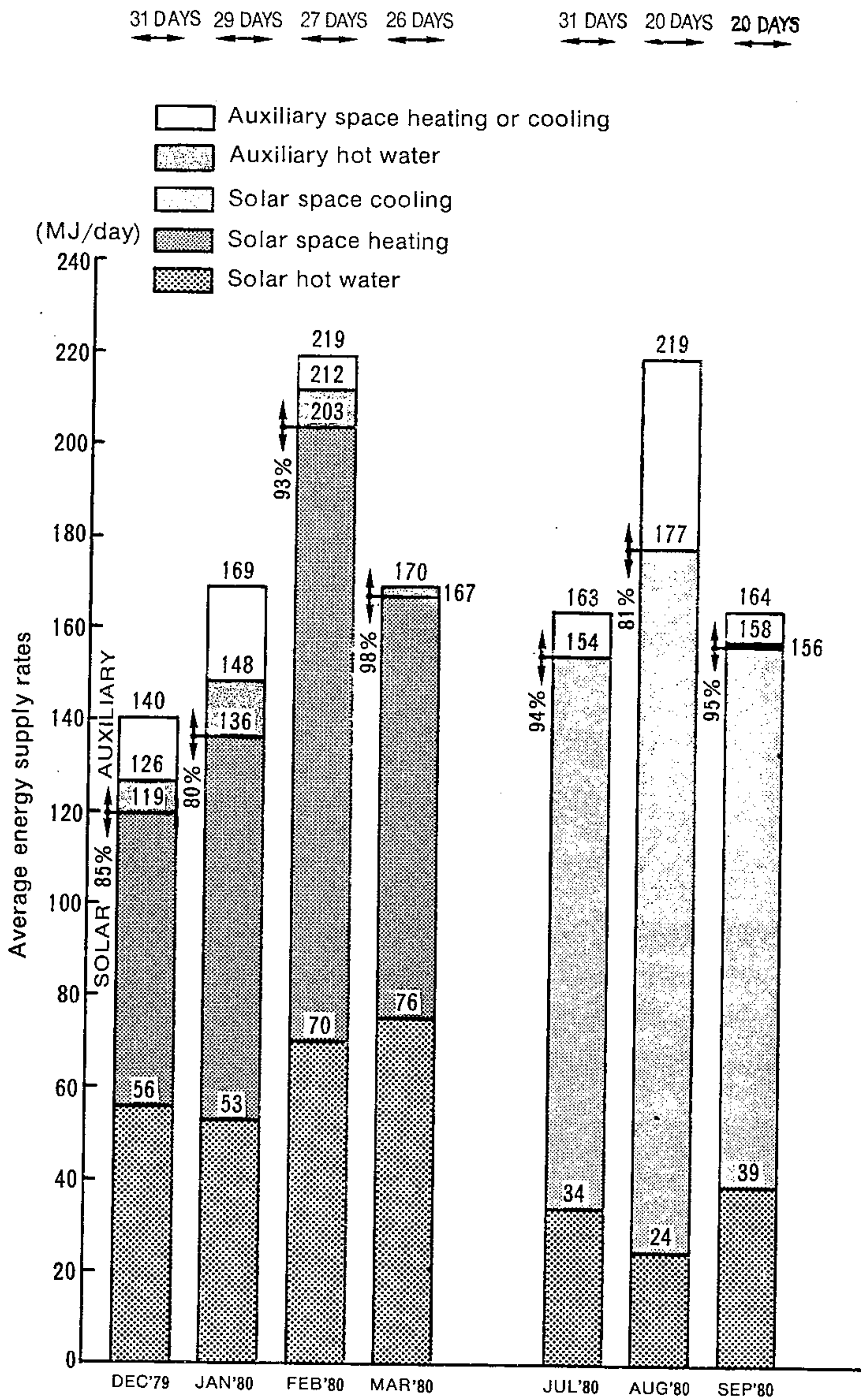


Figure 6-62. J-HTG-1 and CLG-1, Average Energy Use Rates

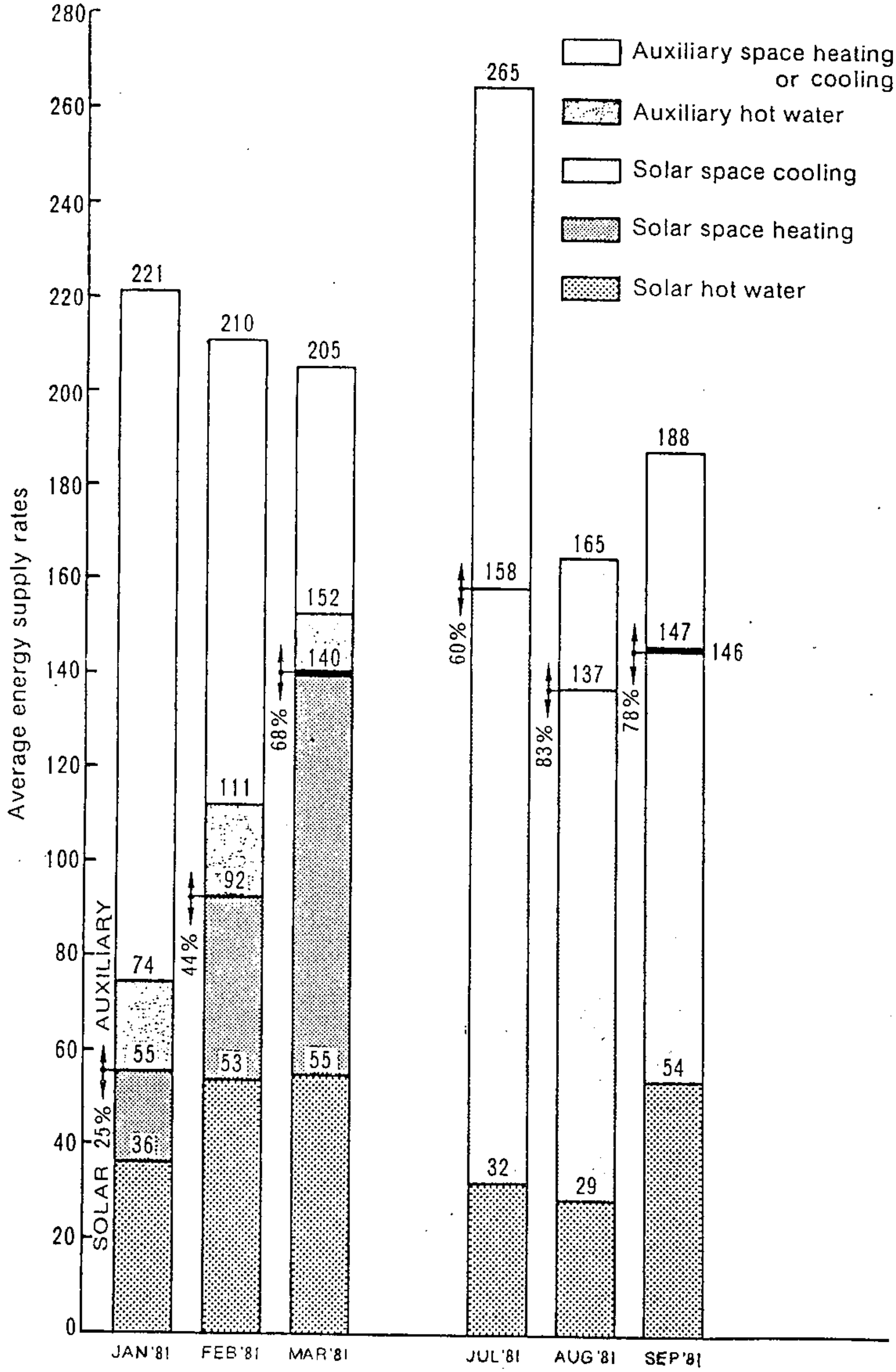


Figure 6-63. J-HTG-2 and CLG-2, Average Energy Use Rates

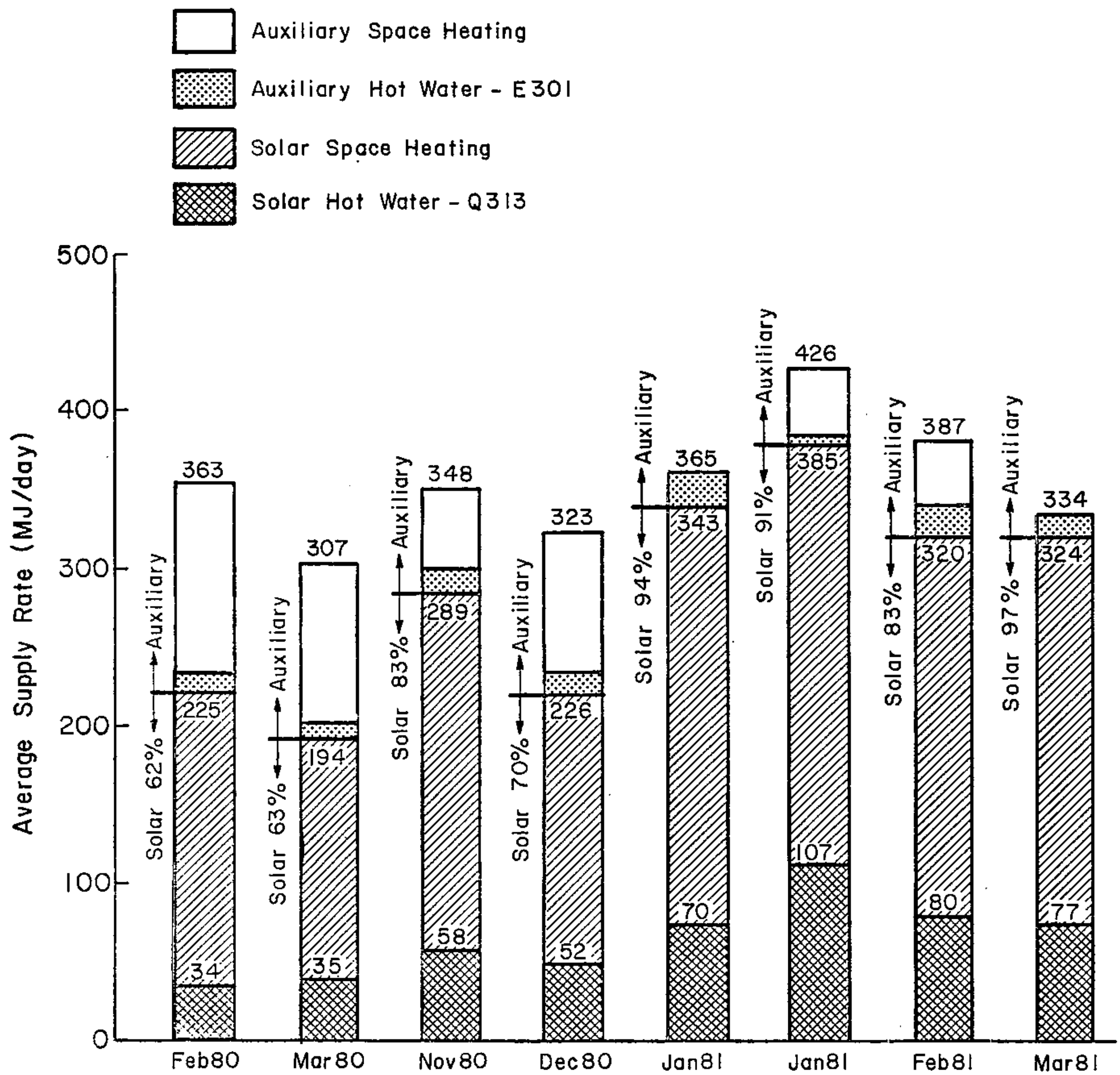


Figure 6-64. USA-HTG-1, 2, 3, and 4, Average Energy Use Rates

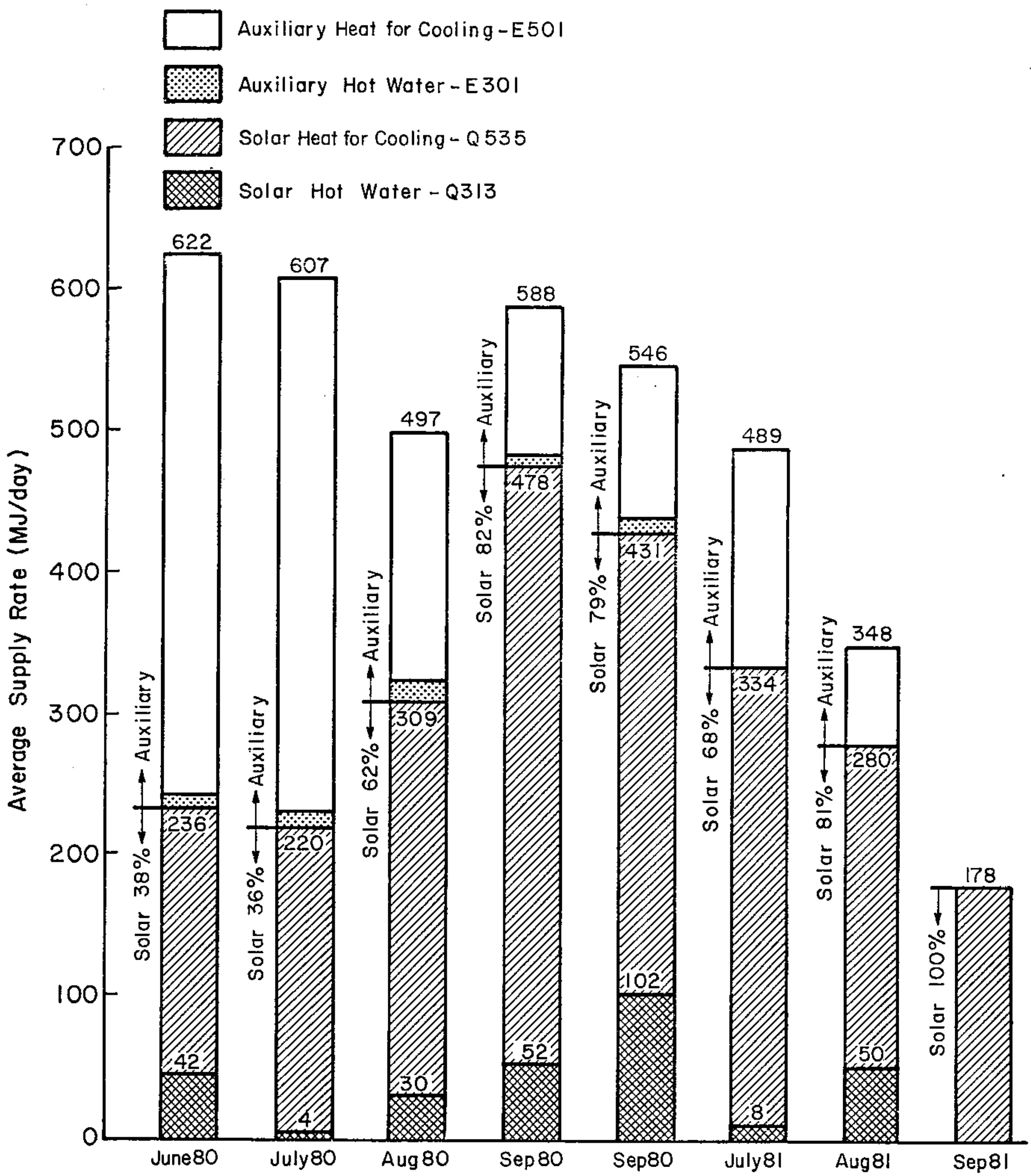


Figure 6-65. USA-CLG-1, 2, 3, and 4, Average Energy Use Rates

excess heat of the solar DHW system (Q150w) plus distribution losses of the solar system are displayed. Thus, the sum of Q102 plus excess heat Q150 plus distribution losses correspond to the collector system output Q112. The solar fraction which has been defined with respect to the total energy consumption of the DHW system i.e. N331 = Q102w/ (Q102w + Q301w) is indicated in the bar charts for each month. The annual solar fraction was 60.9% of a yearly gross DHW load of 77,826 MJ/a corresponding to an amount of 1496 MJ/m^2a (416 kWh/m^2a) of useful solar energy supplied to the DHW system in 1980 per m^2 of aperture area. See Figures 6-66, 6-67 and 6-68.

