INTERNATIONAL ENERGY AGENCY

IEA
SOLAR R&D

program
to develop and test
solar heating
and cooling systems

TASK VI

PERFORMANCE OF SOLAR HEATING, COOLING AND HOT
WATER SYSTEMS USING EVACUATED COLLECTORS

ANNUAL PROGRESS REPORT

JANUARY 1980
ANNUAL PROGRESS REPORT

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Operating Agent, U.S. Department of Energy

Report prepared by Task VI Chairman:

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Fort Collins, Colorado 80523 USA
EXECUTIVE SUMMARY

The objective of this task 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 different systems and climates. Systems using either tubular or flat evacuated collectors may be included in this task.

The task was newly initiated this year. Activities were begun at a working group meeting in Fort Collins, Colorado, USA in early October 1979, prior to final formal approval by the Executive Committee later that month. The task had been approved in principal by the Executive Committee in its previous meeting in the spring.

At the working group meeting, a program of work was developed which specified requirements for participating installations, including requirements for instrumentation, data collection and performance reporting, the role evacuated collector manufacturers will play in the task, task timing, and publication policies. Details of this program are included in the body of this report.

The West German Solarhaus Freiburg, the Japanese Sanyo Osaka Solar House, and the U.S. Colorado State Solar House I were the installations approved for task participation at the first meeting. It is expected that installations from Sweden, Canada, Denmark, Switzerland, and England as well as one or two additional U.S. installations will be presented for approval at the second meeting to be held in the second half of April 1980 in Freiburg, West Germany.
# Table of Contents

Executive Summary.................................................. 1
Table of Contents.................................................. ii

**BACKGROUND** .................................................. 1
**INTRODUCTION** ................................................ 3
  Objective of Task VI............................................. 3
  Approach to the Task........................................... 3
  List of Participants........................................... 4
**STATUS OF TASK** ................................................ 5
  Summary of First Meeting..................................... 5
  Proposed Task VI Structure.................................. 8
  Current Work Plan.............................................. 11
  Significant Accomplishments................................. 11

**APPENDIX A**
  List of Participant Representatives..................... 12

**APPENDIX B**
  Performance Summary Reporting Format.................. 14

**APPENDIX C**
  Selected Technical Details of Approved Installations
    Colorado State University Solar House I................ 25
    Solarhaus Freiburg......................................... 32
    Sanyo Osaka Solar House................................. 35
BACKGROUND

In order to strengthen cooperation in the vital area of energy policy, an Agreement on an International Energy Program was formulated among a number of industrialized countries in November 1974. The International Energy Agency (IEA) was established as an autonomous body within the Organization for Economic Cooperation and Development (OECD) to administer that agreement. Twenty countries are currently members of the IEA, with the Commission of the European Communities participating under a special arrangement.

As one element of the International Energy Program, the participants undertake cooperative activities in energy research, development, and demonstration. A number of new and improved energy technologies which have the potential of making significant contributions to our energy needs were identified for collaborative efforts. The IEA Committee on Energy Research and Development (CRD), assisted by a small Secretariat, coordinates the energy research, development, and demonstration program.

Solar Heating and Cooling was one of the technologies selected by the IEA for a collaborative effort. The objective was to undertake cooperative research, development, demonstrations and exchanges of information in order to advance the activities of all participants in the field of solar heating and cooling systems. Several sub-projects or "tasks" were developed in key areas of solar heating and cooling. A formal Implementing Agreement for this Program, covering the contributions, obligations and rights of the Participants, as well as the scope of each task, was prepared and signed by fifteen countries and the Commission of the European Communities. The overall program is managed by an Executive Committee, while the management of the sub-projects is the responsibility of Operating Agents who act on behalf of the other Participants.

