IEA

SOLAR R&D

INTERNATIONAL ENERGY AGENCY

program
to develop and test
solar heating
and cooling systems

task I

reporting format

for thermal performance of solar heating and cooling systems in buildings

february 1980

INTERNATIONAL ENERGY AGENCY

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. Nineteen 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 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 15 countries and the Commission of the European Communities. The overall program is managed by an Executive Committee, while the management of the subprojects 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
- VI Performance of Solar Heating, Cooling and Hot Water Systems using Evacuated Collectors — United States Department of Energy
- VII Central Solar Heating Plants with Seasonal Storage — Swedish Council for Building Research

Collaboration in additional areas is likely to be considered as projects are completed or fruitful topics for cooperation identified.

Task I — Investigation of the performance of solar heating and cooling systems

In order to effectively assess the performance of solar heating and cooling systems and improve the cost-effectiveness of these systems, the participants in Task I have undertaken to establish common procedures for predicting, measuring, and reporting the thermal performance of systems and methods for designing economical, optimized systems. The results will be an increased understanding of system design and performance as well as reports and/or recommended formats on each of the task activities.

The subtasks of this project are:

- A Assessment of modeling and simulation for predicting the performance of solar heating and cooling systems
- B Development of recommended procedures for measuring system thermal performance
- C Development of a format for reporting the performance of solar heating and cooling systems
- D Development of a procedure for designing economical optimized systems
- E Validation of simulation programs by comparison with measured data
- F Solar-assisted low-energy dwellings

The participants in this task are: Belgium, Denmark, Germany, Italy, Japan, the Netherlands, New Zealand, Spain, Sweden, Switzerland, United Kingdom, United States, and the Commission of the European Communities.

reporting format

for thermal performance of solar heating and cooling systems in buildings

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This report is part of the work within the IEA Solar Heating and Cooling Program, task I: Investigation of the Performance of Solar Heating and Cooling Systems, subtask C: Reporting Format.

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Preface

A rapidly growing number of projects are undertaken in the field of solar energy which in turn means that there is an enormous flow of reports and that the majority of researchers are fairly new in the field. Because of the foreseen shortage of primary energy in the future, the development of the solar energy technique needs to progress fast. In this situation there is a special need for an effective exchange of information that enables the results from projects to be quickly distributed and used. It is felt that a reporting format can be of some help.

Several reporting formats have been developed in recent years. However, the objectives of these formats have been rather specific. Most have dealt with the reporting of experimental data for the evaluation of the performance of a particular system (or component). With the increasing interest in system studies, both experimental and analytical, and the concern with computer program validation, a new set of objectives for a reporting format have evolved. These new objectives are discussed in the introduction to this reporting format and are the impetus for establishing a more encompassing format. It should be noted that the previous formats are incorporated whenever possible to avoid unnecessary duplication of effort.

The preparation of this reporting format was based upon the original Reporting Format for Solar Heating and Cooling Systems in Buildings, which was developed and implemented by the CCMS* Solar Energy Pilot Study.

Valuable comments have been recieved from the participants in the IEA Task I group and from the CCMS format group.

Thanks are due to professor Redfield Allen, University of Maryland, U.S.A., and professor Ingemar Höglund, Royal Institute of Technology, Sweden, for their support and constructive criticism.

Finally, thanks are also extended to Ulla Save-Öfverholm, Swedish Council for Building Research, for her editorial help and unfailingly gentle pressure which kept the work with this format moving.

This reporting format contains a great deal of information. However, it is inevitable that in the implementation of this format that omissions and errors will become apparent.

It is intention that this document shall be used for a period of 2–3 years, whereafter it will be reviewed. Therefore, it is recommended that criticisms of this format be sent to the IEA contact persons so that an improved version may be produced in the future.

Ove Jørgensen
Operating agent, task I

*NATO Committee on the Challenges of Modern Society.

Table of contents

Introduction

Objectives

The following are the objectives of this reporting format and are not necessarily presented in order of importance.

1 To ensure that sufficient information is provided to enable the reader to make his own assessment of the thermal performance of a solar system.
2 To provide the author with a checklist and guide for reporting. This is to ensure the completeness of the report, but must not prevent the author from making his own comments and analyses.
3 To establish a common form in reporting system studies, both experimental and analytical. Due to the increased interest in validation, it has become necessary to report results from experimental and analytical studies in comparable formats. This facilitates cross comparisons and ensures that the reported information is relevant to other work in the field.
4 To define system information which has broad applicability. Often the system characteristics reported by an experimenter will not be sufficient for detailed modeling of that system. This limits the applicability of the test results to validation studies.
5 To present meaningful performance indicators. In describing the performance of a system or subsystem, one must use consistently defined indicators so that the results from various studies can be compared. The performance indicators should be detailed enough to avoid ambiguity yet general enough to be applicable to most systems being studied.

Scope

To accomplish the above objectives, the reporting format must offer sufficient detail to establish uniformity in reporting, yet maintain sufficient flexibility to allow for projects of different types. The format is intended for both experimental and analytical studies as well as for reports of any length from some ten pages and longer. However, due to the comparative nature of many analytical studies, it may in those cases be necessary to modify the contents of certain chapters. It is not intended to limit the creativity of researchers but only to provide simple guidelines which can be used to structure a report. Often, a reporter will accidentaly omit a vital piece of information which is necessary for the reader to appreciate fully the meaning of the results. Before writing a report it is a valuable exercise to asses thoroughly a few reports on similar studies. This format provides a »checklist» of items which should be included in a complete report. It should be noted that although this document is primarily intended as a format which should be followed closely it is written to be useful as a guidance for a broader range of reports. These lists will not only assist the reporters in supplying the necessary information in their reports, but in many cases will give guidance in the initial formulation of their projects. Because of this possible benefit, it is suggested that the researcher carefully studies this document as early in the project as possible.

This format is not meant to be innovative. Its purpose is to enhance the communication within the solar community and not to develop new concepts in report writing. The reporter should realize that the results he presents are part of a much larger effort to establish the practicality of solar energy.

Sections

The reporting format can be reduced to five basic areas.

The first is the description of the project and the system being studied. This is accomplished in Chapters 1, 2 and 3. In these chapters detailed descriptions of various aspects of the system are described.

Chapter 5 then calls for the definition of the various factors which are to be reported and a description of the method for obtaining those factors.

Chapters 6 and 7 describe how these factors should be reported, suggest several possible comparisons and encourage the discussion of experiences.

Chapter 8 describes the economics associated with the project and may or may not be of importance depending on the nature of the project. The rest of the main text should discuss the results, conclusions and recommendations concerning the project.

Each chapter or subchapter of the format is also organized in a specific way. A general discussion of the content of that particular section is given followed by a series of dotted items. The dots indicate action items which should be included in the report, if applicable. They should however not limit the reporter to only those topics.

Throughout the format figures are used to illustrate different items. These figures have been redrawn after figures in published reports and in some respects they may differ considerably from the written recommendations. Thus, the figures are not intended as models to be followed strictly, but rather as illustrative hints.

If at all possible, the titles used in this reporting format should be implemented with little or no modification. This will allow a reader familiar with the format to find the material of interest.

Also, in an effort to promote uniformity in the reporting of results, it is required that values be presented with SI units. Beckman et al. (1979)* discuss the proper use of these units.

*This reference is reprinted as an appendix in this document.

1 Reporting format

The following is a discussion of the reporting format using the titles and numbers recommended for future reports. Each section contains a brief discussion of the type of material which should be included. Following that description there will be a list of dotted items which are considered essential items. 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 the reporter.

1.1 Abstract

A very brief abstract should be included which would be appropriate for inclusion in a listing of abstracts. It should be substantially shorter than the summary.

- ☐ Description of Project
- ☐ Major Results
- ☐ Major Conclusions

1.2 Preface and acknowledgements

The contents of this chapter are left to the discretion of the reporter. However, the author should acknowledge contributing authors and also list the names and addresses of those people who should be contacted for additional information on the project. It may also be beneficial to include a list of additional reports and an explanation of how to obtain those reports.

1.3 Table of contents

The table of contents should be detailed enough to allow the reader to identify the sections of their interest. The table of contents of this document contains a table of contents of the suggested reporting format. The reporter should in his report use the same numbering and titles whenever possible. It may be necessary for the reporter to add additional levels of numbering, depending upon the complexity of the report.

1.4 Summary

The summary should be directed to the layman. It should provide concise yet sufficient detail for a preliminary understanding of the project. The summary should stress the thermal performance results and present the main conclusions. Figures 1.1–1.4 are examples of the type of visual aids which should be used in the summary.

- ☐ Project objectives.
- ☐ Brief description of environment and climate.
- ☐ Diagram showing solar insolation and ambient temperature.
- ☐ Brief description of the building.
- ☐ Artist's view or photo of building.
- ☐ Brief description of solar energy system including collector aperture area, absorber type, type of glazing and number of panes, type of working fluid, storage type and volume and auxiliary systems, orientation and tilt of collector.
- ☐ Simplified drawing of solar and HVAC system.
- ☐ Brief description of operation modes.
- ☐ Brief description of evaluation program.
- ☐ Major results presented in diagrams.
- ☐ Major conclusions.

1.5 Introduction

Here the author can properly introduce the objectives and background of the project. Sufficient detail should be given so that the reader can understand the history of the project and why the project was undertaken.

- ☐ Objectives and project philosophy.
- ☐ Project organization.
- ☐ Conventional use of energy in the area or the country.
- ☐ Typical amount of energy use in similar buildings.
- ☐ Cost of conventional energy.

Project objectives

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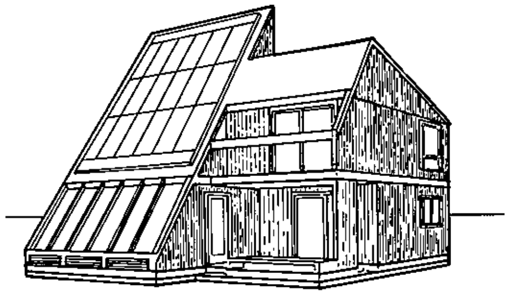

Figure 1.1. Building.

Location

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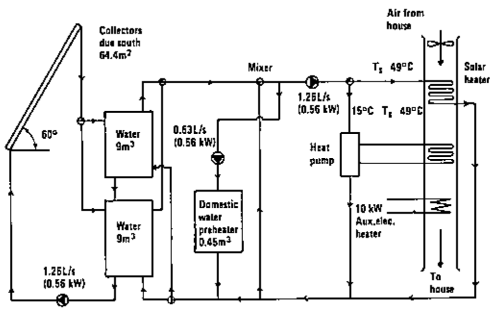

Figure 1.2. System.

Climate, average year

Horizontal insolation, year. . . . .
. . . .
Horizontal insolation, June . . . .
. . . .
Horizontal insolation, Dec. . . . .
. . . .
Mean amb. temp, year . . . .
. . . .
Mean amb. temp, heating season . . . .
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Building and system description

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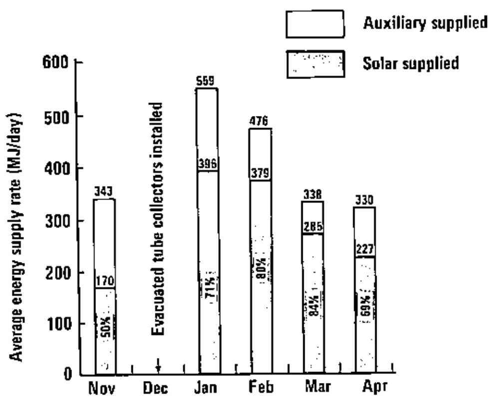

Figure 1.3. System performance.

Performance (year 19XX–19XX)

Total solar incident on collectors . . . .
. . . .
Solar energy utilized . . . .
. . . .
Electric energy saved . . . .
. . . .
Fossil energy saved . . . .
. . . .
Operating energy . . . .
. . . .
Auxiliary energy . . . .

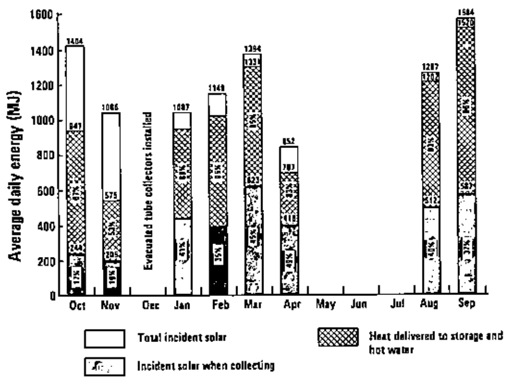

Figure 1.4. Solar system efficiency.

Discussion and conclusions

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. . . .

Figure 1.1–1.4. Example of contents and illustrations in the summary.

2 Description of the surrounding environment

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 Appendix 12.

2.1 Description of location and site

- ☐ General description of location including distance to nearest larger city.
- ☐ Latitude, longitude and altitude of the site.
- ☐ General description 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.
- ☐ Shift in solar time.

2.2 Description of climate

- ☐ 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 is 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 (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).

Figure 2.1–2.2. Different ways of illustrating how the collectors are shaded by the surroundings. The collector in figure 2.2 will be shaded from sunrise to 9–9.30 in the summer and to 10.30 in the winter. (Section 2.1)

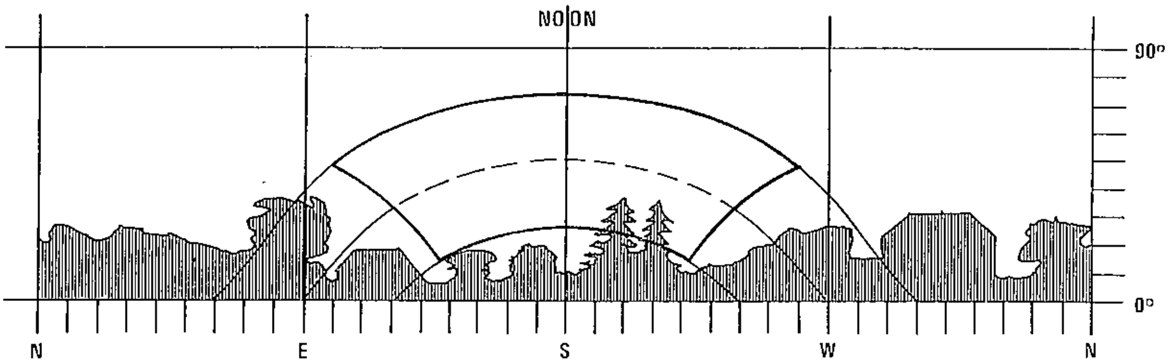


Figure 2.1

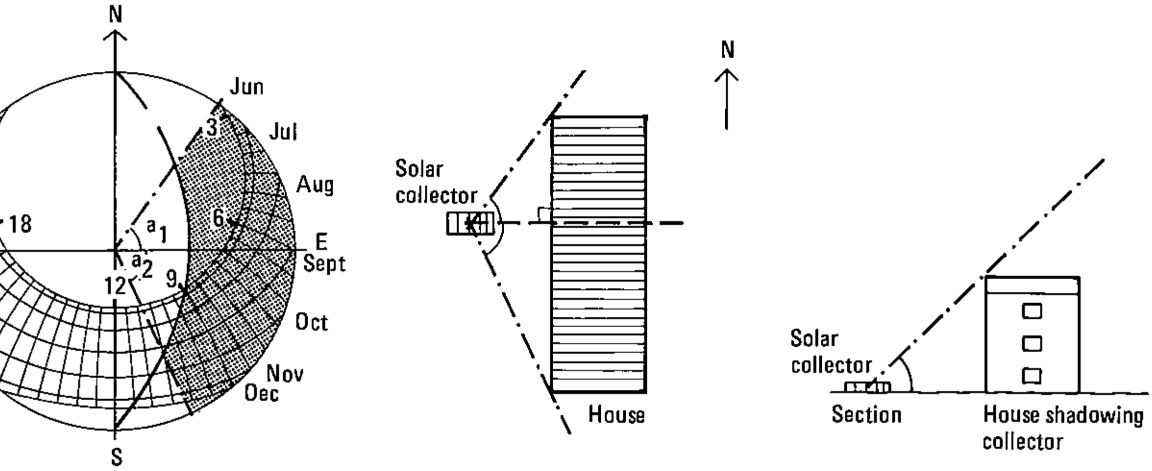


Figure 2.2

3 Description of the overall system

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 presented in Chapter 7.

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 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. The Chapter 3 is then completed by section 3.4 which should provide a systematic description of the modes of operation.

When reporting on a true passive system it would be artificial to divide the description into building and solar energy system (section 3.1 and 3.2) and therefore the author should feel free to change those sections.

Depending on the system being reported, the author should emphasize such sections as he sees fit.

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 Appendix 12.2. This appendix should also be used for presenting information which will not necessarily affect the understanding of the results.

- ☐ 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 the overall system as a whole indicating interactions between the building and the energy system. This is an important item for systems which combine active and passive features. The description of the actual solar energy system should be provided in section 3.2.
- ☐ Simplified section through the house showing main features of the overall system.

3.1 Description of the load (building)

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. For an active system the building may be described very briefly.

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

Regarding passive systems substantial detail should be given in this section. In this case it may also be appropriate briefly to describe a reference house, i.e. a conventional house with similar living area and comfort standard, because the solar house without the solar features is often not meaningful to use as a reference.

Drawings should be used frequently.

- ☐ Hot water load profile.
- ☐ Type of occupance or use.
- ☐ Indoor climate – reference indoor (defined in Section 5.1) temperature and humidity.
- ☐ General description of building construction and design including photo or drawing. Indicate which spaces are continually occupied and which are used for equipment, data collection devices, etc. If an analytical study is being reported, describe assumptions about the conditions described above.
- ☐ Space heat loss factor (UA-value) in W/K, i.e. building thermal losses due to transmission and ventilation per degree Kelvin temperature difference. Indicate if this value was calculated or measured.
- ☐ Special measures taken to achieve air tightness of the building.
- ☐ Relationship of collectors to building structure.
- ☐ Effects on loads due to heat losses from the solar energy system.
- ☐ Description of passive system including drawings showing collector, storage and energy distribution.

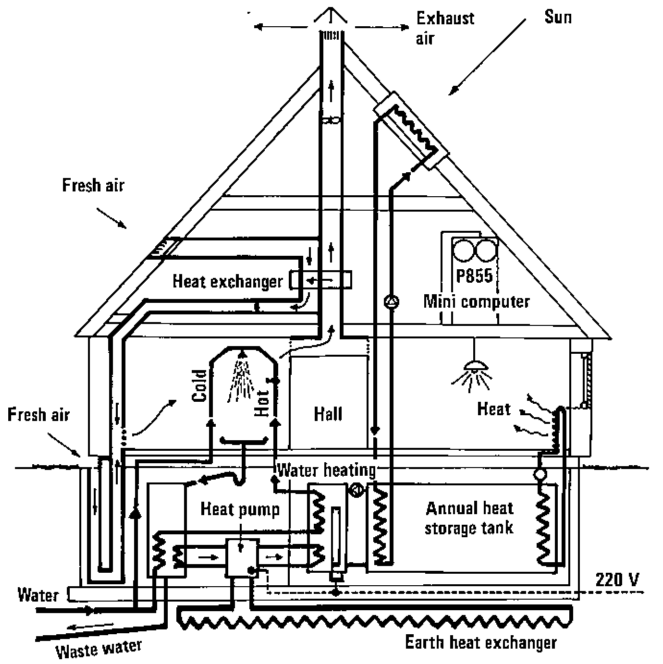


Figure 3.1

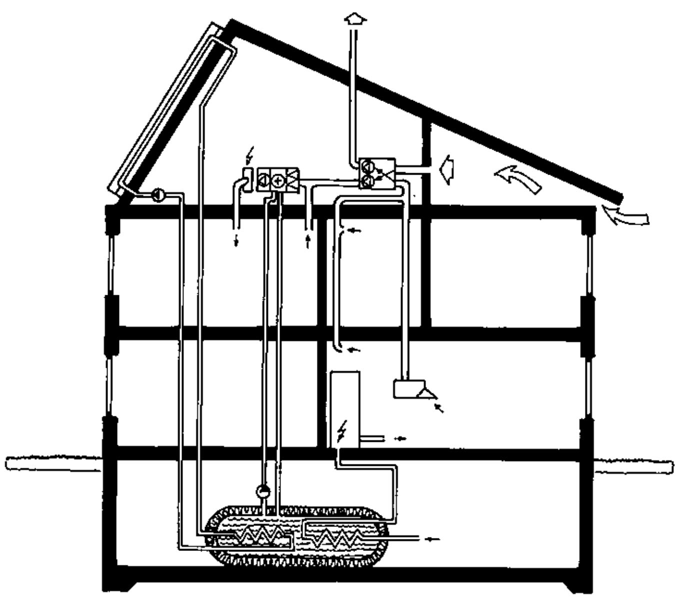


Figure 3.2

Figure 3.1–3.2. Examples of active system schematics. (Section 3)

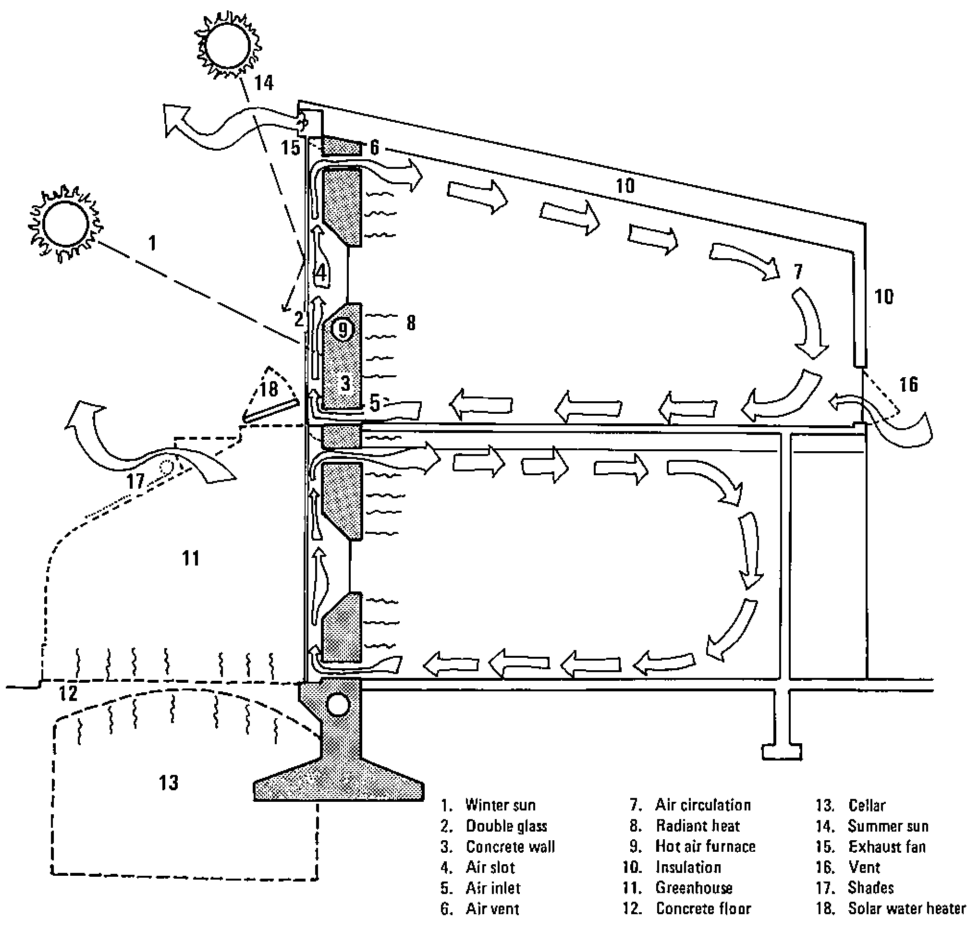


Figure 3.3. Example of passive system schematic. (Section 3)

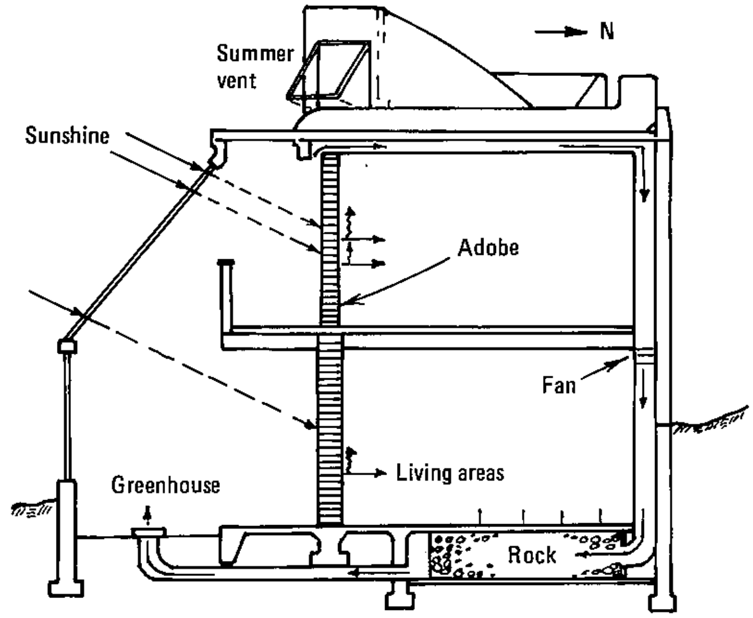


Figure 3.4. Example of section through a passive building with an attached greenhouse. (Section 3)

