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solar heating and cooling programme

Data Collection and Performance Reporting Specifications for Solar Energy Projects

A Report of Task VI: The Performance of Solar Heating, Cooling, and Hot Water Systems Using Evacuated Collectors

June 1986

Data Collection and Performance Reporting Specifications for Solar Energy Projects

A Report of Task VI: The Performance of Solar Heating, Cooling, and Hot Water Systems Using Evacuated Collectors

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ABSTRACT

This report details the data collection and performance reporting specifications for solar energy projects that were developed by the International Energy Agency Task on the Performance of Solar Heating, Cooling and Hot Water Systems Using Evacuated Collectors. It was developed so that the Task Participants could exchange and present information about individual installations, their operating characteristics and performance results in an accurate and consistent manner. One of the main objectives of the effort was to ensure accurate collection and reporting of data, facilitating analysis and exchange of information among the participants. To this end, the format document has served us well and we recommend its use to other researchers involved with data collection and analysis of solar energy systems.

This document is based on the 1980 International Energy Agency document on reporting format which has been considerably revised. Specific requirements concerning the preparation of diagrams, figures, plots and textural material have evolved permitting more detailed comparisons and exchanges of information among installations. Format requirements include both simulated and measured data.

REPORTING REQUIREMENTS AND REPORTING STRUCTURE

The following is a presentation of the data collection and performance reporting specifications for solar energy projects developed by the International Energy Agency Task on the Performance of Solar Heating, Cooling and Hot Water Systems Using Evacuated Collectors. It lists the data that needs to be collected, performance measures to be calculated and describes the titles and numbers recommended for the reports. Each below numbered item (1 through 16), contains a brief discussion of the type of material which should be included. A researcher can use these lists as a checklist for structuring his project as well as his report. Examples of tables and figures are provided in the main text of this report to assist in the preparation of the report. Where appropriate, a chapter number is included next to the item title; these chapter numbers and item titles should be used in the actual report. In some items, specific references to subsection numbers and titles are made which should also be used in the actual report.

Item 1. Preliminary

At the beginning of the report the author may include such notices and disclaimers, etc. as appropriate. Following this discretionary item, a very brief abstract should be included which may be suitable for inclusion in a listing of abstracts. Essential topics for the abstract include:

- Description of Project

- Description of Major Results, specifying only the most important, and

- Description of Major Conclusions, specifying only the most important.

A brief section may also be included as preface and acknowledgements. The contents of this section are left to the discretion of the author. Included also should be a list of contributing authors and the names and addresses of those people who may be contacted for additional information on the project as well as a bibliography.

Item 2. Table of Contents

The table of contents should be detailed enough to allow the reader to identify the sections of interest. The author should, in his report, use the same numbering and titles for chapters whenever possible. It may be necessary for the author to add additional levels of numbering, depending upon the complexity of the report.

A List of Figures and a List of Tables should follow the table of contents if any figures or tables are included in the report. They should be numbered and listed in accordance with the appearance in the report.

Item 3. Summary

The summary should provide concise yet sufficient detail to provide an understading of the project. It should stress the thermal performance results and present the main conclusions. The summary should include the main objectives of the project, climate, brief descriptions of the system (including collector aperture area, type, storage type, volume and load), the operating modes, and the data collection method.

Item 4. Introduction (Chapter 1)

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

- The project background including a history of the project,
- description of the International Energy Agency Solar Heating and Cooling Program,
- the project's role,
- the project objectives, and
- the project's relation to the national program.

Item 5. Description of the Surrounding Environment (Chapter 2)

In this chapter the author should provide a general description of the location, the site and the climate. A detailed list of parameters may be included in an Appendix.

Description of location and site (2.1)

- General description of location including distance to nearest larger city, as appropriate
- Shift in solar time expressed as the difference between solar noon and the standard meridian.
- General discription of the surroundings including significant geographic features such as seas, mountains, etc.

- Plan showing the topography of the nearest surroundings. Height and position of solar and wind obstacles together with the exact position of the solar collector array should be indicated.

- Diagram showing the horizon (if available).

- Ground reflectance (estimated if not measured).

- Latitude, longitude and altitude of the site.

Description of Climate (2.2)

- Description of general seasonal conditions including wind, cloudiness, rain, snow, humidity, temperature and typical day and night conditions.

- Climatic conditions according to Trewartha (1968) worldwide classification system (if available).

- Average monthly global insolation (horizontal plane). If radiation data are not available, sunshine hours or cloudiness may be presented.

- Average monthly ambient dry bulb temperature.

- Average monthly relative humidity (optional). This information is of interest for cooling applications.

- Monthly heating degree days (Celcius) (optional). It should be noted that degree days are calculated differently in different countries and that the definition therefore should be given.

- Monthly cooling degree days (optional).

An example is shown in Figure 1. Define how the averages of the summary sheet are calculated.

Item 6. Description of Building, Solar and HVAC Components (Chapter 3)

This chapter should present sufficient information about the energy systems, their way of operation and the loads so that the reader can understand the thermal performance results. This should include:

- Brief description of the purpose of the system.

- Comment on the design goal (e.g. solar fraction, indoor climate, etc.)

- Comment on the philosophy underlying the solution.

DESCRIPTION OF CLIMATE EDMONDON, Alberta, CANADA

MONTH	YR	Irradiation on horizontal plane GLOBAL	DIFFUSE	Degree Days Base 18°C	Precipitation	Average Ambient Temp.	Average Dew Point Tempera- °C	Average Wind Speed	Prevailing Wind Direction
JAN.		3.72	2.30	1016.1	25.1	-15.0	-17.2	13.0	S
FEB		7.06	4.12	805.9	20.1	-9.6	-13.3	13.4	S
MARCH		12.50	6.14	727.1	16.8	-5.0	-9.9	14.5	S
APRIL		17.48	7.42	4.20.5	23.4	4.0	-3.3	16.3	S
MAY		20.64	8.53	222.1	37.3	11.3	+ 1.7	16.9	S
JUNE		21.98	9.00	109.1	74.7	15.1	+ 6.7	16.1	NE
JULY		22.62	8.35	47.4	83.3	17.4	+10.6	14.3	NW
AUG.		18.28	7.04	82.1	71.6	16.2	+ 9.4	13.7	WNW
SEPT.		12.67	5.36	215.2	35.8	11.0	+ 4.4	15.4	S
-									
OCT		7.73	3.51	388.4	18.5	5.3	- 1.1	14.6	S
NOV.		4.02	2.26	665.5	18.5	- 3.7	- 8.9	14.2	S
DEC.		2.70	1.71	890 4	21.3	-10.4	-13.3	13.2	S
TOTALS		151.45	65.74	5589.8	446.4				
AVERAGE						3.1		14.6	
UNITS		MJ/m² day	MJ/m² day	Degree Days	mm	°C	°C	km/hr	

NOTES: Data for first 5 columns is an average over years of 1941-1970 Environment Canada.

Figure 1: Table Showing Local Climate

- Description of the overall system as a whole indicating interactions between the building, the load and the energy system. The description of the actual solar energy system should be provided in a separate section numbered 3.2.

Some flexibility is provided in the outlined structure to make this chapter usable for reporting on a wide range of solar energy systems. It should commence with a survey of the overall system, especially the interaction between the building and/or load and the energy systems together with some comments on the design goals and the philosophy underlying the solution. Section 3.1 is devoted to the building (or the appropriate load). The solar energy and HVAC system should be described in section 3.2 and in section 3.3 the control system should be described. Chapter 3 is then completed by section 3.4 which should provide a systematic description of the modes of operation. It is strongly suggested that drawings be used whenever possible to illustrate the desired concept. The drawings together with an explanatory text should be put in the main text of the report.

The author is advised to provide sufficient detail so that other researchers may do their own analysis on the system. In this chapter at least the parameters needed to make a calculation with a simplified method using monthly weather data should be provided. A complete list of available system characteristics may be provided in an Appendix. This appendix should also be used for presenting information which will not necessarily affect the understanding of the results.

The writeup in Chapter 3 should be general without reference to detailed experiment design goals.

Description of the Load

Any load which is being partially or fully met by the use of solar energy should be described in the section. The extent of this section will depend heavily on the type of system being studied.

In the case of an analytical study detailed information on all assumptions concerning the load should be reported here. Drawings should be used frequently.

The description should include, if applicable, hot water load profile, indoor climate, general description of building construction and design including photo or drawing, space heat loss factor (UA-value) in W/K, (calculated or measured), relationship of collectors to building structure, effects on loads due to heat losses from the solar energy system, thermal properties of structure and components such as thermal resistance density and heat capacity.

Description of the Solar and HVAC Systems

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 experiment will be given.

This section can be presented at either of two levels of detail. If the solar system is particularly simple, it may be sufficient to present a complete description of the energy system without a system breakdown. However, if the system is complex, it may be necessary to describe the overall energy system and then present a more detailed description of key subsystems.

The set of subsystems presented below is thought to be applicable to many reports, but the author should feel free to use an alternative reporting based on a breakdown of the system into subsystems. When reporting on a simple system the subsections under 3.2 should be condensed into one. The energy balance of a subsystem is a useful tool both for checking the consistency in measured values of energy quantities and for presenting those quantities. In Chapter 7 the recommendations for presenting detailed data on the thermal performance are based on the energy balances of the subsystems. The concept is also used in Chapter 5 when discussing the evaluation program. It is therefore recommended that the breakdown of the overall systems into subsystems is done with the presentation of their energy balances in mind. It is then important that the subsystems are defined so that the interfaces become clear and the subsystems are easily identified in the real system. It is also important that the energy flows across the interfaces can be measured.

Solar collector array (3.2.1):

Description of the solar collectors.

Freeze protection method.

Table with key parameters.

Cross section

Drawings showing special features.

Photos.

Solar collector key parameters should include:

Collector brand.

Collector type.

Working fluid.

Collector aperture area.

Collector gross area.

Orientation (azimuth).

Tilt.

Collector efficiency curve† for aperture area, and at typical operating conditions and normal incidence.

Intercept of Efficiency Curve $F'(\tau a)$

Slope of Efficiency Curve $F' \cdot U_L$

Incident angle modifier†.

Number of panes in the glazing.

Maximum outlet temperature.

Reflectors.

Heat Storage (3.2.2):

Description of heat storage.

Table with key parameters.

Drawings showing special features.

Heat storage key parameters include:

Storage type

Gross volume

Mass of working media

Heat capacity

Maximum temp.

† See ASHRAE standard, 93-77 (1977).

Minimum temp.

Heat Loss factor (UA)

Stratification (yes/no)

Other subsystems (3.2.3):

Other subsystems which it might be appropriate to describe in separate subsections (3.2.3, etc.) are:

- Hot water system
- Energy distribution system (e.g. centralized systems).
- Heat pump.
- Cooling machinery.

Description of the control system hardware (3.2.x):

Number the Description of the Control System Hardware as 3.2.x, where x is the last number in the subsection 3.2. Controls should be described in sufficient detail such that the reader can understand the location and nature of the control system hardware. Detailed description of the hardware, such as branch, calibration, specifications, installation techniques, wiring, etc., should be given in an Appendix. This section describes only the physical control system. Control strategies and modes of operation should be presented in Chapter 4. The description should include:

- Brief description of the control system hardware.
- Table of sensors and controlled devices including type and designation which then should be used throughout the report.

Item 7. System, Experiments and Operation (Chapter 4)

This chapter deals with the Systems, 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 of schematics of the solar and HVAC systems according to the following structure:

System One (4.1)

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

Basic Experiment (4.1.1)

Section 4.1.1 should be entitled "Basic Experiment" with an additional description if appropriate. It elaborates experiment specifics with references to prior work and reports, if necessary.

Interaction of Components and Subsystems (4.1.1.1)

Section 4.1.1.1 should be entitled "Interaction of Components and Subsystems", and describes the operating modes of the experiment. In the operation of most solar systems there are various basic modes in which the system can be operating. For a simple heating system there may only be four modes, such as: heating from collector, heating from storage, storing energy or heating from auxiliary. However, more complex systems may have many operating modes.