The tasks of the IEA Solar Heating and Cooling Program and their respective Operating Agents are:

I. Investigation of the Performance of Solar Heating and Cooling Systems -- Technical University of Denmark
II. Coordination of R & D on Solar Heating and Cooling Components -- Agency of Industrial Science and Technology, Japan
III. Performance Testing of Solar Collectors -- Kernforschungsanlage Julich, Federal Republic of Germany
IV. Development of an Insolation Handbook and Instrumentation Package -- United States Department of Energy

V. Use of Existing Meteorological Information for Solar Energy Application -- Swedish Meteorological and Hydrological Institute


VII. Central Solar Heating Plants with Seasonal Storage -- Swedish Council for Building Research

This report deals with the subject matter of Task VI.
INTRODUCTION

Objective of Task VI

The objective of this task 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 different systems and climates. Systems using either tubular or flat evacuated collectors may be included in this task.

Approach to the Task

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

After adoption of the program of work, the participants shall conduct the following activities:

(a) Design of Evacuated Collector Systems

Each participant shall develop and submit to the other participants a design or modification of its experimental system, including procurement related thereto, in order to accommodate evacuated collectors. Each participant's system design, including data collection instrumentation plan and a plan for conducting the performance evaluation, shall be reviewed by the other participants, who shall also make recommendations. Those participants who already have an evacuated collector system in operation at the time of initiation of this task shall submit to the other participants a description of the existing facility and equipment for a determination by the other participants as to whether this facility and equipment meet the agreed upon requirements. The participants shall determine the content, for and the manner of distribution among the participants of the semi-annual and final results.

(b) Construction and Operation of Installations

For those designs selected by the participants, acting by unanimity, for implementation, each participant will build the installations or make the required modifications to existing installations as the case may be and assemble and install the solar system components and the data collection system. The participants will conduct the system performance tests
in accordance with the program of work. The system performance tests will include, but not be limited to, evaluation of the overall system performance, reduction and analysis of data, and supplemental simulation and system studies as may be required to strengthen and extend the test results.

(c) Analysis and Reporting of System Performance

All of the participants shall prepare and exchange semi-annual status reports on the performance of the selected systems. The participants shall also prepare and exchange reports at the conclusion of the system performance testing.

The operating agent will organize annual meetings of the participants, alternating the location of the meetings among the participants' countries. Status, results and need for modification of the systems will be the main topics for discussion and analysis.

List of Participants

At the time of preparation of this report, the parties interested in participating in this task were in the process of making contractual arrangements with the IEA Secretariat.
STATUS OF TASK

The detailed program of work and operating structure for the task were established at the first meeting at Fort Collins, Colorado, USA in October 1979. The Solarhaus Freiburg in West Germany, the Sanyo Osaka Solar House in Japan, and the Colorado State University Solar House I in the U.S.A. were accepted for task participation at the first meeting. Other installations from Sweden, Switzerland, Denmark, England, Canada, and the U.S.A. are expected to be considered at the next meeting to be held in Freiburg, West Germany in April 1980.

Summary of First Meeting

Presentation of Proposed Installations

Denmark: Mr. Carsten Nielsen
- Proposed installation - put evacuated tubular collectors on test stands, use a simulated load based on real data, and compare with flat-plate collector performance. Denmark does not have an evacuated collector.
- Government interest lies with domestic hot water because of poor results from solar heating to date.

Japan: Mr. K. Hinotani
- Proposed installation - Hirakata, Osaka House, "Project Sunshine"
  - Solar heated and cooled single family residence
  - Hot water
  - Built to test solar system components and evaluate performance
  - Sanyo data acquisition system
  - Sanyo evacuated tube collectors
  - Absorption chiller

- Sanyo evacuated tube collectors
  - Suited for use with absorption chillers
  - Simple structure
  - Designed to last 15 years
  - Now producing 5,000 tubes per month, will increase to 50,000 tubes per month
Switzerland: Jean Goumaz

- Proposed installation - New project in Geneva, district heating 1000 square meters of evacuated solar collectors. Will begin with 20 square meter test system that should be operational in mid-1980. By 1981/1982 systems optimization will be complete. Full sized system should be realized in 1982.