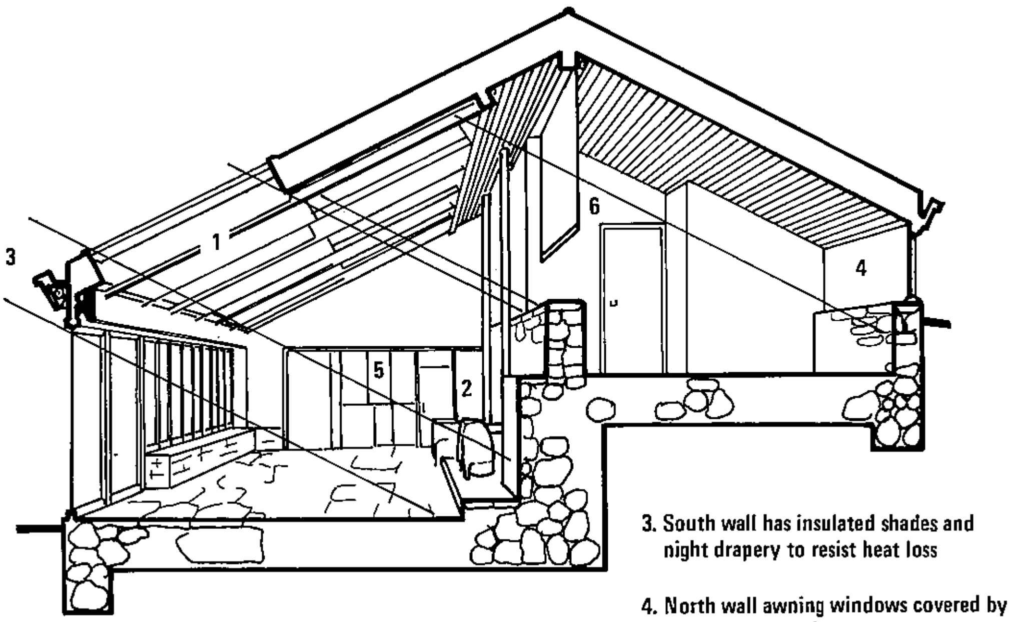


Figure 3.5. Example of section of a passive building with a direct gain system. (Section 3)

Thermal properties of structure

Area:				U-value:		
Orientation:				Absorbance (outside):		
Tilt:						
Layer from inside	Material	Thickness etc	m^2K/W[1]	kg/m^3	kJ/kgK	Comments

1) Weighted in case of compound layers

Thermal properties of windows

Orienta-tion	Area m^2	U-value W/m^2K	Isolating shutters			Comments[2]
			Type	U-value[1]	h/day	

1) U-value for windows and shutters (W/m^2K)
2) Fixed or opening windows - coating, shading etc

Figure 3.6. Examples of tables for presenting building construction properties. (Section 3.1)

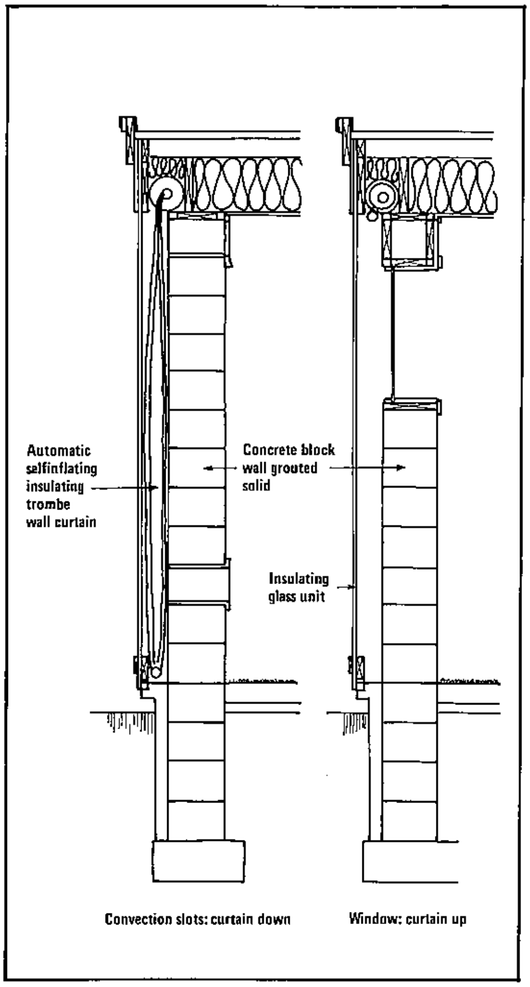


Figure 3.7. Examples of drawings of details from a passive building with indirect gain system. (Section 3.1)

- ☐ Thermal properties of structure such as thermal resistance density and heat capacity. Specify for each building element: area, orientation, tilt, U-value, outside absorbance and thickness.
- ☐ Thermal properties of windows: U-value, orientation and area.
- ☐ Thermal properties of insolating shutters: type, U-value and hours per day in use.

3.2 Description of the solar and HVAC systems

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. Either approach should employ schematics and photos liberally.

The description below applies to a detailed 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 consistence 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 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.

The set of subsystems presented below is thought to be applicable to many reports, but the author should feel free to use an alternative system breakdown as he sees fit.

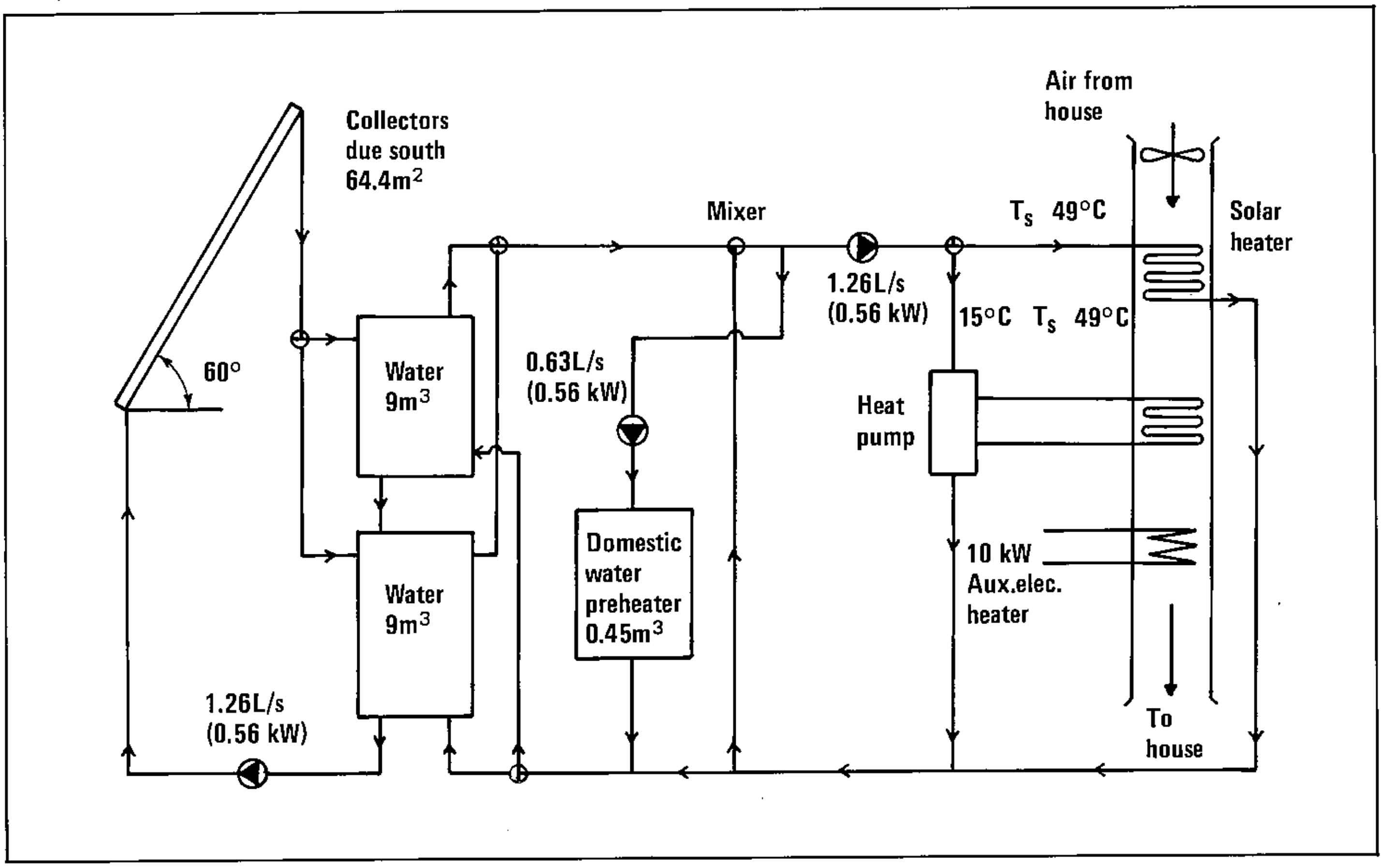


Figure 3.8. Example of a solar energy system schematic. (Section 3.2)

☐ Description of the solar and HVAC system on the system level.
☐ Schematic showing the solar and HVAC system.

3.2.1 Solar collector array

☐ Description of the solar collectors.
☐ Freeze protection method.
☐ Table with key parameters.
☐ Collector efficiency curve if available.
☐ Cross section.
☐ Drawings showing special features.
☐ Photos.

Solar collector key parameters

Collector type, brand.
Collector type.
Working fluid.
Collector aperture area.
Collector gross area.
Orientation (azimut).
Tilt.
Collector efficiency curve* .
  Intercept $F_R\ (\tau\alpha)$
  Slope $F_R \cdot U_L$
Incident angle modifier* .
Number of panes in the glazing.
Maximum outlet temperature.
Reflectors.

3.2.2 Heat storage

☐ Description of heat storage.
☐ Table with key parameters.
☐ Drawings showing special features.

Heat storage key parameters

Storage type	
Gross volume	m^3
Mass of working media	kg
Heat capacity	J/kg · K
Maximum temp.	°C
Minimum temp.	°C
Heat loss factor (UA)	W/K
Stratification yes/no	

3.2.3 Other subsystems

Other subsystems which it might be appropriate to describe in separate subsections are:

☐ The energy distribution system (e.g. centralized systems).
☐ Heat pump.
☐ Cooling machine.

*See ASHRAE standard 93–77 (1977).

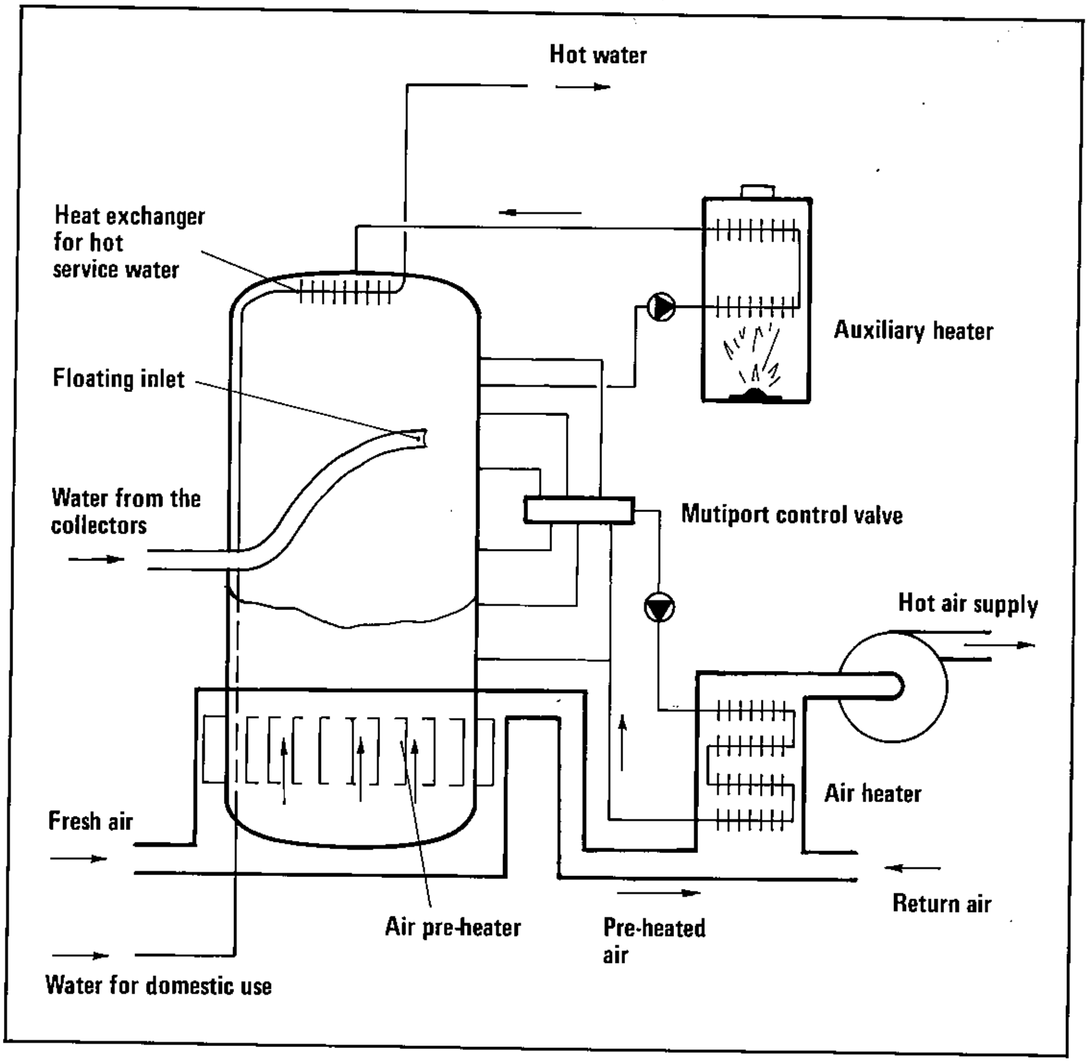


Figure 3.9. Example of schematic of storage and energy distribution subsystem. (Section 3.2.3)

3.3 Description of the control system hardware

Controls can play a major role in the performance of a system. It should therefore 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 Appendix 12.2. This section describes only the physical control system. Control strategies and modes of operation should be presented in Chapter 4.

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

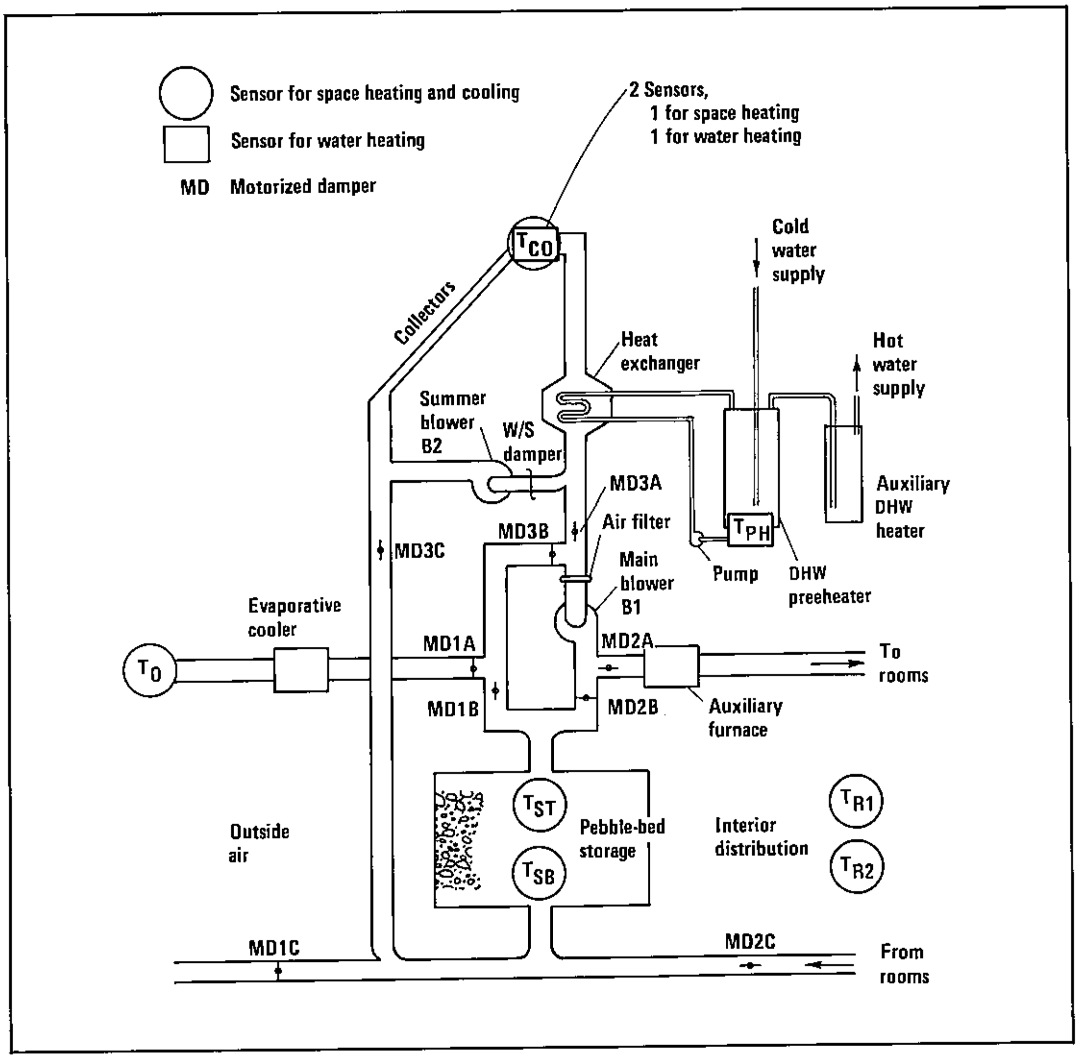
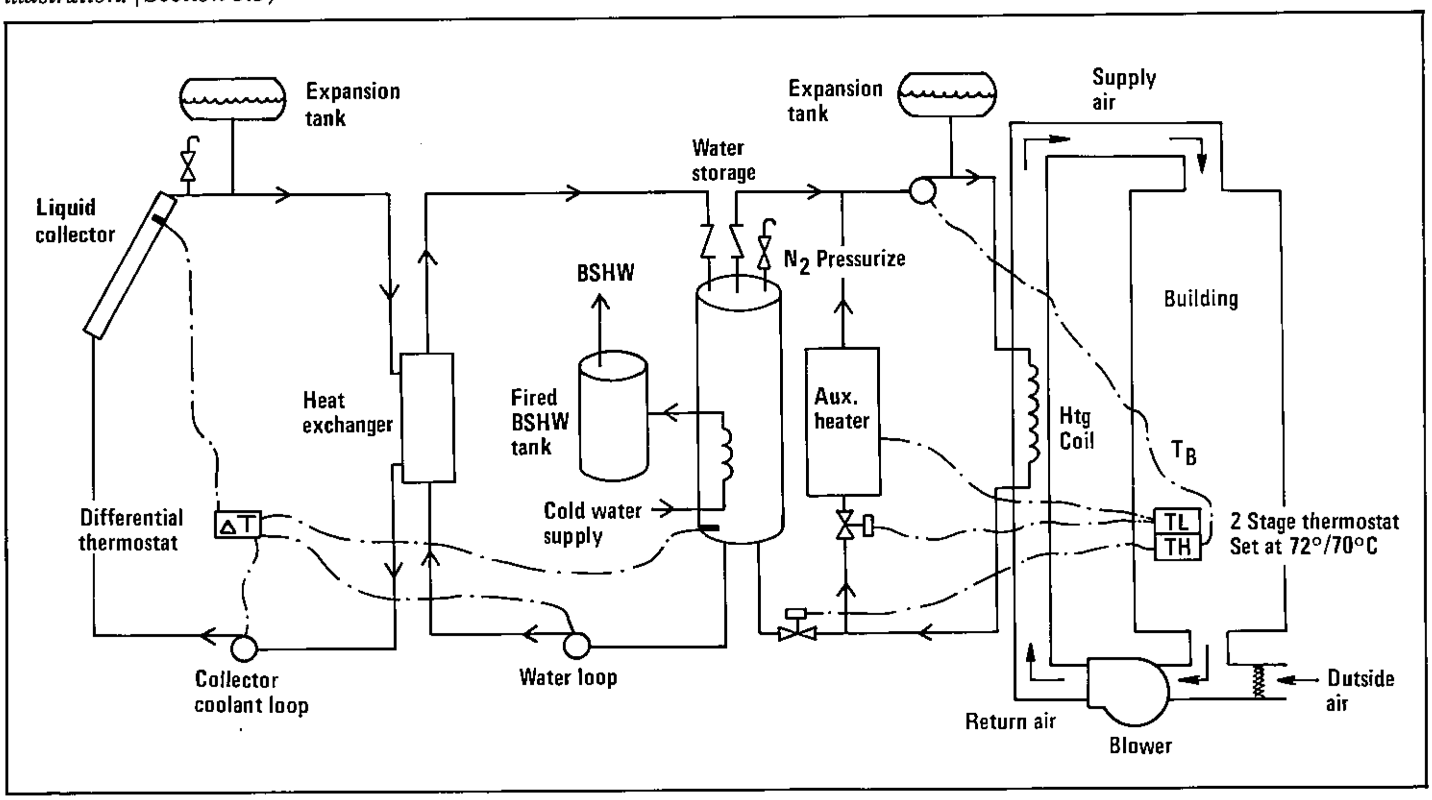


Figure 3.10. Location of control sensors and dampers. (Section 3.3)

Figure 3.11. Control system illustration. (Section 3.3)



4 System operation

Chapter 3 mainly dealt with a static description of the overall system. In this chapter a detailed description on how the system is being operated should be provided.

- ☐ Brief description of the system operation.
- ☐ Comment on the philosophy underlying the control strategy.

4.1 Operating modes

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.

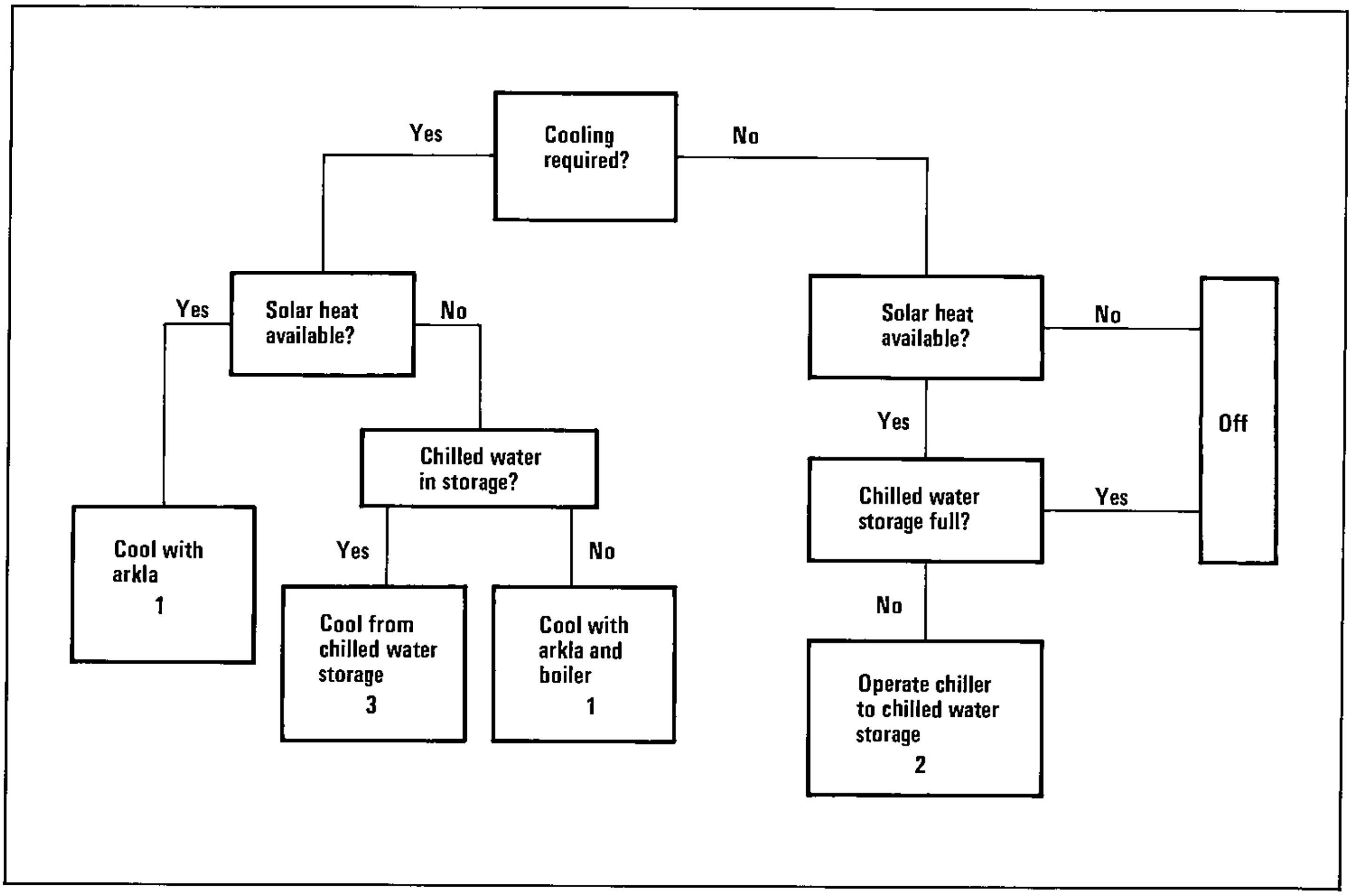
- ☐ Description of the mode of operation.
- ☐ Diagram showing flows of working fluid together with temperature levels. The diagram should be supplemented by a brief text which includes a name and a designation of the mode together with the condition under which the mode is working.