A description which includes the following items should be provided for each mode of operation.

- Description of the mode of operation.

- Diagram showing flows of working fluid together with temperature levels. The diagram should be supplemented by a brief text which includes a name and designation of the mode together with the condition under which the mode is working.

Controls (4.1.1.2)

Section 4.1.1.2 "Controls" describes the control strategies of the experiment. The author should attempt to provide in this section the control strategy which was employed. If on/off control is the only type of controller used, a truth table, may be adequate when supplemented with a brief discussion. However, if proportional or other types of control strategies are used, substantial explanation may be required.

This section should include a diagram of the location of the control sensors.

Other Experiments (4.1.2) and Systems (4.2)

Section 4.1.2 should be entitled "Experiment Two" with an additional description, if appropriate. The breakdown of Section 4.1.1 should be repeated with cross referencing to minimize repetition. That is 4.1.2.1 Interaction of Components and Subsystems, 4.1.2.2 Controls, and other sections 4.1.3, 4.1.4, etc. 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 can be entitled "System Two" and the established pattern repeated.

Item 8. Thermal Performance Evaluation (Chapter 5)

This chapter should describe the objectives of the thermal performance evaluation program together with the measures taken to accomplish these objectives. International Energy Agency 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 International Energy Agency documentation, the use of small letter at the end of the relevant International Energy Agency 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.

Overall System Energy Flow Block Diagram

An Overall System Energy Flow Block Diagram should be presented for each System. An example of such a diagram is shown in Figure 2a. Where possible, only blocks for major subsystems and data groups corresponding to the numbering system in Table 1 should be shown on the diagram.

Table 1 - Subsystem Designations

001 - 009	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 (eg., 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 should be shown in the subsystem Energy Flow Block Diagrams.

Letter Designations

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

Reserved Designations

The second and third digit combinations in Table 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.

System Energy Flow Block Diagram

As shown in Figures 2a, 3a and 3b, there should be one System Energy Flow Block Diagram (Figure 2a) and set of facing page subsystem schematic (Figure 3a) and Subsystem Energy Flow Block Diagram (Figure 3b) for each system identified in Chapter 4. The experiments in Chapter 4 may necessitate changes in some of the diagrams. If so, only present those altered diagrams and make reference to the appropriate preceding diagrams.

Figure 3c shows the facing page diagram arrangement for the subsystem schematic and subsystem energy flow block diagram.

Energy and Performance Quantities

There should be one table of energy quantities, performance quantities and indicators for each system identified in Chapter 4. The table should list and define (including defining equations) all quantitites that will be used in the reporting along with their International Energy Agency nomenclature, calculation method and relevant calculation period and units. Where the above reserved combinations apply, that designator should be used. An example is given in Figure 4.

Where necessary, correspondence between International Energy Agency Acronym and the acronym used by the researcher should be specified.

Performance Quantities and Indicators

The performance quantities and indicators are given in Table 4. The performance quantities and indicators given in the table will be used in all reports where appropriate.

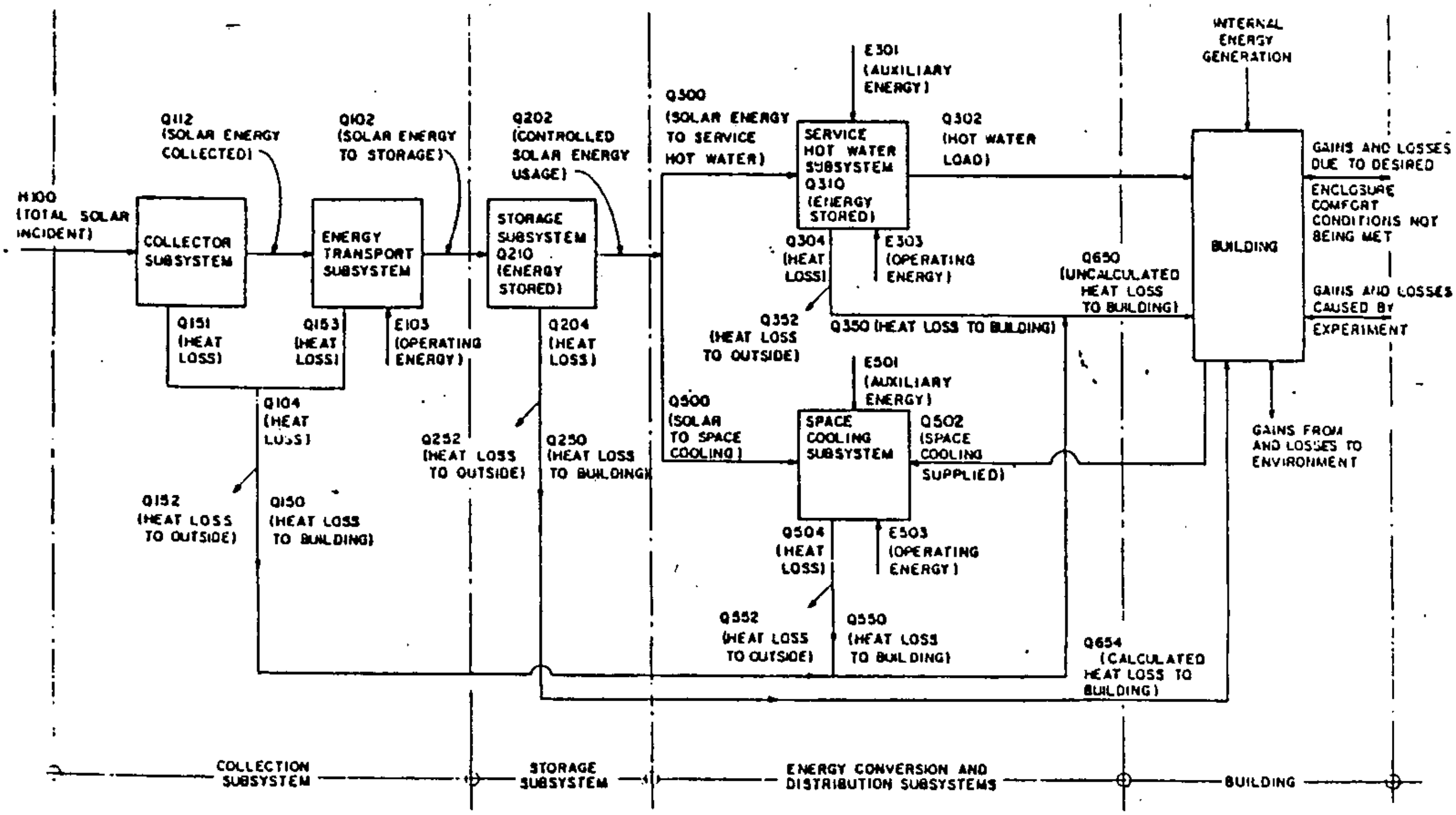


Figure 2a - Example of an Overall Energy Flow Block Diagram

Table 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)
R	Relative Humidity (%)
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 (M^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.

Data Reduction

The manner in which data are stored and their availability should be presented in the data reduction methods subsection.

Subsystem Representation

Subsystems shown in the Facing Pages of Figure 3c provide a detailed presentation of the subsystems used in the overall System Energy Flow Block Diagram. The two tables of Figure 3c 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 diagram should, nevertheless, be included in these tables. For example, the solar portion of an energy flow should be specifically broken out. The division between solar and conventional subsystems should be clearly defined for all subsystems.

Additional Performance Indicators

Performance indicators to be reported, where applicabe, are given in Table 4. 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

Table 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 systems effects
-13	Total useable heat loss
-14	Total nonuseable heat loss
-15	Cooling supplied by solar
-16	Transport heat loss
-17	Operating devices energy loss
-18	Total energy loss from auxiliary energy system
-30	Energy balance error

Additional combinations from 19 to 29 are allocated for future reserve designations. An illustration of use of acronyms in a general subsystem block diagram is shown in Figure 2b.

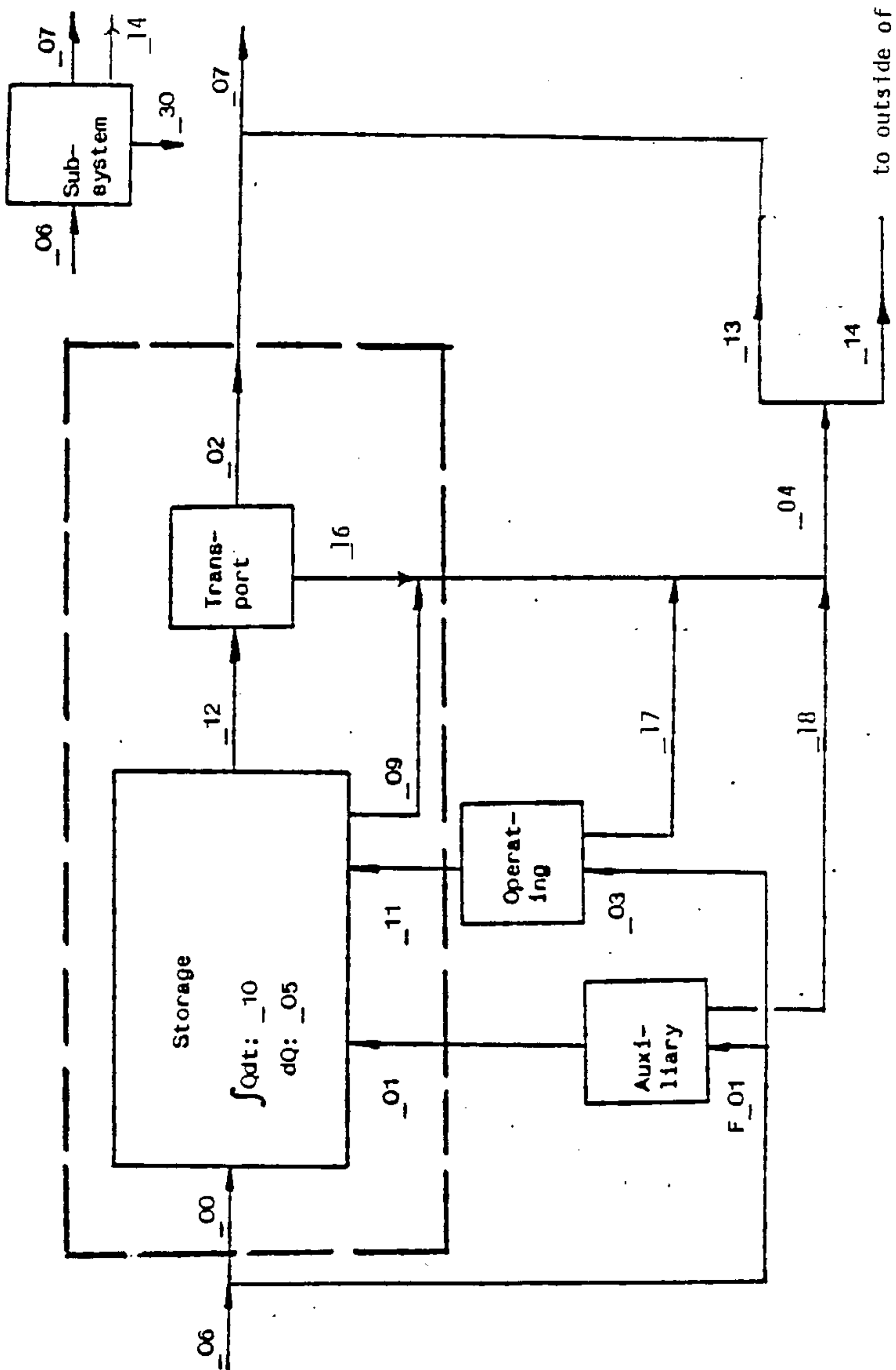
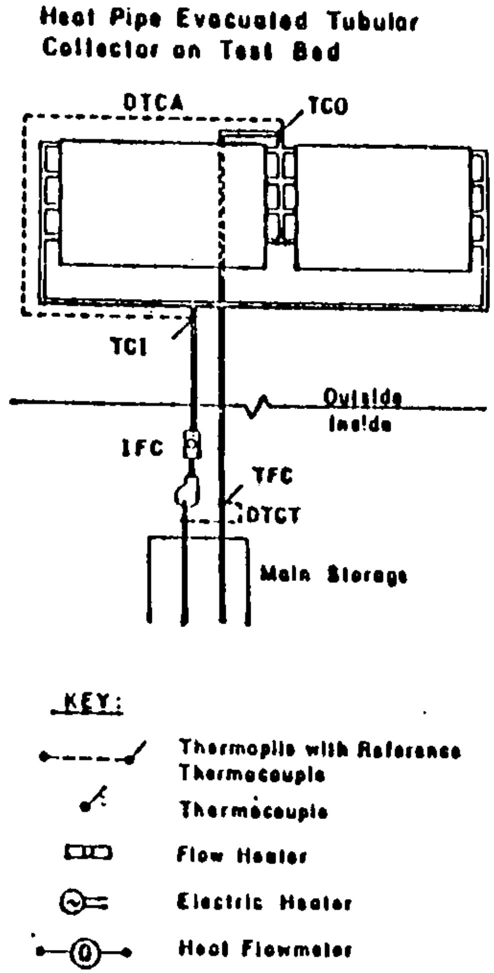