- Existing project - evacuated flat-plate collectors. Prototype will be available by end of year.

United States: W.S. Duff and G.O.G. Löf

- Proposed installation - Solar House I
  - Collector has an ethylene glycol solution which flows through a heat exchanger, providing energy to the storage tank. Storage tank provides energy to a duct through which air flows to heat the house.
  - Arkla WF-36 lithium bromide water chiller, previously a lithium bromide direct air cooler
  - Test bed collector system - house now operates off the test bed system with Philips evacuated tubular collectors, previously used Corning evacuated tubular collectors
  - Electric boiler - initially gas-fired
  - Bally modular highly insulated storage tank, previously a conventional liquid storage tank

- Results presented
  - Monthly average solar radiation received and monthly average energy delivered from system to various uses
  - Solar cooling performance
  - Comparison of evacuated tubular collectors and flat plate collector
  - Incident solar and heat deliveries in the three houses
  - Discussion of cost of solar versus temperature delivery

United States: W.S. Duff

- Additional U.S. installations using evacuated tubular collectors - the U.S. will propose one or more of the following installations for Task VI participation:
  - Industrial process heat
    - Onion and garlic drying - Gilroy, California - 600 square meters of GE TC-100 collectors, 100°C
    - Regal Textile - La Franca, South Carolina - 1000 square meters of GE TC-100 collectors, 120°C
    - Tropicana Citrus - Brayington, Florida - 1000 square meters of GE TC-300 collectors, 200°C steam
    - Coca Cola Bottling Works - Jackson, Tennessee - 10,000 square feet of Owens-Illinois (O-I) collectors
Additional U.S. Installations (continued)

- Public Buildings
  - El Toro Branch Library - El Toro, California - 1300 square feet of GE collectors
  - Troy-Miami Public Library - Troy, Ohio - 3264 square feet of O-I collectors
  - Museum of Science and Industry - Chicago, Illinois - 7072 square feet of GE collectors
  - Participating Arts Village - Amherst, Massachusetts - 5000 square feet of O-I collectors

- Commercial and Professional Buildings
  - Washington Press Specialty Publishing Building - Floorham Park, New Jersey - 5725 square feet of GE collectors
  - Florida Solar Energy Center - Cape Canaveral, Florida - 1781 square feet of GE collectors
  - Kaw Valley State Bank - Topeka, Kansas - 1152 square feet of GE collectors
  - Sunforest Medical Building - Toledo, Ohio - 4024 square feet of O-I collectors
  - Handzlik Dental Clinic - West Bend, Wisconsin - 1000 square feet of O-I collectors
  - Fomento Factory - Puerto Rico - 7000 square feet of O-I collectors

West Germany: K.R. Schreitmüller

- Proposed Installation - Solarhaus Freiburg
  - Twelve unit apartment building with solar heating and domestic hot water
  - A Corning and a Philips evacuated tubular collector - Philips collector gave poor results until cover glass was changed. It was determined that the original cover glass was strongly phototropic, decreasing transmission by 10%.
  - Measuring and monitoring done with various meters and sensors. Have experienced problems with flow meters and pyranometers
  - Results - no data available but solar energy system performed adequately for heating and hot water

Sweden

- Proposed installation - District heating system
- Unable to attend, but intends to participate in Task VI

United Kingdom

- Area of interest - residential heating and hot water system and industrial process heat
- Unable to attend, but would participate if an English firm becomes interested in developing an evacuated collector

Canada

- Likely proposed installation - Bottling plant
- Unable to attend but interested in participating in Task
Proposed Task VI Structure

At the meeting, a detailed task structure was established as follows:

General Requirements for Participating Installations

Projects will provide the equivalent of a 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.

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

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

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

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

Desired Features for Participating Installations

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.