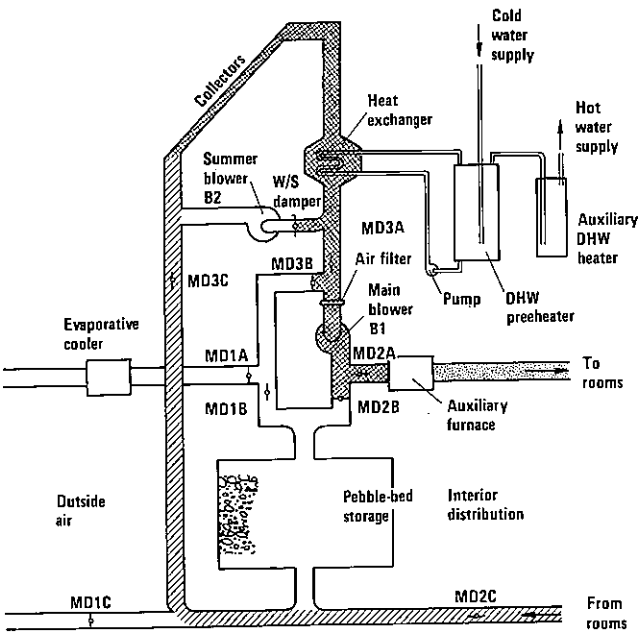
4.2 Control strategy

The researcher 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, such as that shown in Figure 4.10, may be adequate when supplemented with a breif discussion. However, if proportional or other types of control strategies are used, substantial explanation may be required.

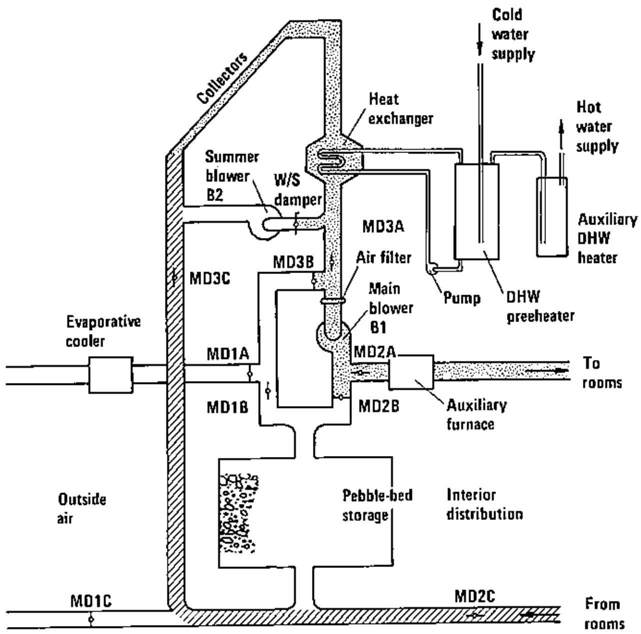
- ☐ Description.
- ☐ Truth table.

Figure 4.1. One way of presenting the control strategy. (Section 4.2)

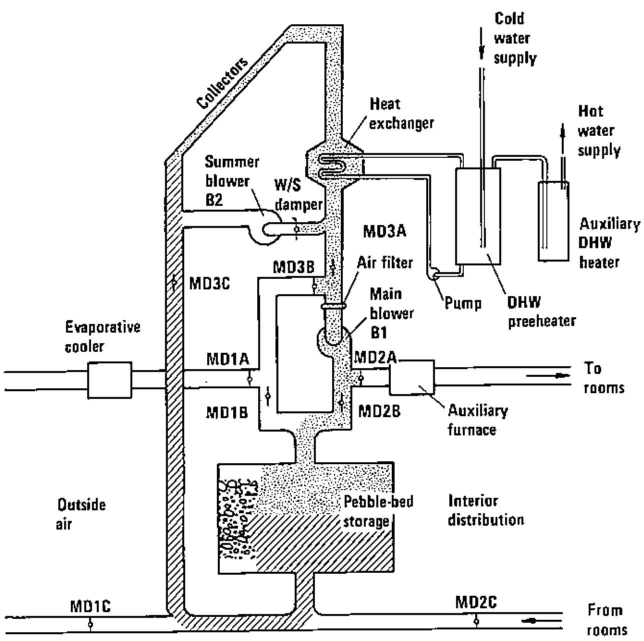




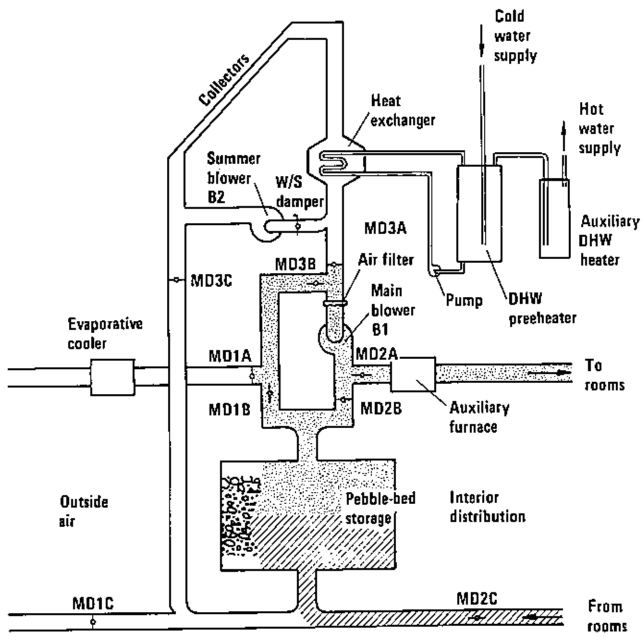
Heating from collector and auxiliary furnace
Figure 4.2



Heating from collector
Figure 4.3



Storing heat
Figure 4.4

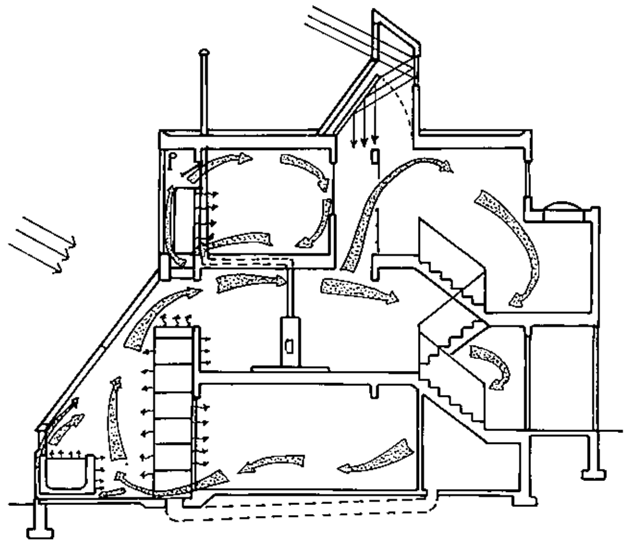


Heating from storage
Figure 4.5

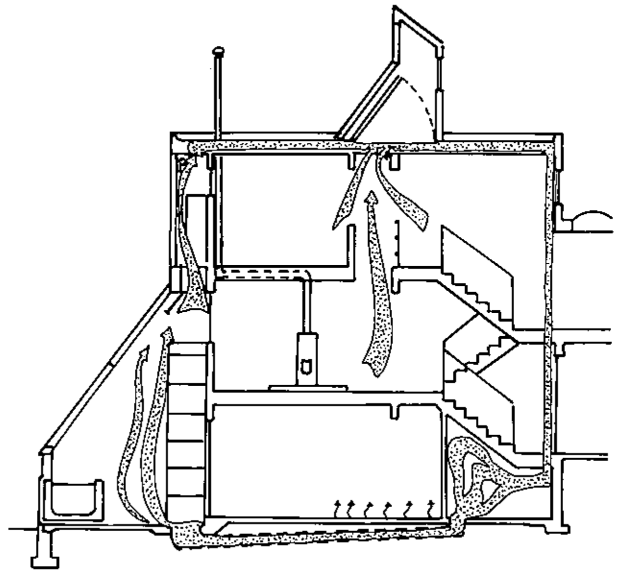
MD Motorized damper

Hot air   Cold air   Warm air

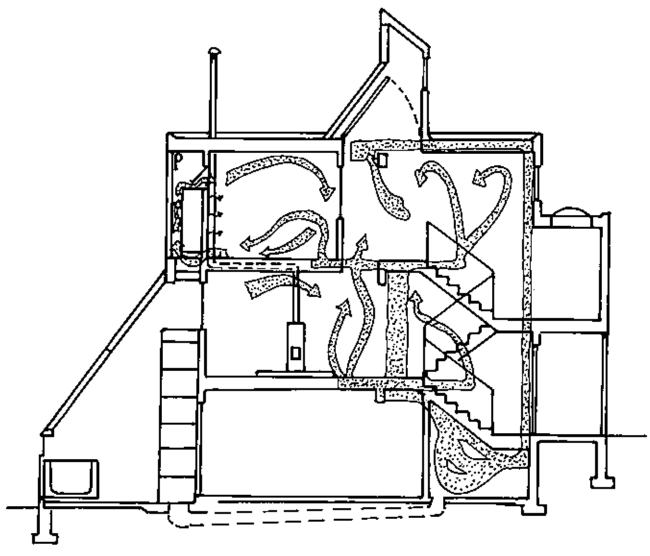
Figure 4.2–4.5. Examples of illustrations of operating modes. The operating conditions should be presented toghether with the figures. (Section 4.1)



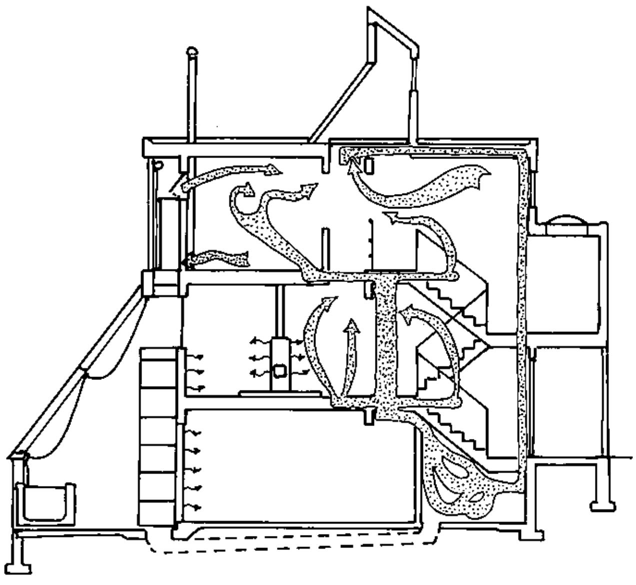
Direct radiation and natural convection
Figure 4.6



Venting to remote storage
Figure 4.7



Circulation and distribution
Figure 4.8



Night-time operation
Figure 4.9

Figure 4.6–4.9. Example of operating mode illustration for a passive system. (Section 4.1)

Winter modes	Input conditions for sensor signals: $T_{SB} > T_{ST}$	$T_{ST} < T_R$	$T_{ST} << T_O$	$T_{CO} > T_{SB}$	$T_{ST} > T_O$	W/S	$T_{CO} < T_R$	$WT_{SB} > T_{WB}$	Aux Off	$T_{R2} > T_R$	$T_{R1} > T_R$	Output to controlled elements: B1	HWPH enable	EVC	Aux	MD 1 AB	MD 2 ABC	MD 3 ABC	MD 1C
Heat From Collector	x	x		x		1	0		0	0	1	1	0	0	0	0	1	1	0
Heat from Collector +Auxiliary	x	x		x		1	0		0	1	1	1	0	0	1	0	1	1	0
Cool Auxiliary Heat Exchanger (AHX)	x	x		x		1	0		1	0	x	1	1	0	0	0	1	1	0
after Heat From Collector +Aux	x	x		x		1	0		1	1	1								
Heat From Storage (HFS)	x	0		x		1	1		x	0	1	1	0	0	0	0	1	0	0
Cool AHX after HFS +Aux	x	x		x		1	1		1	0	x								
HFS +Aux . . . storage cold	x	1		x		1	1		0	0	1	1	0	0	1	0	1	0	0
HFS +Aux . . . high demand	x	x		x		1	1		x	1	1								
Collector to Storage Only	1	x		1		1	0		0	x	0	1	0	0	0	0	0	1	0
	1	x		1		1	0		1	1	0								
Collector to Storage with	0	x		1		1	0		0	x	0	1	1	0	0	0	0	1	0
Hot Water Pump Enabled	0	x		1		1	0		1	1	0								
Do Nothing-Winter	x	x		x		1	1		0	x	0	0	0	0	0	0	0	0	0
	x	x		0		1	x		0	x	0								
Summer Modes																			
Cool From Outside	x		x		x	0		1	0	1	0	1	1	0	0	1	1	0	1
Cool From Evaporative Cooler	x		0		x	0		0	0	1	0	1	1	1	0	1	1	0	1
Cool From Storage	x		1		x	0		0	0	1	0	1	1	0	0	0	1	0	0
Cold Charge . . . $T_{ST} > T_O$	x		0		1	0		x	0	0	0	1	1	1	0	1	0	0	1
Cold Charge . . . $T_{SB} > T_{ST}$	1		0		0	0		x	0	0	0								
Summer Heating . . . T_{R1}	x		x		x	0		x	0	0	1	1	1	0	1	1	1	0	1
Summer Heating . . . T_{R2}	x		x		x	0		x	x	1	1								
Cool AHX after Heating	x		x		x	0		x	1	0	x	1	1	0	0	1	1	0	1
Do Nothing-Summer . . . T_R contradiction	x		x		x	0		x	1	1	0								
Do Nothing-Summer . . . No Cold Charge	0		0		0	0		x	0	0	0	0	1	0	0	0	0	0	0
	x		1		x	0		x	0	0	0								

External ΔT controller completes HWPH control loops

Winter: HWP = $T_{CO} > T_{PH}$ HWPH enable
Summer: HWPB2 = $T_{CO} > T_{PH}$ HPWH enable

1 = YES or ON 0 = NO or OFF x = does not matter

Figure 4.10. Truth table for modes of operation. (Section 4.2)

5 Thermal performance evaluation program

In this chapter the researcher should describe the objectives of the thermal performance evaluation program together with the measures taken to accomplish these objectives. In other words a description of what the researcher wants to quantify and how.

The procedure for the thermal performance evaluation which is outlined in the document »Data requirements and thermal performance evaluation procedures for solar heating and cooling systems» (Streed, 1979) forms the basis for the recommendations which are put forth here.

The researcher is encouraged to obtain the document for a more thorough discussion of evaluating of solar energy systems.

Section 5.1 should be used to define key factors which are being evaluated. To describe how these values are obtained, however, is substantially different for experimental and analytical studies. Therefore two approaches have been outlined. The sections which are appropriate for an experimental study are marked with an asterisk. Those sections which are meant for analytical studies are marked with a double asterisk. If a study includes both experimental and simulation analysis, all sections in this chapter should be used.

- ☐ Describe in detail the objectives of the data evaluation program (i.e. what questions are to be answered).
- ☐ Summary description of the evaluation program.
- ☐ Comment on the approach and methodology of the data evaluation program.

5.1 Definitions of the thermal performance factors

This section should describe those quantities which are reported when describing the thermal performance of the system. The factors described below should be considered as a recommended set for reporting rather than an all-inclusive list. The researcher is therefore expected to form his own set which he feels is relevant to the analysis of the system performance. However, a justification for adding factors should be given using the objectives of the data evaluation program described above.

It should be noted that the definitions of performance factors presented here includes a few minor devations from the recommendation and definitions in Streed, 1979. Some word definitions differ slightly as a result of an effort to make them more general and easier to interpret in an experimental environment.

To avoid ambiguity the word load has been avoided in some names.

Here the definition of solar fraction is based upon the amounts of energy, which are delivered to the subsystems rather than upon the energy output of these subsystems. This is consistent with »Solar fraction of energy consumed» as defined in Streed, 1979, but differs from »Solar fraction of load» which is the factor recommended in that document. The reason for this choice is that the energy flows at the interface between the solar energy system and the load subsystems are easier to measure. For space heating the difference will mostly be small, while in the case of hot water the difference will be larger due to stand by losses.

The definitions presented in this chapter are thus meant to be somewhat general. The researcher should try to present definitions which are more specific to his study. In the case of an experimental study these definitions are supported by the description in Chapter 5.3 where it is shown how the quantities are derived from measured values. Depending on the specific report this section may be presented at either of two levels. One alternative is first to discuss the factors needed for the evaluation program and then present them in diagrams and tables including designations and definitions, all in one section. This presentation may be oriented toward system and subsystem. In the other alternative, which is outlined below, the factors are divided into four categories: temperatures and pressures, energy quantities, performance indicators, and miscellanous, and each group is presented in a separate subsection. One purpose of this section is to provide a quick reference point for the reader to obtain definitions of the key performance factors and it is therefore recommended that the designations and definitions are somewhat separated from the discussion, and presented in tables.

The designations presented in Streed, 1979, together with units are included below to facilitate referencing. The use of these designations is recommended.

It should be noted that although definitions are provided here and in Streed, 1979, the author must provide a complete set of definitions in the report.

Definitions of some key performance factors

It should be noted that this list does not include all performance factors mentioned in Chapter 7 or in the energy flow diagrams. Streed (1979) provides a complete list. Nomenclature of that document is used when applicable.

Energy quantities

Total solar incident in the aperture plane*: the total irradiation in the plane of the solar aperture. (Q001, J/m^2)

Total refers to the sum of beam, diffuse and reflected radiation.

Total solar incident while collecting: the total irradiation in the plane of the collector during the time that the collector loop is active. (Q003, J/m^2)

Solar energy collected: the thermal energy removed from the collector array by the heat transfer media. (Q100, J)

Solar energy utilized: thermal energy originating from solar radiation that is transferred from the solar energy system to the load subsystems (e.g. hot water (Q300), space heating (Q400) and space cooling (Q500) subsystem). Regarding space heating it is suggested that energy losses from the solar energy system to the building are included in the solar energy utilized if those losses are effective in compensating for the reference net heat loss (defined below). (Q203, J)

It is hard to give »solar energy utilized» a strict definition that is at the same time general and consistent with the intuitive notion of the quantity. However, it is felt that »solar energy utilized» must be defined since together with factors like solar fraction of load it is valuable when describing the thermal performance of a solar energy systems.

The researcher is urged to make definition of solar energy utilized on the basis of his system.

In principle solar energy utilized may not include heat originating from operating or auxiliary energy. It is recommended that solar energy utilized is defined as the difference between the thermal energy delivered from the solar energy system to the load subsystems and the operating energy used to operate the solar energy system. A justification for this definition is the fact that this operating energy could have been directly delivered to the load subsystems. Regarding systems where pumps and fans are shared among different subsystems a fair part of the operating energy should be taken into account when defining solar energy utilized. In the definition it should, however, be clearly stated how operating energy is taken into account. Regarding systems where the storage is used to store energy other than solar energy it should be clearly stated how that energy and losses are taken into account.

Subsystem heat losses:

Depending on the system and on the level of the study one or more subsystem heat losses should be defined. The storage heat loss is often the most important. The losses often have an appreciable influence on the building load and therefore it should be indicated where the losses go.

Space heating load: the total amount of heat input (from internal and/or external sources) required to maintain the building dry bulb temperature at a certain level above the ambient temperature. (Q402, J)

Hot water load: the amount of thermal energy required to raise the temperature of the incoming water to the temperature at the outlet of the hot water subsystem (i.e. the difference in thermal energy content of the outlet and inlet water). (Q302, J)

Total energy consumed for space heating: the total amount of electrical and thermal energy delivered to the space heating subsystem (while the indoor temperature is below the indoor reference temperature which is defined below). (Q411,J)

When defining the total energy consumed for space heating the boundaries of the space heating subsystem must be clear and it should be indicated how losses to the building and excess temperatures are taken into account.

Total energy consumed for space cooling: the total amount of electrical and thermal energy which is delivered to the space cooling subsystem. (Q515, J)

Total auxiliary energy: amount of non solar energy supplied to the load subsystems (e.g. hot water space heating and space cooling subsystem) in the form of thermal energy. (Q600, J)

Auxiliary energy may be defined for each subsystem but should as a minimum be defined as a total. When the auxiliary energy is delivered to the load subsystem in the same flow of working fluid as the solar energy utilized, special care must be taken in defining the two.

Total operating energy: the amount of electrical energy required to operate all subsystems. (Q601, J)

*A conflict has occurred with the nomenclature of radiant quantities. The denomination *Total solar incident* which is used by Streed (1979) is equivalent to *Global irradiation* which is recommended by Beckman et al. (1978) (see Appendix). The use of *Total solar incident* in this document reflects the effort to keep to the nomenclature of the former document. However, the author should feel free to use either denomination.

Operating energy may be defined for each subsystem but should as a minimum be defined as a total.

Total energy consumed: the sum of electrical and thermal energy delivered to the hot water, space heating and space cooling subsystems. (Q603, J)

Total electrical energy saved: the difference between the estimated electrical energy requirements of a conventional non-solar system (carrying the full load) and the actual electrical energy requirements of the solar and HVAC system. (Q604, J)

Total fossil energy saved: the difference between the estimated fossil energy requirements of a conventional non-solar system (carrying the full load) and the actual fossil energy requirements of the solar and HVAC system. (Q605, J)
Electrical and fossil energy saved should be defined separately since there is no given way to put them on a common basis. First an assessment of a non-solar system must be made to determine the type of equipment that would be provided if there were not solar equipment. Then the energy consumption of that system should be calculated assuming some equipment performance coefficients and the same building load as for the solar energy system case. It follows from this definition that the respective energy saved depends strongly on the type of conventional system chosen which therefore must be described in the definition. Electrical and fossil energy saved should for the same reason be presented together.

Thermal performance indicators

Daily collector efficiency: total amount of energy collected divided by total amount of insolation incident on collector, both integrated over a specified time period. (N100=Q100/ /(Q001 · A_a), J/m²)

Collector on efficiency: total amount of energy collected divided by total amount of insolation incident on collector while the collector is working. (Q100/(Q003 · A_a), J/m²)

Storage cycle depth: the difference between the maximum and the minimum amounts of energy that has been in the storage during a period divided by the difference between the possible maximum and minimum useful energy stored over the same period.

Machine thermal COP: the total amount of heating or cooling provided, divided by the total amount of thermal energy supplied to the machine (desiccant and rankine cycle machines primarily). $(H_c/(H_s + H_F + E_{ug}))$*

Machine electrical COP: the total amount of heating or cooling provided, divided by the electrical energy required by that subsystem. Air delivery fan power and compressor energy should be included. Fan and pump power associated with heat rejection (including cooling towers) should also be included.
$(H_c/(E_{op} + E_c - E_g))$*

Auxiliary subsystem conversion efficiency: the total amount of energy delivered by auxiliary divided by the total amount of fuel heat content. Includes combustion inefficiencies and heat losses.

Solar energy consumed for space heating per unit area of collector: solar energy input to the space heating system divided by the collector aperture area. (Q441/A_a, J/m²)
See definition of solar energy utilized. Similar indicators can be defined for other load subsystems.