The Philips MK IV collector was operating from January - May, the Corning Glass collector from June - December. The effective aperture area was 31.7 m^2. The COP corresponding to pumping energy was 15. The net solar system efficiency, (useful solar - solar storage losses) divided by the total incident radiation, has been determined to 35%.

In 1981 the gross DHW load increased slightly to 81,648 MJ/a; 62.3% of this energy could be supplied by solar with the Corning Glass collector operating all year on the DHW system. The specific amount of useful solar energy per m^2 of aperture area (33.3m^2) was 1526 MJ/m^2a (424 kWh/m^2a), the COP of collection system (useful solar) was 18.5. The net solar system efficiency of 36% is nearly the same as 1980. The solar fraction of 60-62% of the DHW system energy consumption is a remarkable result compared with conventional DHW collector installations which could furnish a similar solar portion only with 2 to 3 times larger collector area.

The result appears to be in close agreement with the computer simulations of the solar DHW system, on which the system design was based. The predicted steep tilt angle of the collectors of 55° is well adapted to the use of evacuated tubular collectors in a DHW system, because they are producing a considerable amount of useful solar heat even in early spring and late fall. This is indicated in the relatively high solar fractions of February and November, when ambient temperature is below 5°C and radiation is at only 25 - 30% of the summer maximum.

A comment is necessary to explain the simultaneous occurrence of auxiliary energy demand and production of excess heat, as is seen in July 1980. The reason for this behavior was a typical rainy period of about two weeks followed by typical mid summer weather conditions with high availabilty of sunshine.

The production of excess heat had been underestimated in the design period; the explanation being partially a decrease of warm water consumption in summer time for an unknown reason.

There are nearly no solar distribution losses in the winter time because solar energy is used about 50% in the preheat mode and 50% is

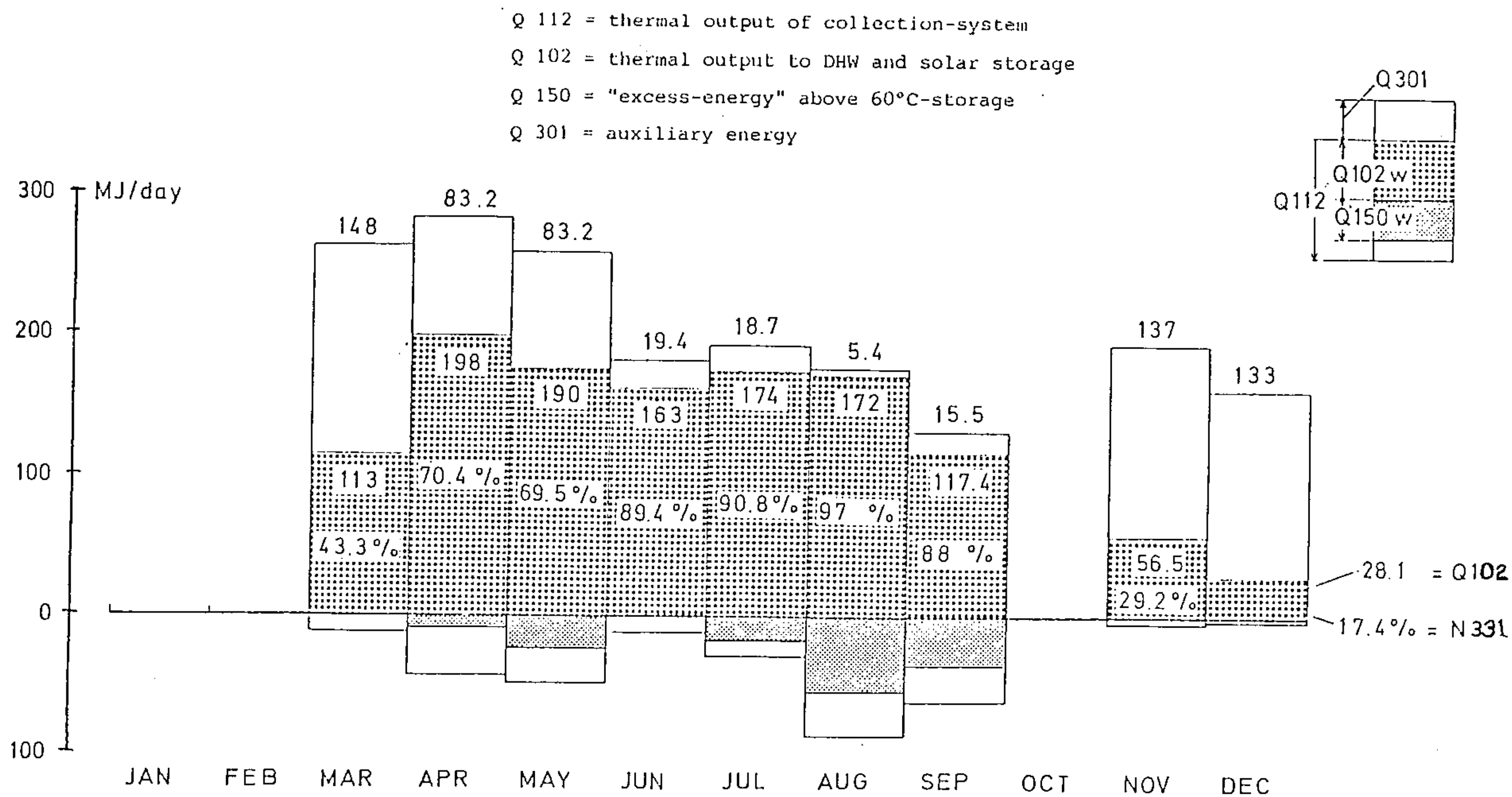


Figure 6-66. WG-DHW-1979, Average Energy Use Rates for DHW

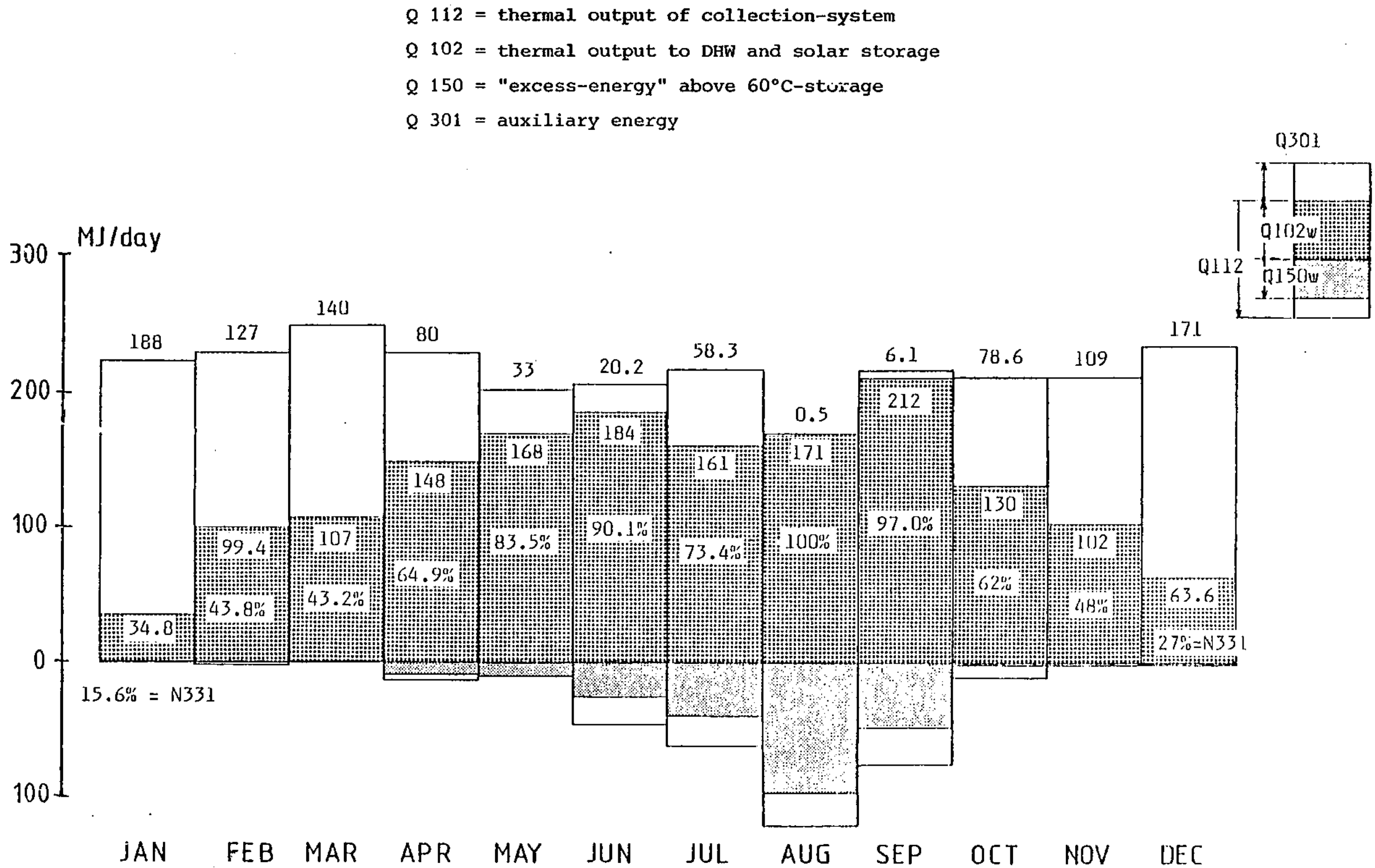


Figure 6-67. WG-DHW-1980, Average Energy Use Rates for DHW

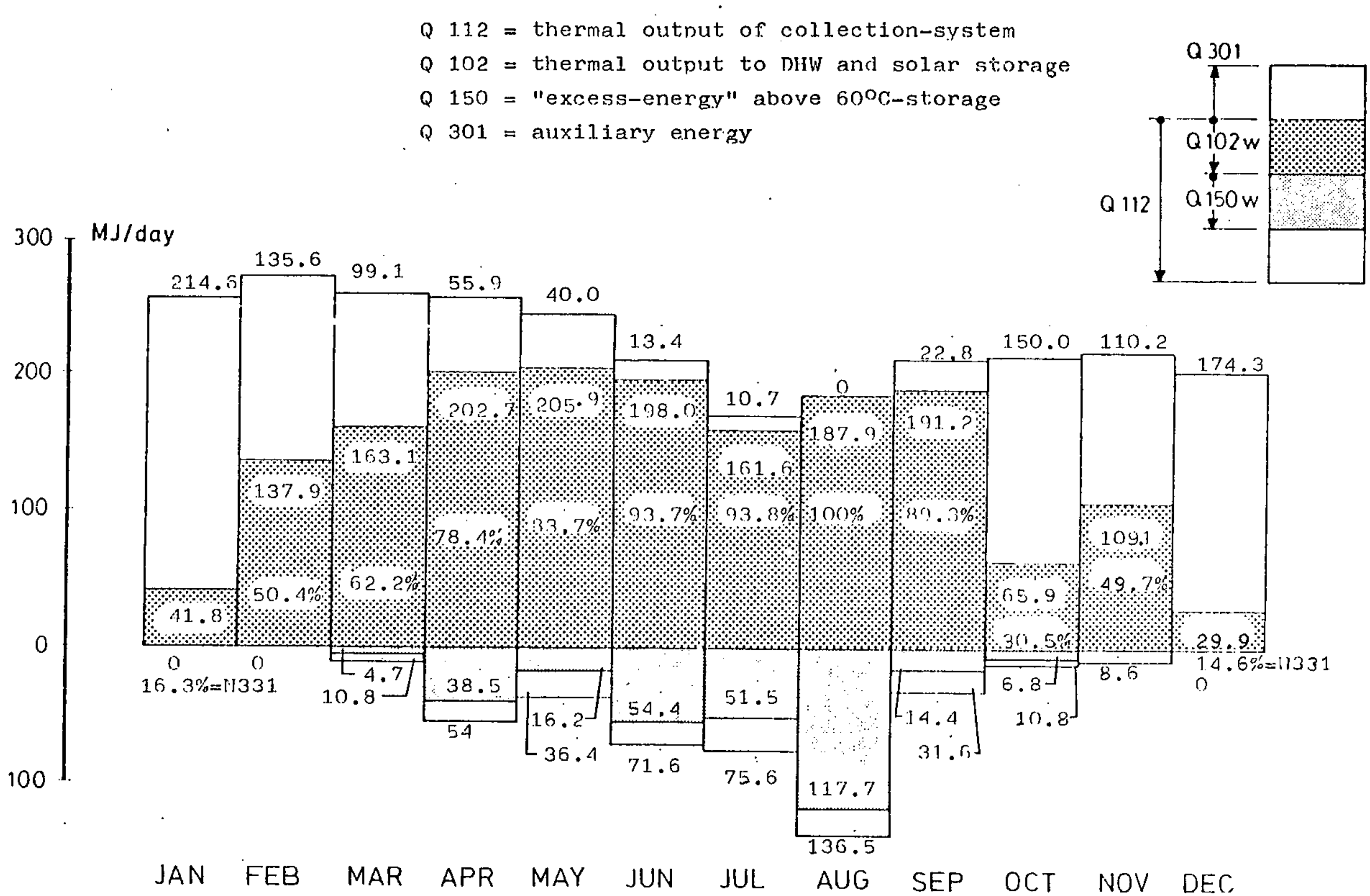


Figure 6-68. WG-DHW-1981, Average Energy Use Rates for DHW

delivered in the hot storage tank with high temperatures. As the preheat mode is obligatory before the end of daily operation, there are only few capacity related losses in the distribution system.

For the solar space heating bar charts of Figure 6-69 and 6-70, a "zero line" separates solar energy delivered into both storage tanks into useful solar energy and into solar storage tank losses, which are plotted in the negative sense of the y-axis. Solar storage losses are calculated with loss coefficients and weighted corresponding to the different energies entering the storage. Thermal auxiliary energy from the oil burner is plotted on top of useful solar energy. A parallel bar indicates each month the useful output of both heating storages (15 m^3 and 5 m^3). This bar is composed of heating energy delivered to the radiator heating system and of auxiliary energy supplied to the heat exchanger of the DHW system (if operational).

Three input/output situations may occur and are briefly discussed using appropriate months in 1980:

1. In January - April and November - December, 1980, the sum of useful solar and auxiliary input is greater than the sum of the output. The difference corresponds to conventional losses of the hot heating storage tank (5 m^3).

2. From June - August 1980, the bar of useful solar is greater than the total output. As there are no conventional losses (no auxiliary input) and solar losses are shown below the zero line, the difference corresponds to storage of solar input, i.e. storage in sensible heat. It is noted that there is a considerable increase of solar losses due to high storage temperatures.