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.

The applications proposed by countries expressing an intention to participate in the Task are oriented to space heating and cooling and hot water production in single and multifamily residences and to district heating. It would be desirable to include an industrial process heating application in a sunny climate with temperature requirements of 120°C to 140°C.

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.

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.
Desired Features for Participating Installations (continued)

Real loads are preferred since simulated loads do not experience 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.

It is desirable that projects accepted in this task be those for which the component supplies and the project participants (investigators) not be the same organization.

Requirements for Instrumentation, Data Collection, and Performance Reporting

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 May 1979 IEA draft report of "Data Requirements and Thermal Performance Evaluation Procedures for Solar Heating and Cooling Systems".

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

Performance reporting of each participant to the other participants will be on a semi-annual basis.

Annual reports will follow the format for reporting the performance of solar heating and cooling systems developed in Task I that is currently being printed. The Task VI participants wish to review this document at the second task meeting and propose alterations or additions as may be best suited for Task VI.

Reporting periods between annual reports will utilize an abbreviated format similar to the attached CSU Solar House I July performance summaries. The first Task VI report due at the second task meeting will be in this format. (See Appendix B)

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.

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.

Task meetings of the participating installations will be held semi-annually for the purpose of discussing the reports, exchanging information among participants, and reviewing proposals for new Task VI installations.
Requirements for Instrumentation, Data Collection, and Performance Reporting (continued)

Performance reporting of each participant to the other participants will be on a semi-annual basis (continued)

The meeting date and location of the next meeting will be set at each meeting.
The second Task VI meeting will be held at Freiburg, West Germany in the second half of April 1980.
Switzerland would like the host the spring 1981 meeting.
The Operating Agent will set the meeting agenda and make any necessary adjustments in meeting dates to accommodate timing of individual projects.

Procedures for Reviewing Proposed Installations

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.

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

The West Germany Freiburg Solarhaus installation, the Japanese Sanyo Hirakata, Osaka Solar House, and the CSU Solar House I installations were approved for Task VI participation. Canadian, Danish, Swiss, and Swedish installations may be presented for adoption at the second Task VI meeting.

Task Timing

In view of the timing requirements of some of the installations proposed for the task, it would be desirable that the program be extended from the present three year term to a four or five year duration. This matter will be brought before the Executive Committee meeting in May 1980.

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

Collector manufacturers are encouraged to take part in projects 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.
Exchange of Collectors Among Installations
While exchange of evacuated collectors among installations may be desirable, it is both expensive and consumes manpower resources that may be needed for other task responsibilities. The use of separate identical collectors is therefore recommended where such comparability among two or more installations is desired.

Desirability of Grouping Task Installations
It was agreed that grouping either by collector type or installation function would not be desirable.
It is agreed that participants which have similar projects, are located in the same geographical region, or have other similar interests, may communicate more frequently than semi-annually and such communication need not be officially routed through the Task VI structure.

Current Work Plan
As of October 1979, commence data collection for the three accepted installations in a form amenable to Task VI requirements. The next task meeting will be held 1 April 1980 in Freiburg, West Germany for the purpose of reporting the three accepted installations performance, discussing these results, presenting proposals for new installations, evaluating these proposals, and initiating the new installations.

Significant Accomplishments
At the first task meeting considerable time was devoted to establishing a detailed task structure. It is felt that the structure developed, as given above, will very satisfactorily meet the stated task objectives and the needs of the participants.
To make the task results completely representative of evacuated tubular collector system potential, the working group at the first meeting felt a need to have a wide range of different installation types. It appears that this will be the case with the likely addition, now, of several industrial process heat (IPH) projects from the U.S.A. and Canada to complement the residential single and multifamily heating, cooling, and hot water and district heating projects currently programmed and proposed.
APPENDIX A
List of Participant Representatives

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Colorado State University
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Federal Republic of Germany
APPENDIX B
Performance Summary Reporting Format
July 1979 hourly data

**ABBREVIATIONS AND UNITS**

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**July 1979 hourly data**
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### Notes:
- **DAILY MEAN TEMPERATURES:**
- **DAILY MEAN VPD:**
- **INSULATION:**

- Data are representative of full year and may be updated from performance summaries. See current data.