Solar energy utilized per unit area of collector: solar energy utilized per unit area of collector aperture. (Q203/A_a, J/m²)

Solar fraction of energy consumed: solar energy utilized divided by the total amount of thermal energy and operating energy that is delivered to the load subsystems (e.g. hot water, space heating and space cooling subystem). (N603=Q203/ /Q603)
It should be noted that it is not the energy content in fuels but the thermal energy output of the burner that is counted in this definition.

Solar fraction of energy consumed for space heating: solar energy utilized for space heating divided by the total amount of thermal energy and operating energy delivered to the space heating subsystem. (N401=Q400/Q411)

Solar fraction of energy consumed for hot water: solar energy utilized for hot water divided by the total amount of thermal energy and operating energy delivered to the hot water subsystem. (N301=Q300/Q307)

Solar fraction of energy consumed for space cooling: solar energy utilized for space cooling divided by the total amount of thermal and operating energy delivered to the space cooling subsystem. (N501=Q500/Q515)
The performance of a cooling machine depends on the temperature of the thermal energy utilized which in turn means that the proposed definition will give a misleading value on the solar fraction when solar and auxiliary energy are delivered at different temperature levels. Therefore it is left to the judgement of the researcher

*Nomenclature is found in Figure 5.4.

to find a definition which is more appropriate to his study.

Solar energy system conversion efficiency: solar energy utilized divided by the total solar incident on the collector array aperture area. (Q203/ (Q001 · A_a))

Solar energy system COP: the sum of the solar energy utilized plus the thermal energy originating from operating energy transferred from the solar energy system to the load subsystems (i.e. the total thermal energy delivered from the solar energy system) divided by the total amount of operating energy. (N110 = Q203/Q601)

Source energy COP: the total amount of heating and/or cooling provided, divided by the total amount of fossil energy required to operate the machine. $(H_c/(H_F/\eta_B + E_u/\eta_P))$*

Temperatures and pressures

Average ambient DB temperature: the time and spatial average temperature of the outdoor air at the site. (N113, °C)

Average building DB temperature: the time and spatial average space heated or cooled area dry bulb temperature. (N406, °C)

Storage media average temperature: the spatial average temperature of the storage. (T200, °C)
For phase change systems, this may need to be replaced by percent solid storage.

Make-up water temperature: will normally be the water main temperature for DHW systems. (T301, °C)

Average building WB temperature: (T601, °C)
An indication of the average relative humidity within the conditioned space.

Temperature of solar energy delivered to..:
The temperature of the working fluid delivering the solar energy from the solar energy system to the load subsystem. The temperature should be weighted with the energy delivered when averaging.

Miscellaneous definitions

Operating hours:

Variable indicating mode of operation:

Collector aperture area: the aperture is the opening or projected area of a solar collector through which the unconcentrated solar energy is admitted and directed to the absorber. (A_a, m^2)

Special performance factors for passive buildings

In this section some performance factors, which should be useful when reporting on passive systems, are defined. Performance factors, which are defined above and which are applicable to passive systems, are not included below.

A number of references (Balcomb 1979, Ducas et al. 1978, Palmiter 1979 and Streed 1979) have been used when preparing this section.

Regarding passive systems it is necessary to make two distinctions when defining the building heat losses. The first distinction has reference to the indoor temperature and the second to the solar aperture. Note that this distinction is relevant both to non-solar buildings and buildings with active solar energy systems as well as to passive buildings.

With a passive system the indoor temperature may, due to inadequate temperature control, exceed the desired indoor temperature, which in turn causes excess heat losses. Because of these heat losses distinction is made between »actual» and »reference» indoor air temperature. The reference indoor temperature should be defined by the author as a fixed temperature or a schedule of temperature levels deemed desirable. Often the thermostat set point of the auxiliary system may be taken as the reference temperature.

The heat losses through the solar aperture form an essential part of the total heat losses from a building with a direct gain system. Distinction is therefore made between the »total heat loss» and the »net heat loss» which does not include the losses through the solar aperture.

Actual degree hours: the integrated difference between the actual indoor air temperature and the outdoor air temperature. This quantity may include periods with indoor temperature both above and below the normal comfort level. (K · h)

Reference indoor temperature: an indoor temperature level or schedule of temperature levels deemed desirable. (°C)
The reference indoor temperature will normally coinside with the thermostat set point(s).

Reference degree hours: the integrated difference between the reference indoor air temperature and the outdoor air temperature. (K · h)

Solar energy utilized: the part of the solar energy transmitted which is effective in compensating for the reference net heat losses (defined below). (Q203, J)

Internal heat gain: thermal energy which heats the building space and which originatets from occupants, appliances, lightings, the hot water systems, etc. (J)
Solar gain through windows, which are not part of the passive system, may be included. The

*Nomenclature is found in Figure 5.4.

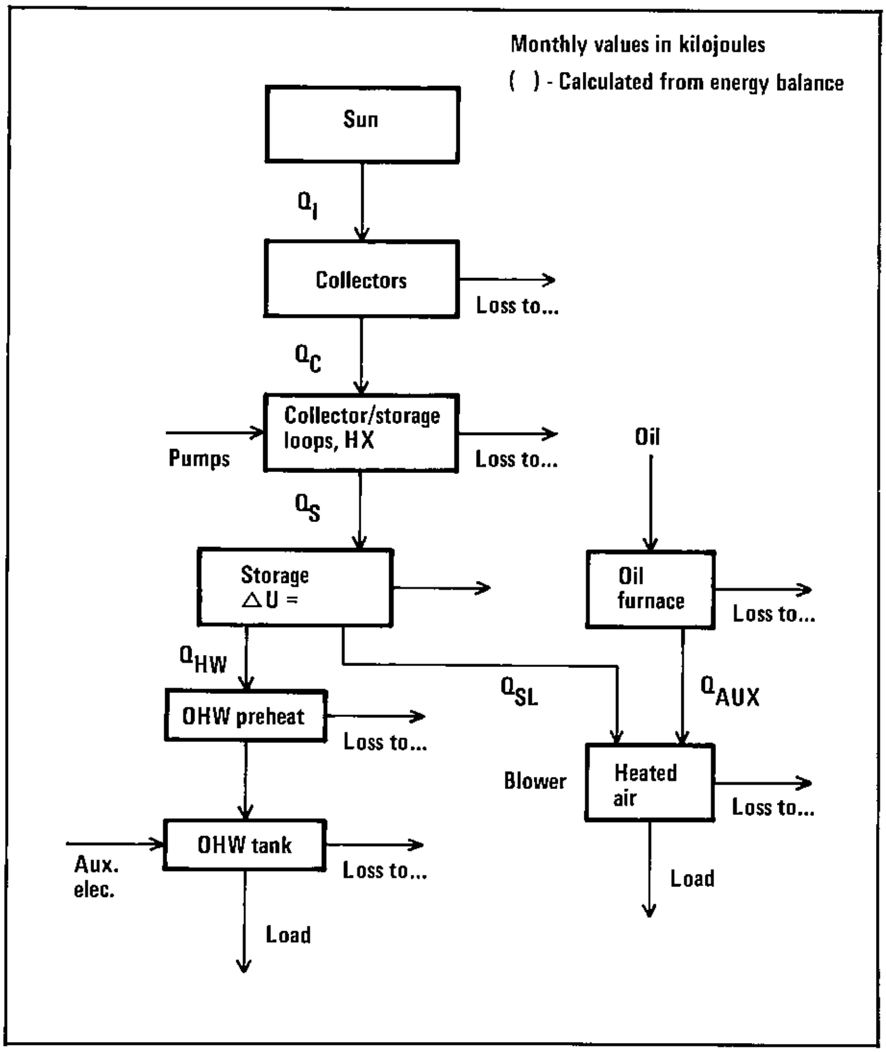


Figure 5.1. Example of a simple energy flow diagram. (Section 5.1)

internal heat gain may be defined for each different source but should as a minimum be defined as a total.

Reference net heat loss: the ventilation (not including intentionally rejected heat) and transmission losses through the building envelope when the solar aperture is replaced by a perfectly insulated wall (i.e. a wall without losses) and when the building is maintained at the reference indoor temperature. (J)

It is noted that this definition is less suitable for attached sunspace systems. Therefore, it is suggested that the solar aperture losses in that case are included and that the reference temperature of the sunspace is given a low value.

Auxiliary heating demand index: the ratio between the total auxiliary energy (Q600) and the product of floor area and reference degree hours. ($J/(m^2 \cdot K \cdot h)$)

Solar fraction of space heating: the ratio between solar energy utilized and the sum of solar energy utilized and the auxiliary energy for space heating. (Q203/(Q203 + Q401))

Note that auxiliary energy is thermal energy delivered to a space heating system.

The reason for not including the internal heat gain in the denominator is mainly that solar fraction of active and passive buildings should be comparable.

5.1.1 Energy quantities

These variables describe the transport of energy within and about the system being studied. The researcher should list the energy flow quantities which he proposes to present and describe each quantity in this section. His description should be supplemented by an energy flow diagram. This diagram may be similar to that shown in Figure 5.1, 5.2 or it may be more pictorial as illustrated in Figure 5.3.

- ☐ Discussion.
- ☐ Energy flow diagram showing the energy input and output of all subsystems in the entire system. The set of subsystems should be chosen with the presentation of results in mind and the boundaries between the subsystems should be the same as those defined in Chapter 3. All energy flows of any importance, both those which are measured and those which are not, should be included in the diagram. Regarding losses it should be indicated whether they go to other subsystems, the building or the surroundings. The energy flows which are measured and reported on should be indicated in a special way.
- ☐ Table including the energy quantities, which are used in the evaluation of the system, together with definitions, designations and units.

5.1.2 Thermal performance indicators

In this section the researcher should present definitions of performance indicators which describe how well the system or subsystem has performed a specific function. The performance indicators are broken into system and subsystem values. When describing performance indicators for a subsystem, considerable care should be taken to describe all subsystem boundaries and assumptions in the calculation of the values.

There are many possible subsystems within a typical solar system design. Only a few subsystem indicators are described in the table. The researcher should add definitions as appropriate.

- ☐ Discussion.
- ☐ Table including the thermal performance indicators which are used in the report together with designations and definitions. In conjunction with the description, equations should be provided.

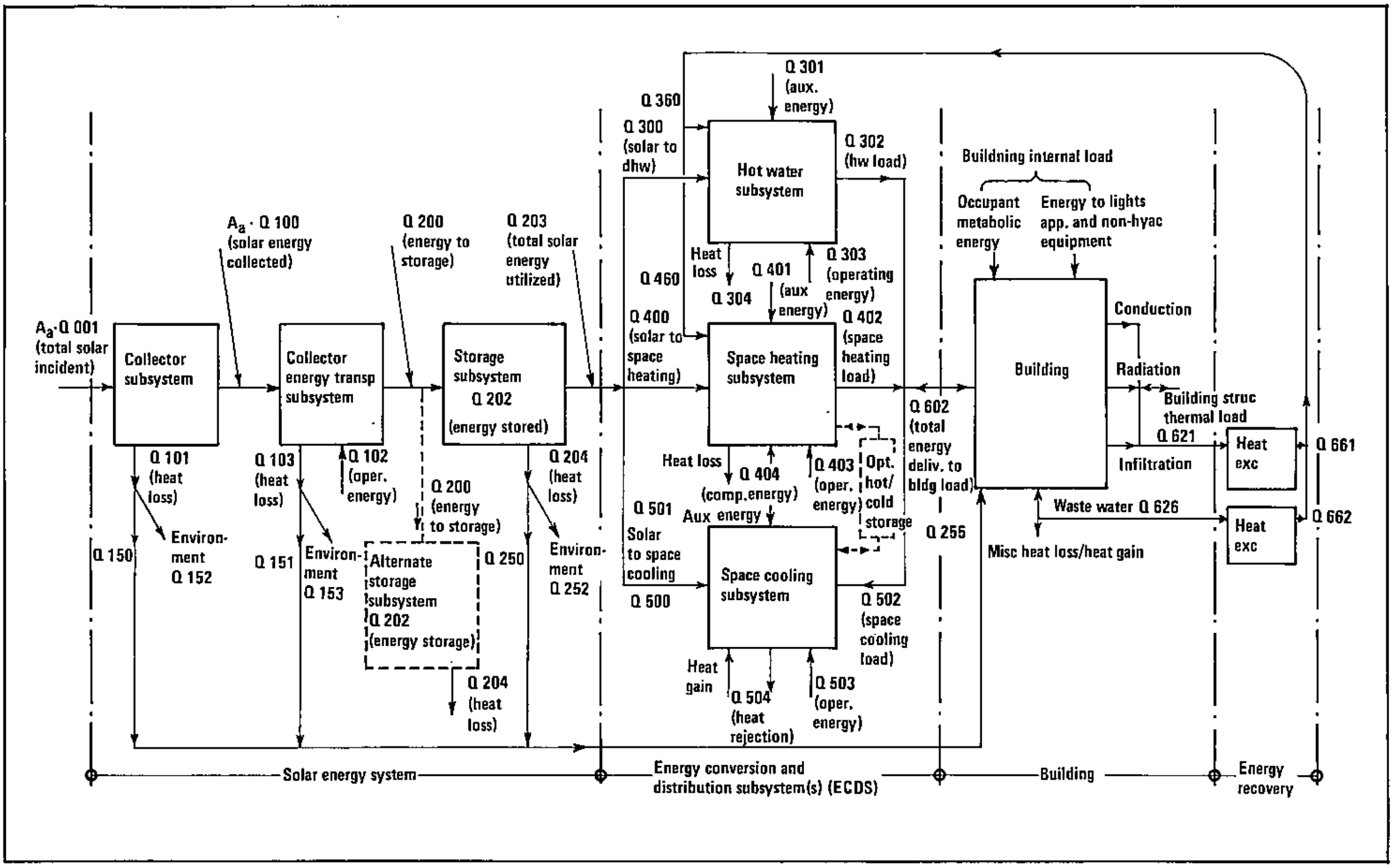


Figure 5.2. This energy flow diagram illustrates part of the nomenclature of Streed, E. R. (ed.), 1979. (Section 5.1.1)

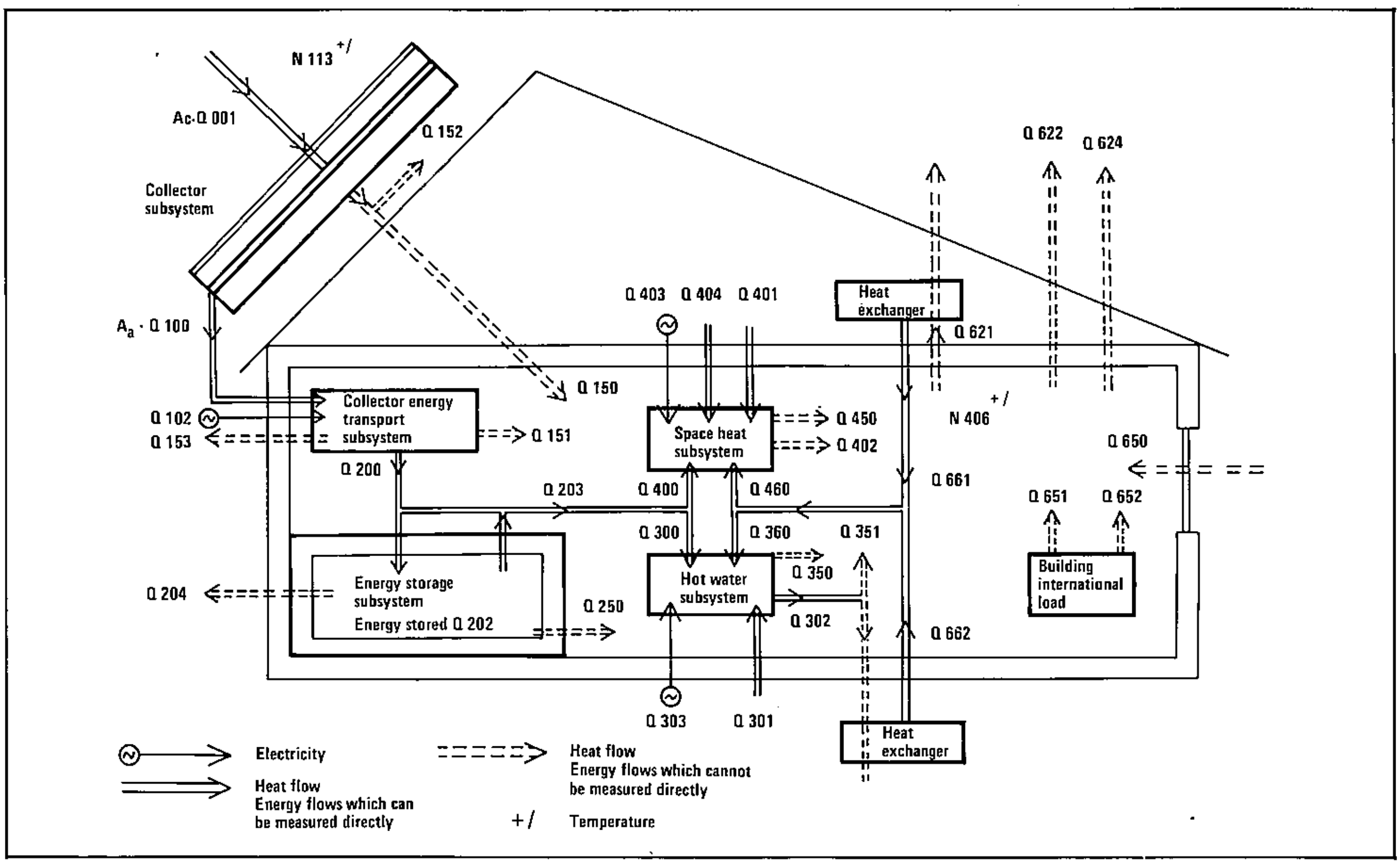
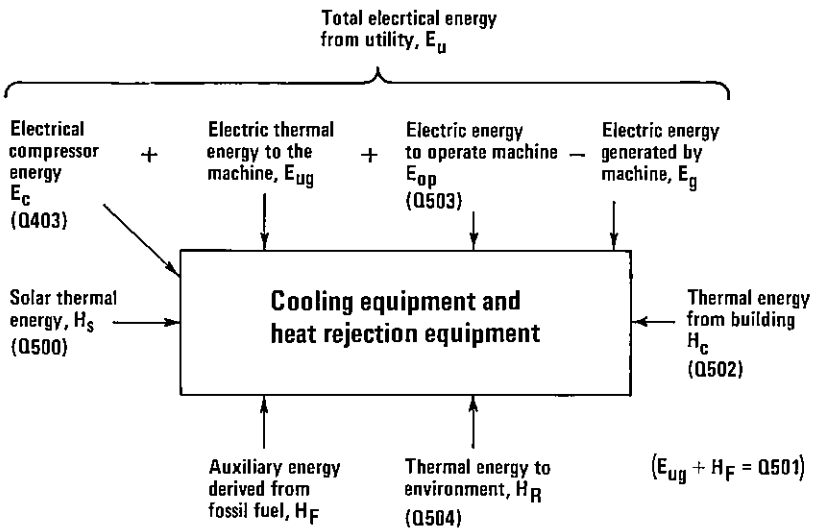


Figure 5.3. Example of energy flow diagram. (Section 5.1)



Machine subsystem energy quantities definitions

1. E_c – Electrical energy supplied to the compressor. (Usually applies to a heat pump only.) (Q403)
2. E_{ug} – Electrical thermal energy supplied to the machine to thermally drive the machine cycle.
3. E_{op} – Electrical energy required to operate the machine (Q503). Does not include compressor energy (E_c) or electric thermal energy (E_{ug}).
4. E_g – Electric energy generated by the machine which is utilized by the machine, utility grid or building. Electricity generated but not used should not be included.
5. E_u – Total electrical energy required by the machine from the utility grid ($E_c + E_{ug} + E_{op} - E_g$).
6. E_{fan} – That portion of E_{op} which is attributable to the pressure drop across the cooling element. For desiccant systems, all power required for wet and dry beds should be included.
7. H_S – Solar thermal energy supplied to the machine. (Q500)
8. H_c – Thermal energy withdrawn from the building. This is equal to the air mass flow rate times the delta temperature across the intake and exhaust ducts. If the energy into a coil is what is available (as is normally the case), then the fan energy (E_{fan}) should be subtracted to obtain actual building load met. In the heating mode, the E_{fan} should be added to the coil energy to evaluate the building thermal load. (Q502)
9. H_R – Heat rejected to the environment. (Q504)
10. H_F – That portion of auxiliary energy derived from fossil fuels. (Note: $E_{ug} + H_F$ = Q501)
11. η_B – Auxiliary boiler efficiency.
12. η_P – Electric power plant efficiency. (η_P = .3 recommended)

Figure 5.4. Nomenclature for energy flows of cooling subsystem. (Section 5.1)

5.1.3 Temperatures and pressures

The most common state variables which are associated with solar systems are the temperatures and pressures. The researcher should discuss in this section the temperatures and pressures which he feels are adequate to describe his system. Note that these quantities are the factors which are to be reported and are not sufficient for the determination of the energy quantities described in Section 5.1. The researcher should indicate in the appendix which temperatures were available for analysis and show those variables on a system schematic.

☐ Discussion.
☐ Table including designations and definations.

Section 5.2* is relevant only to an experimental study. If a simulation study is being reported, Section 5.2** should replace this section.

5.2 Description of the monitoring system*

Section 5.2* should present sufficient information about the monitoring system such that the reader can appreciate the background of the data being reported in Chapter 7. Information which does not assist the reader in understanding the thermal performance factors such as brand names, details on sensor installation, etc., should be reported in Appendix 12.3.

☐ Description of the procedure for checking and validating data.
☐ Brief discussion of the monitoring procedure.

5.2.1 Instrumentation*

Detailed information on the instrumentation, such as calibration, etc., should be presented in Appendix 12.3.

☐ Diagram showing sensor locations.
☐ Table of sensor information giving:
  Type
  Range
  Accuracy
  Reference number for diagram.
☐ Comments on finding appropriate locations for sensors.
☐ Brief description of calibration results.

5.2.2 Data acquisition*

General information should be presented in this section. More detailed material should be given in Appendix 12.3.

☐ Block diagram of data acquisition system.
☐ Brief description of computer hardware and other tools for data reduction.

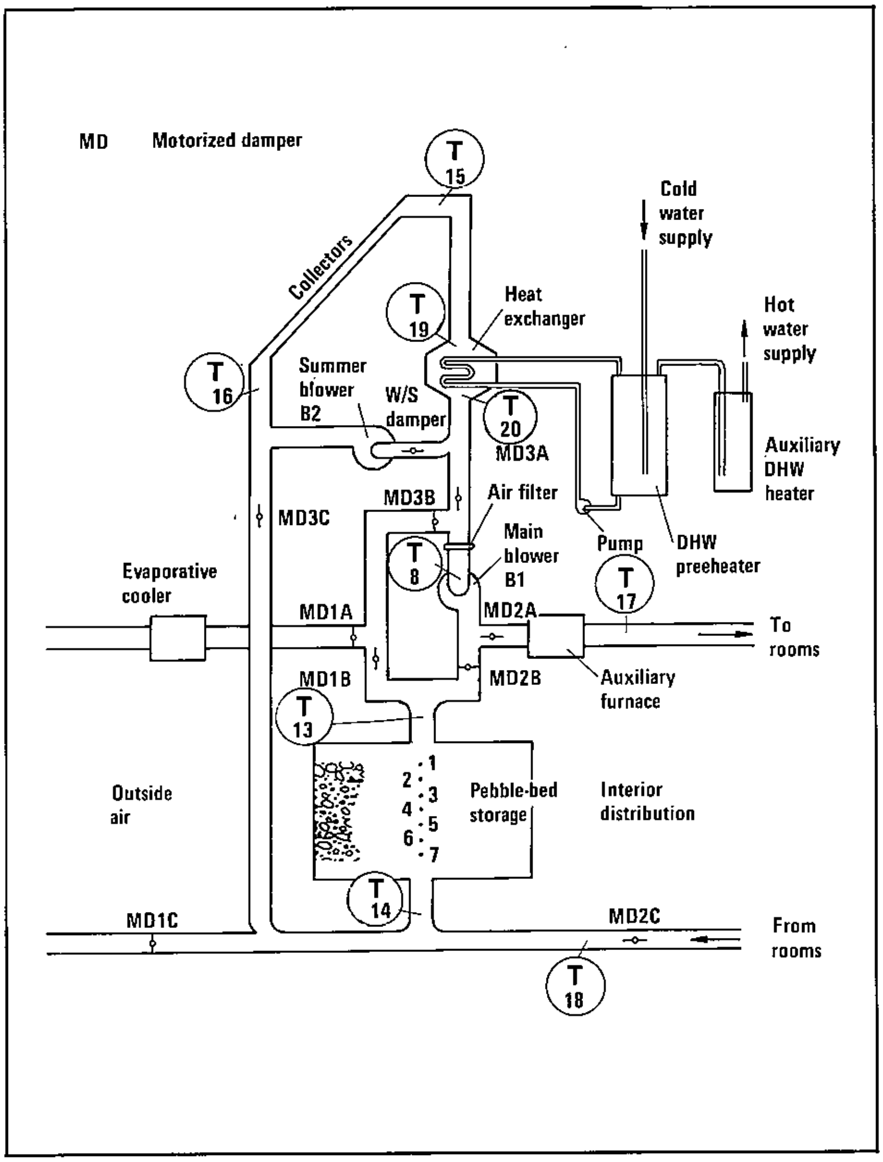


Figure 5.5. Temperature measurement stations. (Section 5.2)

☐ General description of data acquisition procedure.