Figure 2b: Subsystem Energy Block Diagram Showing



[illegible] Acronym	[illegible] Acronym	Definition	Calculation Period: Hour	Calculation Period: Day	Calculation Period: Month
[illegible]	[illegible]	Total solar incident in the aperture plane per unit area		x	x
[illegible]	[illegible]	Total solar incident in the aperture plane while collecting per unit area		x	
[illegible]	[illegible]	Total solar incident in the aperture plane on the collector aperture ([illegible] x A_a)			x
[illegible]		Total solar incident in the aperture plane on the absorber ([illegible] x A_c)			x
[illegible]	[illegible]	Total solar incident in the aperture plane on the collector aperture while collecting ([illegible] x A_a)	x	x	
[illegible]		Solar incident in the aperture plane on the absorber while collecting ([illegible] x A_c)			x
[illegible]		Solar energy collected			x
[illegible]	[illegible]*	Operating energy for solar collection ([illegible] + [illegible])		x	x
[illegible]	[illegible]	Solar energy delivered to storage [illegible] [illegible]	x	x	x

*Operating energy for solar collection is combined with [illegible] in recording [illegible]

Figure 3a: Subsystem Schematic Example (left hand page)

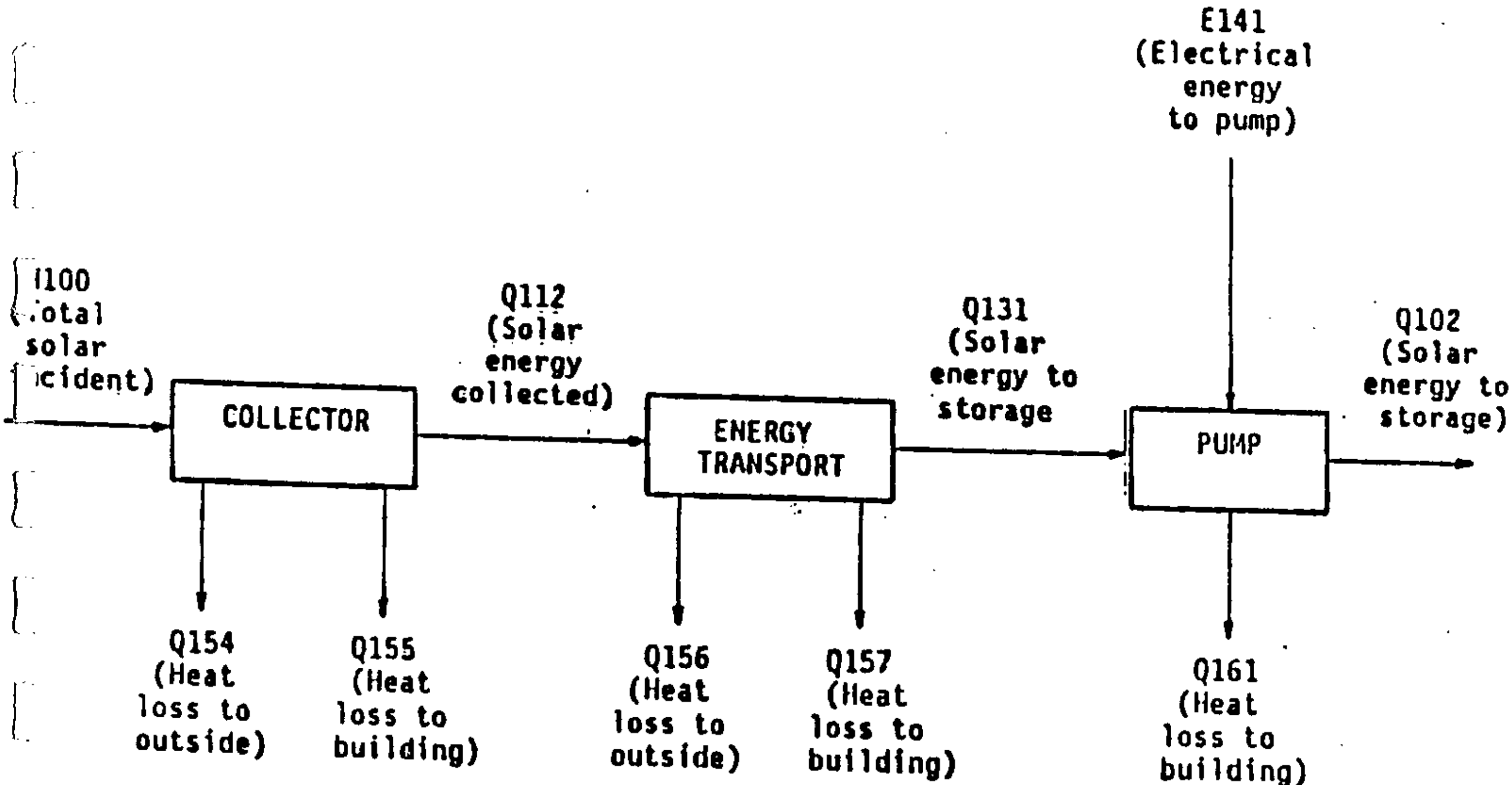


Figure 3b: Subsystem Energy Flow Block Diagram (right hand page)

left hand page

(place Subsystem Schematic
here - see Figure 3a for example)

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

the two "facing pages"

right hand page

(place Subsystem Energy flow Block Diagrtam
here - see Figure 3b for example)

Note: Include the following two tables as part of one or both facing pages. wherever there is room.

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

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

Figure 3c: Facing Page Diagram Arrangement

IEA	M/C/D	Description	Units	Period H/D/M	Method of Calculation (Equation)
T001	M	Ambient temperature	C	HDM	
H001	M	Total solar incident on collector plane per unit area	MJ/m2	HDM	
H004	M	Total solar incident on collector plane per unit area while collecting	MJ/m2	HDM	H004=H001 if collectors on
H002	M	Total solar incident on horizontal plane per unit area	MJ/m2	HDM	
H001	M	Wind speed	m/s	HDM	
D001	M	Wind direction	Deg	HDM	Remark - zero degree = North
H100n	C	Total solar incident on north collector array	MJ	HDM	H100=H001*An; An=131.9 m^2
Q112n	C	Total solar energy collected by north collector array	MJ	HDM	Q112n=(T145-T144)*(W141-2*W151)* FNR((T145+T144)/2)* FNR ((T145+T144)/2)
N110n	C	Unadjusted collector efficiency for the north array	-	HDM	N110n=Q112n/H100n
N108n	M	Ratio of (collector inlet temp.-ambient temperatures) and incident radiation	(K-m^2)/W	HD	DTIn=(T144-T001)/H001
H100e	C	Total solar energy collected on southeast collector array	MJ	HDM	H100e=H001*Ae; Ae=32.2 m2
Q112e	C	Total solar energy collected by southeast collector array	MJ	HDM	Q112e=(T152-T151)*W151*2* FNC((T152+T151)/2* FNR((T152+T151)/2)
N110e	C	Unadjusted collector efficiency for the southeast array	-	HD	N110eQ112e/H100e
N108e	M	Ratio of (collector inlet temp.-ambient temperatures) and incident ratiation	(K-m2)/W	HD	DTIe=(T151-T001)/H001

M: Measured or calculated from measured quantities	H: Hourly	FNC(T)- Specific heat = fn(T)
C: Calculated from measured and empirical data	D: Daily	FNR(T)- Density = fn(T)
D: Deduced from manually measured parameters, physical properties and quantities such as M and/or C	M: Monthly	

Figure 4: Energy Quantities, Performance Indicators, and Their Method of Calculation

Table 4
A LIST OF PERFORMANCE AND OTHER INDICIES

adjusted collector efficiency (see Note 1)	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 = Q102/103
solar collection system and storage conversion efficiency (see Note 2)	N104 = Q212/H100
solar collection and storage COP	N106 = Q212/E103
solar collection and storage system COP	N107 = Q202/(E103 + E203)
normalized temperature difference	N108 = (T100-T001)/G001
estimated shading factor	N109d (diffuse) N109b (beam)
solar energy collected per unit area	N112 = Q112/A100
solar energy system efficiency (see Note 3)	N200 = (Q102 - Q 209, - Q216, /H100
solar fraction energy consumed for domestic hot water (see Note 4)	N301 = Q300/(Q300 + Q301 + Q303)
solar fraction of energy delivered for hot water	N302 = solar energy into hot water tank ÷ (Q312 + Q301)
solar fraction of energy	$N401 = \frac{Q400 + Q908}{Q400 + Q913 + Q401}$
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	$N902 = \frac{Q202}{Q903}$

Notes are provided on the following page

Notes for Table 4

Note 1: $Q105 = (T100_n - T100_{n-1})\ C100$, where T100 is the average collector temperature and n and $n-1$ refer to the end points of the interval over which Q112 is measured. T100 $= \frac{T102 + T101}{2}$ where T102 is the collector outlet temperature and T101 is the collector inlet temperature. $F'\tau\alpha$ and $F'U_L$ are estimated by a regression analysis of Q112 $= F'\tau\alpha H101 - F'U_L A100$ (T100-T001) - Q105 using data where $T100_n = T100_{n-1}$ and collector steady state operating conditions have been established. C100, capacitance between T101 and T102, is then estimated by a regression analysis where collection has been continuously occurring for some time, but $T100_n \neq T100_{n-1}$. The values of $F'\tau\alpha$, $F'U_L$ and C100 and their estimating errors are to be reported.

Alternative procedures for calculating C100 have been suggested (notably, by Klaus Vanoli, "Cooking Recipe for Capacitance Correction to be Used for Evaluation of Collector Array Efficiency", International Energy Agency Task VI meeting, Geneva, 1982 and by Steven R. Hultin, Dept. of Mech. Eng., Colorado State University, Report entitled "Analysis of Evacuated Tubular Collector Performance", September 1983, pp. 97-101). Please indicate clearly the method used.

Note 2: Where auxiliary energy is added to the storage or there is no main storage, it is not appropriate to reference N104.

Note 3: The numerator (Q102 - Q209 - Q216) in the definition of N200 represents net solar contribution where Q209 and Q216 represent portions of solar energy lost from storage and piping systems respectively. There may be alternate methods of calculating solar contribution and the formula used should be presented in the text.

Note 4: In some systems N301 is equal to N302.

second two digits or the primary energy quantity appearing in the numerator.

Additional quantities may be reported, if available, on hourly, daily, monthly basis as shown in Table 5:

Definition of Collector Aperture Area

Definition of Collector Aperture Area (Figure 5) is given as

$$\text{Aperture Area } A100 = \text{LW}$$

where, L = exposed transparent part along the collector tubes or cover (excluding boxes or black cups or headers, etc.)

$W = n \times p$, $n =$ number of tubes and

$p =$ the pitch of the tubes, or the distance between the centres of adjacent tubes.