3. In September and October 1980, the sum of useful solar and auxiliary input is smaller than the sum of output. This is the situation, when stored solar energy is used after a certain time delay. After discharge, solar losses decrease within one month.

In 1980, with operation of Corning Glass collector from January - May and Philips MK IV collector from June - December, a yearly amount of 30,781 MJ/a of useful solar energy has been supplied by the heating storages; this yields a specific value of 990 MJ/m^2a per m^2 of aperture area (31.1 m^2). This amount of useful solar energy provided 10.6% of the annual heating load of 287,580 MJ/a (output of heating storages) and 5.6% of the thermal auxiliary energy, which was delivered to the DHW system since October 1980 (9,490 MJ/a).

In 1981, with all year operation of Philips MK IV collector, a solar fraction of 9.6% of the heating load and of 6.8% of the thermal DHW auxiliary energy (operating all year) was measured.

Excess heat of the solar DHW system contributed in both years only 12 - 16% of the annual amount of useful solar energy.

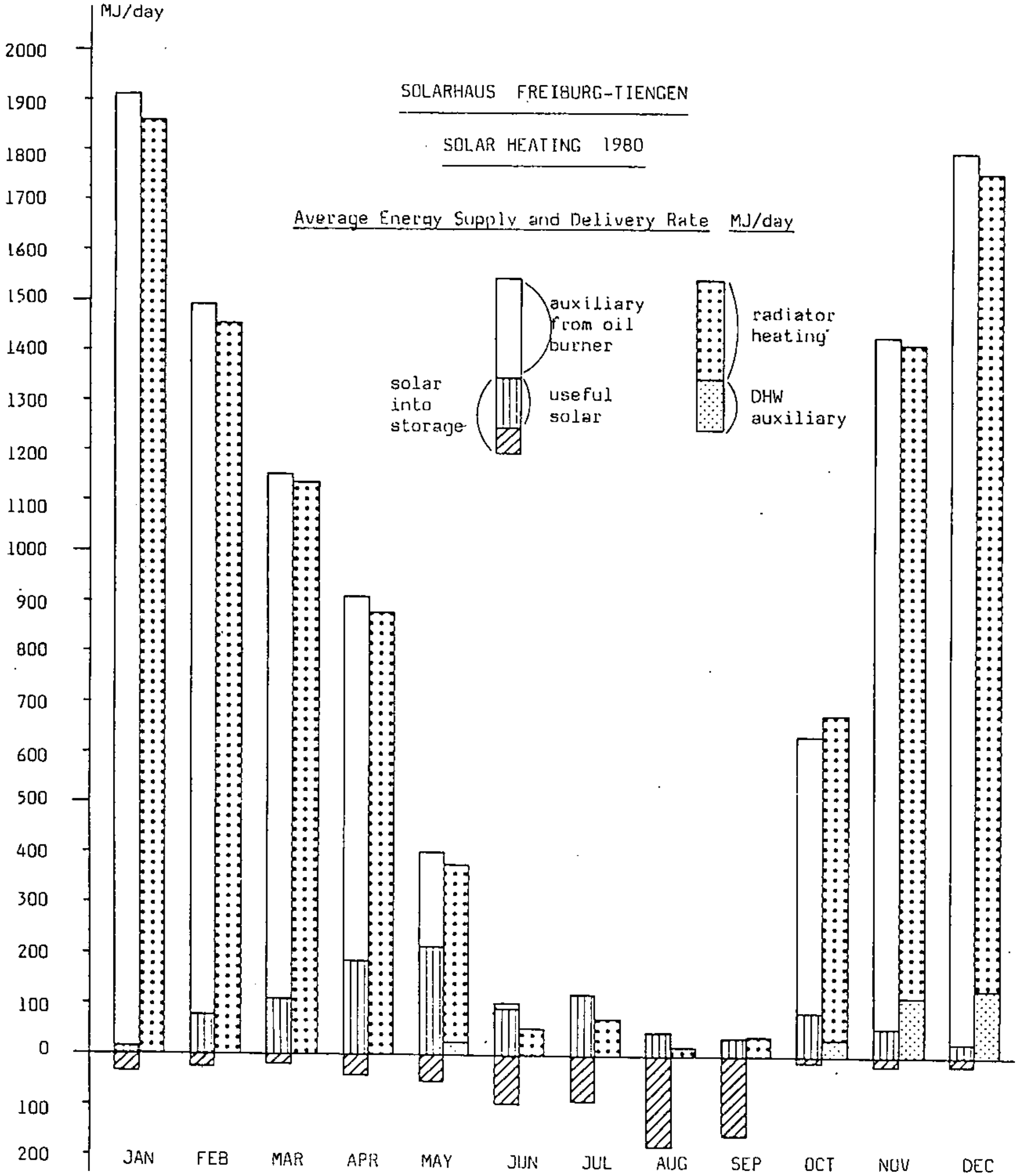


Figure 6-69. WG-HTG-1980, Average Energy Use Rate

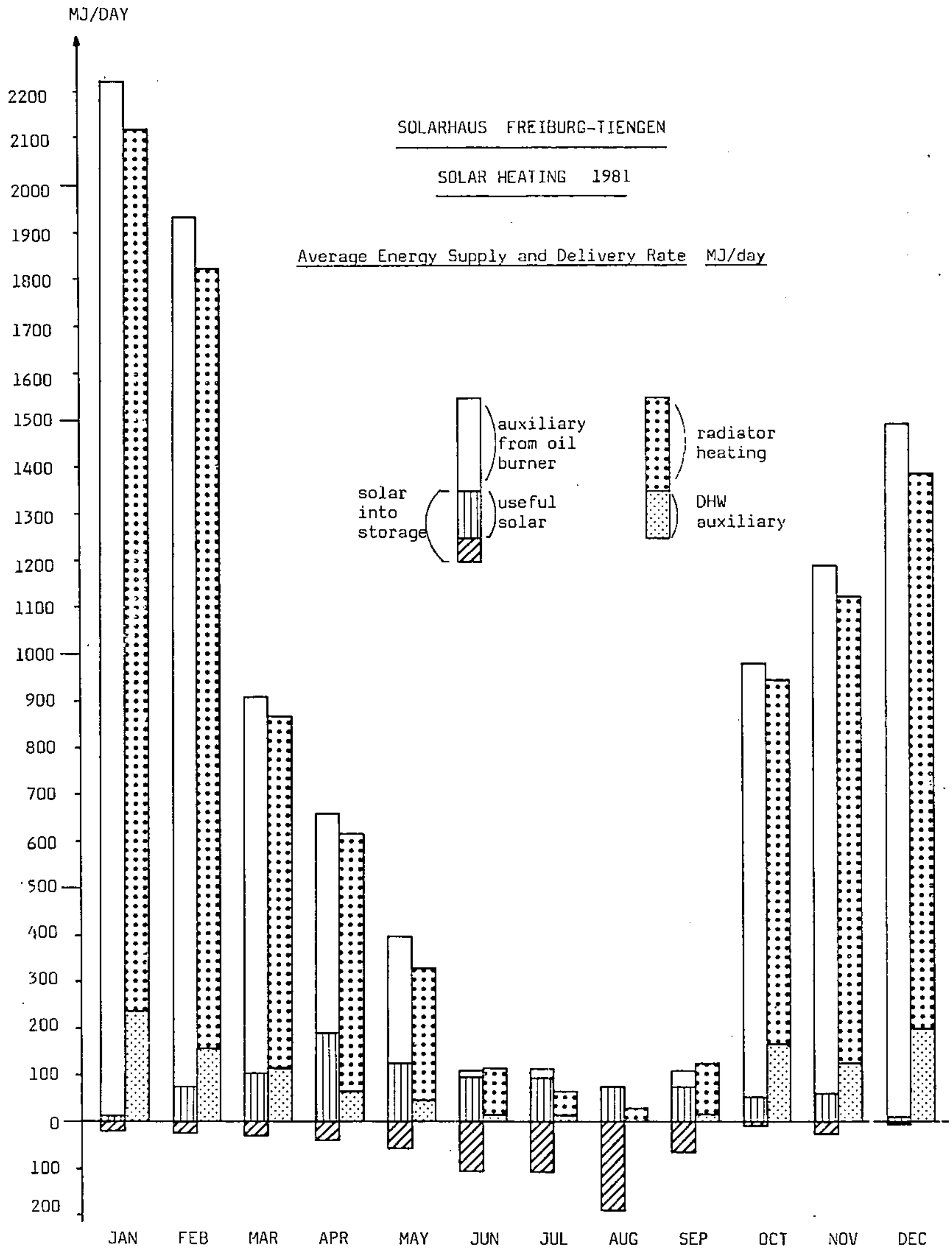


Figure 6-70. WG-HTG-1981, Average Energy Use Rate

If the absolute size of the collector area is taken into account (it covers less than 5% of the heated living area) these results show, that solar space heating with evacuated collectors is feasible even under mid-Eurpoean climate conditions. Solar energy was used in spring and fall, when solar radiation was available together with a moderate heating load. However, 57% of the annual useful solar energy was delivered in the spring heating season (February - May), and only 18% was delivered from September to November. These figures indicate that direct use of solar energy with only short term storage performed better than sensible heat storage from mid-summer to fall.

6.6 COMPARISONS

As shown in Figures 6-71 through 6-74, a systematic increase in collection performance occurs in winter as compared to summer with the Sanyo, GE and Philips VTR 141 collectors. This increase was also observed with the Philips MK IV collector, as may be seen in Duff and Löf [43]. This difference is all the more remarkable since load dependent factors, lower collector start up temperatures and monotonic storage temperature increase in the winter, would suggest the opposite effect. Many factors may be responsible for the increase. Among them are increased ground albedo, decreased collector-sky temperature difference, pyranometer versus collector response to beam/diffuse radiation, load induced capacitance effects, and so forth. Some of the more important factors may be differences in radiation incidence angles and differences in radiation intensity distributions throughout the day. Although there have been specialized studies of these factors for individual collectors or instruments, no general theory quantifying these decreases exists.

The task is presently working to accurately quantify these factors and produce a general model to adjust collection performance. Until this model is available, care must be used when comparing collection performance results. Where possible, comparisons should be made at similar collector tilts, for similar latitudes and over the same seasonal periods. Obviously, these conditions vary for the Task VI installations reporting results. For the comparisons that follow, conditions have been made as similar as possible.

When the collector tilt, latitude load type, seasonal period and control are the same; the same collector will produce the same energy input/output plot for different loads and variations in weather. This may be seen by comparing Figures 6-29 through 6-31 and Figures 6-32 through 6-35. In fact, as long as conditions are reasonably comparable and controls are optimized, the same energy input/output plots should result for the same collectors regardless of the location or climate.

As may be seen in Table 4-1, CSU Solar House I and the Solarhaus Freiburg have both used the Corning Cortec A and Philips MKIV collectors. The Corning collector is, in fact, the same collector that was used at CSU Solar House I. It was shipped to Freiburg and installed on the solar house. Controls and other operating factors were finely tuned for both installations. So, it might be expected that each collector would produce the same energy input/output plot for both locations.

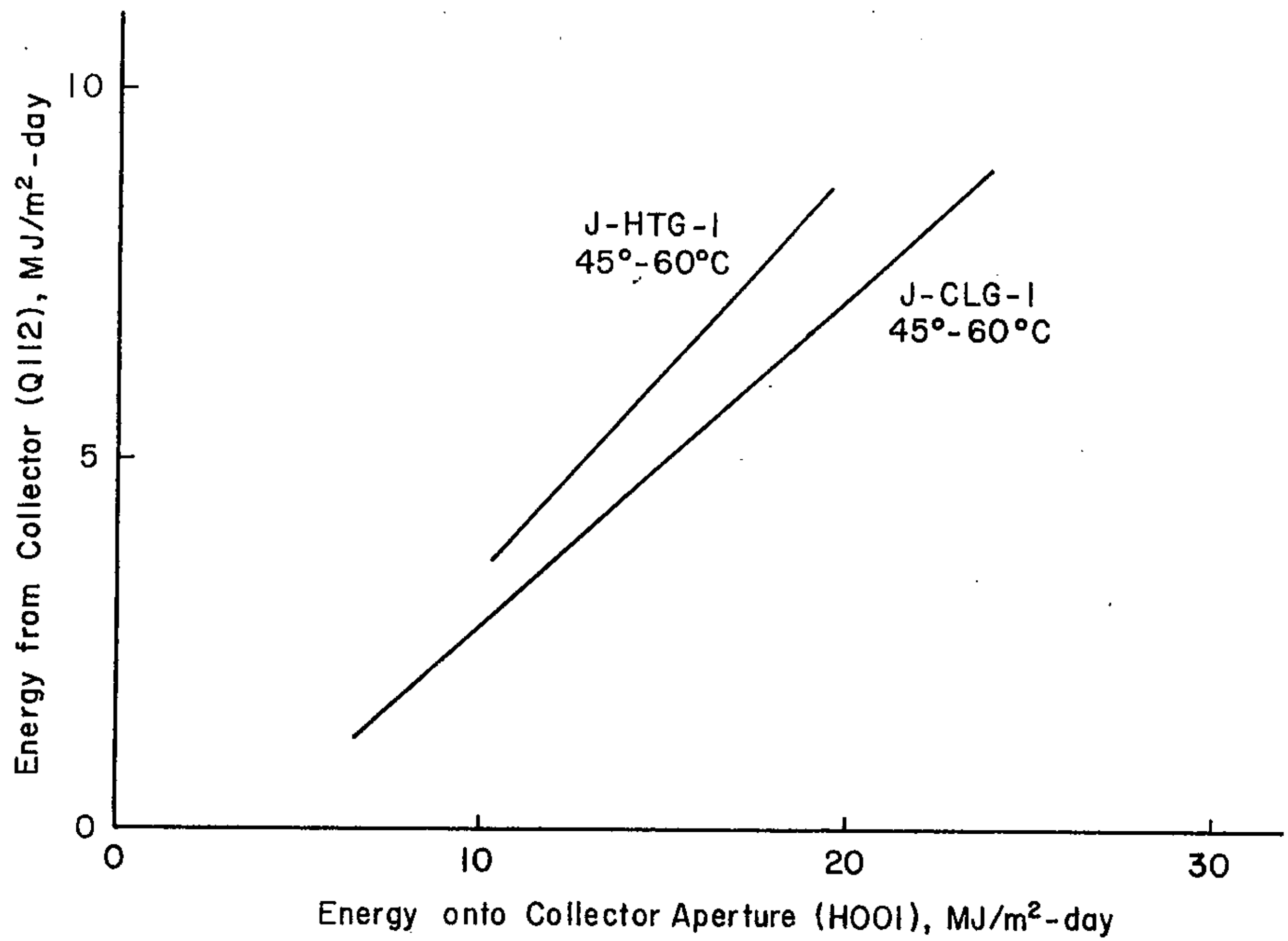


Figure 6-71. Winter-Summer Comparison for Japan's Sanyo Collector Experiments at Temperature Differences of 45°-60°C