*5.2** Simulation and analysis*

This section should be used to describe the simulation methods which were used in the study. For the reporting of an experimental study, this section may be omitted. In 5.2** a general description should be given of the simulation. Sections 5.2.1** and 5.2.2** should include more detailed information about the simulation.

☐ Brief description of program(s) used.
☐ Time period of analysis.
☐ Brief description of inputs to program (e.g. weather or load tapes, degree days, etc.).

*5.2.1** Description of the computer program*

The brief description given in 5.2** should be expanded on to give the reader an understanding of the operation of the simulation.

☐ Analysis methods used (integration method used, simplifying assumptions, etc.).
☐ Time steps used.
☐ Stability problems.
☐ How program can be accessed.
☐ Brief description.

*5.2.2** Program inputs*

The reporter should provide a discussion of the inputs which were used in the simulation of the system. Information used from tapes or files or directly entered by the analyst should be described. Detailed information on tape formats and where the tapes can be obtained should be given in Appendix 12.5. System characteristics need not be repeated in this section as they are already called for in Chapter 3 and Appendix 12.2.

☐ Type of inputs.
☐ Source of values.
☐ Assumptions concerning use of inputs.

5.3 Data reduction methods

In Section 5.1 a set of quantities for reporting the system performance is chosen. Section 5.3 should provide detailed information on how these quantities are calculated from measured or simulated values. It is particularly important to include the methods for determining transient energy flow rates and for estimating accuracies in calculated quantities. Details should be provided on approximations, timesteps in summations, uncontrolled heat losses, and the way to take account for the system changing between different operating modes. It should be possible for the reader to decide which measured data are used to calculate the different performance factors.

☐ Solar energy incident on collector array (describe technique of calculation).
☐ Thermal energy flow (describe technique for calculations).
☐ Stored thermal energy (describe technique for calculations).
☐ Heat loss from components (describe technique for calculations).
☐ Table showing the performance factors and the measured data from which they are calculated.
☐ Preliminary discussion of errors associated with calculations. (Detailed error analysis should be given in Appendix 12.4.
☐ Brief statement on the total inaccuracies of the data.

Data Required \ Performance Factors	Solar Collected	Aperture Heat Loss	Collector Operating Energy	Energy to Storage	Energy from Wall Mass to Space	Energy from Wall Vents to Space	Useful Energy from Storage	Collector Efficiency	Storage Efficiency	Solar Utilization Efficiency	Coefficient of Performance
Total Solar Incident	○	○						○		○	
Collector Cover Temperature	○	△						□		□	
Collector Cover Heat Flow	○	○						○		○	
Outdoor D.B. Temperature[4]	□	□						□		□	
Wind Velocity & Direction[4]	□	□						□		□	
Coll./Storage Operating Power (Timer)[1]			△								△
Avg. Storage Temperature[2]	○[3]	○[3]		□				○	○		
Stor./Space Wall Surface Temp.[2]	△[3]	△[3]			□[3]		△	△	△	△	△
Stor./Space Wall Heat Flow[2]	○[3]	○[3]			○		○	○	○	○	○
Avg. Space Temperature	□[3]	□[3]			□[3]		□[3]		□[3]		□[3]
Space Air Supply Temperature	○[3]	○[3]				○	○		○	○	○
Space Air Return Temperature	○[3]	○[3]				○	○		○	○	○
Collector Air Flow Rate	○[3]	○[3]				○	○		○	○	○

[1]May require more than one sensor to determine power for fan, shades, dampers or other electrically operated devices

[2]May require more than one sensor if large gradients expected

[3]Used for alternate method

[4]Used for calculation during solar irradiation times

○ Data measured and used directly for performance factors
△ Data needed to establish an operating point or time
□ Data used for calculations

Figure 5.6. Specification of measured data required to determine the performance factors of the solar energy system. (Section 5.3)

6 Description of operation period

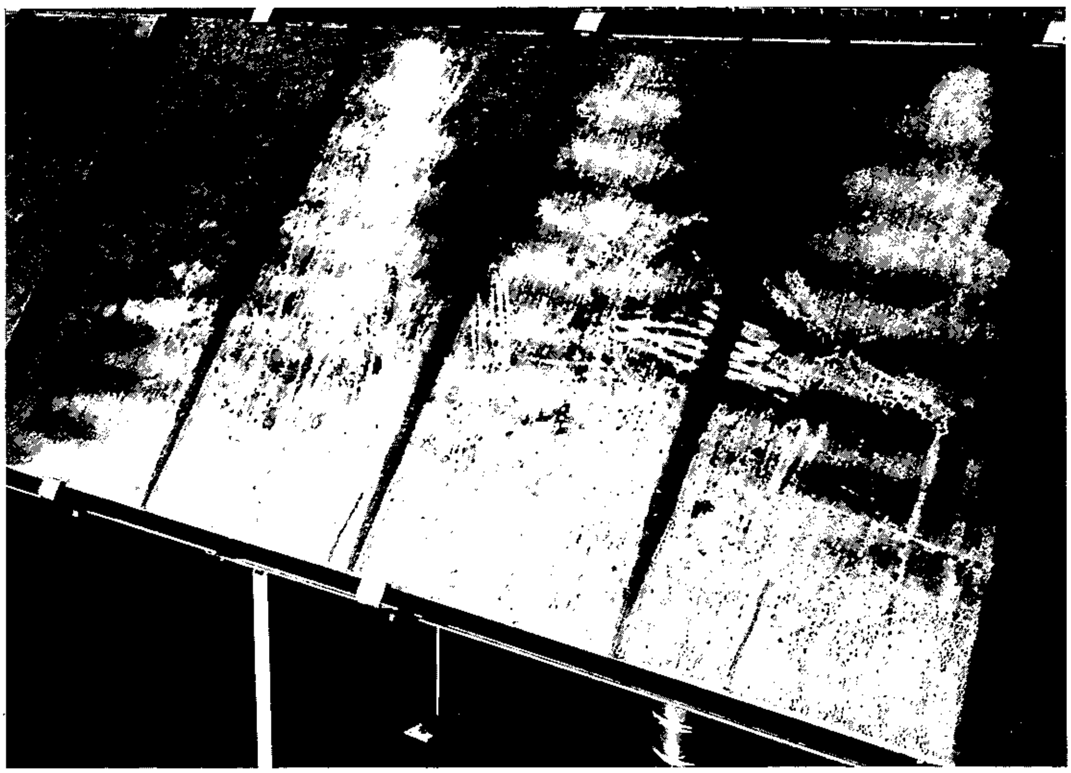
During the period of operation of a solar system most projects will encounter problems and occurrences which influence the thermal performance of the system. Information on these items is of importance for the reader to be able to fully understand the result and this information should be provided in 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. These experiences should be provided in Appendix 12.6.

Regarding a simulation study, limitations in the program capabilities of modelling and excessive computer run times, are problems that should be reported in this chapter.

It is essential that it becomes clear from the description when problems have occured so that the reader knows which performance data that possibly have been affected. Part of the description could take the form of notes in a diary.

- ☐ Description of the way the system has been used.
- ☐ System down times.
- ☐ Malfunctions and shortcomings of the energy system (e.g. leaking ducts, drifting set temperatures, poor insulations, etc.).
- ☐ Changes in the system hardware and the system control.
- ☐ Significant changes in the usage (i.e. the load).
- ☐ Snow, condensation, white frost or dust on the collectors.
- ☐ Malfunctions and down times of monitoring system (e.g. snow and condensation on pyranometers, cold bridges at temperature sensors etc.).
- ☐ Data gaps.
- ☐ Changes in monitoring system and measuring program.
- ☐ Recalibration.



7 Presentation of results

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 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.

Although some guidance can be offered as to what to report, it is up to the researcher to decide on the scope of the reporting. Here a rather extensive report is outlined but since some indications are given on the relative importance of different items it is thought that the format will be helpful even for minor reports. The lists of thermal performance factors which are presented here should thus be considered as recommended sets of factors.

It should be noted, however, that information about thermal performance is most essential and that substantial effort should be put into this chapter.

The outline of this chapter reflects to some extent the description of the overall system in Chapter 3. After an introductory survey of the thermal performance result, the indoor climate and the performance of the building are presented in Section 7.1. The following sections are devoted to the thermal performance of the solar and HVAC systems beginning with Section 7.2 which includes the main description of the performance together with monthly data. Sections 7.3 and 7.4 should provide the short term data (e.g. daily and hourly data) which is thought to be needed for a deeper understanding of the system performance. The chapter is then completed by a comparison with the expected result.

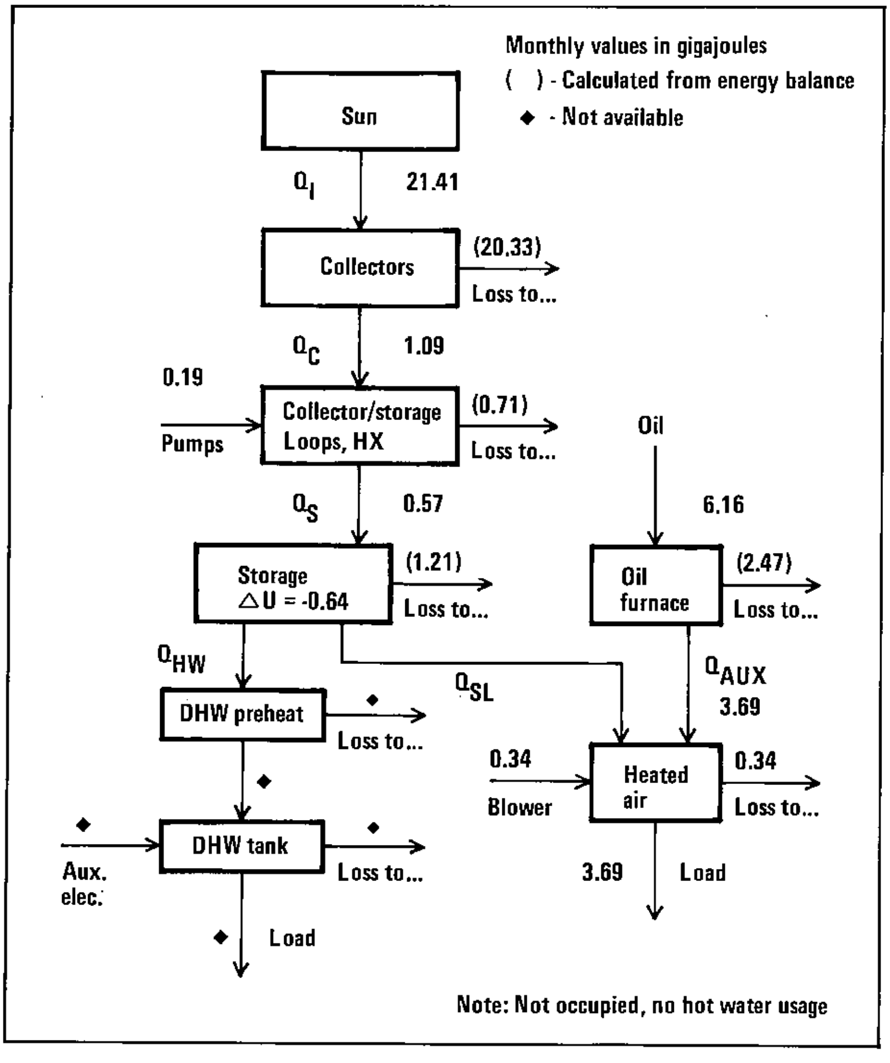
To avoid ambiguity the presentation of the result should rely completely on the designations and definitions of performance factors introduced in Chapter 5 in the report, as well as the description and designations of subsystems and modes of operation provided in Chapters 3 and 4.

Carefully drawn up tables and diagrams will have a major influence on the understanding of the results by most readers. A table as well as a diagram should be compiled of the factors needed to demonstrate a certain aspect. Within the table the factors should be grouped in such a way as to best illustrate that aspect. In the table head one should try to use abbreviations together with the designations and units to facilitate the understanding. A label should be put together with the designation to indicate whether the values are calculated directly from measured data or not. The tables should preferably be supported by a text where some key information is duplicated and where datagaps and anomalies are noted.

The purpose of the tables and diagrams presented here is rather to serve as examples than as specific formats.

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

Figure 7.1. Energy flow diagram. (Section 7)



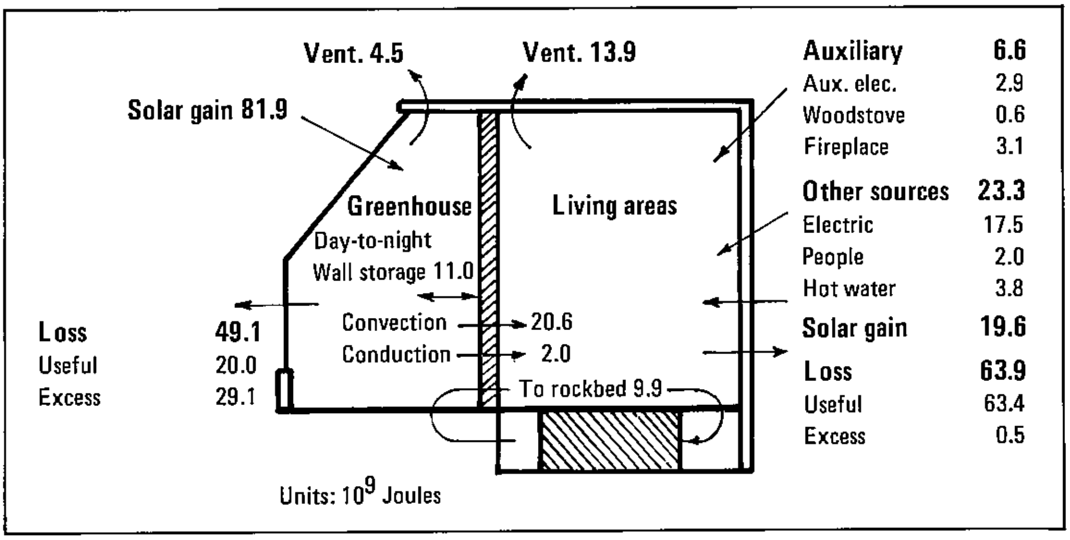


Figure 7.2. Example of an energy flow diagram for a passive building. Total energy flows for the 176-days-period from Nov. 1, 1978 to Apr. 25, 1979. (Section 7.1)

Energy Summary

Month	Incident Solar Radiation, (all windows)	Solar Collected ($\bar{Q}_u A$) Transmitted Solar-Venting	Useful Solar ($\bar{Q}_u^*$) − excess load)	Non-Auxiliary Sources	Auxiliary Heat	Electricity to Operate System	Non-renewable resources displaced, $\bar{Q}_H$	Useful Load, Living Area Only	Useful Load, Greenhouse Only	Rockbed COP	Overall COP, (SCOP')	Collection Efficiency	System Efficiency	Non-renewables Eff.	Solar Heating Fraction, Living Areas Only	Solar Heating Fraction, Whole House
	Average daily energy, MJ															
Nov	679	388	217	133	14	5	205	306	70	10.2	43.7	57.2	32.0	30.1	92.2	94.4
Dec	726	524	372	159	59	5	360	436	163	10.1	78.2	72.2	51.2	49.6	78.7	86.6
Jan	728	534	420	131	129	4	410	463	206	11.5	100.6	73.4	57.7	56.3	61.2	76.1
Feb	1014	573	370	128	8	7	352	388	123	11.9	51.2	56.5	36.5	34.7	96.8	97.8
Mar	890	449	246	125	4	5	235	312	67	10.6	52.6	50.4	27.7	26.3	97.8	98.4
Apr	814	328	160	116	1	5	147	233	41	10.9	31.3	40.3	19.7	18.1	99.0	99.3
Total	806	469	301	113	38	5	289	360	114	11.0	60.2	58.2	37.3	35.9	88.3	88.9

Figure 7.3. Example of a thermal performance summary for a passive building. (Section 7.2)

- ☐ Brief discussion on the actual and the expected result of the system.
- ☐ Brief recapitulation on the quality of reported values including estimated inaccuracies.

7.1 Building performance

This section should provide a description of measured or calculated results on the building and the indoor climate. Regarding buildings with passive features this section is especially important, but on the other hand this section should be dealt with briefly for buildings with tightly controlled indoor climate. Regarding energy »consumers» other then buildings (e.g. swimming pools, etc.) this section may be used for data on the degree to which desired conditions were achieved.

- ☐ Table of the energy balance of the building. In the table below some factors are marked with a P indicating that those are of special interest for passive systems.
- ☐ Performance of the building envelope (e.g. air tightness and U-values).
- ☐ Quantitative data on the measures taken to regulate the temperature (e.g. ventilation, shutters, draperies drawn over hot storage walls, curtains drawn over windows).
- ☐ Endurance diagram of indoor temperature.
- ☐ Scatter plot on psychrometric chart.
- ☐ Other measures of the comfort level (e.g. mean radiant temperature, etc.).

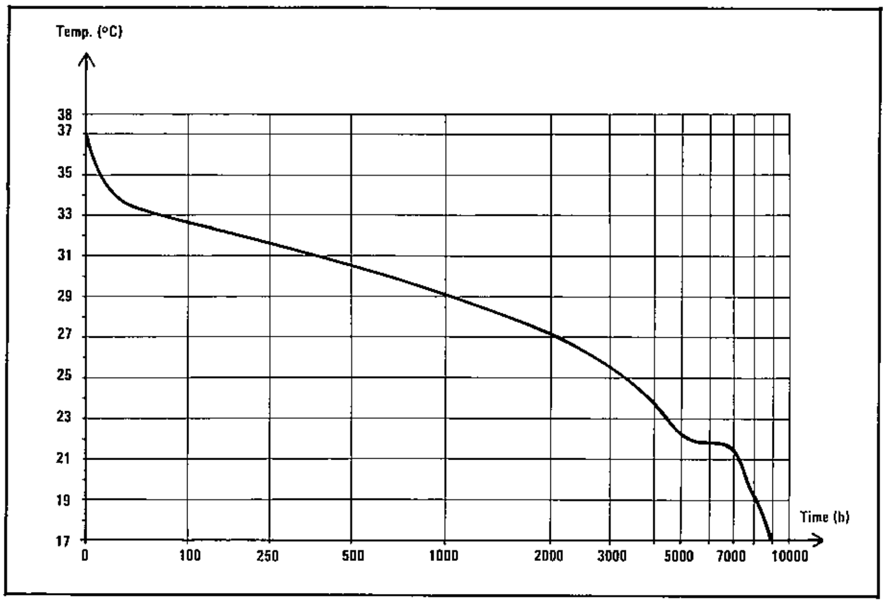


Figure 7.4. Endurance diagram of indoor temperature. (Section 7.1)

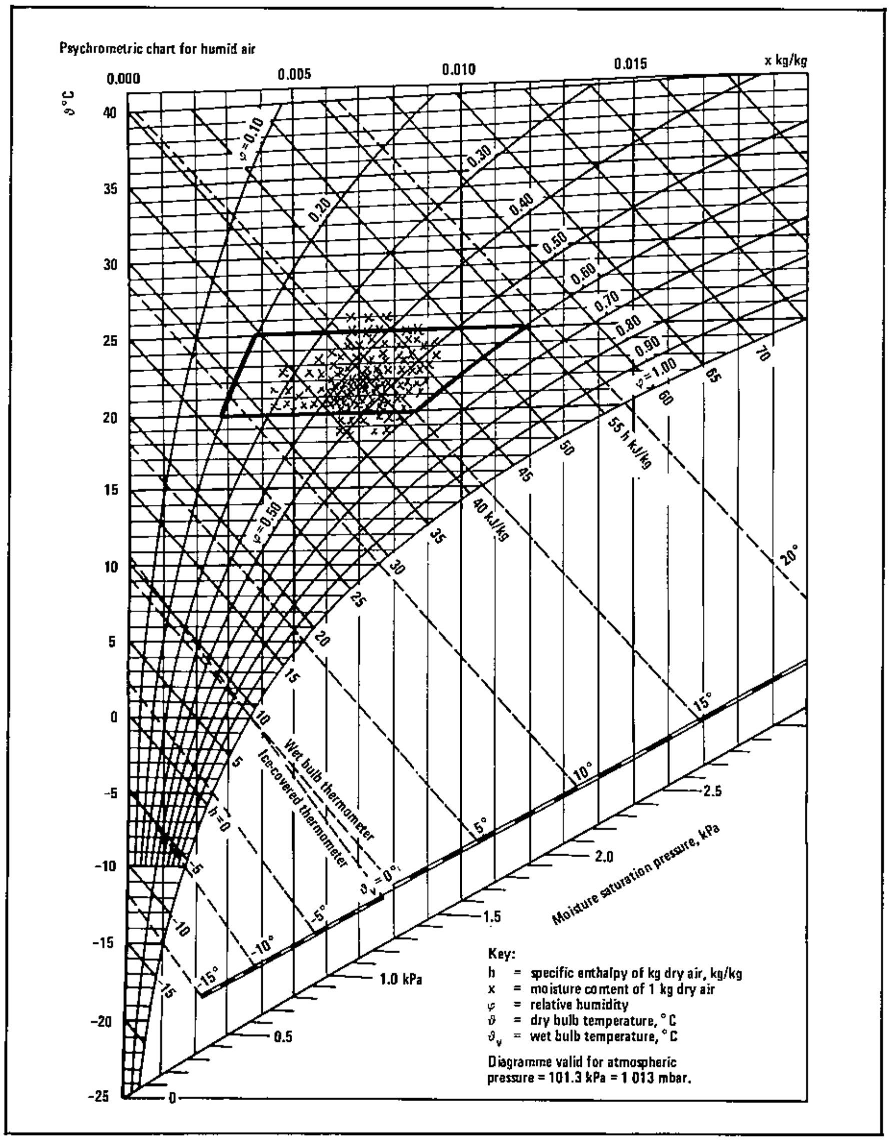


Figure 7.5. Scatter plot of house conditions in a psychrometric chart for humid air. (Section 7.1)

Some factors for reporting on monthly building performance	
Total solar incident in the aperture plane (P)*	(Q001)
Ambient dry bulb temperature	(N113)
Building dry bulb temperature	(N406)
Actual degree hours (P)*	
Reference degree hours (P)*	
Solar energy transmitted (P)*	
Solar energy utilized (P)*	(Q203)
Auxiliary energy for space heating (P)*	(Q401)
Internal heat gain may be divided into: metabolic heat, heat gain from domestic electricity and heat gain from installed systems	(Q658)
Solar heat gain through windows**	(Q650)
Hot water load	(Q302)
Reference net heat loss	
Transmission losses through the building envelope (floors, walls, windows, foundation)	(Q624)
Ventilation losses	(Q620)
Energy removed by space cooling system	(Q502)
Humidity added to and removed from the building	
Total operating energy for passive solar system including energy for rejecting excess solar heat (P)*	
Purchased electrical energy (P)*	
Purchased fossil energy (P)*	
Auxiliary heating demand index	
Solar fraction of space heating (P)*	
Passive solar system COP (P)*	

*(P) indicates special importance for passive systems.

** Windows which are not included in the passive system.

7.2 Monthly performance of the solar energy and HVAC systems

The results presented under this headline may be organized in either of two ways. The first alternative is to present a complete description without a system breakdown. This is thought to be applicable to reports on fairly simple systems without any subsystem of special interest. The second alternative, which is applicable to systems with a more complex energy flow pattern, is to present the various energy inputs and outputs together with some key performance factors for each subsystem of interest. This case which is outlined below, contains a summary including essential results and detailed descriptions of various subsystems under special headlines. It is important that the subsystems, which are reported here, are idencital with the subsystems described in Chapter 3 and discussed in Chapter 5. It should be noted that the mere fact that the description of the thermal performance of several subsystems is included in this format, is in itself no recommendation that these subsystems should be dealt with in separate subsections. It is the complexity of the system and extent of reporting that should justify this structure of the report.

- ☐ Description of the thermal performance of the solar energy and HVAC system.
- ☐ Table(s) including monthly values of key performance factors.
- ☐ Diagrams.