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Note: The table contains data that may require specific formatting or context to fully understand. Please provide any necessary information or context for a more accurate representation.
<table>
<thead>
<tr>
<th>MONTHLY TOTALS</th>
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<tr>
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<td>GREENHOUSE TOTAL HEAT</td>
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<tr>
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<td>PROGRAM FINISHMENT HEAT BALANCE</td>
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(This page left blank intentionally)
APPENDIX C
Selected Technical Details of Approved Installations

Colorado State University Solar House I . . . . . . 25
Solarhaus Freiburg. . . . . . . . . . . . . . . . . . . . 32
Sanyo Osaka Solar House . . . . . . . . . . . . . . . . 35
Colorado State University Solar House I

Solar House I is a residential-size building located in the Solar Village at the Foothills Research campus of Colorado State University in Fort Collins, Colorado. The building is a three-bedroom house, although the interior is utilized for offices. The first floor is the "living" area with 128.5 m² floor space and the full basement has additional office space as well as space for the solar equipment. A photograph of the building is shown in Figure C-1.

The building faces due south. The roof is partially supported by four walls which extend outward 1.83 m from the south wall of the building. A 1.83 m overhang shades the south-facing windows on the first floor in the summer and admits sunlight during the winter. Shading of the south-facing windows in the early morning and late afternoon is provided by the vertical support walls extending from the south wall.

The building walls are constructed of 5 by 10 cm studs on 40.6 m centers. The sheathing on the exterior is 1.27 cm thick with 1.1 cm cedar siding over the sheathing. The interior wall is 1.6 cm gypsum board and 8.9 cm fiberglass batt insulation in the walls (R = 2.11 °C·m²/W; 12 hr·ft²·°F/Btu). The ceiling consists of joists, 5 by 15 cm on 51 cm centers, with 1.6 cm gypsum board overlaid with 14 cm fiberglass blanket insulation (R = 3.35 °C·m²/W; 19 hr·ft²·°F/Btu).

The exposed wall area of the building totals 110 m² and the underground wall area is 73 m². There are 20.35 m² of triple-glazed windows set in wood frame with 80% glass area, 3.9 m² of 4.5 cm wood solid-core exterior doors, and a 5.76 m² double glazed wood frame sliding glass door. The design heating load was computed to be 16.1 kW at -23°C (55,000 Btu/hr at -10°F), corresponding to 33.65 MJ/°C·day (17,600 Btu/°F·day). The calculated overall UA of the building is thus 390 W/°C (1.4 MJ/hr·°C; 740 Btu/hr·°F). The design cooling load is approximately 10.5 kW (3-tons or 36,000 Btu/hr).

The expected heating load is at least 20% less than the design value because the design calculation was based on double glazed windows and neglected the vestibule entry and the heat generated internally by electric equipment and occupants. The internal heat generation and heat lost from storage into the house also increased the cooling load significantly.
Figure C-1. CSU Solar House I
In July 1978, shown in Figure C-2, the Corning collector, which had supplied energy for the house since December 1976, was shipped to the joint FRG project and was replaced by the Philips evacuated tubular collector, shown in Figure C-3.