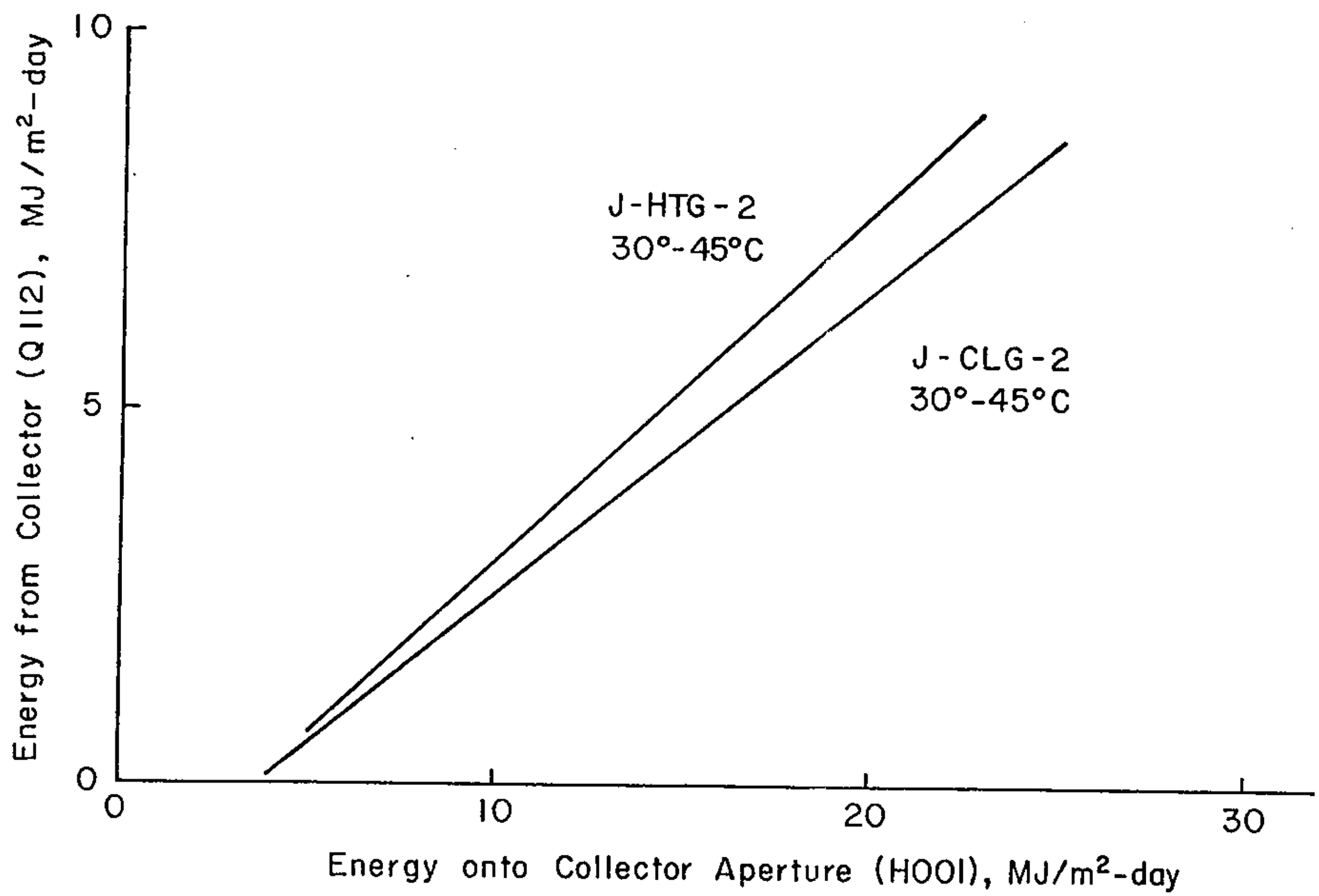


Figure 6-72. Winter-Summer Comparison for Japan's General Electric Collector Experiments at Temperature Differences of 30°-45°C

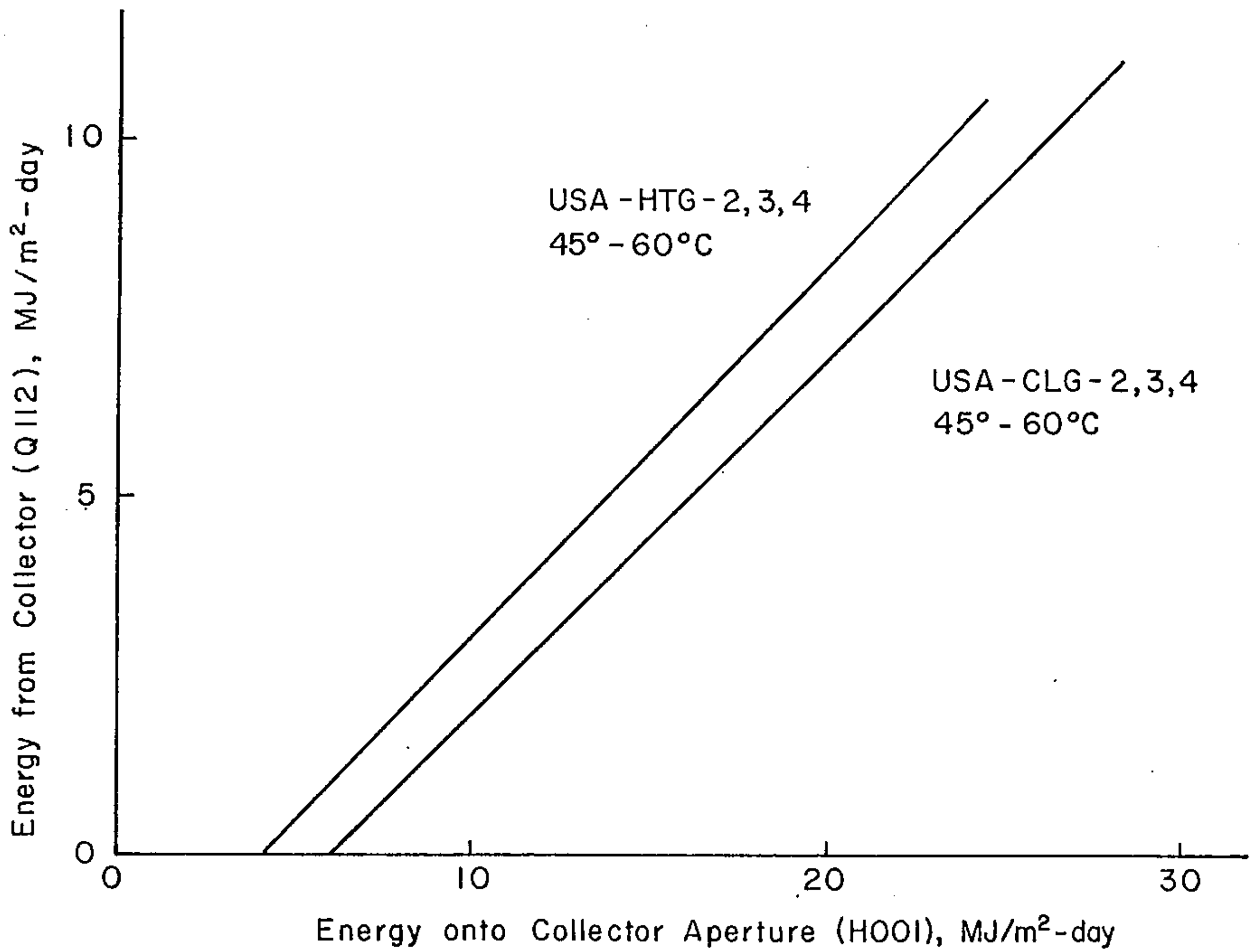


Figure 6-73. Winter-Summer Comparison for the USA's Philips VTR 141 Collector Experiments at Temperature Differences of 45°-60°C

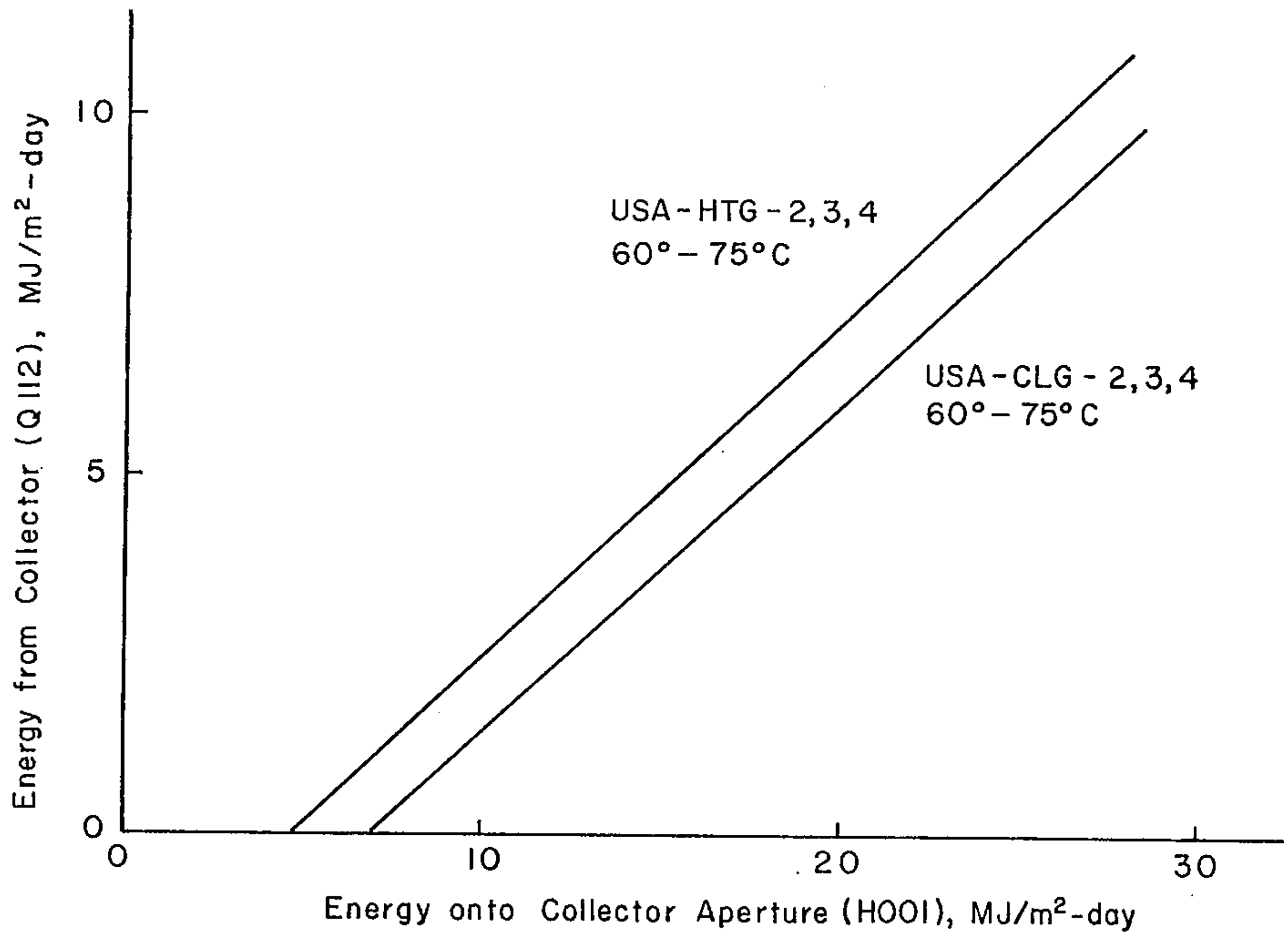


Figure 6-74. Winter-Summer Comparison for the USA's Philips VTR 141 Collector Experiments at Temperature Differences of 60°-75°C

The plots are given in Figure 6-75. Plots for the Corning collector over an entire year were available for each location. A plot for the Philips collector for an entire year is available for the Freiburg location. Separate summer and winter plots for the Philips collector are available for the CSU location. The summer plot was chosen for two reasons: 1) a change over had just been made to the high transmittance cover glass of the Freiburg installation and 2) the exceptionally high ratio of summer to winter insolation levels in Freiburg makes a summer comparison reasonable. See Figures 6-56 through 6-61.

Adjustments to collector energy output for installation differences must be made before the plots are compared. The adjustments for the CSU Solar House I Corning collectors are a two to three percent increase to account for pipe losses between the collector and tank, a zero to two percent increase for a broader ΔT range and a two to three percent decrease due to higher pumping energy contribution. The adjustment for the Solarhaus Freiburg Corning collector is an eight to fourteen percent increase if the collector had had the CSU diffuse reflective backing. See Löf and Duff [A] for these adjustments. The adjustments for the CSU Solar House I Philips collector are a two to three percent increase for pipe losses between the collector and tank and a one to two percent increase for the narrower ΔT range. The adjustment for the Solarhaus Freiburg Philips collector is a two to three percent increase due to shading. With these adjustments the appropriate plots are essentially coincident.

In Figures 6-76 through 6-78 collection performance is plotted for the three evacuated collector systems having the greatest energy produced in each of three different temperature difference ranges; 15°-30°C, 30°-45°C and 45°-60°C. When available, CSU Solar House I flat plate collection performance is also plotted. Several observations are made below.

A number of remarks can be made from these figures. First, for each temperature range, the comparative performance between two collectors will be consistently higher or lower throughout the entire range of insolation levels. In some cases not listed, this consistency was not maintained. This may be attributed to uncertainties in the regression fits. Second, as the operating temperature ranges get higher, the energy output advantage of the "best" energy producing collector becomes even greater. This tendency may be even more pronounced than shown in the figures because of the "summer like" climate bias at Freiburg discussed previously. Finally, the ratio of evacuated collector to flat plate collector output increases as operating temperature increases. Also, the ratio of evacuated collector ouput to flat plate collector output increases dramatically as insolation levels decrease.