Some factors for reporting on monthly performance of the entire system

Climate	
Average ambient temperature	(N113)
Total solar incident	(Q001)
Average wind velocity	(N114)
Solar energy	
Solar energy collected	(Q100)
Solar energy utilized	(Q203)
Solar energy system efficiency	(N111)
Temperature of solar energy utilized	
Hot water	
Total energy consumed for hot water	(Q307)
Solar fraction of energy consumed for hot water	(N301)
Average make up water temperature	(T301)
Space heating	
Total energy consumed for space heating	(Q411)
Solar fraction of energy consumed for space heating	(N401)
Space cooling	
Total energy consumed for space cooling	(Q515)
Solar fraction of energy consumed for space cooling	(N501)
Building	
Average building temperature	
Transmission and ventilation losses	(Q620 + Q624)
Passive and internal energy gain	
Space heating load	(Q602)
Reference net heat loss	

7.2.1 Monthly performance of the solar collecting subsystem

A separate description of the thermal performance of the solar collecting subsystem is appropriate when solar energy collected is delivered to several different subsystems or when the interest is focused on the collectors. An alternative for many conventional solar energy systems is to treat the collector together with the storage as one subsystem.

- ☐ Description of the thermal performance of the solar collecting subsystem.
- ☐ Tabular presentation of the thermal performance of the solar collecting subsystem.

Some factors for reporting on monthly performance of the solar energy system

Average ambient dry bulb temperature	(N113)
Average wind velocity	(N114)
Total solar incident	($Q001 \cdot A_a$)
Total solar incident while collecting	($Q003 \cdot A_a$)
Solar energy collected	(Q100)
Collector daily efficiency	(N100)
Collector on efficiency	
Collector operating hours	(N120)
Operating energy	(Q102)
Energy delivered to storage	(Q200)
Energy delivered from storage	(Q201)
Heat losses from storage	(Q204)
Change in stored energy	(Q202)
Storage cycle depth	
Solar energy utilized	(Q203)
Temperature of solar energy utilized	
Solar energy system operating energy	(Q102)
Solar energy system conversion efficiency	(N111)
Solar energy system COP	(N110)

7.2.2 Monthly performance of the thermal storage

A special subsection for reporting on the storage is well justified for systems with seasonal storage, systems where energy from different sources are stored and all storages which use a concept other than sensible heat in rock or water.

- ☐ Description of the thermal performance of the thermal storage subsystem.

7.2.3 Monthly performance of the heat pump

It is usually justified to present a separate description on the thermal performance of a heat pump, when it gets energy from different sources or delivers energy to different loads. Together

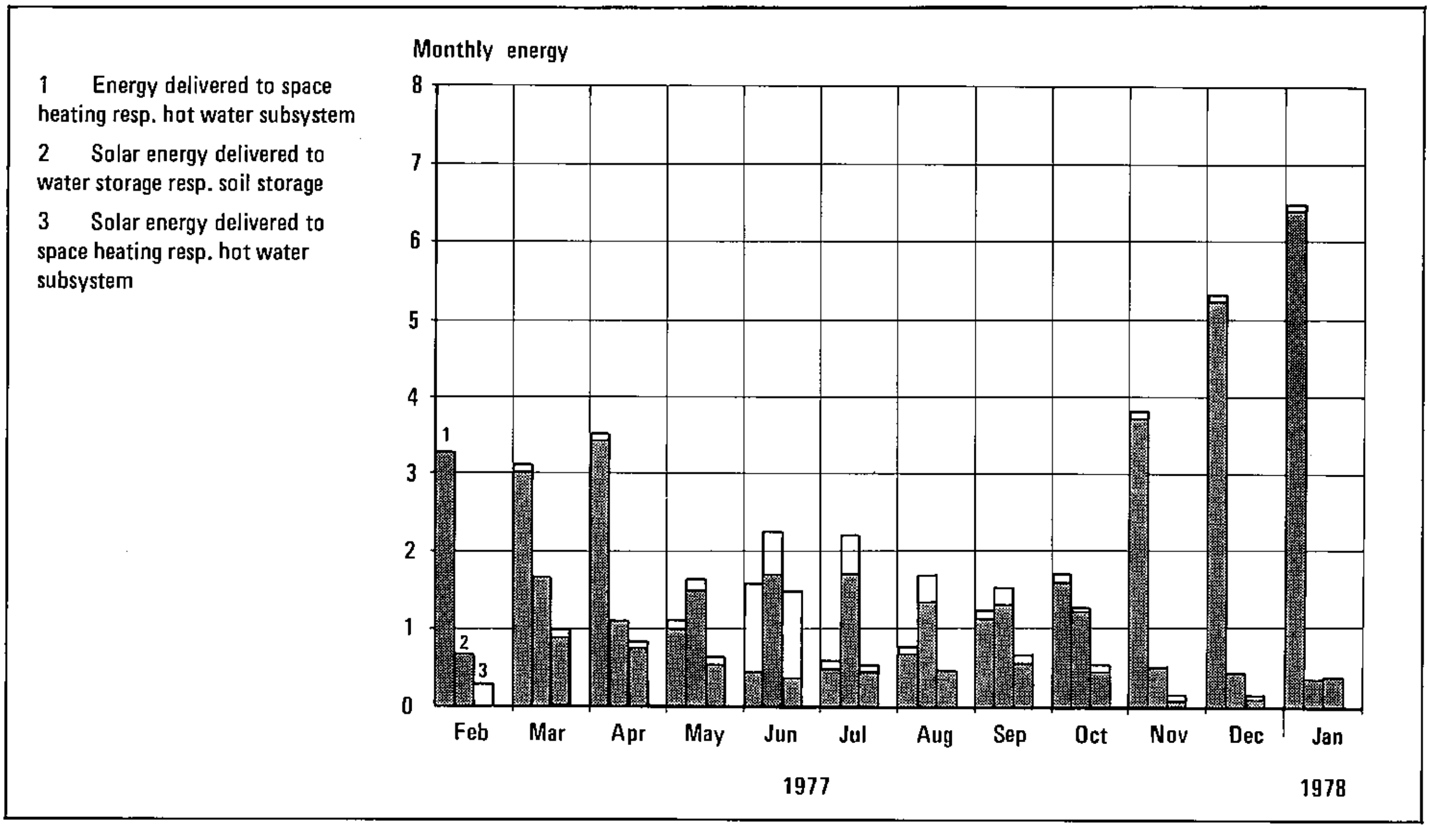


Figure 7.6. Example of bar chart presenting usage of solar energy. (Section 7.2)

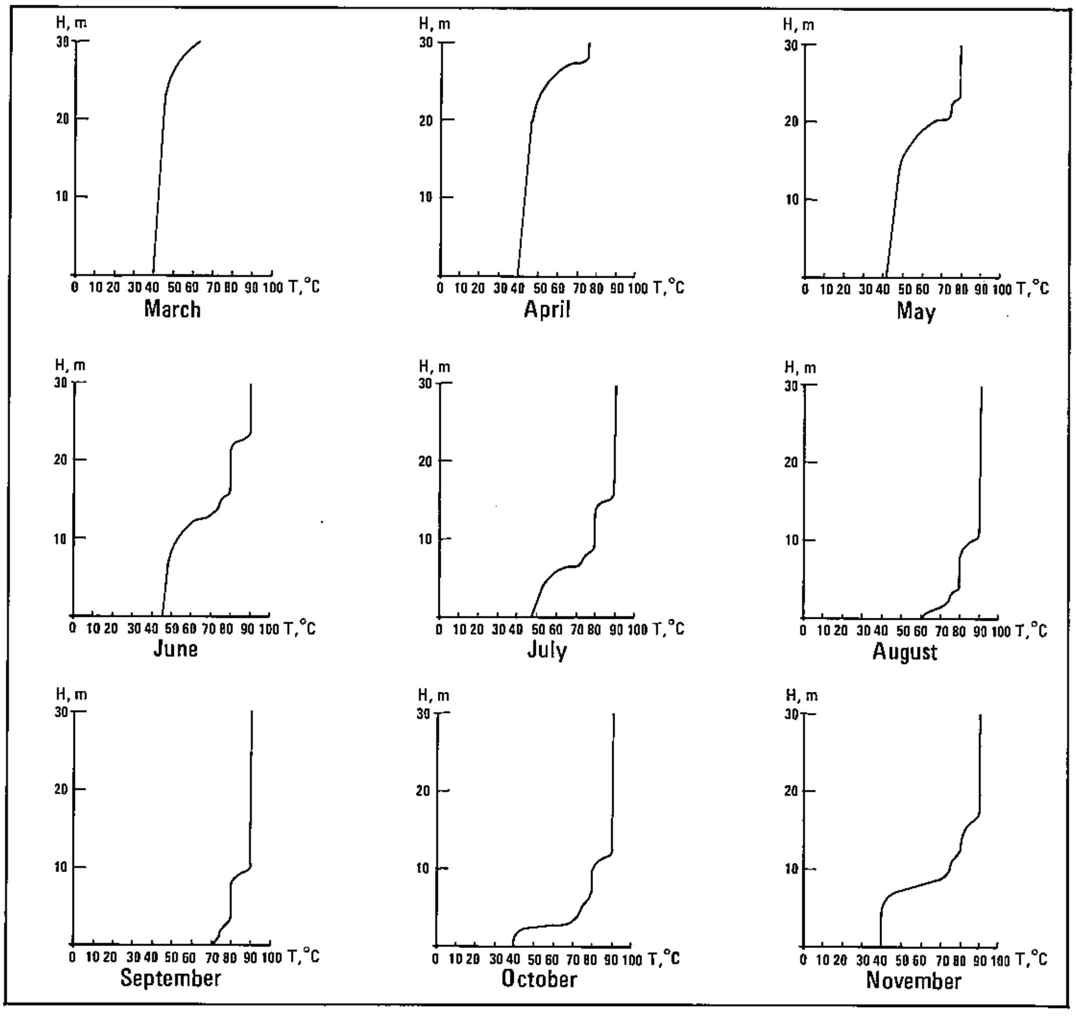


Figure 7.7. Vertical temperature profile in the storage. Height indicates distance from bottom of storage. (Section 7.2.2)

with the amounts of energy it is essential to show the temperature levels.

- ☐ Description of the thermal performance of the heat pump.
- ☐ Tabular presentation of the thermal performance of the heat pump.

7.2.4 *Monthly performance of the heat transport system*

When the system being studied is a centralized system which delivers heat to many separate units a separate description may be appropriate.

- ☐ Description of the thermal performance of the heat transport subsystem.
- ☐ Tabular presentation of the thermal performance of the heat transport system.

Other subsystems

Other subsystems which may deserve a separate subsection are:

- ☐ Space cooling subsystem.
- ☐ Space heating subsystem.

7.3 Daily system performance

The detail data provided in this section is devoted to the researchers and other technical readers who want a deeper understanding of the system performance, and who therefore must at the very least scrutinize the daily performance data. In order to limit the length of the report one, or at most two, different tables per month should be presented. One month of daily data fits into one page and a year of daily values for twenty performance factors can be squeezed into twelve pages. Which performance factors to choose for presenting in the tables depends on the system configuration and the objective of the evaluation program.

The tables should in principle include the energy input and output of the main subystems together with the most essential temperatures and performance indicators described in Chapter 5. Furthermore, the change in stored energy Q202 and a note indicating whether the system has worked without disturbance that day should be included. An example table is included in the appendix.

- ☐ Tables with daily values of important performance factors for the whole measuring period. Note that it could be advantageous to use a slightly different set of performance factors for the summer compared to the winter. Use a row for remarks regarding the operation.

Some factors for reporting on monthly cooling machine performance	
Solar energy utilized for space cooling	(Q500)
Average temperature of solar energy	
Auxiliary for space cooling	(Q501)
Energy withdrawn from building	(Q502)
Operating energy for space cooling	(Q503)
Space cooling system heat rejection	(Q504)
Average building temperature	(N406)
Average temperature of cold air to building	(N506)
Average temperature of generator, evaporator and condensor	
Machine thermal COP	
Machine electrical COP	
Solar fraction of space cooling	(N501)

Some factors for reporting on monthly space heating performance	
Solar energy utilized for space heating If appropriate it should be separated into energy delivered from collector and storage	(Q400)
Energy delivered from heat pump	
Energy delivered from heat recovery system	(Q460)
Auxiliary for space heating	(Q401)
Operating energy for space heating system	(Q403)
Total energy consumed for space heating	(Q411)

Some factors for reporting on daily performance	
Climate	
Average ambient temperature (possibly separated into day and night values)	(N113)
Total solar incident	(Q001)
Total solar incident while collecting	(Q003)
Collector	
Solar energy collected	(Q100)
Daily collector efficiency	(N100)
Collector on efficiency	
Storage	
Energy delivered to storage	(Q200)
Energy delivered from storage	(Q201)
Heat loss from storage	(Q204)
Change in stored energy	(Q202)
Storage media average temperature	(T200)
Storage cycle depth	
Hot water	
Total energy consumed for hot water	(Q307)
Solar energy utilized for hot water	(Q300)
Solar fraction of (energy consumed for) hot water	(N301)
Space heating	
Total energy consumed for space heating	(Q411)
Solar energy utilized for space heating	(Q400)
Solar fraction of (energy consumed for) space heating	(N401)

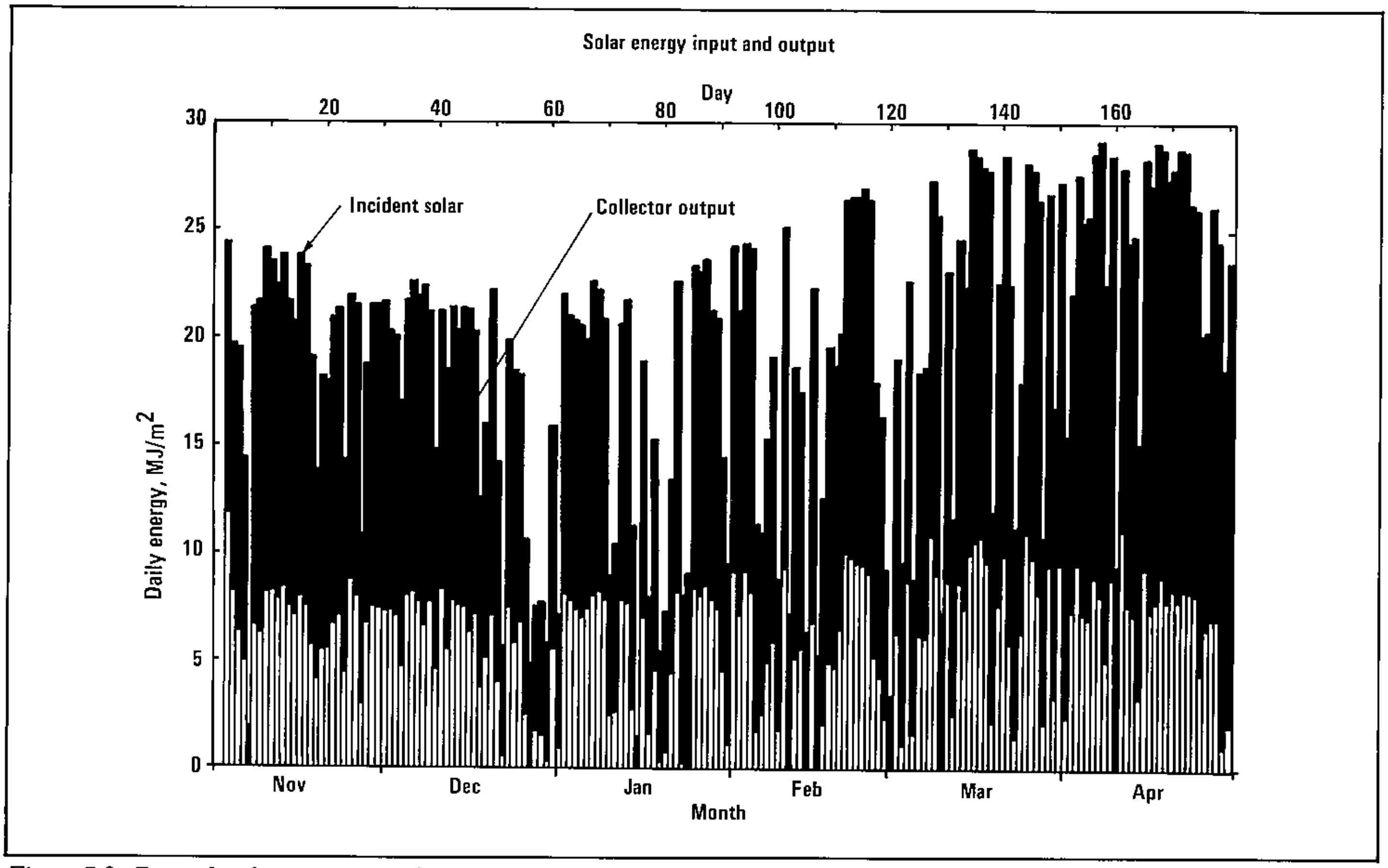


Figure 7.8. Example of presentation of daily performance of the collector array. (Section 7.3)

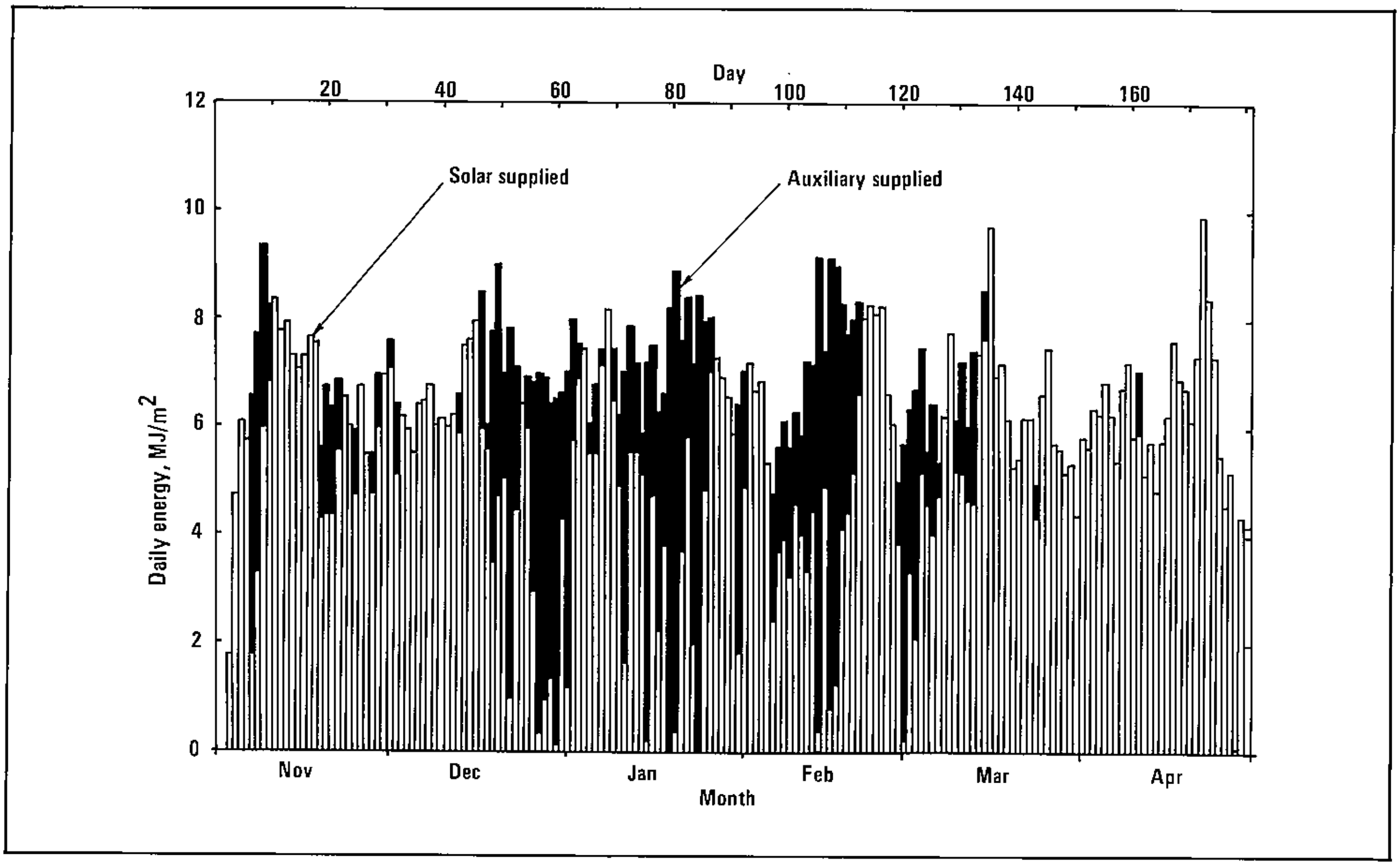


Figure 7.9. Example of presentation of daily energy delivered to the load subsystems. (Section 7.3)

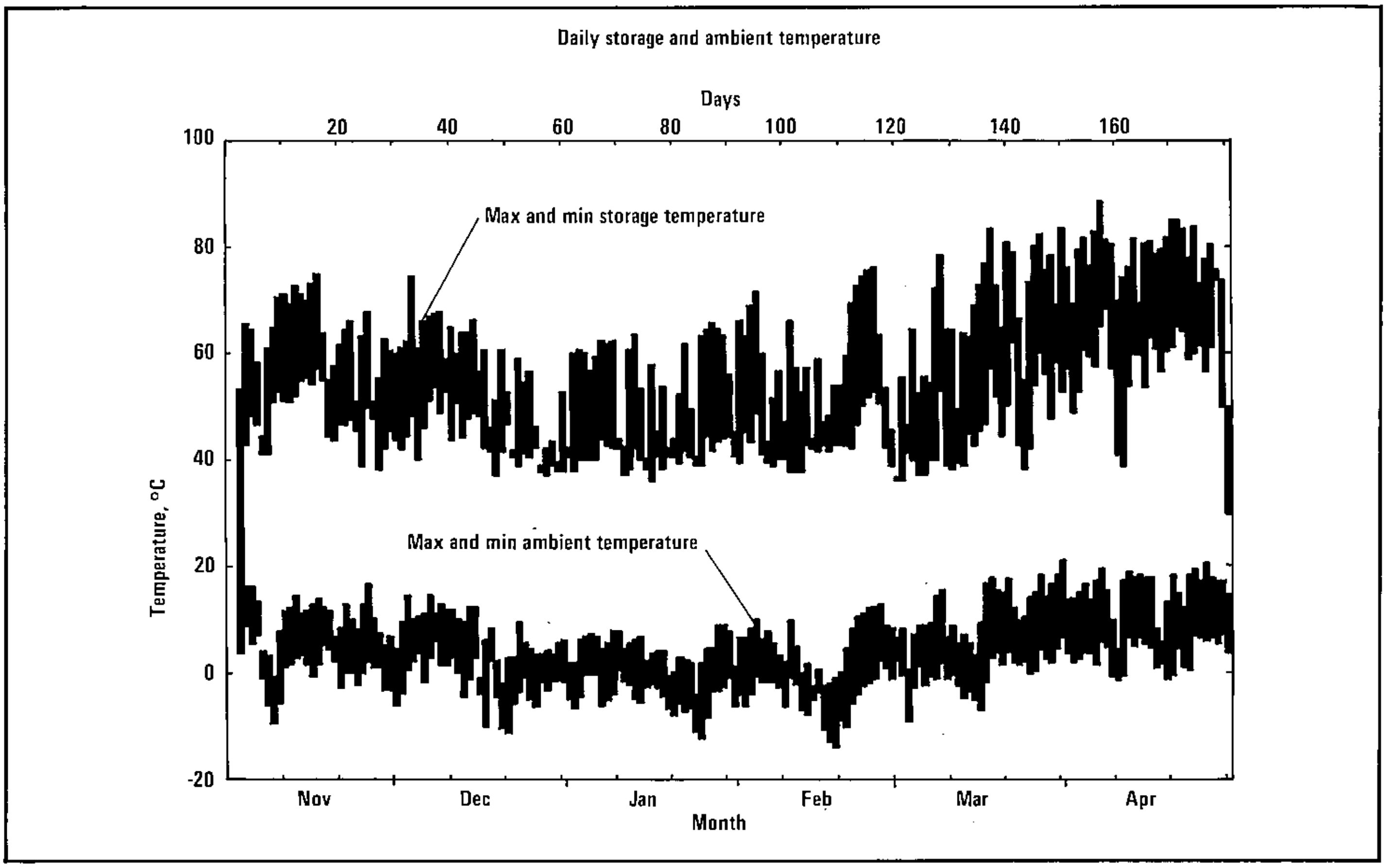


Figure 7.10. Example of illustration of the daily storage and ambient temperature swings. (Section 7.3)

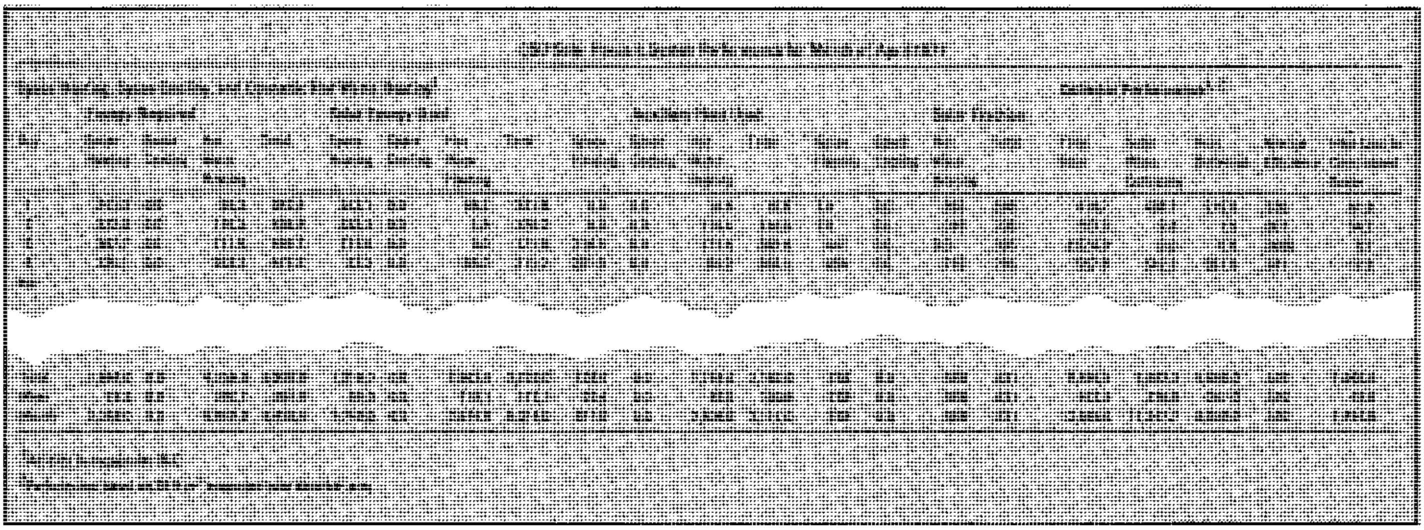


Figure 7.11. Example of table showing daily system performance data. (Section 7.3)

7.4 Hourly system performance

This section should provide information on the system's dynamic behaviour under different conditions. A sample set of performance factors are presented below. However, these may need to be replaced by values more instructive for the actual system.