The Philips collector is essentially a heat exchanger plate covered by evacuated tubes with internal solar absorbing coatings. Both the glass tubes and the aluminum heat exchanger channels are produced by low cost, high speed extrusion processes. A unique feature of this collector is a selective surface (cobalt sulfide) on a thin silver mirror, deposited in the lower half of the evacuated glass tube. The tubes are spring clamped to the aluminum channel and heat is transferred to the fluid by conduction through the glass wall into the aluminum heat exchanger. Each 4.75 m by 1.9 m module contains 108 tubes. Four tubes, approximately 1 m long, are laid end to end in each of the 27 aluminum channels. Silicone hoses are spring clamped to the aluminum fluid tubes and to the headers. Each module has a net absorbing area (projected on the collector plane) of 6.77 m², a glazed area of 7.45 m², and a coverage area of 9.03 m². Thus the gross surface area occupied by the three arrays of two modules each on the test bed is 54.2 m², exclusive of space between modules for access and piping.

Solar and auxiliary heat supplies are delivered to a forced air, space heating system through a refrigeration-type duct coil. Solar heated water is used unless the tank temperature is below 38°C or the house air temperature drops to the stage two (lower) thermostat setting. Auxiliary heat is provided by a natural gas-fired "cold" contains no storage and uses fuel only when water is circulated through the boiler to the load boiler 1/, nominally rated at 29.3 kW input, 23.5 kW output at sea level, derated 20% for the 1585 m elevation of Solar House I.

An Arkla Model WF-36 lithium bromide absorption water chiller, designed specifically for solar hot water operation, was installed in September 1976. The WF-36 has a nominal rating of 10.5 kW cooling output (3 refrigeration 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. Full cooling output is obtained within 20 minutes after start-up. Solution concentration was reduced from the standard 52% to approximately 50% to take advantage of
Figure C-2. Corning Evacuated Tube Collector Detail
Figure C-3. Cross-Section Schematic of the Philips Evacuated Tubular Collector
lower condenser water temperatures (24°C) available in the dry Colorado climate. Minimum useful hot water generator temperature was thereby reduced to 68°C from the normal design minimum of 77°C for operation with 30°C condenser water.

Collector efficiency as a function of temperature and incident solar radiation has been experimentally determined by operation of single collector test modules of the flat-plate and Philips types. A single Corning evacuated collector tube was similarly tested. Wind speed was less than 0.3 m/sec. The results are shown in Figure E-4.

The thermal loss coefficients for the three collectors are:

- Flat-plate: $U_L = 4.20 \text{ W/}°\text{C-m}^2$
- Corning: $U_L = 1.35 \text{ W/}°\text{C-m}^2$ (based on the area occupied by the glass tubing and space between tubes, i.e., aperture area)
- Philips: $U_L = 2.18 \text{ W/}°\text{C-m}^2$ (based on the cover plate area, i.e., aperture area)

It should be noted that the collector efficiency curves were obtained under steady-state conditions and are not representative of typical operation in a house heating system.
Figure C-4. Solar Collection Efficiency Based on Aperture Area (Manufacturer's Data)
The objectives of the experiment can be summarized as follows:

- tests of evacuated tubular collectors with different climatic conditions (Colorado and Freiburg) and realistic operating conditions.
- the detailed recording of all relevant data as the basis for computer simulation of solar energy systems.
- the comparison of analytic models with experiments.
- the specification of the influence of various energy saving and recovery components and methods, of several operational modes and of improved thermal insulation on the gross energy consumption of the house.
- the specification of the influence of various energy economizing arrangements on the convenience of the occupants.
- the verification of the acceptability of various energy economizing components and methods by the users.

The main parts of the solar energy system are two collectors with about 30 m$^2$ net solar absorbing area, the same designs used in the Colorado State University installation, and each operating either separately or together. The domestic hot water or space heating systems. Both collectors are evacuated tubular designs, one from Corning Glass Works and the other from Philips Forschungslaboratorium Aachen. The collector areas and storage tanks were sized to the climatic conditions in Freiburg and the energy needs of the occupants by computer simulation. The greatest flexibility, maximum efficiency and least use of auxiliary energy are obtained by connecting one collector to a two tank heating system and the other collector to a two tank hot water production system.