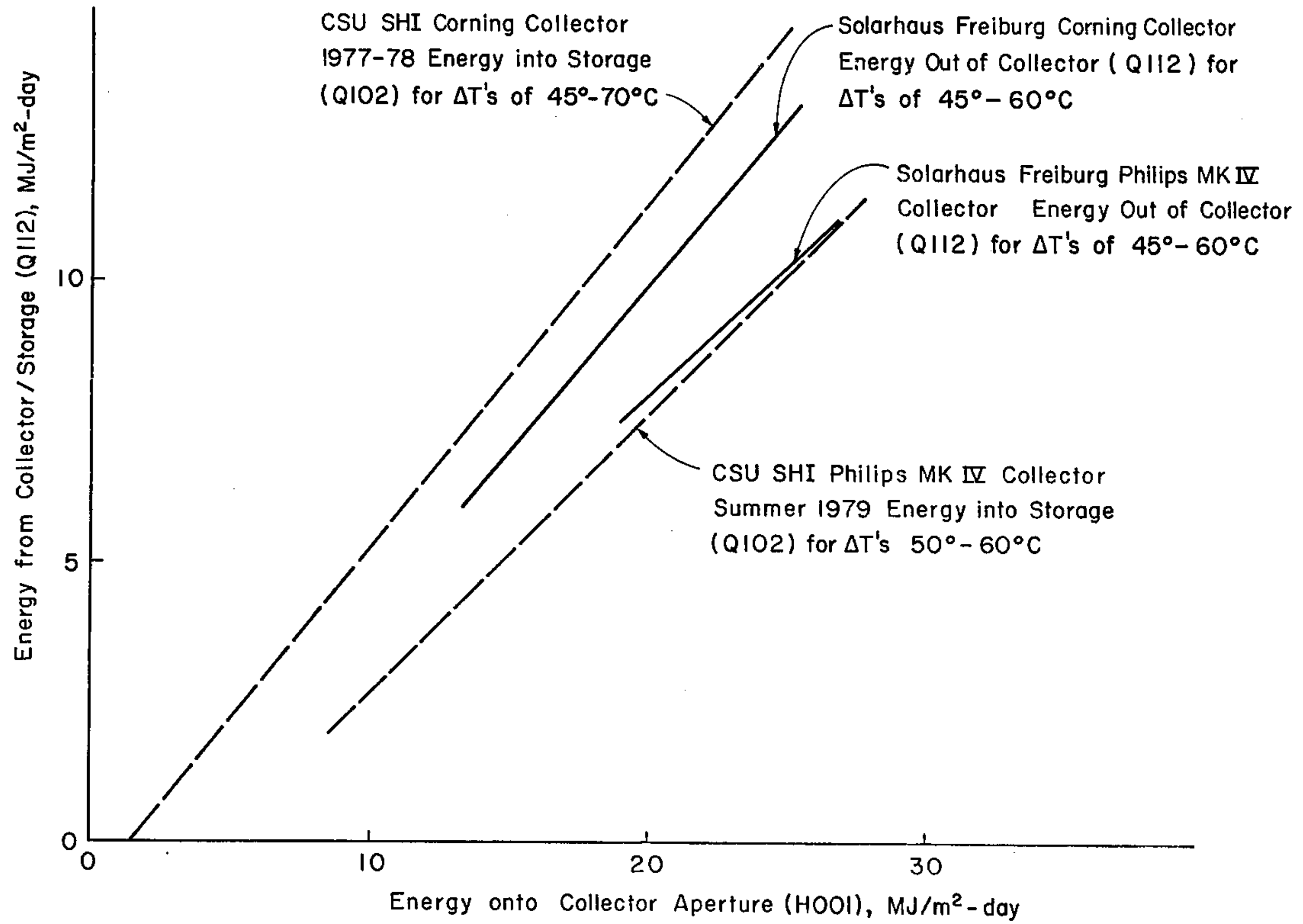


Figure 6-75. Collector Performances of the Corning and Philips MK IV Collectors at the Solarhaus Freiburg and at the CSU Solar House I

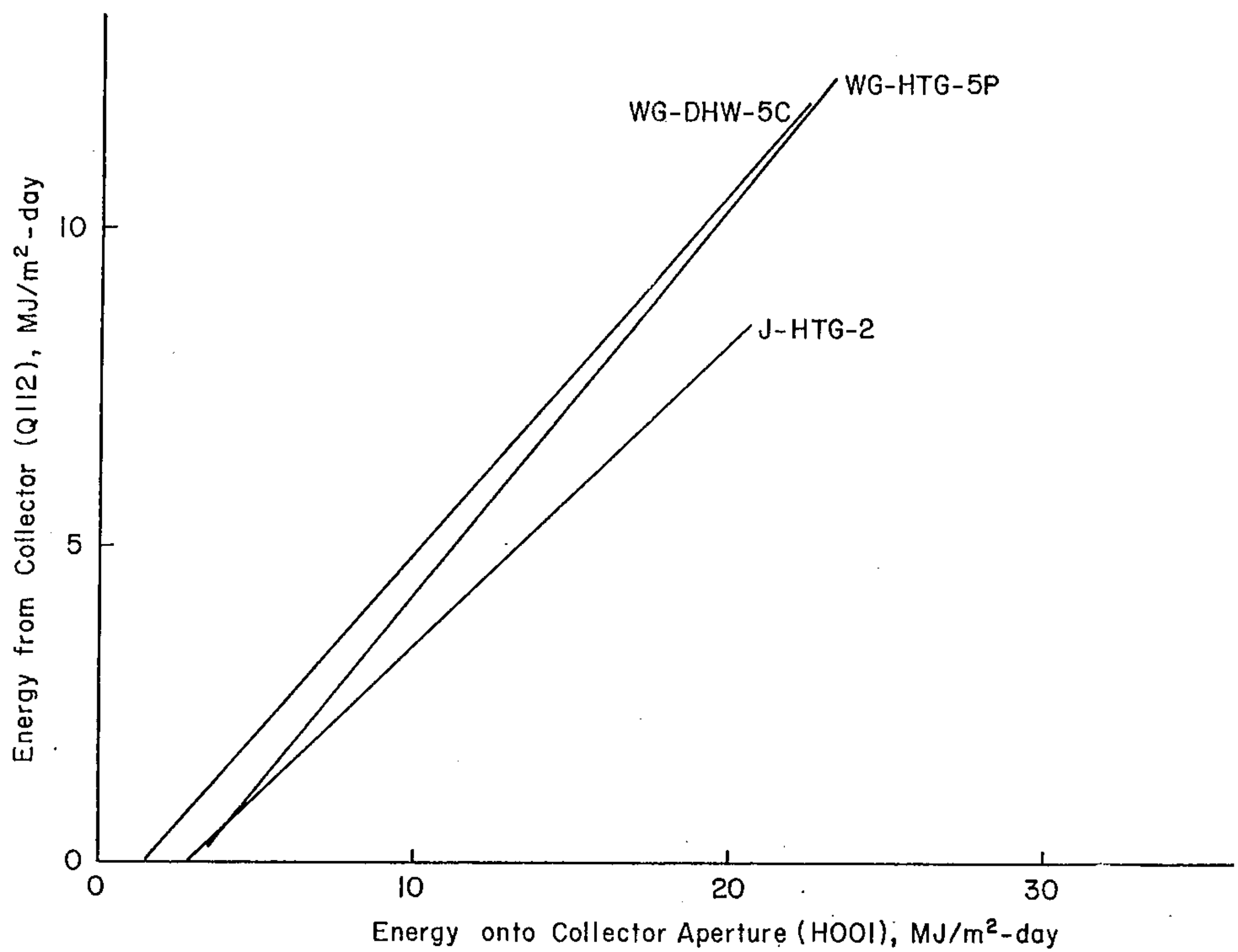


Figure 6-76. Collection Performance Comparison for Ambient to Average Collector Differences of 15°-30°C

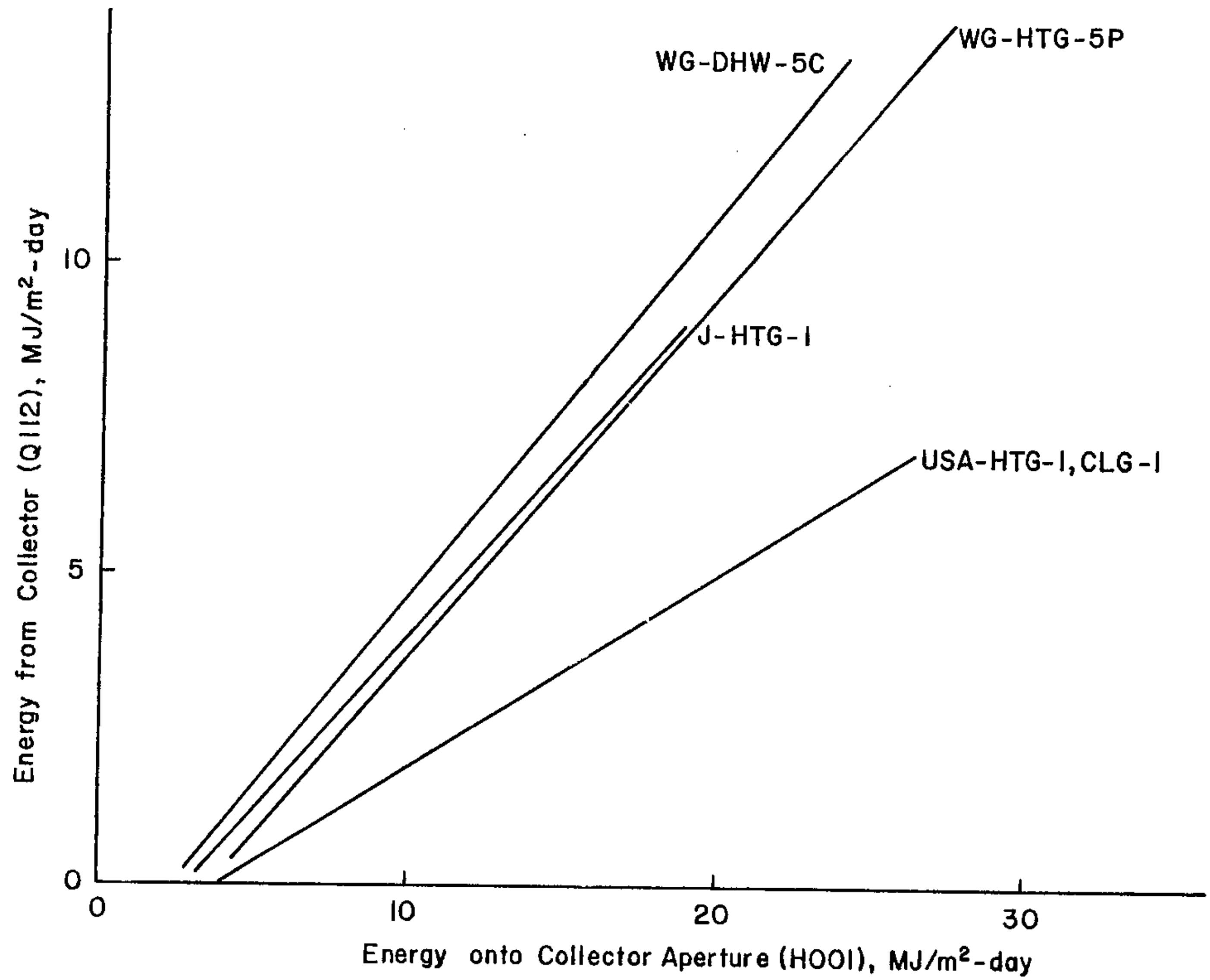


Figure 6-77. Collection Performance Comparison for Ambient to Average Collector Temperature Differences of 30°-45°C

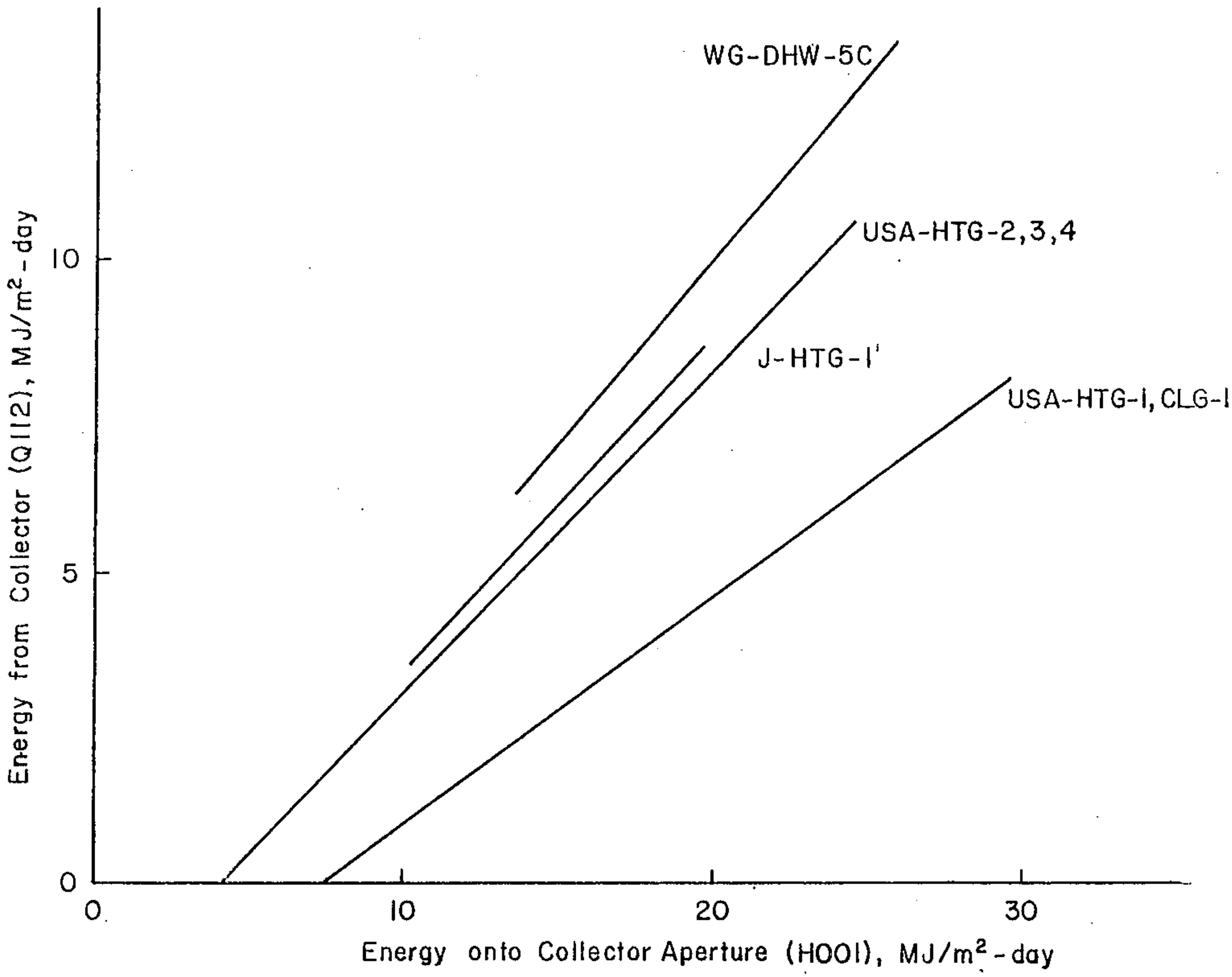


Figure 6-78. Collection Performance Comparison for Ambient to Average Collector Temperature Differences of 45°-60°C

Figures 6-76 through 6-78 displayed only the evacuated collectors having better performance. By examining Figures 6-19 through 6-35 it may be seen that, though all evacuated collectors outperformed the flat plate collector, a wide variation in performance among different evacuated collector types is evident.

System efficiency is a good comparative performance measure that reflects the influence of system differences if the load types, load to collector area ratios, and insolation levels are similar. (See Bruno and Duff [1].) Table 6-1 presents this information along with some other pertinent data, such as ambient to average collector temperature differences and solar fractions for the duration of each experimental period. High systems efficiencies were achieved for all task experiments as compared to the flat plate collector experiment.

Some systems efficiencies are lower than those from comparable experiments, such as J-CLG-1. In this case, the value may be lower due to the small primary storage which causes energy collection to cease whenever it becomes fully charged.

6.7 FUTURE TASK REPORTING

As discussed in section 5, present results are limited to a few design points and climates. This imposes a limitation on interpretation of results as is especially evident in Table 6-1 where single summary values are presented for each design point.

This problem will be alleviated in subsequent Task VI reports which will provide results from many more installations. To further enhance the value of the research in subsequent Task VI reports, results will be extended using validated models to achieve comparability at many design points and climates. Thus, it will be possible to draw a broader range of conclusions, especially about the systems aspects of the experiments.

Experimental results will continue as the best evidence for many conclusions, since only real systems can provide insight into problems of component selection and matching, system and subsystem design, reliability, longevity, controls and operating strategies.