Table 5: Additional Data to be Reported

H001	total solar energy on collector plane	
H002	total horizontal	
H003	horizontal diffuse	In Units
H004	total solar energy on collector plane while the collector is on	of
		MJ/m^2-period
H1005	diffuse solar energy on collector plane	
H006	beam solar energy on collector plane	
H007	total solar energy on collector plane corrected for shading	
H100	total solar incident on collector aperture	In Units
	(see item j for definition)	of
H101	solar incident on collector aperture while collector is on	MJ/period

Item 9. Description of Operating Period (Chapter 6)

During the period of operation of a solar system most projects will encounter problems and occurrences which influence the thermal performance of the system. Information on these items is of importance for the reader to be able to fully understand the result and this information should be provided in this chapter.

During the course of the study the researcher will typically learn a great deal about matters which do not affect the thermal performance of the system. Reliability and maintainability aspects (including starting problems, shipping, loss of vacuum, freezing, thermal shock, corrosion, shading, snow, etc.) should be included with hours of downtime (scheduled - changing filters, experiments and unscheduled - leakage, pump failure) reported chronologically in a table. Give estimates of time and man-hours spent for maintenance. All failures and problems due to either the design, components, controls, operation or some other source should be reported. See Table 6 for an example.

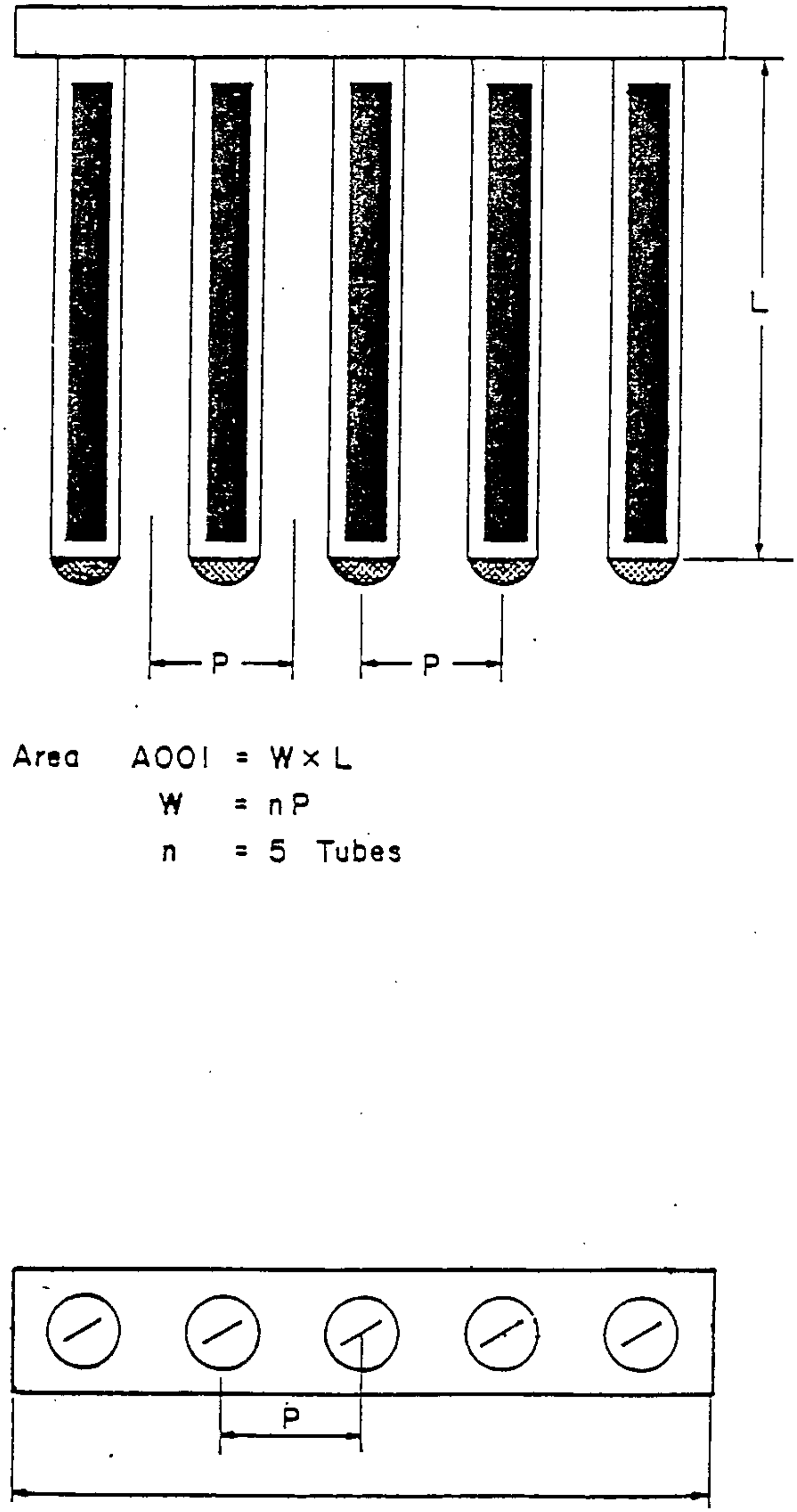


Figure 5: Task Definition of Collector Aperture

Date	Problem Description and Action Undertaken	Source of Problem: Design	Component	Control	Operation	Monitoring	Time [hrs]
22.-25.3.83	Automatic data recording down due to software debugging					x	
1.4.83	Multiple printout on Digistrip II occurs		x			x	
6.-8.4.83	Collector heat meter down due to damaged flow meter - stand-by flow meter mounted		x			x	3
11.4.83	Installation of solenoid valves to isolate collector loops from hot water tank	x			x		7
13.4.83	Testing of Apple II software (automatic record off after 12.30 p.m. - reconnected at night)					x	
15.4.83	Digistrip II problem of multiple printout repaired		x			x	2
15.4.83	Mounting of new room thermostat			x	x		
3.5.83	Aux. heater control in heating mode does not work			x			1
5.5.83	Checking of tank water quality. New corrosion inhibitor added				x		2
6.5.83	Rectification of heater control problem			x			2
11.5.83	Checking events in data acquisition software						1
23.5.83	Aux. heater operation faulty		x	x			
1.6.83	Identification of collector pump operation control problem (Evac. Tubular Collectors)			x	x		1
14.6.83	Adjustment of evacuated tubular collector pump controller			x			0.5

Table 6: Reliability and Maintainability Table

If simulation studies have been carried out, then limitations in the program capabilities of modelling and excessive computer run times, are problems that should be reported in this chapter.

Item 10. Presentation of Results (Chapter 7)

There are three types of results which should be presented in this chapter:

1. Annual and monthly results which should give the reader a perspective on the average thermal performance of the system.

2. Detailed results on daily and hourly basis for technical readers who want to scrutinize subsystem and system performance.

3. Comparative results which allow the reader to relate the performance to other alternatives.

Chapter 7 should be organized such that each section, that is Section 7.1, 7.2, 7.3 and 7.4 is 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. Section 7.7 should make comparison of simulated and measured data.

Although some guidelines can be offered as to what to report, it is up to the researcher to decide on the scope of the reporting. It should be noted, however, that information about thermal performance is most essential and that substantial effort should be put into this chapter.

To avoid ambiguity the presentation of the results should rely completely on the designations and definitions of performance factors introduced in Chapter 5 in the report, as well as the description and designations of subsystems and modes of operation provided in Chapters 3 and 4.

Tables and diagrams will be useful in the understanding of the results. The table heading should try to use abbreviations together with the designations and units to facilitate the understanding. The designation should include whether the values were calculated directly from measured data or not. Datagaps and anomalies should be noted.

The description should include:

- Brief description of the thermal performance result including seasonal and annual values of some key performance factors.

- Brief discussion on the actual and the expected results of the system.

- Summary of the quality of reported values including estimated inaccuracies.

In particular the following subsystem characteristics should be reported:

Collector System Performance

In order to obtain an overall assessment of evacuated collector performance when operating in a system it is necessary to:

1. Tabulate and graph the energy inputs and outputs from the 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.

Analyses of the individual data produced under 1 and 2 above should make reference to unexpected results and advance possible reasons which would explain such results. Relationships between the performance of a collector in a controlled test and its dynamic performance in a system should also be reported where applicable.

In cases where additional component performance data would clarify the analyses, such additional information should be included.

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.

Performance comparisons with expected results

This section should include information on comparisons performed as part of the study. The length of this section is very dependent upon the objectives of the study. For experimental facilities, comparisons may be made between, on the one hand the measured performance and on the other hand the design performance, the performance during previous years and/or the performance of similar nearby buildings. For simulation studies the author may provide extensive detail of the performance results *vs.* the performance of alternative system designs. Information should be provided concerning the weather encountered during the study *vs.* the average weather for that region.

Item 11. Required Report Graphics for Chapter 7

In the following sections, the required figures, charts and their format are described in greater detail. Additional data may be included at the discretion of the author.

Energy Input/Output Diagrams: There should be one set of energy input/output diagrams for each collector, and for each experiment if variations require it. An example is given in Figure 6.

The following specifications should be used for the definition of axes and title:

TITLE - DAILY INPUT/OUTPUT DIAGRAM FOR "COLLECTOR NAME" AT "PROJECT SITE". "PERIOD"

Y-axis

Title: Energy from Collector (Q112/A100), MJ/m^2 - day

Scale: 1 cm = $1MJ/m^2$ - day

X-axis

Title: Energy Onto Collector Per Unit Aperture (H001), MJ/m^2 -day

Scale: 1 cm = 2 MJ/m^2 - day

The diagram should show the measured daily points indicating the different temperature difference ranges by different plot symbols. Regression lines should be included. There should be a plot for each experimental period.

Each diagram will consist of separate plots for temperature ranges (ΔT) given by:

A:		$\Delta T \leq 15$ C
B:	15 C $<$	$\Delta T \leq 30$ C
C:	30 C $<$	$\Delta T \leq 54$ C
	...	...
G:	90 $<$	$\Delta T \leq 105$ C, etc.