- ☐ Diagram showing values of some key performance factors during a few different periods. Hourly values or averages values over a few hours should be used. The periods, which should be a few days to a week long, should represent typical conditions both regarding weather and the storage temperature of the different seasons.
- ☐ Description of the control system operation during the days that were chosen for the diagrams above.

Some factors for reporting on hourly performance	
Total solar incident	$(Q001 \cdot A_a)$
Total solar energy collected	$(Q100 \cdot A_a)$
Ambient temperature	(N113)
Average storage temperature	(T200)
Average building DB temperature	(N406)
Average building humidity	
Solar energy utilized	(Q203)
Significant mass flow rates in the system	

7.5 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.

- ☐ Method for obtaining other performance values.
- ☐ Discuss weather data.
- ☐ Method for calculating load.
- ☐ Table or diagram showing the result of the comparison for important key performance factors.

Some factors for reporting on comparisons	
Solar incident	(Q001)
Solar energy collected	(Q100)
Temperature of solar energy collected	
Solar energy utilized	(Q203)
Temperature of solar energy utilized	
Total energy consumed	(Q603)
Energy saved	
Solar fraction	

Figure 7.12. Example of diagram showing hourly system performance data. (Section 7.4)

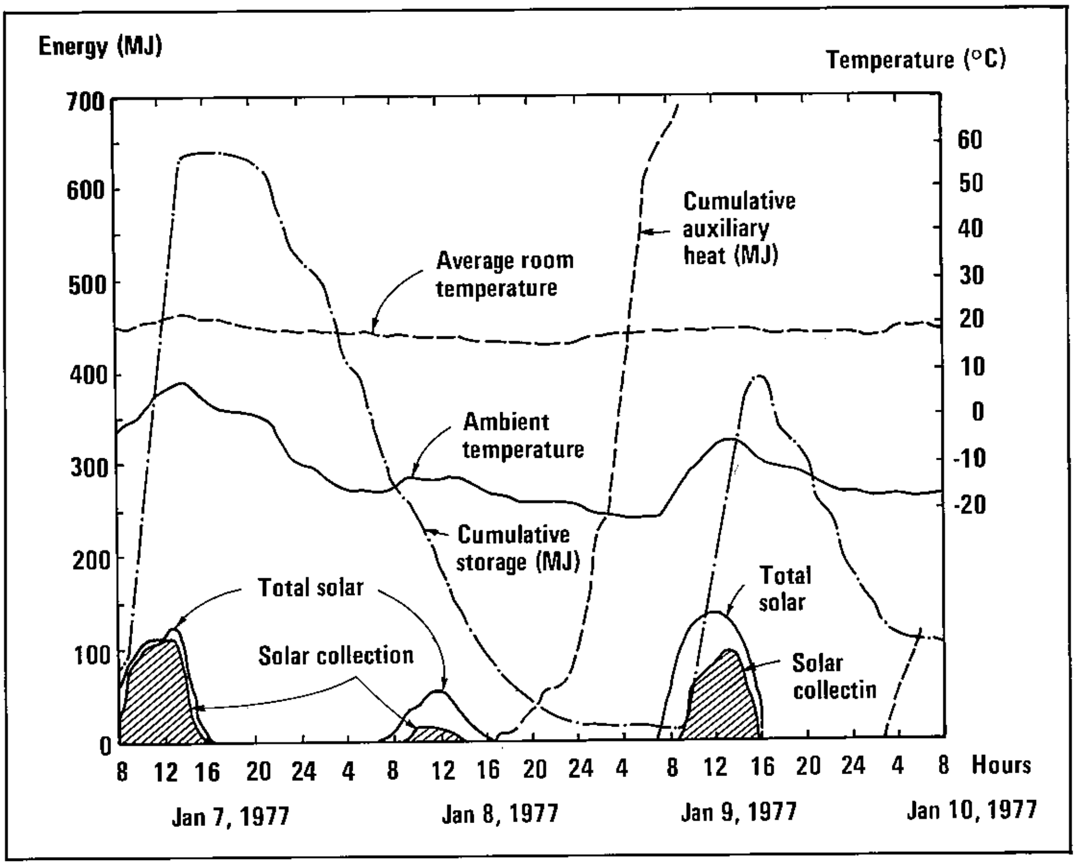
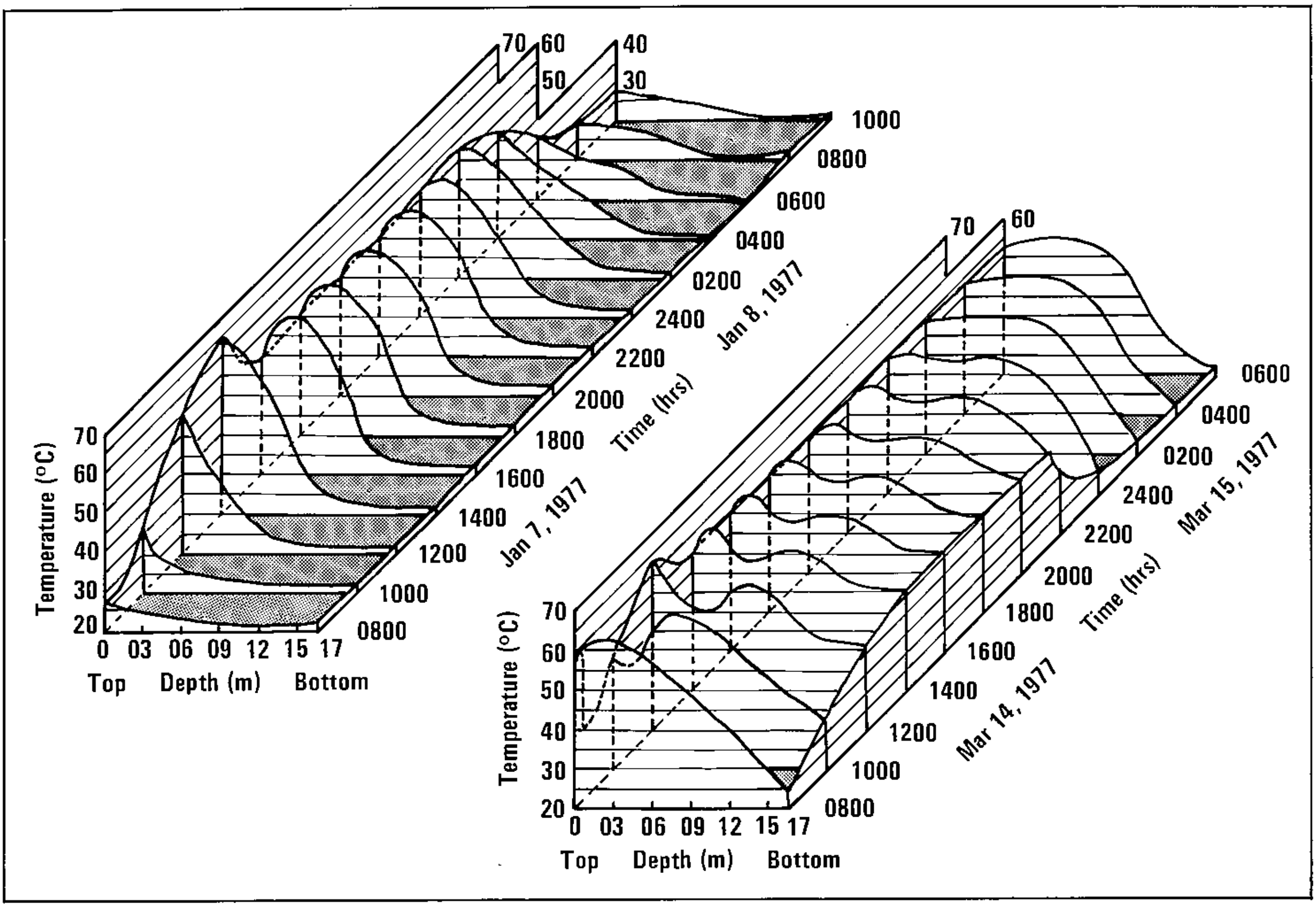


Figure 7.13. Example of diagrams showing temperature profiles in a pebble bed. (Section 7.4)



8 Economics

The importance of the information presented in this chapter will depend upon the nature of the study. For the research test facility, costs may not reflect actual production costs. Therefore values presented in this chapter should be carefully explained as to source and cause. For research facilities the reporter may choose to omit this chapter entirely.

For the analytical study the economic analysis chapter may very well be the most important part of the report. Therefore, the basis of all values used, whether actual, estimated or projected, should be thoroughly documented. Any default values supplied by the economic analysis program should also be described.

- ☐ Basis for cost figures.
- ☐ Brief description of economic indicator being used.

8.1 Economic values

This section should be used to present the economic values necessary for the economic analysis. A detailed description of the source of these values should also be presented.

Costs

- ☐ Design.
- ☐ Installation.
- ☐ Material and components (current and projected).
- ☐ Space.
- ☐ Auxiliary equipment.
- ☐ Additional costs due to low temperature handling requirements.
- ☐ Total cost due to solar system.

Economic parameters

For simulation studies a set of suggested default values are provided in the table below. These may be used if more reliable local values are not available. These values are not meant to be »correct» for any particular study but rather a common basis so that studies can be compared. When available, local economic factors should be used rather than the default values.

- ☐ Interest rate.
- ☐ Term of mortgage.
- ☐ Effective net income tax rate.
- ☐ True property tax rate.
- ☐ Cost of auxiliary energy (by type).
- ☐ Fuel escalation rate.
- ☐ Inflation rate.

Default values of economic parameters	
Down payment	20%
Interest rate	8.5%
Discount rate	10%
Tax bracket	30%
Period of analysis	20 years
Mortgage length	30 years
General inflation rate	5%
Energy escalation rate	
Electricity and oil	7%
Natural gas	10%
Additional property tax	0

Subsidies and tax incentives

8.2 Economic analysis methods

There are many ways of presenting the results to an economic analysis. It is recommended that a Life Cycle Cost calculation be presented as a minimum to allow comparisons with other system performance reports. The calculation procedure should be thoroughly discussed and the significance of the economic parameters explained. The author should attempt to explain the relevance of the economic variables which are being calculated.

- ☐ Definitions of economic values.
- ☐ Description of calculation procedure.

8.3 Economic results

The results from the economic analysis should be presented here along with any additional information which might assist the reader in understanding those results.

- ☐ Total energy saved (by type).
- ☐ System operating costs (including maintenance if available).
- ☐ Capital costs per year.
- ☐ Auxiliary costs.
- ☐ Life cycle cost.
- ☐ Playback period.
- ☐ Definitions of all the above.

9 Discussion

The results presented in Chapters 7 and 8 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.

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.

10 Conclusions and recommendations

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.

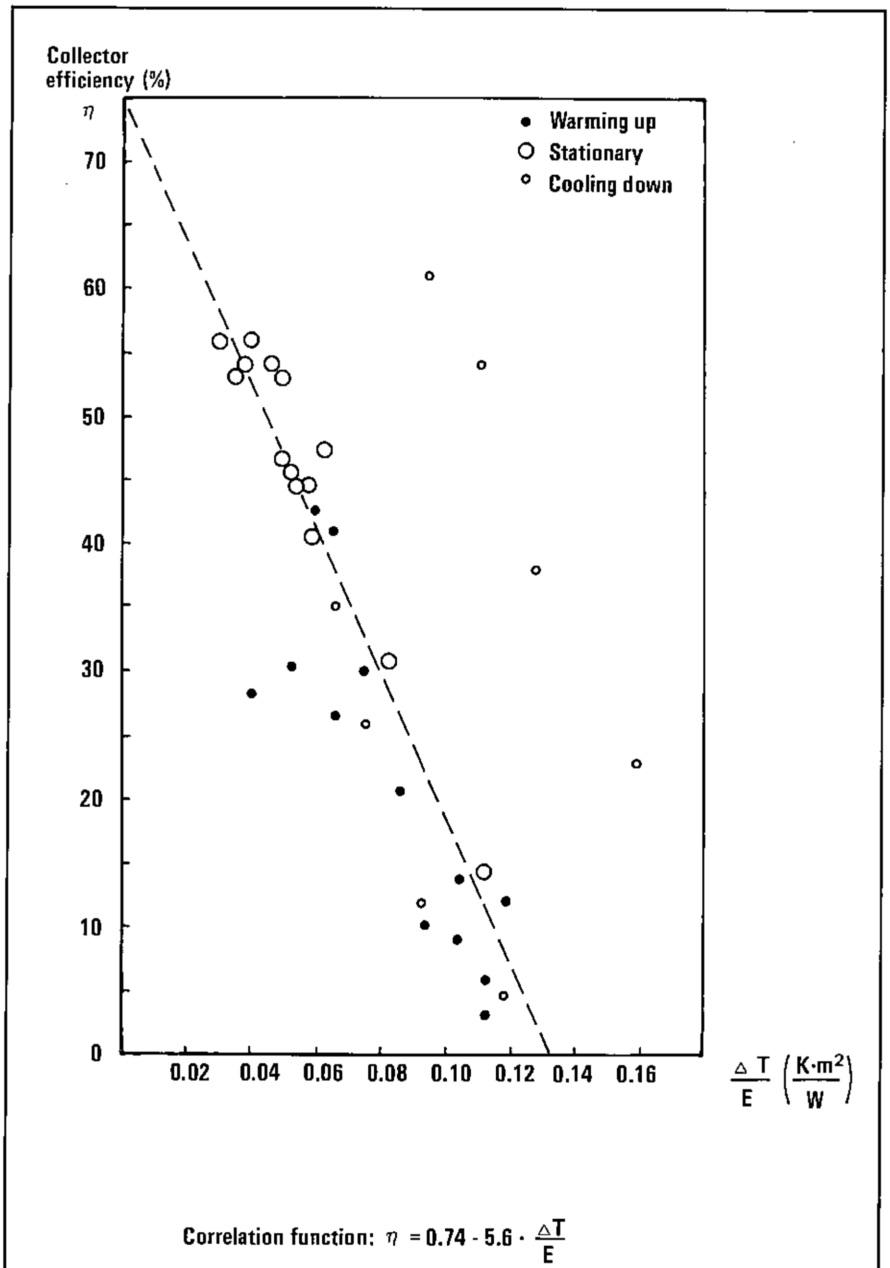
11 References

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

12 Appendices

The information in the body of the report should be limited to items which are related to or are needed for an understanding of the thermal performance of the system. In these appendices supplemental information and informations on item which do not affect the thermal performance may be provided. Which appendices to provide is left to discretion of the author. Some examples which will often be appropriate to include in a report are given below.

Figure 12.1. Example of illustration of measured efficiency data for the collector array. (Section 12.1)



12.1 Nomenclature, definitions and units

A complete list of nomenclature and definitions being used should be provided in the report. This is essential to avoid ambiguity. It is recommended that such a list is provided in this appendix.

SI-units should be used exclusively. Some valuable comments on the use of SI-units are found in »Units and Symbols in Solar Energy» by W. A. Beckman et al. (1977), which is included as an appendix below.

Although the designations and definitions in IEA-document (1979) have been used for reference, the author should not assume that those variables are universally defined and understood. All variables should be carefully defined with respect to the specific system being reported.

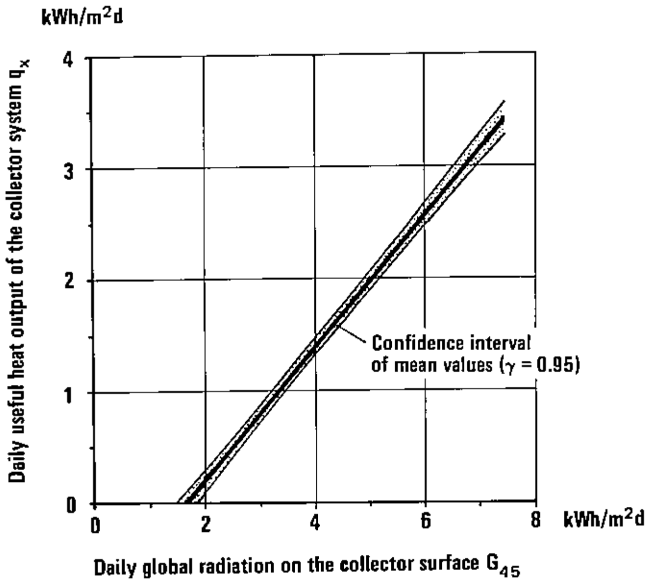
12.2 Detailed system description

Detailed information on subsystems and components of special interest should be given here. Information which does not necessarily affect the thermal performance of the system but may be of interest to other researchers should also be included.

The following is a partial list of typical details which might be presented in this appendix.

- ☐ Description together with photo or drawing of physical configuration including dimensions, construction, materials, working fluids and insulation.
- ☐ Thermal performance characteristics including design temperature, mass flow rates, capacity, coefficient of performance, efficiency curves, optical efficiency vs. angle of incidence, thermal loss (coefficient), pressure drop, operating energy, and for storages: charging and discharging capacity, temperature stratification.
- ☐ Comment on the durability characteristic including corrosion, leakage, infiltration, hotspots, breakage, stability of working fluid, changes in thermal performance over monitoring period, degradation of phase change material in storages (number of cycles).
- ☐ System characteristics for simulation studies.

The parameters listed below are given to help the researcher decide which parameters should



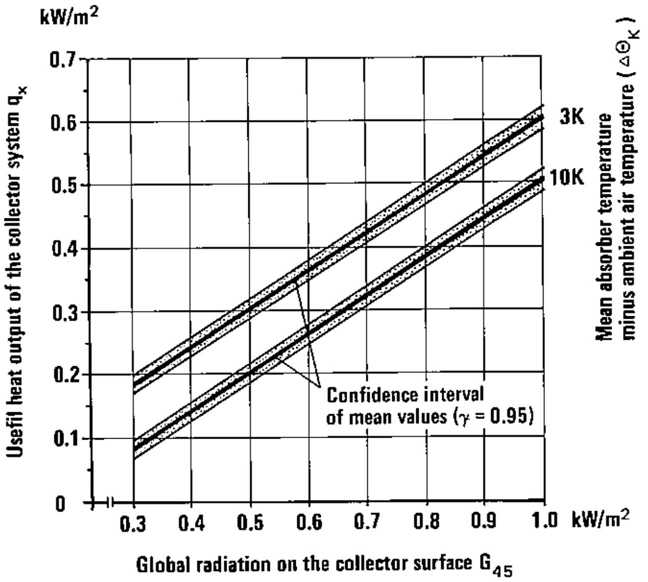
Useful heat output of the pool water collector system in 1977 (May-September)

Correlation function: $q_K = -0.951 + 0.585\ G_{45}$

$n = 131$

$r^2 = 0.77$

Figure 12.2



Useful heat output of the pool water collector system in 1977 (June)

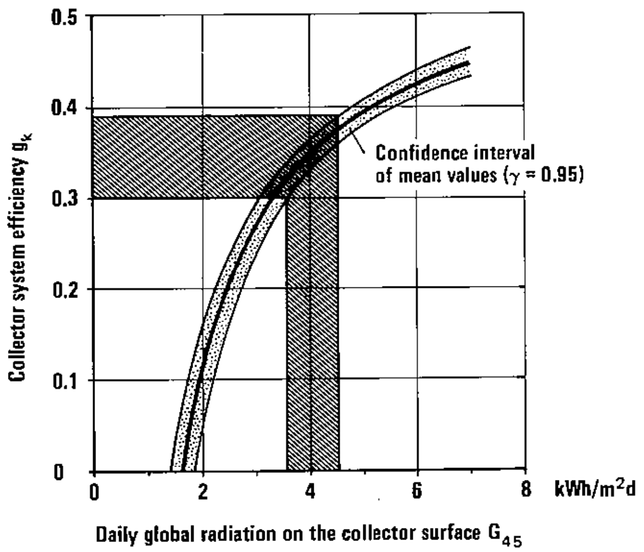
Range of measured values of G_{45} : 0.3 - 1.0 kW/m²

Correlation function: $q_K = 0.040 + 0.605 \cdot G_{45} - 0.014 \cdot \Delta\vartheta_K$

$n = 352$

$r^2 = 0.87$

Figure 12.3



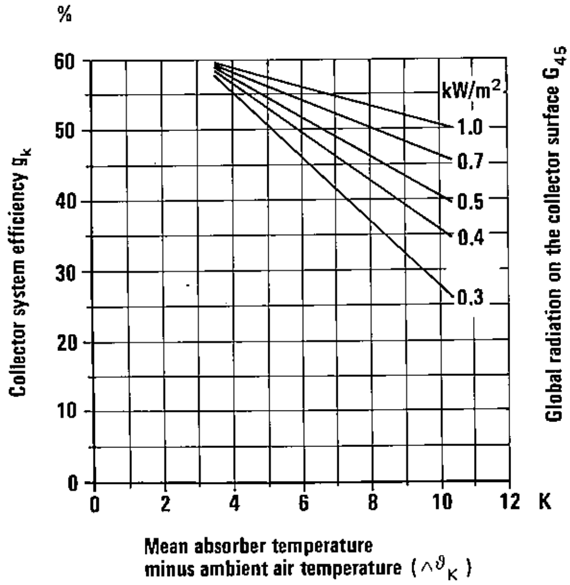
Solar energy transfer efficiency of the collector system in 1977

Correlation function: $g_K = 0.585 - \frac{0.951}{G_{45}}$

$n = 131$

$r^2 = 0.77$

Figure 12.4



Efficiency curves of the pool water collector collector system in I977 (June)

Range of measured values of G_{45} : 0.3 - 1.0 kW/m²

Correlation function: $\eta_K = 0.605 + \frac{0.040}{G_{45}} \frac{0.014}{G_{45}} \cdot \Delta\Theta_K$

$n = 352$

$r^2 = 0.87$

Figure 12.5

Figure 12.2–12.5. Example of illustration of collector performance results. (Section 12.2)