Table 6-1. Systems Results Summary

Experiment	Net Delivered Energy $\left(\frac{Q102 - Q111}{A100}\right) \frac{mJ}{m^2 \cdot day}$	System Efficiency $\frac{Q300 + Q400 + Q500}{H100}$ %	Collection Subsystem COP $\frac{Q102}{E103}$	System Solar Fraction $\frac{Q202 + Q208}{Q202 + Q303 + Q901 + Q913}$ %	Average Daily Load per Aperture Area mJ/m^2	Average Collector Minus Average Ambient Temperature ΔT °C	Average Daily Insolation mJ/m^2
Japan							
J-HTG-1	3.35	31.0	20.2	89.0	2.46	37.	9.2
J-HTG-2	3.89	24.0	13.2	38.0	4.92	31.	11.8
J-CLG-1	4.11	21.7	29.4	90.	1.46	44.	13.1
J-CLG-2	5.51	25.1	17.8	72.0	3.20	43.	17.3
Sweden							
S-HTG-1	1.76	22.0	15.11	N/A	N/A	56.	8.5
S-HTG-2	1.78	22.0	18.3	N/A	N/A	62	8.5
S-HTG-3	2.03	26.0	15.3	N/A	N/A	57	8.5
USA							
USA-HTG-1	4.13	21.1	27.1	62.7	5.91	39	17.5
USA-HTG-2	4.77	31.8	23.9	36.8	10.27	45	14.2
USA-HTG-3	6.70	37.0	42.5	67.4	8.76	49	17.5
USA-HTG-4	8.86	28.8	45.6	79.0	9.16	62	18.9
USA-CLG-1	4.29	19.1	19.1	78.9	6.07	48	21.0
USA-CLG-2	5.33	30.0	N/A	90.5	7.15	64	19.8
USA-CLG-3	5.60	28.2	22.7	90.2	9.16	62	25.7
USA-CLG-4	5.02	24.7	49.1	80.7	6.03	63	19.0
West Germany*							
WG-DHW-1980	3.9	35.0	15.	60.9	5.27	28.3	10.86
WG-DHW-1981	4.11	36.0	18.5	62.3	5.46	30.2	10.76
WG-HTG-1980	3.93	25.9	16	10.6	26.22	27.5	10.64
WG-HTG-1981	3.55	23.8	15.5	9.6	27.01	24.5	10.38

* All WG system summaries contain data from both Philips and Corning collectors.

7. CONCLUSIONS AND FUTURE TASK ACTIVITIES

Conclusions and anticipated activities are provided in this section. Material specific to individual installations is provided separately in Tables 7-1 and 7-2.

Conclusions on performance and task methodology are, for the most part, specific to the systems and components tested during the two year reporting period. Conclusions on reliability and maintainability draw upon experience over a substantially longer period.

7.1 SYSTEM AND COMPONENT PERFORMANCE

Performance is reported for four installations having six different evacuated collectors and one flat plate collector. Though this is probably the most comprehensive set of results from highly instrumented solar energy systems ever reported in such a detailed and proscriptive common format, it is still a small sample for making performance comparisons among collector types, applications and climates. With only one flat plate collector, whose performance fell somewhat below manufacturer expectations, specific numerical results should not be generalized. However, the general performance superiority of evacuated collectors exhibited in the specific conclusions, especially for the best performers, is supported by other results. See references [1], [27], [30], [37], [43] and [52], for example. More generalizable results will obviously be provided in the next task report where results will be available from up to forty collectors, including ten flat plate collectors.

7.1.1 Conclusions

Though excellent performance results were achieved for all task experiments relative to conventional systems, not all evacuated collectors or systems performed the same. There was a substantial range of results among the different experiments, collectors and climates.

System efficiencies for the experiments ranged from 21.7 to 36.0 percent, with the highest value coming from the Solarhaus Freiburg installation.

System efficiencies of the flat plate collector experiments were lower than those of all the evacuated collector experiments.

The highest seasonal system efficiencies recorded by Task VI installations were with the Corning collector at CSU Solar House I from 1975 to 1978. Values were 44 percent for heating and 47 percent for cooling. See Bruno [1].

For the evacuated collectors, the ratio of monthly energy produced to the energy falling on the collector aperture ranged up to more than three times that of the flat plate collector.

TABLE 7-1. Conclusions

Osaka Sanyo Solar House Osaka, Japan	Solar cooling and heating experiments were performed under real loads generated by a family of four people living there, using two kinds of evacuated glass tube collectors. The Sanyo collectors were employed from December 1979 to September 1980 and the GE collectors from January 1981 to September 1981. The heating and cooling experiments, J-HTG-1 and J-CLG-1, performed well with solar fractions greater than 80%. Experiments J-HTG-2, however, did not perform as well mainly due to problems with the microprocessor control. Though the instantaneous collector performances in the experiments, J-HTG-1 and J-CLG-1, were as good as in the experiments, J-HTG-2 and J-CLG-2. In order to improve the solar system performance, amorphous silicon solar cells have been introduced in order to activate the collector pump that has been changed to a DC pump since Janaury 1982, while reducing the required pump head by replacing the GE collectors by Sanyo evacuated tubular heat pipe collectors.
Knivsta District Heating Project Sweden	The experiences gained during the summer lead to some practical requirements for solar collector arrays, namely: it must be possible to easily replace a solar collector without emptying the system. Bleeding air from the system should be simple. The solar collectors must be able to withstand overheating due to boiling. All obvious leakage risks must be eliminated. There is no doubt that not all types of evacuated solar collectors fulfill these requirements and that further development is essential before large-scale installations with rational operation can be considered. From the limited measurement period (August - November 1981) the following conclusions can be drawn: 1) Availabilities of both solar collector systems and measurement system are reduced in the initial phase of system operation. 2) Operating procedures must be carefully worked out in order to incrase system availability 3) The array efficiency for the Philips and the O-I systems were almost the same for the period August - November, however, the Philips system exhibited considerable heat loss due to defective insulation in some parts of the piping. 4) Heat capacity effects play an important role for the start up conditions of solar collector systems. However, when the operational temperature has been reached, high capacitance collectors tend to continue operation even under varying levels of insolation.

Solarcad District Heating Project Geneva, Switzerland	Our activities being delayed compared to those of other members of the task. We recognize and even emphasize that we have learned from the experience of other members. This must be considered as one very positive output of Task VI. Generally speaking, the methodology developed in IEA Task VI is very useful and powerful. It facilitates the exchange of information, promotes the understanding of how a solar energy system works and how to improve or optimize it and provides guidance for designing a new system. Although we have just begun taking good data, that is, we have not yet analyzed recorded data, we feel that we satisfactorily understand our system and we know how to proceed with the forthcoming detailed analyses and optimizations. We are convinced that the collaboration within Task VI will continue to be very helpful. We also feel that in a few months from now we will be ready to properly design the future 1000 m^2 installation, our initial national goal.
Evacuated Collector System Test Facility Bracknell, United Kingdom	Preliminary comparisons of the model's predictions and actual measurements indicate the following: 1) The model can give reasonable predictions of energies collected (usually to within 5% or so, though subject to 2) and 3) below). 2) Changing the number of strata in the storage tank within the model can significantly affect the level of agreement. Generally speaking, the larger number of strata in the storage model, the better the agreement between the model's predictions and actual measurements. 3) Control behavior is not always modelled satisfactorily. 4) There are areas where consistent differences between theory and measurement occur (e.g. storage heat loss coefficients). Further validation work is continuing in these and other areas.
Colorado State University Solar House I Fort Collins, Colorado USA	From the results of operating and monitoring four solar energy systems for space heating and four systems for space cooling, in all of which hot water was also supplied, the following conclusions have been drawn: (1) a well-desinged, open-return, drain-back solar collection and storage system is reliable and effective for space heating and hot water supply. It is more efficient and requires less electric power than the closed-loop, dual liquid type. About one-fourth of the incident solar energy was collected for use in the system evaluated. (2) A drain-back system comprising a typical, medium-efficiency flat plate collector and a very well insulated storage tank can be used for space cooling and hot water supply with a commercial absorption chiller. The average ratio of cooling delivered/incident solar energy was about 0.09. (3) The dual-loop heat exchange system employing an aqueous glycol heat transfer fluid in an evacuated tube heat-pipe collector provided about 87% of the total space heating for five winter months, at average collection efficiencies of 28 to 33%. (4) The Arkla WF36 chiller can be operated at average COP levels of 0.47 to 0.59 by solar heat from flat plate collectors and from evacuated tube collectors at average heat supply temperatures of 70°C. Higher average COP levels, exceeding 0.6, should be obtainable with minor modifications and improved control. (5) Solar cooling delivered by the WF36

chiller averaged about 135 MJ/day (11 ton-hours) for two months when supplied from the flat-plate collector and 175 MJ/day (14 ton-hours) for about one month when supplied from the evacuated tube collector. (6) Under the best operating conditions (for one week in September), 235 MJ/day, equivalent to 18 ton-hours, of solar cooling were provided by a WF36 chiller supplied with hot water at approximately 80°C from a Philips VTR141 evacuated tube collector having an aperture area of 60 m^2. The corresponding ratio of cooling delivered/incident solar energy is 0.18. (7) The water cooling tower has been successfully eliminated by use of the evaporatively cooled experimental XWF3600 chiller, which can be operated by solar heated water at 80° to 90°C from an evacuated tube collector. Average daily solar cooling of 130 MJ (10 ton-hours) was delivered, with solar collector efficiencies of 28 to 30 %. (8) Reduction in hot water flow to the XWF3600 chiller to two-thirds of the normal rate while increasing chilled water output temperature from 6° to 7.5°C resulted in increased COP_{th} (to 0.51 average) while providing adequate cooling of 248MJ/day. (9) The requirement for higher temperature heat supply to the XWF3600 chiller than to the WF36 unit indicates preference for an evacuated tube collector, and, if a heat pipe type, the use of a fluid having a critical temperature not less than 150°C. (10) Effective storage stratification was achieved with the previously developed vertical perforated baffles, in well insulated rectangular and cylindrical tanks, with and without heat exchange, and in an open-return drain back system. (11) The storage of solar heat in water at temperatures above 100°C was successfully accomplished by use of a pressurized tank. Temperatures as high as 106°C were recorded. Heat storage capacity above 80°C is substantially increased by use of pressurized storage. The performance of an efficient high temperature (evacuated tube) collector in combination with a chiller requiring heat supply at or near 90°C is considerably improved with pressurized water storage. (12) In nearly every summer and winter month, 35 to 75 MJ/day were supplied as solar heated water, representing 50 to 80% of total hot water used. The figures are typical for a family of 4 to 6 persons. The single tank system delivered 48% more solar heated water than the double tank system. (13) Electric power requirements for solar collection and storage were 4 to 5% of energy collected by the flat plate system and 2 to 5% of energy delivered by the evacuated aube collector. A change in the evacuated tube collector pump from 1/3 HP to 1/8 HP (which did not cause a significant change in collector efficiency) resulted in a decrease in electric usage to less than 1% of collected energy. Ratios of solar collection/electricity use for collector pump as high as 129 were obtained, and values over 100 prevailed for three weeks. (14) Average daily electric energy required for operating the XWF3600 chiller (pumping hot water, cooling water, chilled water, and absorbent solution, and operating cooling fan) ranged from 12 to 39 MJ; average electric COP (cooling delivered/electric use) levels were 5.6 to 8.2 Cooling delivered/total electric use (including collector pumping) ranged from 4.8 to 5.4 (15) By effective system design and judicious selection of pumping rates and motor sizes, electricity consumption for solar heating and hot water supply can be kept below 2% of collected energy (COP_E greater than 50), and electricity use for solar cooling, including collection, can be in the range of 10 to 15% of cooling delivery, for an electric COP (cooling output/electric input) of 7 to 10.

Solarhaus Freiburg Freiburg, West Germany	Three years of measuring the collection system efficiency found the typical low heat loss parameters of evacuated tubular solar collectors unchanged during four years of operation. In general, the parameter values of the optical efficiency show less variation than measurement accuracy of about 3%. For more than four years, collectors, systems and controls have operated with a high degree of reliability, showing that there are no unsolved technical problems. The application of evacuated tubular solar collectors in optimized DHW and heating systems with temperature ranges of 10 - 70°C, lead to an improvement in systems performance by a factor of 2 - 3 as compared with conventional flat plate collector systems.

TABLE 7-2. Future Plans

Mountain Springs Bottle Washing Facility Edmonton, Alberta, Canada	Once commissioning is completed the basic system operation over a period of six months will be analyzed. During this period, data will be analyzed and used for simulation validation of computer models. Collector array characteristics, including transport lag, capacitance effect and incident angle modifiers will be determined. The interaction of the solar system with that of an industrial process heat facility is unique. Though the solar radiation is concurrent with load, the shape of the load profile is not flat and is of no fixed pattern. This requires the optimization of the control strategy for the system and will be the subject of investigation in the near future.
Osaka Sanyo Solar House Osaka, Japan	The next performance study will be made with the Sanyo heat pipe evacuated tubular collector. The collector pump will be actuated by amorphous silicon solar cells.
Eindhoven Technological University Solar House Eindhoven, Netherlands	Different control strategies will be implemented to realize optimal system performance. Stratification enhancement will be investigated as well as the general testing of the complete solar system.
Knivsta District Heating Project Knivsta, Sweden	A flat plate collector may replace one of the evacuated collectors. The only other major change planned is the introduction of different control strategies. Dynamic effects will also be studied.
Solarcad District Heating Project Geneva, Switzerland	The precise monitoring of the Sanyo system will start before the end of 1982. The final 1000 m^2 system will be designed and built starting next year. The data analysis of the Corning system is starting now and will be performed in detail. Simulation and modeling will also be investigated. Task activities will include: 1) Reporting the performance of the studied systems, especially the new one, 2) finding agreement in modeling and simulation activities, and 3) combining results, especially the daily input/output diagrams, and validating models in order to define a simple and accurate method to design new evacuated collector installations for conditions such as collector type, climate, load and so forth.
Evacuated Collector System Test Facility Bracknell, United Kingdom	During the summer of 1982 we will proceed with analysis of data from the 1981-82 heating season and validation of the system model for this period. The system will be operated for domestic hot water only. The heat loss coefficient of the space heating storage will be measured and the system modifications selected for the 1982-83 heating season will be carried out. During the 1982-83 heating season the modified system will be run and data collected for the validation of a revised model. In the near future we will examine the question of whether we can find a more appropriate load than small-scale domestic heating for an evacuated collector system in the British climate. Possibilities which will be considered are domestic hot water heating for large users, such as hospitals or hotels, and process water heating for industrial applications, both of which are substantial energy users in summer. If it is considered worthwhile, we will modify the installation to simulate one or more of these other loads.

Colorado State University Solar House I Fort Collins, Colorado USA	A new system is planned for Solar House I that includes a phase-change storage to be used with the Carrier air-cooled absorption chiller during the 1983 cooling season. Modeling activities will continue along with additional analysis of existing data.
Solarhaus Freiburg Freiburg, West Germany	The Philips Mark IV Collector will be replaced by the Philips Heat Pipe Evacuated Tubular Collector, using the longtube version VTR261 with neopentane as the heat pipe fluid. In the theoretical area, various simulation techniques will be validated with Solarhaus Freiburg data. Detailed component models will be used to investigate the effect of modified control strategies and stratification in storage tanks. Furthermore, measured data will be exchanged with other task participants in order to test the developed models with a variety of system types and climate conditions.

At all insolation levels and for collector to ambient temperature differences of 30°C and greater, all evacuated collectors delivered more daily energy per unit aperture area than the flat plate collector. The greater the temperature difference the greater the evacuated collector advantage.

For all evacuated collectors, the relative difference in daily energy per unit aperture area delivered by evacuated collector compared to the flat plate collector increased substantially as insolation levels decreased. For the best evacuated collector at temperature differences between 45° and 60°C, the relative difference ranged from double at 25 MJ/m^2-day to an infinite ratio at about 8 MJ/m^2-day.