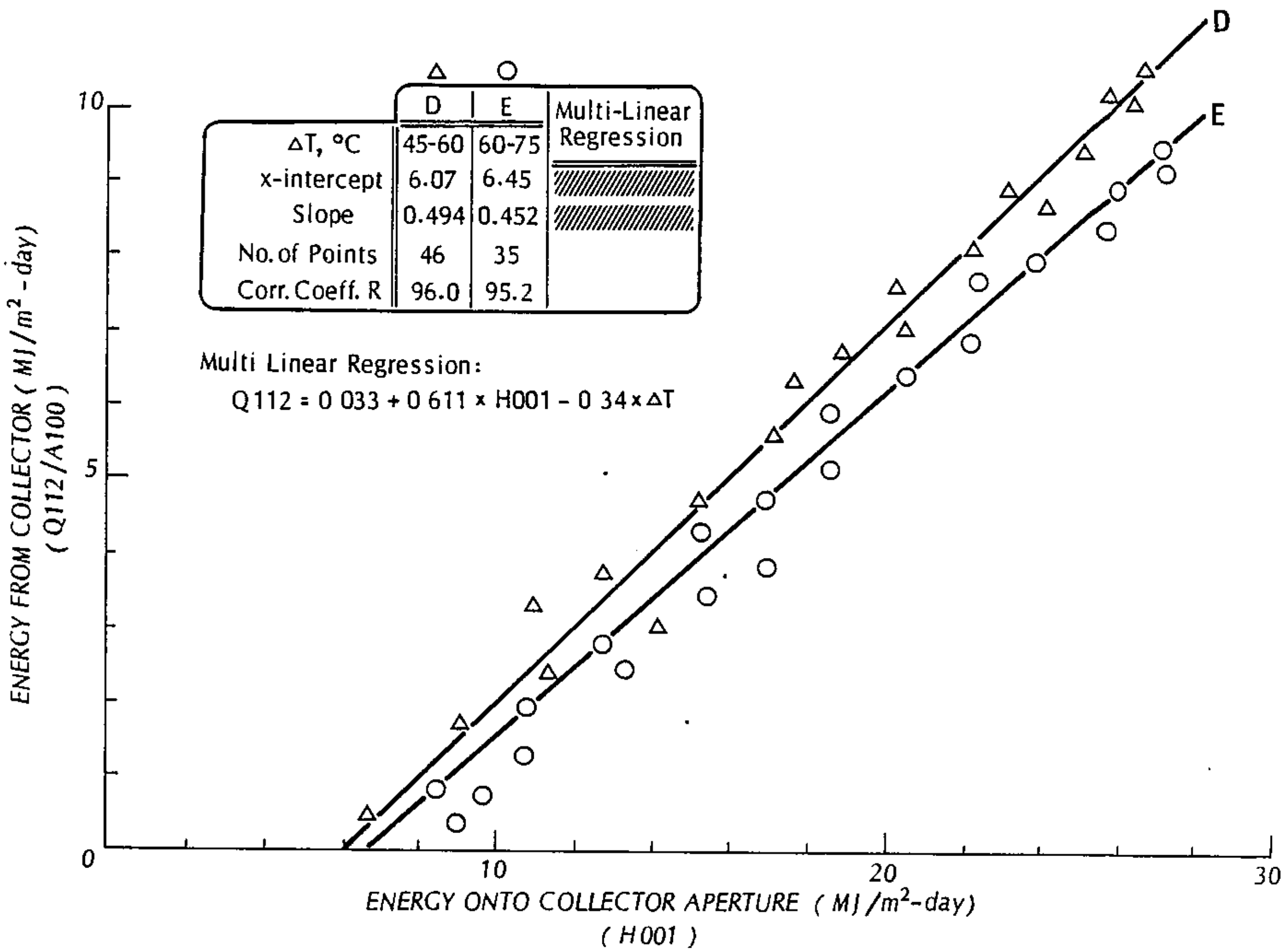


Figure 6: Daily Input/Output Diagram for "Collector Name" at "Project Site". "Period".

where Δ T is defined as the difference between average collector temperature and ambient temperature = T100 − T001. If only a few points appear, a plot may be omitted and the points placed on the adjacent temperature difference range plot. The temperature difference range shown should be suitably modified (e.g., 45-60 and 60-75 modified to 45 - 75).

Statistics

Each I/O diagram will include a table showing the following statistical information: X-intercept, slope, number of points and the correlction coefficient R, where R is defined as*:

$$R = \frac{n\sum xy - \sum x \sum y}{\sqrt{n\sum x^2 - (\sum x)^2}\sqrt{n\sum y^2 - (\sum y)^2}}$$

where n is the number of pairs of $\{x, y\}$ values, and summation is over n.

Collector System Efficiency Diagrams: 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 Figures 7. The points will be selected at times when the system has been running continuously during each hour and from one hour before noon to two hours after noon. Noon is apparent solar time corrected for collector array azimuth. The capacitance correction will be applied to the results. H100 and H101 are to be the energy incident on the collector aperture. Points on a monthly or seasonal basis may be included. The plots should use the average collector temperature T100 and ambient temperature T001 in the definition of X-axis (i.e., [T100 - T001]/G100).

Include the values of the aperture area A100, $F'\tau\alpha$, $F'U_L$ and C100 on the collector system efficiency diagrams. Discussion of the method of calculation of C100 should be included in the test.

The following specifications should be used for the definition of axes and titles.

TITLE: COLLECTOR ARRAY EFFICIENCY FOR "COLLECTOR NAME" AT "PROJECT SITE". "PERIOD"

Y-axis

*From "Regression Analysis" by W. E. Carscallen, National Research Council, Canada, paper presented at International Energy Agency TASK VI meeting, London, Aug. 1981.

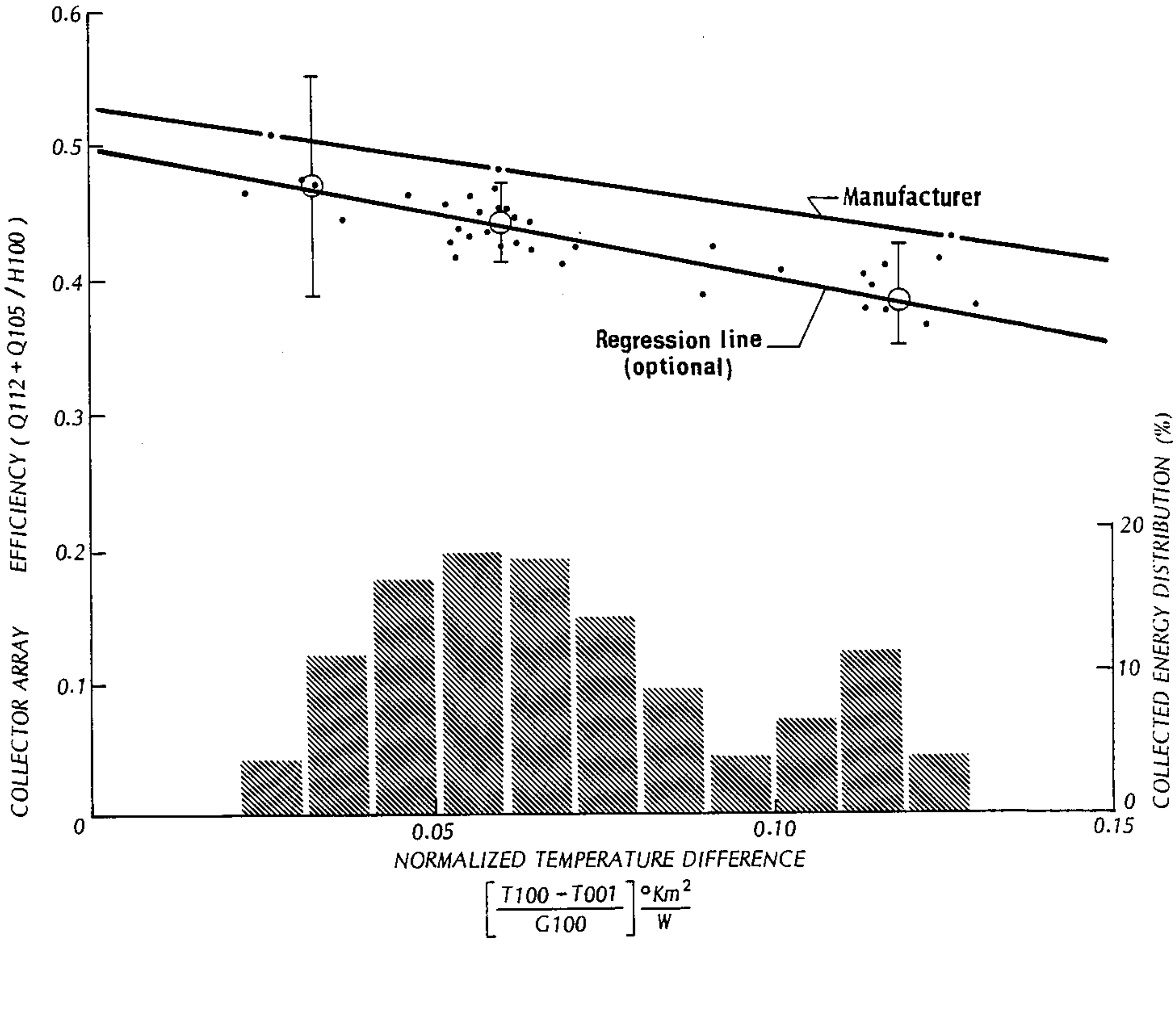


Figure 7a: Collector Array Efficiency Diagram 11 a.m. - 2 p.m. for "Collector Name" at "Project Site" "Period"

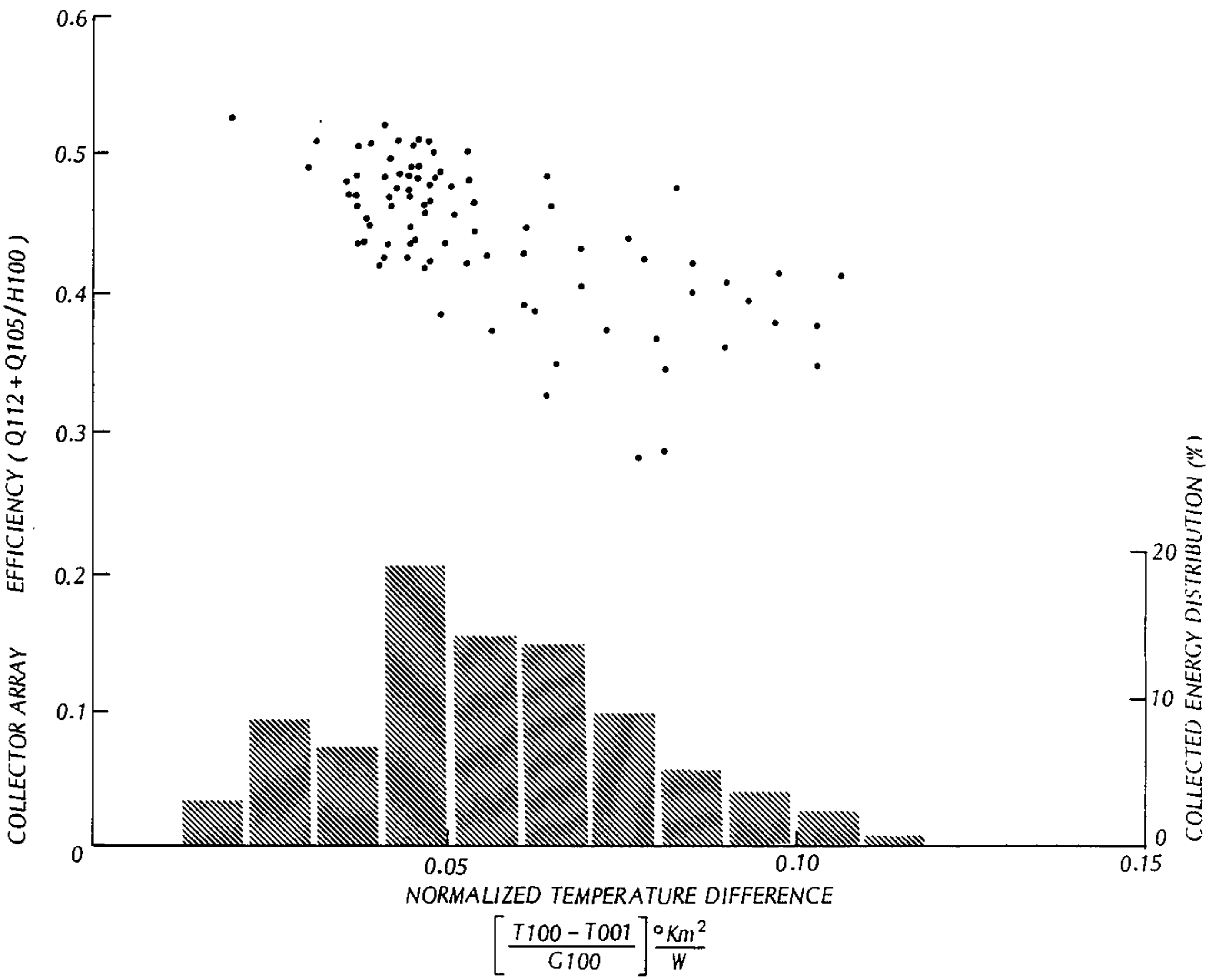


Figure 7b: Collector Array Efficiency Diagram all day for "Collector Name" at "Project Site" "Period"

Title: Collector Array Efficiency (Q112 + Q105)/H100

Scale: 2cm ≡ 0.1 ≡ 10%

X-axis

Title: Normalized Temperature Difference (N108 = [T100 - T001]/G100)

Unit: $K\,m^2/W$

Scale: 5cm ≡ 0.05 $K\,m^2/W$

Energy Histogram

Each collector efficiency plot shall include an energy histogram showing the distribution of collected energies as a function of N108 (normalized temperature difference). The N108 interval width should not be greater than 0.01 $K\,m^2/W$.