Because the collector area has been dimensioned for existing economic conditions an auxiliary energy system is needed during particularly cold weather and extended periods of poor sunshine. This energy is supplied by an oil fired heating system whose consumption is kept at a low level due to the improved thermal insulation and solar collectors. During summer the domestic hot water system can also be operated by electricity in order to investigate the efficiency of different auxiliary sources. The antifreeze and water solution circulating in the collectors is separated from the domestic hot water storage by heat exchangers. To prevent poisoning of the domestic hot water in the improbable event of leakage in the heat exchanger a non-poisonous antifreeze is used. This "safe" antifreeze has been certified for use in food by the US Food and Drug Administration.

To adjust different energy systems to different boundary conditions (weather, occupant behaviour, storage temperature) in an optimum way a multitude of different operating modes are necessary. For instance more than 40 different operational modes can be realized in the Freiburg Solar House. The complex control system is accomplished with a microprocessor smaller than a collar button. This microprocessor has the advantage of flexibility and reliability and thus is well suited to an experimental application.

The conventional oil heating boiler delivers the lion's share of the energy which is needed for space and hot water heating during the winter months. In spite of that its power is only 72 kW (about 62,000 Kcal/h) which is only one-third the size required in present buildings of similar size. This reduction in heating power required is due to insulating the building on both the inside and outside. For example the outer wall, cellar ceiling, floor of the attic, walls between apartments and staircases have been insulated with thick layers of mineral wool. The triple glazed windows and the doors have a special tight fitting frame construction. The balconies have been pre-hung by means of a special construction to avoid thermal bridges. Compared to this measure the air lock at the entry may be called conventional.

The large radiators in the living areas require low inlet temperatures and are, therefore, well suited for solar installations. An inlet temperature of 54 $^\circ$C is sufficient for comfortable heating even at the minimum design temperature of -12 $^\circ$C (lowest temperature expected). The inlet temperature is controlled by the outdoor temperature and is somewhat reduced during night. To further reduce energy consumption each radiator is equipped with its own thermostat. During the transition periods between warm and cold weather and on cool summer days the house can be heated from storage.

During extended bad weather periods domestic hot water can be heated by either electricity or oil. Normally hot water production during the summer using oil has high losses due to extended periods required to heat the system to the operating temperatures and high standby losses. These losses are substantially reduced in the Freiburg Solar House, because energy sufficient for the daily hot water load is stored in the large heating system tank. Therefore the oil burner is switched on only once a day for about an hour. Thus the starting losses are relatively low and the efficiency is correspondingly high.
The accuracy of the measuring and data acquisition system is a most important feature of the Freiburg Solar House experiment. About 180 sensors are installed inside and outside of the house to deliver information on the house operation, climate temperatures, energy flows and so forth. Only selected sensors of demonstrated high accuracy have been used. Each of these has been carefully calibrated. For instance, the readings of the flow meters were calibrated as a function of the volume passed and the temperature and viscosity (water, antifreeze mixture, heating oil). Each of the (electric) temperature sensors was calibrated over the total range of temperature with an accuracy of a few hundredths of a degree. The other sensors were similarly carefully selected (those used for meteorological measurements, for measuring air flows and humidity in the ventilation channels).

The signals of all instruments are scanned by the data acquisition system in periods of a few seconds and their average recorded on magnetic tape at five minute intervals. The flood of data of about 50,000 daily readings can be reduced by electronic computers using precise mathematical models to arrive at a concise description of the house energy system. The influence of different subsystems can be established with exact and reliable data. The sophisticated measuring and data acquisition system permits one to evaluate the performance of the solar energy system; gives a detailed analysis of the total energy system with its interdependencies with climate and occupant habits and provides sound estimates of the influence of modified subsystems on the energy consumption.
Technical Data