For the same daily average levels of insolation and average collector to ambient temperature differences there are significant differences between summer and winter operation in the daily energy outputs of evacuated collectors. Causes of these differences are not yet adequately modeled.

7.1.2 Future Activities

The scope of results will increase substantially as many more Task VI collectors and systems become fully operational. Results from up to thirteen installations with up to 30 collectors should be available in the next Task VI report.

The next task report will have results from up to ten more flat plate collectors and a concentrating collector.

A concerted effort will be made to identify and model factors that cause differences in performance among similar installations. Both load dependent factors, such as capacitance, and climate dependent factors, such as angles of incidence, will be studied. These factors will be incorporated into performance measures and comparisons as is practical.

Module versus array performance will continue to be examined by the task.

7.2 RELIABILITY AND MAINTAINABILITY

Lengthy operating periods are required to achieve a comprehensive assessment of the reliability and maintainability of solar energy systems. This report has focused on a relatively short two year period and thus little reliability/maintainability information has been included. However, some task collectors have been in operation for much longer periods and some shorter term experiences, such as installation and start up, are relevant. Support for the conclusions in this section may be found in references [3],[4],[5],[6],[8],[9],[11],[12],[17],[21], [24],[27], [30],[35],[36], [27],[38],[39],[40],[41],[42],[43],[44], [45],[46],[47], [48],[51],[52],[53],[54],[55],[56], and [57].

7.2.1 Conclusions

The Corning collector operated at CSU Solar House from 1975 to 1978 and at the Solarhaus Freiburg from 1978 to the present. During that time one tube was broken during installation and less than two percent of the tubes lost their vacuum. Of those, most lost vacuum during shipment or installation.

During the seven years of operation of the Corning collector there has been no degradation of collection performance.

There has been no tube breakage or performance degradation in four years of operation of the Philips MK VI collector at the Solarhaus Freiburg.

The Corning collector is now commercially available with a ten year warranty against breakage, loss of vacuum and loss of performance.

Fewer than one percent of the Philips VTR141 tubes removed from CSU Solar House I after two years of operation had lost vacuum. Several tubes, less than two percent, were broken in shipping, unpacking or installation.

Some substantial early breakage problems were encountered with the systems using O-I tubes, mainly from freezing due to failure to drain. After minor modifications there has been little trouble. The O-I and GE types seem to have a greater susceptibility to breakage and thus greater care must be exercised in system design and installation.

Storages have boiled routinely in several of the systems with no resultant problems or damage. A joint that was not silver soldered melted when the Corning collectors stagnated. Few other problems have occurred in the eight installations despite the 300°C potential of some of the collectors. Such problems have been eliminated by design changes. Careful attention to system design and installation is an obvious requirement for evacuated collector systems.

No collector maintenance has been required at any of the installations. System maintenance needs have been minor and, for the most part, have been for the conventional parts of the system.

7.2.2 Future Activities

Achieving reliable operating systems remains a primary task activity.

Longer term assessments of reliability and maintainability will be available as the task approaches its December 1985 termination date.

As there is reason to believe that evacuated collectors may have superior reliability/maintainability characteristics, this area will be emphasized in the remaining task work.

7.3 TASK METHODOLOGY AND REPORTING

In an experimental systems research and development program like Task VI the systems are, in at least some respects, prototypes. Consequently, components require considerable care in their design and installation. To provide maximum benefits the installations are heavily instrumented. Results come slowly and only with a great deal of hard work. After inception, good data may not be achieved for several years. The experimental conditions are partially uncontrolled and the experiments are lengthly, often lasting a season or more. The task has ten participants each of whom, under such circumstances, must be able to easily and unambiguously communicate all important aspects of their experiments to the other participants. This can only be accomplished through a carefully worked out task methodology and reporting structure.

7.3.1 Conclusions

Some of the world's most fully instrumented, carefully designed and well run installations have been assembled into Task VI.

Uniform formats and reporting structures developed by the task and based on the reporting format produced by Task I have provided easily understood unambiguous internal task communication.

Information provided by the three participants having fully validated operating and data acquisition systems has speeded the design and implementation of the other participants' installations.

Analysis activities have been conducted jointly to increase the quality and quantitiy of participants' accomplishments.

Comparisons between experiments have been made that would have been difficult in the absence of the task structure.

Daily collection energy input/output plots can be used to compare experiment performance if certain precautions regarding differences in climate, loads and other factors are exercised.

7.3.2 Future Activities

Various means of extending results to other climates and applications will continue to be investigated.

Data will be even more closely scrutinized and carefully evaluated.

Detailed clean hourly data sets in a form suitable for direct computer input will be exchanged among installations.

Cooperation in appropriate ways with IEA Solar Programme Tasks I, III and VII will continue.

The task experiment reporting format will be reworked to refine it and to make it easier to use and more accessable by others. A modeling reporting format will also be implemented.

Other ways to increase the use of task results by ourselves and others will continue to be explored.

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Note: Please write directly to the authors to obtain any of these documents.

APPENDIX A

ADDRESSES OF TASK VI NATIONAL CONTACT PERSONS AND RESPONSIBLE RESEARCHERS

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APPENDIX B

IEA TASK VI NOMENCLATURE

Part 1 - Task VI Pingree Park Modifications to the IEA Format

Part 2 - Definitions of Non-Standard Designators

APPENDIX B

EXCERPTS FROM THE TASK VI PINGREE PARK MODIFICATIONS TO THE IEA FORMAT

A. Collection System Performance

In order to obtain an overall assessment of evacuated collector performance when operating in a system each participant will:

1. Tabulate and graph the energy inputs and outputs from his collector arrays as detailed later in this document and

2. Produce monthly efficiency curves with selected hourly values as detailed later in this document. A common method of correcting for capacitance will be applied to the results.

The operating agent will produce analyses of the individual data produced under 1 and 2 above. Reason for differences in results for similar collectors will be discussed at the semi-annual meetings.

The participants will individually and jointly investigate the relationships between the performance of a collector in a controlled test and its dynamic performance in a system. Tasks I, III, VI and VII will also work on this matter and efforts will be coordinated by Task I through the operating agents of each task.

Participants should inform the operating agent if they feel additional component performance data should be collected.

B. Measurement of System Characteristics

The following characteristics of the system will be measured or estimated and reported:

1. Loss factors and capacitances of storage and distribution systems.

2. Energy balance on principal subsystems.

3. Total power and thermal energy contribution of pumps, fans, auxiliary heaters or any operating or measuring devices that could affect a system heat balance.

Standard methods of estimating these quantities will be adopted by the task.

C. Reporting Structure for Task VI Installations

The title page should include IEA as well as national reference. The following alterations of the order and structure are to be used in Task VI:

1. Notices, disclaimers, etc.
2. Table of contents
3. List of tables
4. List of figures
5. The abstract will be unnumbered and consist of:
    a. a description of project including areas investigated,
    b. a description of major results with only the most important results specified and
    c. a description of major conclusions with only the most important conclusions specified.
6. Preface

The preface, which will be unnumbered, will be as in the IEA document. It should also describe the project organization.

7. Summary

The summary, which will also be unnumbered, will be a brief condensation of the report chapter by chapter. It will be in sufficient detail to show the reader where he must look for specific items of interest. The summary in conjunction with the introduction, should be able to function as an executive summary. However, care should be taken to insure that the summary is not overly elaborate.

8. Introduction

The introduction is the first proper chapter and is numbered as such. It will consist of:

a. the project background including a history of the project,

b. description of the IEA Solar Heating and Cooling Program and

c. *the project's role in Task VI,

d. the project objectives and

e. the project's relation to the national program

All other items specified in the IEA document should be omitted.

9. Description of the Surrounding Environment

a. In the "Description of the Location and Site," Section 2.1 in the IEA format document, all items should be treated as indicated in the IEA document.

b. The shift in solar time should be expressed as the difference between solar noon and the standard meridian. Position this item after the latitude, longitude and altitude of the site entries.

c. For Section 2.2 in the IEA format document use the same summary sheet as the EC with the addition of a column giving cooling degree days and its calculation base. Define how the averages of the summary sheet are calculated. It is not necessary that the numbers correspond when new sections are added.

It is not necessary that the numbers correspond when new sections are added.

10. Description of the Building and Solar and HVAC Components

The writeup in Chapter 3 should be general without reference to detailed experiment design goals. Reference may be made to the flexibility of the systems,

a. Section 3.1 is the same as in the IEA format document. In Section 3.2 the solar and HVAC systems should be described component by component. Ranges of values or several values should be used when necessary because of multiple experiments. Footnote these multiple values referring the reader to Chapter 4 where the corresponding systems and experiments will be given.

b. Section 3.2.3 should include the hot water components. Omit the descriptions and schematic of the solar and HVAC systems. Number the "Description of the Control System Hardware" as 3.2.x, where x is the last number in subsection 3.2.0; omit the diagram showing locations of the control sensors.

11. System, Experiments and Operation

An explanation of the overall rationale of the experiment or multiple experiments will be given in 4.0, that is, before subsection 4.1 begins, as well as any other general introductory matter on the experiments and operation. Include the description and schematics of the solar and HVAC systems as explained in Chapter 3 of the IEA format document and according to the following structure.

a. Section 4.1 will be entitled "System One" with an additional description such as "Cooling". Material immediately under 4.1 will include the descriptions and schematics of the solar and HVAC systems.

b. Section 4.1.1 will be entitled "Basic Experiment" with an additional description if appropriate. It will elaborate experiment specifics providing referencing prior work and reports, if necessary.

c. Section 4.1.1.1 will be entitled "Interaction of Components and Subsystems", and will describe the operating modes of the experiment as per the IEA document.

d. Section 4.1.1.2, "Controls" will describe the control strategies of the experiment as per the IEA document and will include a diagram of the location of the control sensors.

e. Section 4.2 will be entitled "Experiment Two" with an additional description, if appropriate. The breakdown of Section 4.1.1 will be repeated with cross referencing to minimize repetition. That is 4.1.2.1 "Interaction of Components" and Subsystems, 4.1.2.2 Controls. Sections 4.1.3, 4.1.4, etc., will repeat in the same pattern established for the remainder of the experiments conducted for System One. After all experiments related to System One are reported, the next section, 4.2, will be entitled "System Two" and the established pattern repeated.

12. Thermal Performance Evaluation

IEA acronyms should be used unless it is clearly impractical to do so. Where multiple components are present and no provision is made for them in the IEA documentation, the use of a small letter at the end of the relevant IEA acronym is recommended, for example Q100a, Q100b, and Q100c. Where there are multiple components the acronym without a small letter refers to the combined evaluations.

a. An "Overall System Energy Flow Block Diagram" will be presented for each "System". An example of such a diagram is shown in Figure B-1.Where possible, only blocks for major subsystems and data

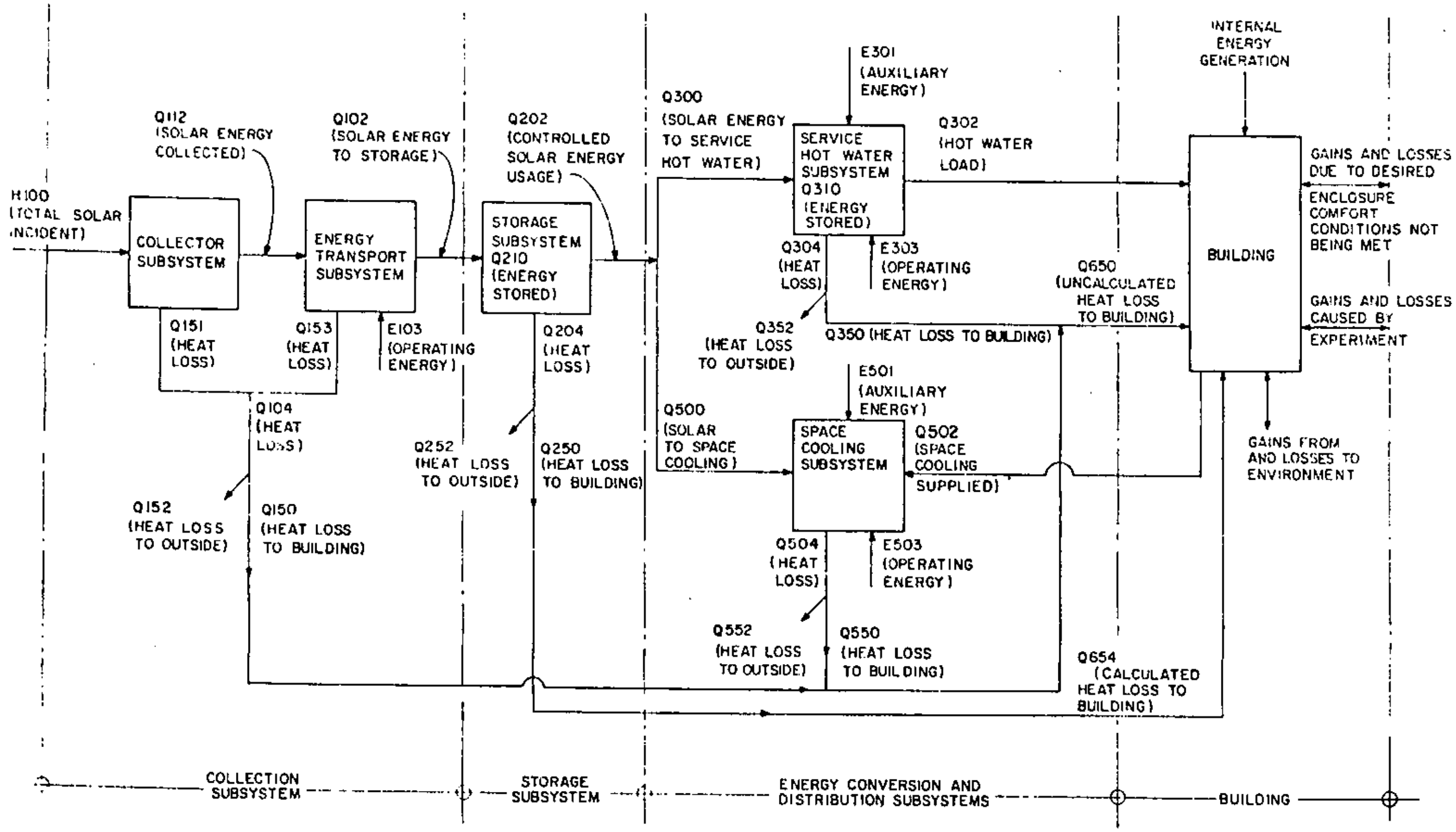


Figure B-1. Example of an Overall Energy Flow Block Diagram groups corresponding to the numbering system in Table B-1 should be shown on the diagram.

Table B-1. Subsystem Designations

001 - 099	Climatological data group
100 - 199	Collection
200 - 299	Storage
300 - 399	Domestic Hot Water
400 - 499	Space Heating
500 - 599	Space Cooling
600 - 699	Energy Demand (e.g., building, IPH)
700 - 899	Reserved for Future Use
900 - 999	Summary Data Group

Energy transport subsystems belong with their predecessor subsystems and may be considered as an integral part of the predecessor subsystems when the magnitude of their losses is considered relatively minor in overall system evaluation. If this is the case, the transport systems should not be shown as separate blocks in the overall System Energy Flow Block Diagram. If the loss is not minor, then the overall System Energy Flow Block Diagram must show the relevant blocks. In either case energy transport subsystems would be shown in the subsystem energy flow block diagrams.

b. Numbered quantities should be preceded by one of the letter designations in Table B-2.