Only those points which are plotted on the diagram should be included in the calculation of the energy histogram. The histogram should be vertically scaled in order to avoid overlapping of the histogram with the data points. Sum of bar heights must add up to 100.

There should be a separate collector efficiency plot with all hourly efficiency points without the "centre of day" restriction. The plot should also include the energy distribution histogram.

Regression Analysis

i) Regression lines should be drawn provided the range of the points is sufficiently large. For each plot the x-axis will be divided into bins ($0 \leq x < 0.05$, $0.05 \leq x < 0.1$, $0.1 \leq x < 0.15$, etc. For ith bin on the x-axis, calculate the average value of x- and y-measurements as $\overline{X}_i$ and $\overline{Y}_i$, and evaluate the standard deviation S_i as

$$S_i = \left[\frac{\sum_{j=1}^{n_i} (y_j - \bar{y}_i)^2}{n_i - 1} \right]^{1/2}$$

where n_i is the number of (x, y) measurements in the ith bin. Then calculate the weighted regression coefficients m'' and b'' as follows*:

*From "Regression Analysis" by W. E. Carscallen, National Research Council, Canada, paper presented at International Energy Agency TASK VI meeting, London, Aug. 1981.

$$m'' = \frac{\left[\sum \bar{x}_i/S_i^2\right]\left[\sum \bar{y}_i/S_i^2\right] - \sum \bar{x}_i\bar{y}_i/S_i^2}{\dfrac{\left[\sum \bar{x}_i/S_i^2\right]^2}{\sum 1/S_i^2} - \sum \bar{x}_i^2/S_i^2}$$

and

$$b'' = \frac{\sum \bar{y}_i/S_i^2}{\sum 1/S_i^2} - m'' \frac{\sum \bar{x}_i/S_i^2}{\sum 1/S_i^2}$$

Plot the line $y = m''x + b''$. For each $\bar{x}_i$ and $\bar{y}_i$ plot a $3S_i$ vertical bar and indicate the centre of gravity $(\bar{x}_i, \bar{y}_i)$ by a circle; see Figure 7a for an example.

ii) Manufacturers collector curve should be included where available.

Energy Flow Arrow Diagram: There will be an energy flow arrow diagram, one for each system and one for each experiment if warranted. These plots are preferably seasonal, but may be on a monthly basis.

Auxiliary energy contribution and total load need not be drawn to scale, however, actual quantities should be indicated. See Figure 8.

Energy Supply and Delivery Bar Charts: There will be bar charts depicting energy supply and use. See Figure 9.

The following specifications should be used for the definition of titles and axes.

TITLE: AVERAGE ENERGY SUPPLY RATES FOR "COLLECTOR NAME" AT "PORJECT SITE". "PERIOD"

Y-axis

Title: Average Solar Energy Supply and Delivery Rates,

$$MJ/day - m^2$$

Scale: User defined, left side: $MJ/day - m^2$

right side: MJ/day

X-axis

Title: Months

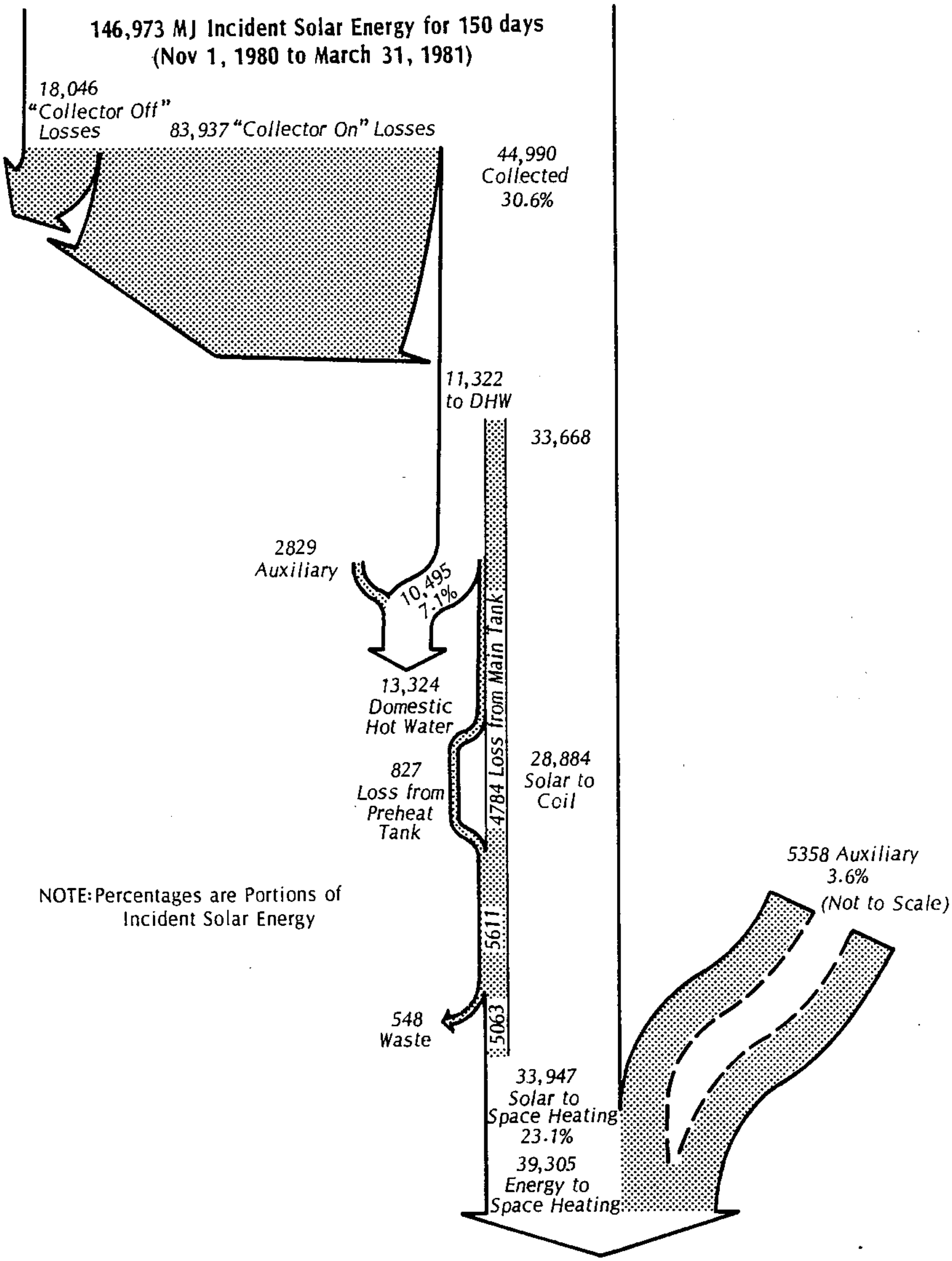


Figure 8: Energy Flow Diagram for "Collector Name" at "Project Site". "Period".

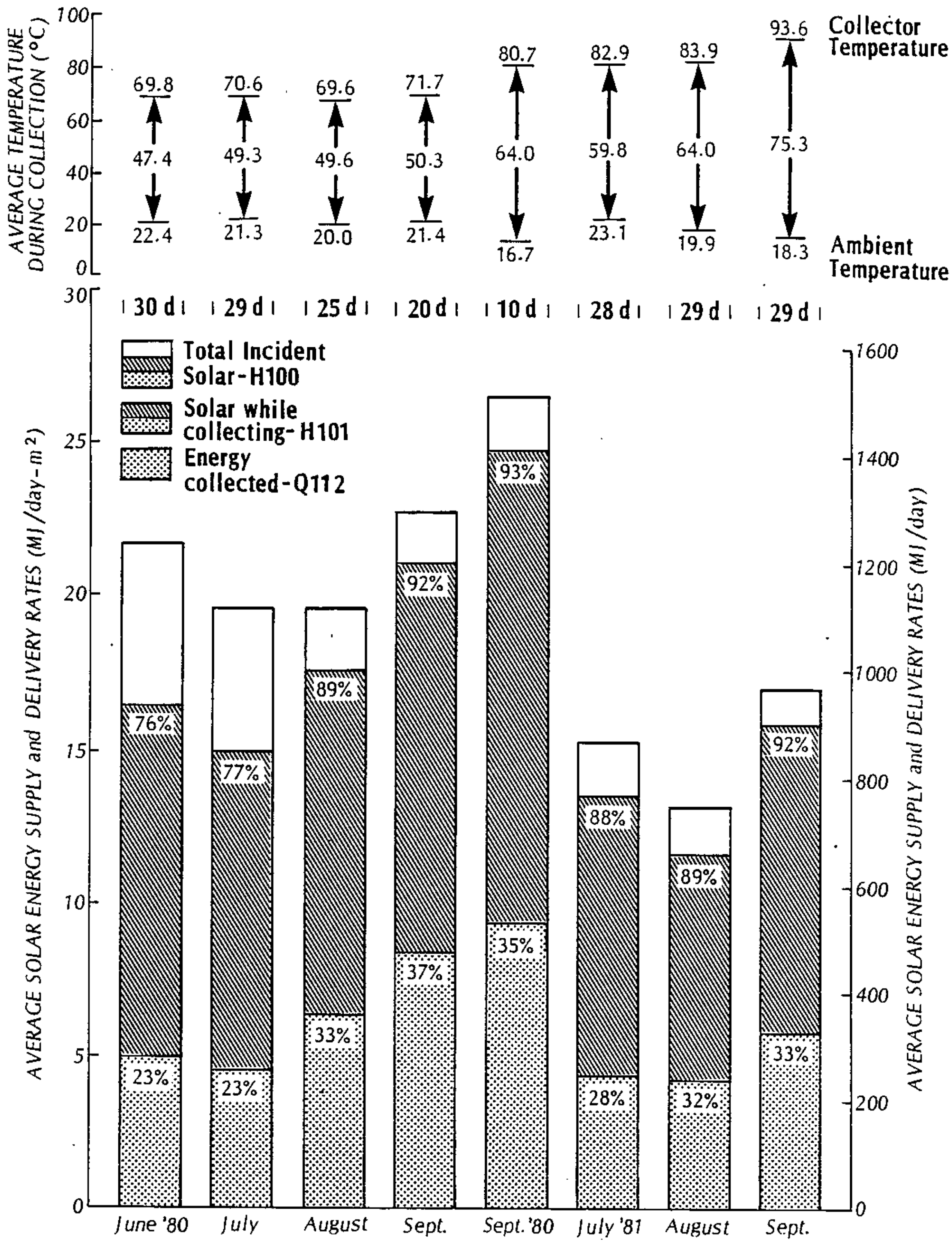


Figure 9: Average Energy Supply Rates for "Collector Name" at "Project Site". "Period".

Scale: It is recommended that the width of the bars and spaces between the bars be 1 cm and 1/2 cm, respectively. Show only percentages.

Monthly average collector operating (T100) and ambient (T001) temperatures should be included with the energy supply and delivery bar charts. Also show number of days included in each month. See Figure 9.

Average Energy Use Rate: There will be bar charts depicting energy use rate. See Figure 10. The following specifications should be used.

TITLE: AVERAGE ENERGY USE RATE FOR "COLLECTOR NAME" AT "PROJECT SITE". "PERIOD"

Y-axis

Title: Average Energy Use Rate

$$MJ/day - m^2$$

Scale: as in Energy Supply and Delivery Bar Charts above.

X-axis

Title: Months

Scale: as in Energy Supply and Delivery Bar Charts above.

Monthly average storage and ambient (T001) temperatures should be included with the energy use bar chart. Also show number of days included in each month.

Average Monthly System Efficiency and Solar Fraction: There will be a histogram depicting average monthly system efficiency (N200, see Table 4) and solar fraction (N901). Also, include average annual values. See Figure 11. The following specifications should be used.

TITLE: AVERAGE MONTHLY SYSTEM EFFICIENCY AND SOLAR FRACTION FOR "COLLECTOR NAME" AT "PROJECT SITE". "PERIOD".