A. Gebäude
Building

6 x 1-, 4 x 2-, 2 x 3-Zimmerwohnungen/room apartments

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<th>Value</th>
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<tr>
<td>umbauter Raum (DIN 277)</td>
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<td>interior space</td>
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<td>Dachneigung (Süden)</td>
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<tr>
<td>(Norden)</td>
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Wärmedurchgangskoeffizienten
thermal conduction coefficients

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<td>Außenwand</td>
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<tr>
<td>Wohnungstrennwände und -decken</td>
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<td>Wärmeisolierung Dach</td>
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<td>Fensterkonstruktion</td>
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B. Solaranlage
Solar System

1. Kollektoren
Collectors

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2. Brauchwassersystem
Duty Hot Water System

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3. Heizsystem
Heating System

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<td>(out-door temperature -12 °C)</td>
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<td>Vorlauftemperatur (-12 °C)</td>
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<td>max. Heizleistung</td>
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<td>required heating power</td>
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<td>Vorspeicher</td>
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<td>Heißspeicher</td>
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<td>hot water tank</td>
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</table>
SANYO OSAKA SOLAR HOUSE

Construction: Box frame type reinforced concrete
Scale: Two stories
Floor area:
- First floor: 74.00 m²
- Second floor: 59.26 m²
Total floor area: 133.26 m²

Energy saving design in the solar house for a new private home:

(1) Architectural energy saving design
- The outer wall, floor, and ceiling are covered with thick insulation
  The overall heat transfer coefficient of the outer wall is:
  \[ K = 3.3 \text{ Kcal/m}²\text{.hr.}°\text{C} \] without insulation
  \[ K = 0.3 \text{ Kcal/m}²\text{.hr.}°\text{C} \] with insulation
- The window area is as small as possible. The window area is 15% of the total outer wall area, which is half the percentage of a conventional home
- Double windows are used. The outer window frame is made of aluminum and the inner one of wood. The overall heat transfer coefficient of a window is:
  \[ K = 5.7 \text{ Kcal/m}²\text{.hr.}°\text{C} \] for a single window
  \[ K = 2.3 \text{ Kcal/m}²\text{.hr.}°\text{C} \] for a double window
- Thermal insulation shutters are used. Closing the thermal insulation shutter over the large glass area to the south lessens the heat loss from that opening. The overall heat transfer coefficient through the window is:
  \[ K = 2.3 \text{ Kcal/m}²\text{.hr.}°\text{C} \] with the shutter open
  \[ K = 0.46 \text{ Kcal/m}²\text{.hr.}°\text{C} \] with the shutter closed

(2) Energy saving design in the equipment
- Heat is recovered from exhausted air. A heat exchanger is used to exchange heat between intake and exhausted air.
- A second storage tank is installed in the middle of the house. The second storage tank of 8 m³ stores chilled water in summer and hot water in winter. The installation of the tank in the house enables the heat loss of the tank to decrease the house loads.
- The amount of intake air is lessened. Use of a balance type hood in the kitchen and a fresh seat vent helps the amount of intake air to be less.

- Floor heating with warm air is employed. Warm air is sent to the second floor to heat both the first and second floors with radiation.

**Composition and Construction**

Concrete
Polystyrene foam bead
Mortar
Glass fiber mesh
Mortar
Spraying materials

**Solar Collector Arrangement**

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<tr>
<td>Number of collector tubes/unit</td>
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<tr>
<td>Number of collector tubes</td>
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<td>30</td>
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<tr>
<td>Area of total absorber plates</td>
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<td>6.9 m²</td>
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<tr>
<td>Installation area</td>
<td>64.0 m²</td>
<td>9.6 m²</td>
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</table>

**Chiller Specifications**

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<tbody>
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<td>Chilling capacity</td>
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<td>Flow rate</td>
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<tr>
<td>Hot water capacity</td>
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<tr>
<td>Hot water temperature</td>
<td>85°C 80°C</td>
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<tr>
<td>Flow rate</td>
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<td>Cooling capacity</td>
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