Table B-2. Quantity or Energy Form Letter Designators

E* - Electrical energy (MJ)

F* - Fossil or chemical energy equivalent (MJ)

Q* - Thermal energy (MJ)

H - Solar irradiant energy or energy density (MJ or MJ/m^2)

G - Solar flux density (W/m^2)

T - Temperature (°C)

D - Spacial temperature difference (°K)

W - Mass flow rate (kg/sec)

S - Status information

V - Velocity (m/sec)

N - Performance (units as derived)

A - Area (cm^2)

C - Capacitance (MJ/°k)

U - Heat transfer factor (W/°k)

* time base for quantities will be given when values are stated.

All designators are reserved. Additional Designators will be allocated by the operating agent.

c. The second and third digit combinations in Table B-3 are reserved for specific designations in the energy flow block diagrams and all such quantities should be so designated. In the subsystem energy flow block diagrams the participant may choose additional non-reserved two digit combinations whenever a reserved combination is not applicable. These combinations apply to the number sequences from 100 to 699 and from 900 to 999 and the letter designators E, F, Q, H, and G.

Table B-3. Reserved Designations Applicable to All Subsystems

Number	Designation
-00	Controlled energy from other subsystems
-01	Subsystems auxiliary energy
-02	Controlled energy to other subsystems
-03	Total subsystem operating energy
-04	Total subsystem heat loss. This quantity is frequently derived in more than one way. In such cases different derivations should be given different designations in the sub-system energy flow block diagram tables
-05	Change in stored energy
-06	Total energy from other subsystems
-07	Total energy to other subsystems
-08	Useable heat loss from solar
-09	Unuseable heat loss from solar stored energy
-10	Stored energy
-11	Thermal energy contribution to the subsystem by the operating energy
-12	Controlled energy to other subsystems excluding distribution system effects
-13	Total useable heat loss
-14	Total nonuseable heat loss
-15	Cooling supplied by solar
-30	Energy balance error

Additional combinations from 16 to 29 are allocated for future reserve designations.

d. As shown in Figure B-2 there will be one system energy flow block diagram and set of facing page subsystem energy flow block diagrams and subsystem schematics for each system identified in Chapter 4. The experiments of Chapter 4 may necessitate changes in some of the diagrams. If so, only those altered diagrams will be presented and reference will be made to the appropriate preceeding diagrams. There will be one table of energy quantities for each system identified in Chapter 4. All acronyms identified in each experiment will be shown and the appropriate experiment referenced.

e. The manner in which data is stored and its availability in the data reduction methods subsection.

f. There should be tables listing and defining (including defining equations) all quantities that will be used in the reporting along with their IEA nomenclature and relevant calculation period. Where the above reserved combinations apply, that designator should be used.

g. The performance quantities and indicators given in Table 4 will be used in all reports where appropriate. There should be a table which lists, defines, provides the equation for, and periods of calculation of the quantities and indicators.

h. Subsytems shown in the "facing pages" of Figure B-2 provide a detailed presentation of the subsystems used in the overall "System Energy Flow Block Diagram".

See Figure B-3

left hand page

Subsystem Schematic

Note: On this diagram instrumentation should be shown in its proper location identified with nomenclature of the participant's choice. Nomenclature from the IEA document, "Data Requirements and Thermal Performance Evaluation Procedures for Solar Heating and Cooling Systems" should be used where possible.

See Figure B-4

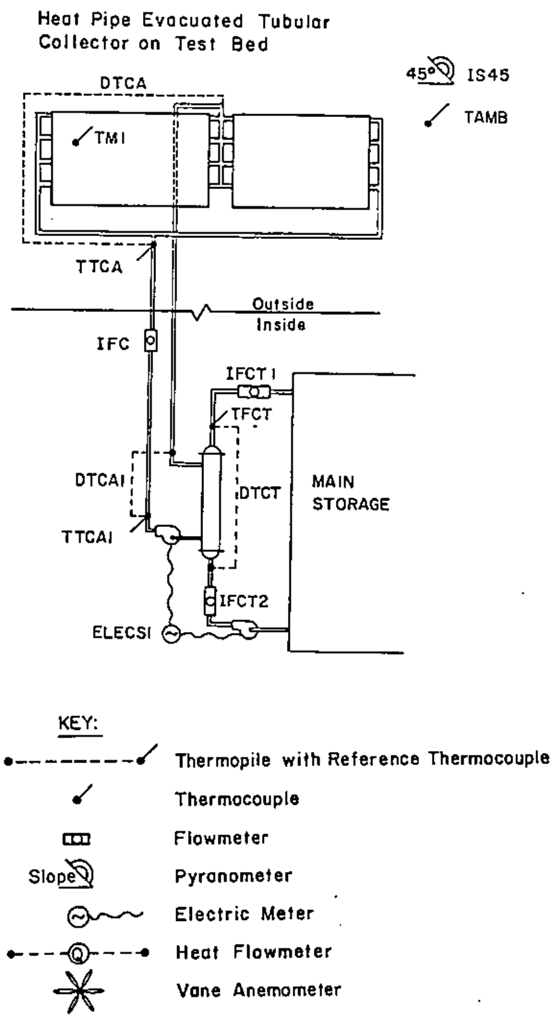
right hand page

Subsystem Energy Flow Block Diagram (for the same system as in the facing page)

Quantities Derived Totally from Measurements		
IEA Acronym from the Diagram	Participant Acronym	Calculation Formula

Quantities Not Derived Totally from Measurements		
IEA Acronym from the Diagram	Participant Acronym	Calculation Formula

Figure B-2. Facing Page Diagram Arrangement



IEA Acronym	CSU Acronym	Definition	Scan	Calculation Period Hour	Day	Month
H001	S45M2	Total solar incident in aperture plane per unit area	X	X	X	X
H003	S45M20	Total solar incident in aperture plane while collecting, per unit area	X	X	X	X
H100	S45	Total solar incident in aperture plane on the collector aperture (H001 x A_a)		X	X	X
H101	S450	Total solar incident in aperture plane on the collector aperture, while collecting (H003 x A_a)		X	X	X
H102		Total solar incident in the aperture plane on absorber				X
H103		Total solar incident in the aperture plane on the absorber, while collecting	*			X
Q112	QUA	Useful energy collected, measured at array (TP)	X	X	X	X
Q102	QU	Useful energy collected, measured at collector (TP)	X	X	X	X
E103	ELECS1	Operating energy for solar collection	X	X	X	X

Figure B-3. Subsystem Schematic Example (left hand page)

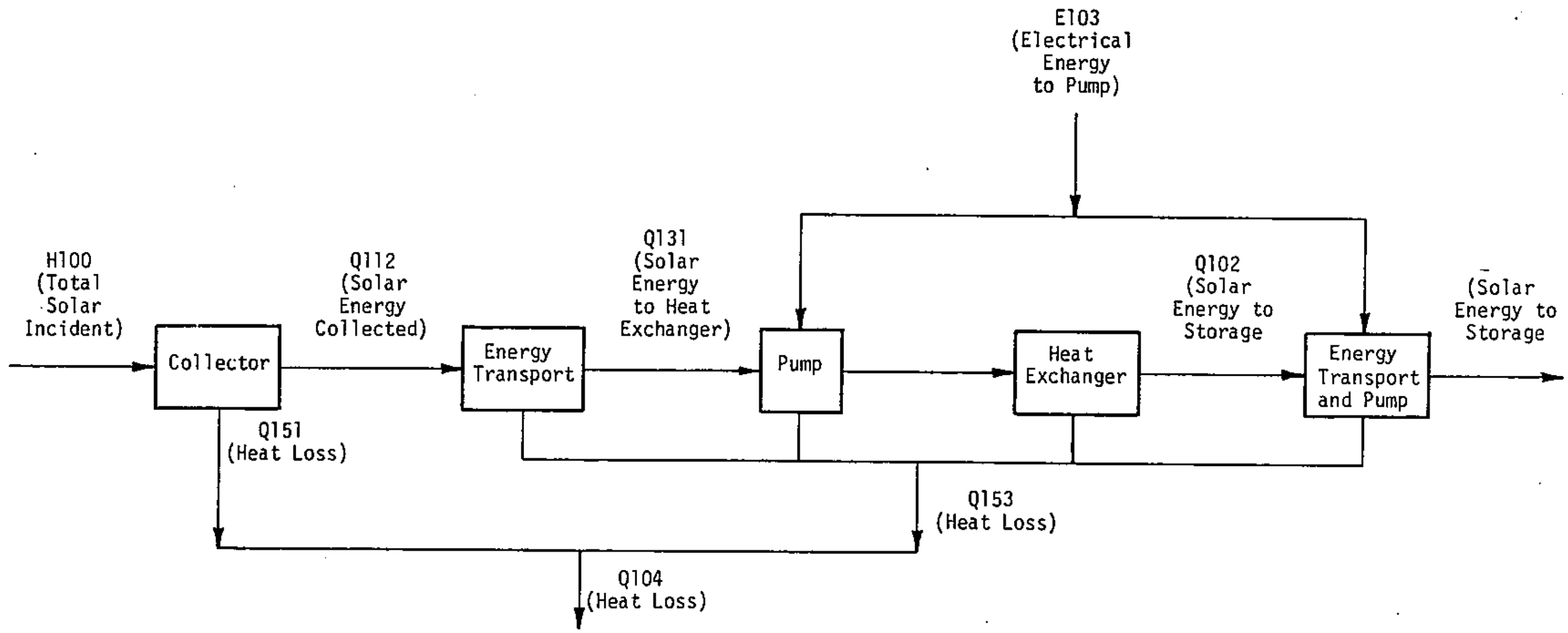


Figure B-4. Subsystem Energy Flow Block Diagram (right hand page)

The two tables of Figure B-2 should be included as part of one or both facing pages, wherever there is room. Relevant quantities that do not appear in the block flow diagrams should, nevertheless, be included in these tables. For example, the solar portion of an energy flow should be specifically broken out.

i. Performance indicators to be reported by all participants, where applicable, are given below. The nomenclature for additional performance indicators should start with the same digit as the subsystem to which it makes primary reference, if possible, and use the second two digits of the primary energy quantity appearing in the numerator.

adjusted collector efficiency	N100 = (Q112 + Q105*)/H100
unadjusted collector efficiency	N110 = Q112/H100
adjusted collector on efficiency	N101 = (Q112 + Q105*)/H101
unadjusted collector on efficiency	N111 = Q112/H101
system collection efficiency	N102 = Q102/H100
system collection on efficiency	N103 = Q102/H101
system collection COP	N105 = Q102/E103
solar collection system and storage conversion efficiency	N104 = Q212/H100

*Q105 is the capacitance correction

Where auxiliary energy is added to the storage or there is no main storage, it is not appropriate to reference N104.

solar collection and storage COP	N106 = Q212/E103
solar collection and storage <u>system</u> COP	N107 = Q202/(E103 + E203)
solar fraction energy consumed for domestic hot water	N301 = Q300/(Q300 + Q301 + Q303)
solar fraction of energy delivered for hot water	N302 = solar energy into hot water tank ÷ (Q312 + Q301)

In some systems N301 is equal to N302

solar fraction of energy consumed for space heating	$N401 = \frac{Q400 + Q908}{Q400 + Q913 + Q401}$
solar fraction of energy consumed for space cooling	N501 = Q500/(Q500 + Q501)
solar fraction of space cooling supplied	N502 = Q515/Q502
solar cooling thermal COP	N503 = Q515/Q500
auxiliary cooling thermal COP	N504 = (Q502 - Q515)/(Q501)
system solar fraction	$N901 = \frac{Q208 + Q202}{Q202 + Q901 + Q303 + Q913}$
system COP	$N902 = \frac{Q202}{Q903}$

Additional quantities reported, if available

H001	total solar energy on collector plane MJ/m^2
H002	total horizontal
H003	horizontal diffuse
H004	total solar energy on collector plane while the collector is on MJ/m^2

H100 total solar incident on collector aperture (MJ)

H101 solar incident on collector aperture while collector pump is on

j. The division between the solar and conventional subsystems should be clearly defined for all subsystems.

13. Description of Operating Period

This section will be as in the IEA format document.

14. Presentations of Results

Chapter 7 should be organized as in the IEA document with each section, that is 7.1, 7.2, 7.3 and 7.4, broken down by the system/experiment organization of Chapter 4. Section 7.5 should make comparisons of the different system/experiments and section 7.6, comparisons with other systems and experiments, if desired.

15. Required Report Graphics for Chapter 7

a. There will be three sets of energy input/output diagrams for each collector, and for each experiment if variations require it. See Figure

Set 1	X - axis (H100) Y - axis (Q112)	Each set will consist of separate plots for individual temperature difference ranges of 16 to 30, 31 to 45 46 to 60, 61 to 75, 76 to 90°C etc. Plots where only a few points appear may be omitted and the points placed on the adjacent temperature difference range plot with temperature differences indicated (See example.)
Set 2	X - axis (H101) Y - axis (Q112)	
Set 3	X - axis (H100) Y - axis (Q102)	

The temperature difference, T100 - T001, is to be based on the average ambient temperature while the collector is on and the average collector inlet temperature while the collector is on.

b. H100 and H101 are to be the energy incident on the collector aperture. Points will be identified by month. There will be plots of collector system efficiency curves and selected hourly efficiency points for each different collector array and for each experiment, if variations require it. See Figure 6-5. The points will be selected at times when the system has been running continuously and from one hour before noon to two hours after noon. The capacitance correction will be applied to the results.

X axis $\frac{\Delta T}{G} = \frac{T100 - T001}{G100}$

Y axis $\frac{Q112 + Q105}{H100}$ only where H100 = H101

The plots are to be used on average collector inlet T100 and ambient T001 temperatures. H100 is to be the energy incident on the T100 collector aperture. There will be an energy flow arrow diagram, one for each system and one for each experiment if warranted. See Figure 6-43. These plots are preferably seasonal, but may be on a monthly basis.

c. Wherever practical, tables should be present in the reports that enable the reader to reconstruct any of the required summary graphics.

d. There will be bar charts depicting energy supply and use. See Figures 6-51 and 6-62.

e. There will be a several day long hourly history of key quantities.

DEFINITIONS OF NON-STANDARD DESIGNATORS

Non-standard Definitions: West Germany, Chapter 6

Q150w : excess heat of the solar DHW system
Q301w : auxiliary energy delivered to DHW storage
Q102w : daily average collected solar energy into DHW storage tanks

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3 February 1983

TO: Executive Committee Members and Operating Agents

FROM: W.S. Duff, Task VI Chairman

SUBJECT: Task Interim Report

Enclosed is a copy of the final version of the Task VI Interim Report. Please destroy any previous copies.

WSD/jo

ERRATA SHEET

Corrections should be noted as follows:

Page 28	Substitute for Sunmaster data - Sunmaster TRS 81, 8/152, 0.632, 1.08, 2.14 m^2, 1.89 m^2, Proprietary, water, .9 l/minute, 8.8 l/m^2, Borosilicate, Compound Parabolic Cusp.
Page 31	Table 4-4. IAM for Philips VTR361 for 15° is 0.99.
Page 38	New Figure Title - Figure 4-8. Philips VTR 141 collector with white enamel reflector. Available with various numbers of tubes per module, tube spacing, and types of reflector.
Page 39	New Figure Title - Figure 4-9. Efficiency of the 12 tube Philips VTR 141 collector module, based on the absorber area.
Page 231	14th line - The plots are . . . delete "inlet".