Y-axis

(Left) Title: Monthly Solar System Efficiency N200 (%)

Scale: 2 cm ≡ 10%

(Right) Title: Monthly Solar Fraction of Gross Load N901 (%)

Scale: 2 cm ≡ 10%

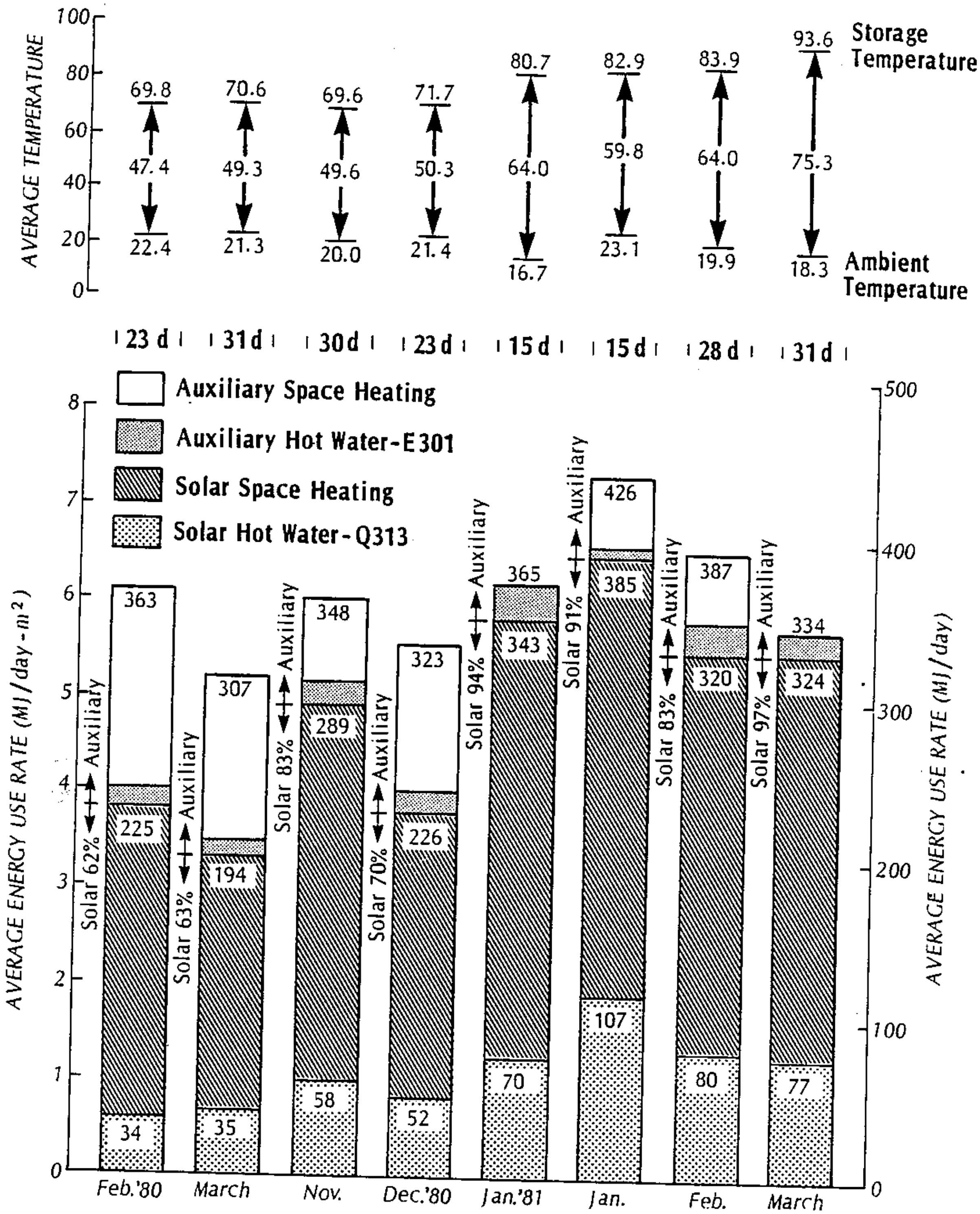


Figure 10: Average Energy Supply Rates for "Collector Name" at "Project Site". "Period".

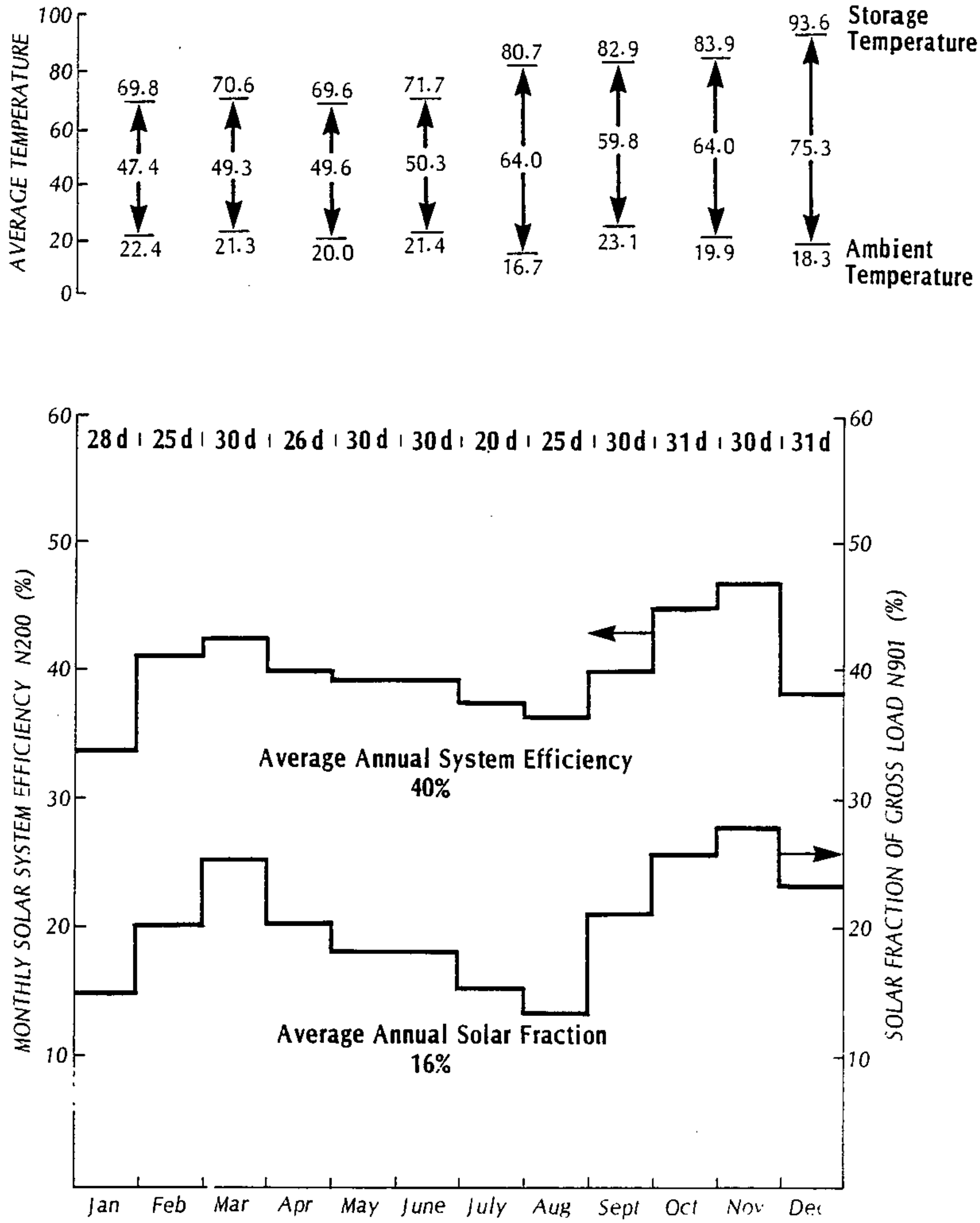


Figure 11: Average Monthly System Efficiency and Solar Fraction for "Collector Name" at "Project Site". "Period".

X-axis

Title: Month

Scale: as in Energy Supply and Delivery Bar Charts above.

Monthly average storage and ambient (T001) temperatures should be included. Also show number of days included in each month.

Additional Data

There will be several day long hourly history of key quantities. Wherever possible, tables should be present in the reports that enable the reader to reconstruct any of the required summary graphics.

Item 12. Format for Presentation of Simulation and Modelling Results and Comparison with Measured Data

In presenting this section, it would be identified as Section 7.7. The following specifications may be used for the definition of axes and titles. Suffices "s" and "m" represent simulated and measured quantities respectively. The nature of the plots and charts is clear from the titles.

Title: Simulated vs. Measured Daily Colector Output (see Figure 12)

Y-axis

Title: Q112s (MJ/day)

Scale: User Defined (MJ/day)

X-axis

Title: Q112 (MJ/day)

Scale: User Defined (MJ/day)

Title: Absolute Error of the Simulated Collector Output (see Figure 13)

Y-axis

Title: (Q112s - Q112m) (MJ/day)

Scale: User Defined (MJ/day)

X-axis

Title: (Q112m/A100) (MJ/day)

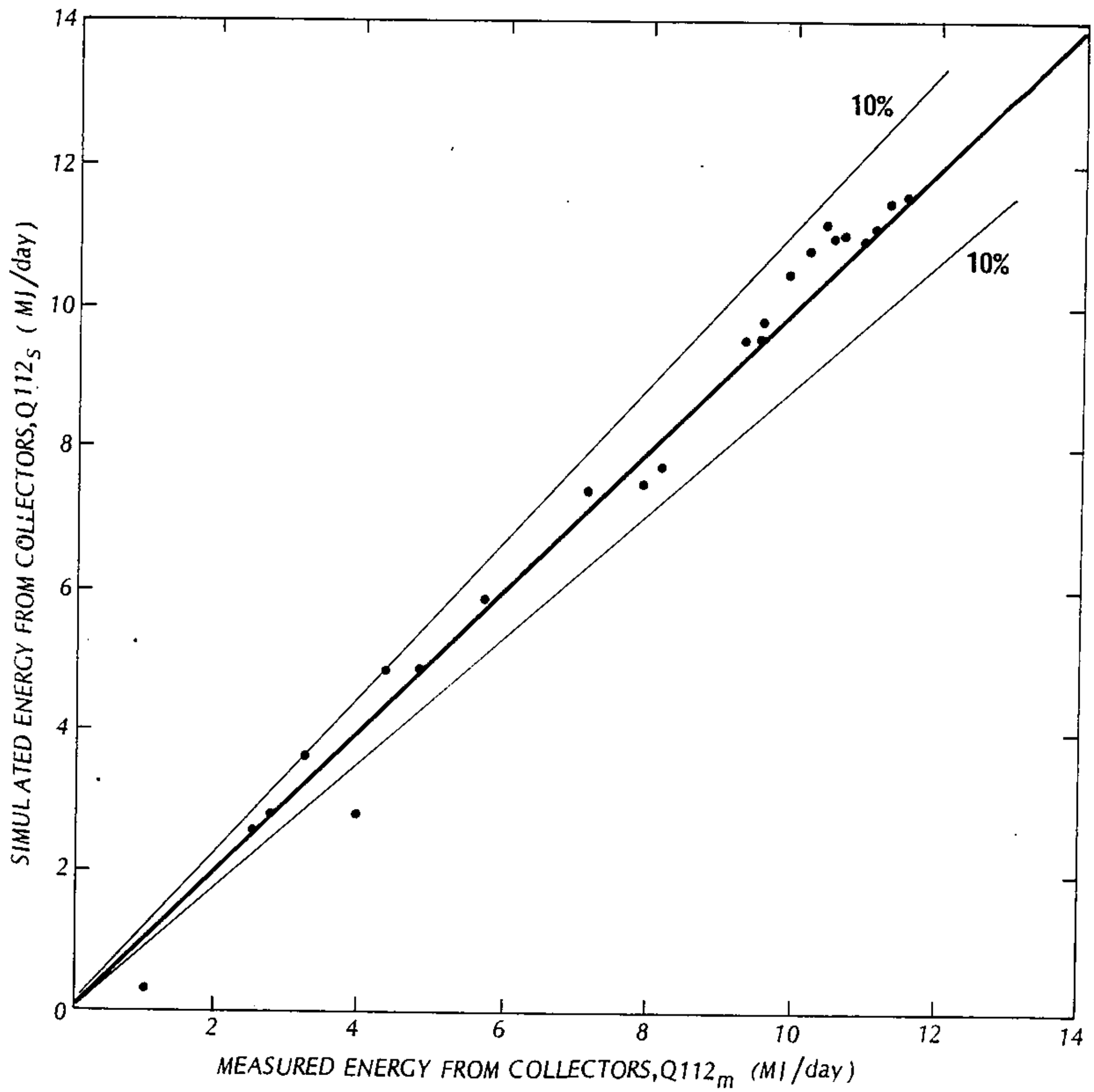


Figure 12: Simulated vs. Measured Daily Collector output for "Collector Name" at "Project Site". "Period".

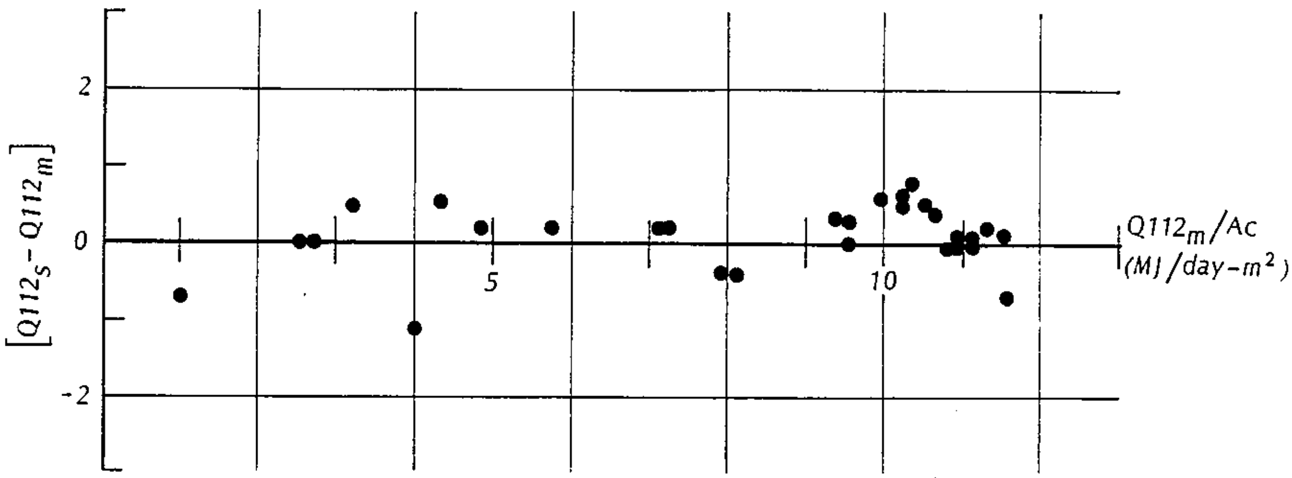


Figure 13: Absolute Error of the Simulated Output for "Collector Name" at "Project Site". "Period".

Scale: 1cm = 1 $(MJ/m^2 - day)$

Title: Relative Error of the Simulated Collector Output (see Figure 14)

Y-axis

Title: 100* (Q112s - Q112m)/Q112m (%)

Scale: 1cm = 10% (or 1cm = 1%)

X-axis

Title: Q112s/A100 $(MJ/m^2 - day)$

Scale: 1cm = 1 $MJ/m^2 - day$

Title: Monthly Measured and Simulated Collector Output (see Figure 15)

Y-axis

Title: Q112/A100 $(MJ/m^2 - day)$

Scale: 1cm = 1 $MJ/m^2 - day$

X-axis

Title: Month

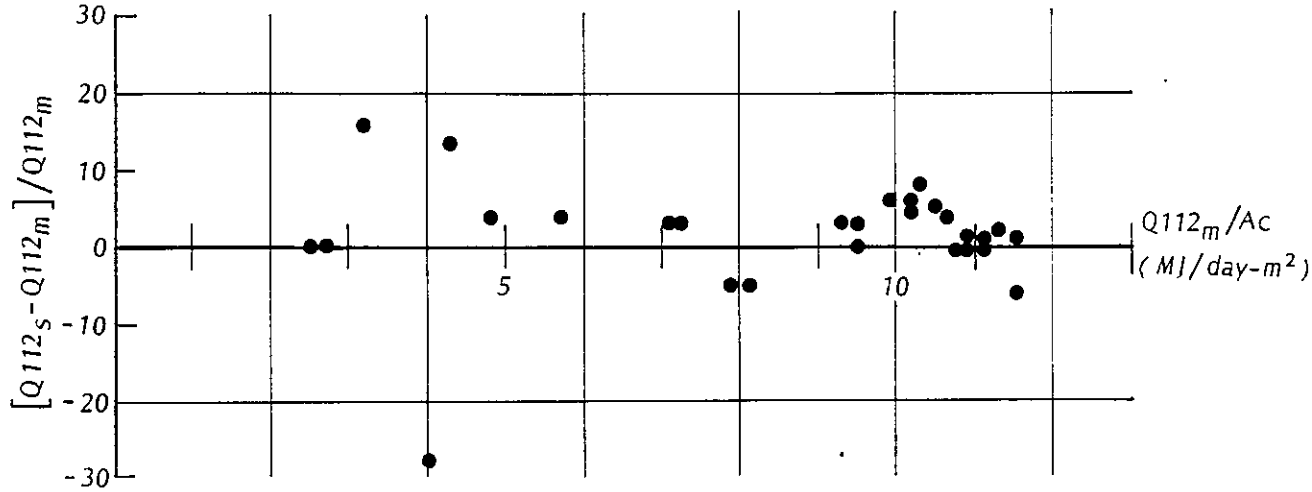


Figure 14: Relative Error of the Simulated Specific Output for "Collector Name" at "Project Site". "Period".

Scale: -

Storage

Plot of simulated and measured storage temperatures (e.g. mixed or stratified) as a function of time may be provided.

Simulation I/O Diagram

Plot of simulated Q112s/A100 *vs* H001 may be included. Scales as in corresponding measured I/O diagram.

Alternate Presentations

Comparison of other variable quantities (e.g. solar fraction, energy balance, etc.) may be presented as bar charts, histograms, phase plane plots, etc.

Item 13. Discussion (Chapter 8)

The results presented in Chapters 7 should be thoroughly discussed. Anomalies in system or subsystem performance should be explained. The discussion should refer directly to the tables and figures and should not rely on values which are not presented. Experiences described in Chapter 6 should be related to the results in Chapter 7.

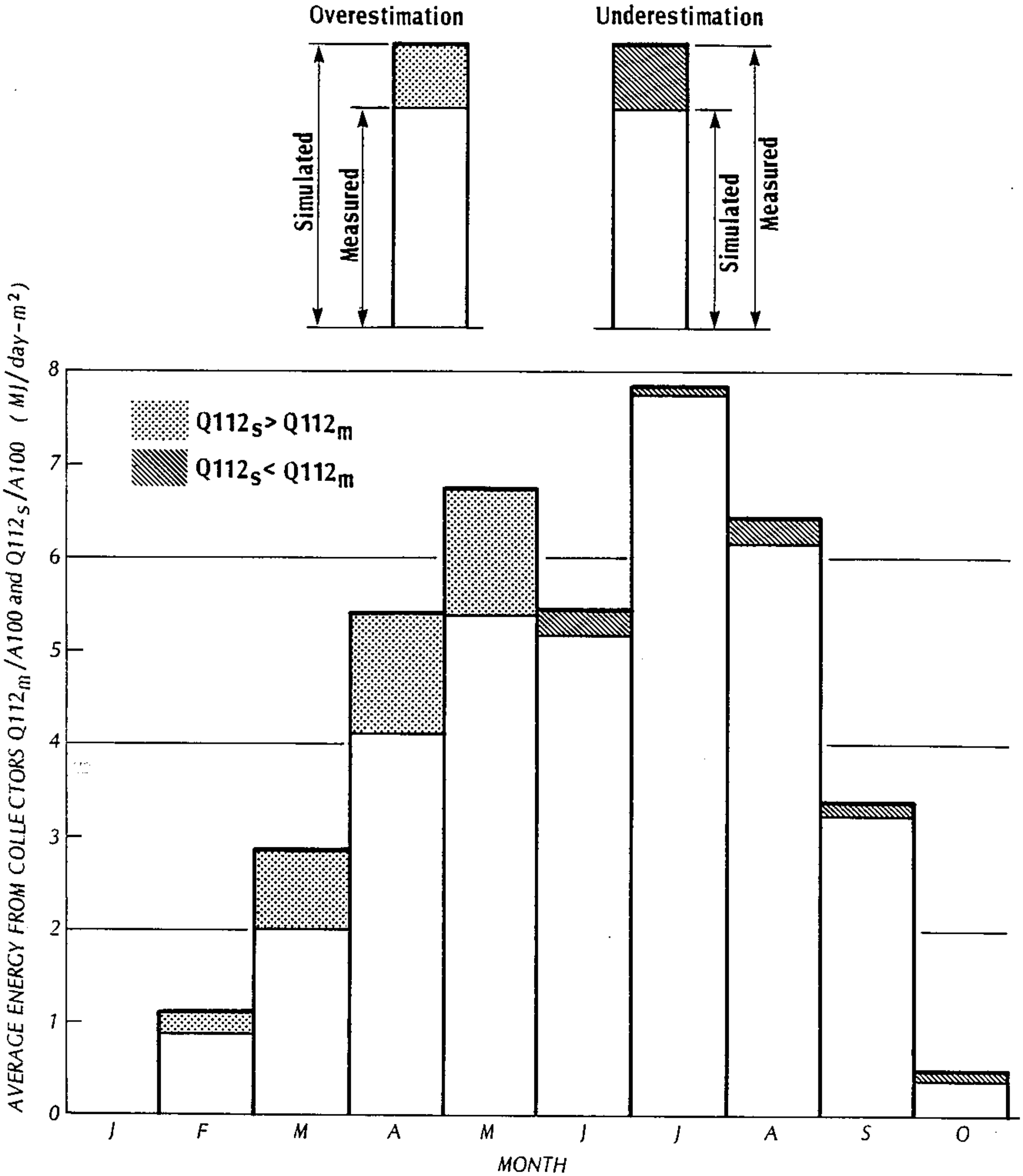


Figure 15: Monthly Measured and Simulated Collected Collector Output for "Collector Name" at "Project Site". "Period".

After reading this chapter the reader should have an understanding of the thermal performance of the system. Sufficient information should be presented such that the reader could develop his own conclusions.

Item 14. Conclusions and Recommendations (Chapter 9)

Based on the information provided in all previous chapters, the researcher should now be in a position to present his own conclusions and resulting recommendations. They should be distinct and concise with the discussion being limited to qualifying the conclusions. State the feasibility of the evaluated solar energy system and/or subsystems. Indicate the extent to which project goals have been met. If appropriate, the economic conclusions should be discussed. From the conclusions should follow the researcher's recommendations, and scope for future work.

Item 15. References and Bibliography

Information on all related backup reports is requested including specific instructions as to where they may be obtained.

Item 16. Appendices

Appendices should be included in the order they were cited in the text. It is recommended that appendices be numbered in relation to the chapter numbers (i.e. Appendices referenced in, for example, Chapter 4 should be numbered as Appendix 4.1, 4.2, etc.)

Notes on Preparation

Δ
TOP

Notes on preparation of diagrams, plots and chars

1. Please make sure that your diagrams, plots and charts fit within this rectangle

▷

2. The titles for the axes may lie outside this rectangle.

3. Use $8\frac{1}{2}$ inch by 11 inch paper, if possible.

Bibliography

International Energy Agency Task I: Reporting Format for Thermal Performance of Solar Heating and Cooling Systems in Buildings, February 1980.