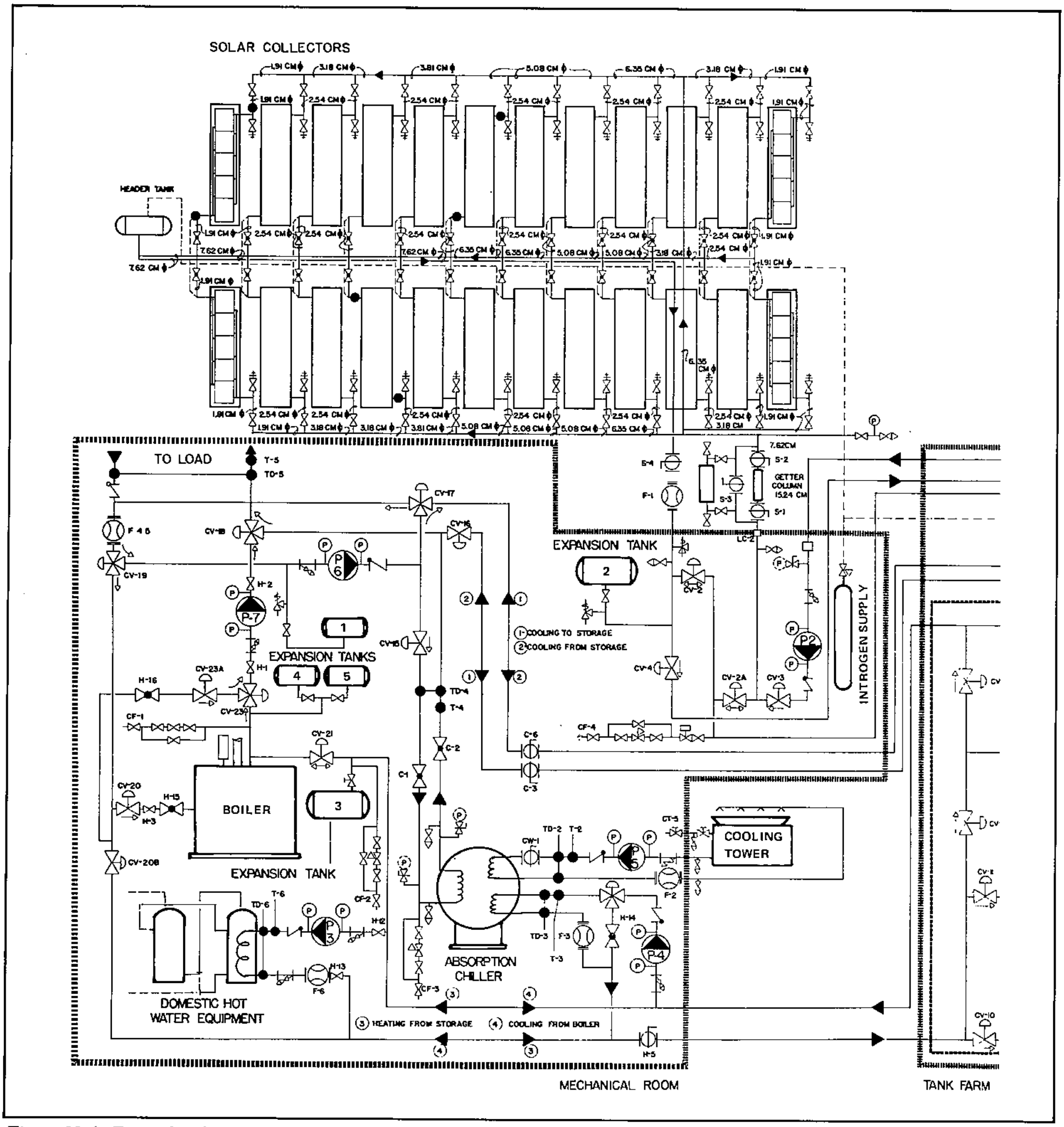


Figure 12.6. Example of schematic of a solar and HVAC-system. (Section 12.2)

be measured and reported. They are divided into long term and short term values. Long term analysis refers to calculations with simplified methods typically using monthly weather data (e.g. f-chart Univ. Wisconsin) and short term analysis refers to analysis with simulation programs typically using hourly weather data (e.g. TRNSYS Univ. Wisconsin). The list was derived by identifying those parameters which are usually necessary for the long term or short term analysis of a solar system. They are also listed by subsystem to facilitate future referencing.

The list below is not intended to be an all inclusive list. For some researchers it may not be within the scope of their project to identify all of the parameters listed. However, it is suggested that the researcher be as thorough as possible to maximize the usefulness of the report.

Suggested characteristics (long term)

Collector

Collector area
Azimuth angle
Collector tilt
Collector efficiency curve
Intercept $F_R\ (\alpha\tau)$
Slope $F_R \cdot U_L$
Incidence angle modifier
Number of covers
Maximum outlet temperature
Initial collector inlet temperature

Storage

Storage capacity
Storage/unit collector area

Building

Effective building UA
Building gross floor area
Number of occupants
ASHRAE STD 90–75 building description

Controls

Water set temperature

System

System type (Air SH & WH, LIQ SH & WH, LIQ WH only)
If air (flow rate/collector area) x (specific heat)
If LIQ ($\epsilon\, C_{min}$/UA)
Solar system efficiency
Solar system fuel type for auxiliary heating and efficiency

Suggested characteristics (short term)

Collector

Collector aperture area
Azimuth angle
Collector tilt
Collector fluid specific heat
Collector fluid flow rate at design condition
Boiling point of fluid
Collector efficiency curve
Intercept $F_R\ (\tau\alpha)$
Slope $F_R \cdot U_L$
Collector plate absorptance
Transmittance of the cover
Number of glazings
Collector plate emittance
Collector efficiency factor
Loss coefficient for bottom and edges
Product of the extinction coefficient and the thickness of each glass cover
Pressure drop through collectors
Optical efficiency vs. angle of incidence
Mass/unit area; empty; filled
Maximum operating temperature and pressure

Storage

Volume of tank
Height of tank
Mass of main hot storage
Storage tank loss coefficient
Initial storage tank temperature
Initial value of load return temperature
Main storage stratification factor
Location of auxiliary heating element in storage tank
Location of storage tank thermostat
Initial temperature of service water preheat tank
Mass of service water preheat tank
Maximum operating temperature
Mass flow rate from main storage to space heating load
Charging and discharging capacity at typical and flow rate

Rock bed

Air capacitance
Length of rock bed
Cross-sectional area
Perimeter of rock bed
Capacitance of rock
Apparent rock density
Loss coefficient
Effective thermal conductivity in the axial direction
Average rock diameter

Building

Sensible heat gain generation from occupants and equipment
Sensible heat gain factor
Building heat loss factor (UA) (including both transmission and ventilation losses)
Construction weight (light, medium, heavy)
Solar heat gain factor
Constant building internal heat generation
Number of occupants

If building heat loss factor UA is not to be used, then the following information is needed:

Each room

Volume of room
Air changes per hour
Floor area
Capacitance of room
Floor loss
Perimeter of building
Height of basement walls
Window screening and shutters
Temperature in unheated space
Area of surface of unheated space adjacent to heated space

Walls or flat roof

Absorptance of solar radiation
Infrared emittance
UA of each wall, or section of wall

Coefficient of previous flux terms
Total area of surface
Effectiveness transmittance of window
Number of glazings in windows
Fraction of surface that is window
Fraction of surface that is shaded
Area of south wall, east wall, north wall, west wall
Fraction of each wall that is window
Fraction of each window that is shaded

Pitched roof

Collector location
Ceiling insulation
Absorptance of solar radiation by non-collector surface
Emittance of non-collector surface
Area of north, south, east, west surfaces
Ceiling area
Slope of south surface
Slope of north surface

Heat exchanger

Overall heat transfer coefficient (UA) (for parallel, counter flow, cross flow modes)
Heat exchanger effectiveness (for constant effectiveness mode)
Specific heat of hot side fluid
Specific heat of cold side fluid
Hot side inlet temperature
Hot side mass flow rate
Cold side inlet temperature
Cold side mass flow rate

Controls

Set room temperature
Dumping temperature
Minimum collector outlet temperature for direct supply to load
Temperature differential to turn collector pump on
Temperature differential to turn collector pump off
Temperature differential for direct supply
Temperature differential to turn on service water heat exchanger pumps
Service water set temperature
Upper dead band difference
Lower dead band difference
Room temperature above which room is to be cooled
Room temperature below which 1st stage heating is commanded
Room temperature below which 2nd stage heating is commanded
Specific heat of cold side fluid
Hot side inlet temperature
Hot side mass flow rate
Cold side inlet temperature
Cold side mass flow rate

Controls

Set room temperature
Dumping temperature
Minimum collector outlet temperature for direct supply to load
Temperature differential to turn collector pump on
Temperature differential to turn collector pump off
Temperature differential for direct supply
Temperature differential to turn on service water heat exchanger pumps
Service water set temperature
Upper dead band difference
Lower dead band difference
Room temperature above which room is to be cooled
Room temperature below which 1st stage heating is commanded
Room temperature below which 2nd stage heating is commanded

Modes of supply

If system is passive, indicate measures to regulate temperature.
Type of controller
Type of sensors

Auxiliary

Auxiliary maximum heating rate
Auxiliary heating C_p
Auxiliary heat for space heating, modes: parallel, boost, no boost
Energy source
Design air temperature rise
Parasitics (not delivery fan)
Mass flow rate

Domestic water heater

Recovery rate
Standby heat loss
Tank volume
Energy source
Maximum pressure
Maximum temperature
Design water output temperature
Efficiency
Fluid mass flow rate
Maximum heating rate

Machines

Heat pump

Mass flow rate of liquid entering heat exchanger
Minimum liquid source temperature
Minimum air source temperature for parallel
Specific heat of liquid entering heat exchanger
Minimum liquid source temperature for direct heating from liquid source
Maximum ambient air temperature when heating is allowed

Minimum ambient temperature when cooling is allowed
Design evaporator, condensor temperature
COP vs. temperatures
Design parasitics (compressor and delivery)
Time constant

Cooling machine

Absorption machine coefficients for evaporator and generator
Capacity at design temperature at inlet
Chilled storage mass
Chilled water storage temperature above which chilled water should not be used
Initial storage temperature
Design heat rejection
Time constant
Mass flow rate of hot water to generator of absorption chiller
Capacity and COP curves (inlet temperature as variable)
Sensitivity of the capacity and COP to variations in inlet temperature, evaporation temperature, wet and dry bulb temperature

Pump

Maximum pump flow rate
Parasitic power at design conditions
Operating head

Plumbing

Total heat capacitance of pipe or duct and internal fluid
Initial pipe or duct temperature at beginning of simulation
Loss coefficient to surroundings (UA)

Delivery subsystem

Parasitics
Duct loss coefficients
Duct environment description
Design head loss
Leakage rate at design pressures

12.3 Detailed description of data system

For the experimenter there exists a wealth of information concerning the equipment and procedures used to gather the data. This may include sensor brand names, calibration techniques, instrumenting procedures, scan rates, etc. This information is not necessary in the body of the report but can be very valuable if provided in this appendix. The level of detail is left to the discretion of the reporter.

12.4 Error analysis

In the reporting of performance values there exists a level of uncertainty due to errors in the data acquisition process. These errors may include sensor error, drift, noise, profile assumptions, installation of instrumentation, assumptions about space and time distributions, assumptions inherent in a model about the physical system, etc. These errors should be aggregated to generate estimates of the accuracy of the reported values. The details of how this error analysis is done, and the resulting confidence limits, should be presented in this chapter.

12.5 Data tape formats

The experimenter may generate a substantial amount of data which is stored on tape. If tapes are used, the author should describe the format of the tapes and the availability of those tapes in this appendix. If simulation studies are reported, the data tapes used as input should be described (format and source).

12.6 Lesson learned

During the course of the study, the researcher will typically learn a great deal about running such a project. This format is mainly focused on thermal performance but in this chapter the researcher should document his experiences on matters which do not effect the thermal performance of the actual system being studied. The researcher should feel free to form this appendix, but the outline below points at some topics of interest.

12.6.1 Designing experiences

- ☐ Have building codes affected the design?
- ☐ Problems with localization of solar collectors and storages.
- ☐ Shading problems.

12.6.2 Installation experiences

- ☐ Delivery problems.
- ☐ Installation and integration of components in building.
- ☐ Running in of the system.

12.6.3 Operating experiences

- ☐ Freezing and boiling in collectors and storage.
- ☐ Occurrence of critical temperatures and pressures.
- ☐ Problems related to maintenance, serviceability, leakage and mechanical breakdown.
- ☐ Comments on durability characteristics.
- ☐ Time used to operate the system.
- ☐ Time used to maintain the solar energy system.
- ☐ Actual operating time of the pump/fan in the collector loop.
- ☐ Solar energy system off-time due to malfunctions.
- ☐ Users reactions (e.g. comfort level, noise, draught).

Table Transducer Specifications

Function	Instrument Type	Manufacturer, Description	Quantity	Instrument/ Data Range	Accuracy (1)	Comments
Temperature measurement (2)	Thermocouple Type T	Leads and Northrup, Omega, Thermo-Electric: 22 and 26 gage ThermoElectric, sheathed: Grounded (3) Ungrounded (3)	67 2 2	−184 to +390°C -40 to +150°C	±.4°C	Consider: Temperature gradients, heat transfer to and from the measuring junctions, thermoelectric homogeneity of wire, reference junction calibration, linearization errors, use of extension wire and connections, mechanical integrity, grounding, common mode voltage sources (including lightning).
Differential temperature measurement (2), (4)	Thermopile, Type T	Leads and Northrup, Omega 26 gage	7	−184 to +370°C ±100°C diff.	±(1%R+.05°C)	
Outside ambient temperature and humidity	Aspirator	Modified Cambridge Systems, Inc., Model nr.1105 — contains 1 T.C. and 1 R.H. sensor	1			
Air flow measurement (velocity pressure)	Total/static pressure tap array	Air Monitor Corp., duct air monitor device	7	+1 to +20 m/sec +1 to +3 m/sec	±(1.0%R+.02 N/m²), after calibration	More uniform pressure tap geometry and placement w.r.t. air straightener, more taps and better pneumatic averaging should give more uniform pitot coefficients between units. Suitability of materials for high temperature should be checked.
Pneumatic multiplexer	Ganged wafer valves, actuator and electrical driver	Fluid Wafer Switch SCANCO Actuator: LEDEX S2 Controller: CTLRP10/S2–56	2 1 1	10000 N/m² max operating pressure	N/A	Desiccant needed to prevent condensation of water vapor inside tubulation, wafer valve, and differential pressure transducer.
Differential pressure	Variable capacitance diaphragm type	Datametrics (Gould) Transducer: 570D–1T–2C1–V1 Signal Conditioner: 1173–A1A–10A1–D1 Thermal Base: Model 525	 1 1 1	±133 N/m² 0 to +4 N/m²	±(.2%R+.02%F) (5)	RC=5 seconds filter inserted to mask turbulence induced fluctuations. Controlled temperature transducer environment essential to maintaining quoted error limits.
etc.						

NOTES:

(1) R = of Reading; F = of Full Scale.

(2) All thermocouples and thermopiles are fabricated from premium grade wire. All except sheathed junctions are twisted, electric arc welded junctions and are directly exposed to the surrounding air.

(3) The two thermopile circuits — each comprised of one grounded and one ungrounded thermocouple — potentially available in the four absolute temperature measuring thermocouple circuits specified are used. This simultaneous use of thermocouple junctions for absolute and differential temperature measurements is possible because the A/D unit (Ooric) has a very high input impedance, and because its input terminals are isolated from one another and from ground.

(4) Each thermopile circuit is fabricated from a single spool of wire.

(5) ±1.0% of reading is typical accuracy achieved in this application because the readings are a small fraction of the instrument's full scale range.

Figure 12.7. Example of a specification of transducers and sensors. (Section 12.3)

Appendix: Units and symbols in solar energy

Units and symbols in solar energy†

W. A. Beckman,‡ J. W. Bugler,§ P. I. Cooper,¶ J. A. Duffie,‡ R. V. Dunkle¶ P. E. Glaser,‖ T. Horigome,†† E. D. Howe,‡‡ T. A. Lawand,§§ P. L. van der Mersch,¶¶ J. K. Page,††† N. R. Sheridan,‡‡‡ S. V. Szokolay,‡‡‡ and G. T. Ward,§§§

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Many disciplines are contributing to the literature on solar energy with the result that variations in definitions, symbols and units are appearing for the same terms. These conflicts cause difficulties in understanding which may be reduced by a systematic approach such as is attempted in this paper.

It is recognized that any list of preferred symbols and units will not be permanent nor can it be made mandatory, as new terms will emerge and old ones become less used with the development of the subject. But in the meantime, a list would be appreciated by the many workers who are entering this multi-disciplined field.

An examination of symbols and units, particularly those for radiation, reveals several inconsistencies which should be removed at this time when new units are being introduced. Further, while editorial policy has made S.I. units mandatory for journal papers, there is uncertainty as to their use, as is evident from recent papers.

First, the application of S.I. units to some common solar energy quantities is discussed and some interpretations made for particular cases. Then, a list of names, symbols and units is recommended.

S.I. UNITS

This new system of units (Système International d'Unités) is rational and based on metric quantities, but it is not the same as any previous system of metric units[1]. Thus, both Metric and Imperial units will need to be changed to conform to the new system.

While S.I. units are clearly defined, some modifications are being adopted by various countries to solve transitory problems or to suit local convenience[2]. However, it is believed that for scientific papers only those units derived from the basic S.I. quantities should be used, viz. mass kg; length m; time s; and temperature K.

Prefixes to alter the numerical value of units in powers of ten can be used though it is recommended that preference be given to those which effect a change of a thousand times, e.g. μ(micro)-10^{-6}; m(milli)-10^{-3}; k(kilo)-10^{3}; M(mega)-10^{6}. In compound units, the prefix should only be applied to the first unit in the series except for the special case of the kilogram.

Several common compound units have been given agreed names which will become familiar with usage. The use of these names will be encouraged.

†Produced by the Ad-hoc Committee on Education and Standardisation, ISES.

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§§§Lincoln College, Christchurch, New Zealand.

The S.I. units of several quantities common in solar energy literature are discussed below together with some alternative units. Some alternatives are inconsistent with S.I. and should not be used. Others, that are in widespread practical use, can be quoted in parenthesis after the equivalent S.I. value.

Energy: The S.I. unit is the joule ($J \equiv$ kg m^2 s^{-2}). The calorie and derivatives, such as the langley (cal cm^{-2}), are not acceptable.

No distinction between the different forms of energy is made in the S.I. system so that mechanical, electrical and heat energy are all measured in joules. However, the watt-hour will be used in many countries for commercial metering of electrical energy. Its use is discouraged in technical papers as it is derived from the hour which is not a basic S.I. quantity.

Power: The S.I. unit is the watt (W $\equiv$ kg m^2 $s^{-3} \equiv$ Js^{-1}). The watt will be used to measure power or energy-rate for all forms of energy and should be used wherever instantaneous values of energy flow are involved. Thus, energy flux density will be expressed as Wm^{-2} or specific thermal conductance as $Wm^{-2}K^{-1}$.

Energy-rate should not be expressed as Jh^{-1}.

When energy-rate is integrated for a time period, the result is energy which should be expressed in joules, e.g. an energy-rate of 1.2 kW would if maintained for one hour produce 4.3 MJ. It is preferable to say that

Hourly energy = 4.3 MJ

rather than

Energy = 4.3 MJ h^{-1}.

Similarily,

Daily energy = 104 MJ

is preferable to

Energy = 104 MJ day^{-1}.

Force: The S.I. unit is the newton (N $\equiv$ kg m s^{-2}). The kilogram-weight is not acceptable.

Pressure: The S.I. unit is the pascal (Pa $\equiv$ $Nm^{-2} \equiv$ kg m^{-1} s^{-2}). The unit kg cm^{-2} should not be used.

The atmosphere (1 atm $\equiv$ 101.325 kPa) and the bar should be in parenthesis.

Manometric pressures in metres or millimetres are acceptable.

Velocity: In S.I. units, velocity should be measured in ms^{-1}. Popular units such as kmh^{-1} should be in parenthesis.

Flow: In S.I. units, flow should be expressed in kg s^{-1}, m^3s^{-1}, or ls^{-1}. If non-standard units, such as l min^{-1} or kg h^{-1}, must be used, they should be in parenthesis.

Temperature: The S.I. unit is the kelvin (K). However, it is permissible to express temperatures in the equivalent practical scale for which the unit is the degree Celsius (°C).

When compound units involving temperature are used, they should be expressed in terms of the basic unit, e.g. specific heat capacity $Jkg^{-1}K^{-1}$.

Solar Energy, Vol. 21, pp. 65–68.

CONVERSION TO S.I. UNITS

When data is taken in some system of units other than S.I., it should be rounded off after conversion to a number of significant figures equivalent to that of the original data. Thus, an energy amount of 731 Btu will be converted to 771 kJ (1 Btu = 1.05506 kJ) or 15.3 ft^3 will be converted to 433 litre (1 ft^3 = 28.3168 litre).

The original quantity can be quoted in parenthesis if some details need to be preserved. Thus it might be desired to show that an integral value had been used in the original units, e.g. 828 MJ (230.0 kWh) or 31800 kJ m^{-2} (760 langley).

Care should be taken in converting data for graphical presentation, particularly where parameters separated by integral increments are used to cover a range of values. "Soft conversion" should not be applied to the parametric values but rather the data should be recalculated to insure integral parametric values in the new units. In the example (Fig. 1), direct conversion of parameters would give values of 444.4 K, 388.9 K and 333.3 K but the chosen values, 450 K, 400 K and 350 K, are more appropriate.

Table 1. Recommended symbols for material quantities

QUANTITY	SYMBOL	UNIT
specific heat	c	J kg^{-1} K^{-1}
conductivity	k	W m^{-2} K^{-1}
extinction coefficient	K	m^{-1}
idex of refraction	n	-
absorptance	α	-
diffusivity	α	m^2 s^{-1}
specific heat ratio	γ	-
emittance	ε	-
reflectance	ρ	-
density	ρ	kgm^{-3}
transmittance	τ	-

Table 3. Recommended symbols for miscellaneous quantities.

QUANTITY	SYMBOL	UNIT
area	A	m^2
heat transfer coefficient	h	Wm^{-2} K^{-1}
system mass	M	kg
air mass (or air mass factor)	m	-
mass flow rate	$\dot{m}$	kg s^{-1}
temperature	T	K
temperature	t	^{o}C
overall heat transfer coefficient	U	Wm^{-2} K^{-1}
efficiency	η	-
wavelength	λ	m
frequency	υ	s^{-1}
Stefan-Boltzmann Constant	σ	Wm^{-2} K^{-4}
time	τ,θ	s

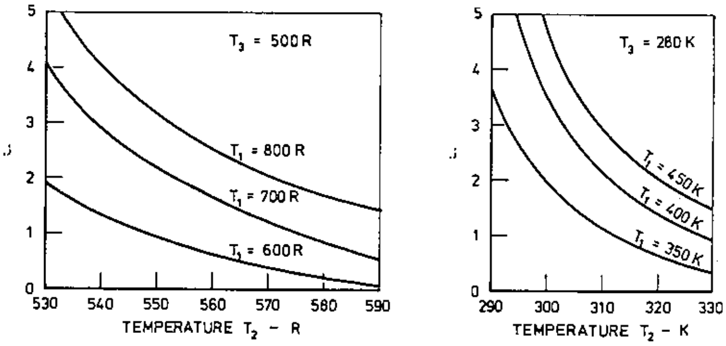

Fig. 1. Conversion of a parametric graph to S.I. units

Table 2. Recommended symbols and sign convention for sun and related angles

QUANTITY	SYMBOL	RANGE AND SIGN CONVENTION
altitude	α	0^o to $+90^o$.
surface tilt	β	0^o to $\pm 90^o$; towards equator is +ive
azimuth (of surface)	γ	0^o to 360^o; clockwise from North
declination	δ	0^o to $\pm 23.45^o$; North is +ive.
incidence (on surface)	θ,i	0^o to $+90^o$.
zenith angle (zenith distance)	θ_z	0^o to $+90^o$.
latitude	φ	0^o to $\pm 90^o$; North is +ive
hour angle	ω	0^o to 360^o; Noon is 0^o, afternoon is +ive
reflection (from surface)	r	0^o to $+90^o$.

Table 4. Recommended subscripts

ambient	a
black-body	b
beam (direct)	b
diffuse (scattered)	d
horizontal	h
incident	i
normal	n
outside atmosphere	o
reflected	r
solar	s
solar constant	sc
sunrise (sunset)	ss
total	t*
thermal	t, th
useful	u
spectral	λ

* The need for a subscript for total radiation is not great as the recommendation suggests that global irradiance, i.e. the sum of beam and diffuse irradiance, be unsubscripted.

NOMENCLATURE AND SYMBOLS

Obviously, historical usage is of considerable importance in the choice of names and symbols. But conflicts do arise between lists that are derived from different disciplines. Generally, a firm recommendation has been made for each quantity except for radiation where two lists of symbols are given.

Material quantities (see Table 1). The emission, absorption, reflection and transmission of radiation by materials are described in terms of quantities where suffixes, either "ance" or "ivity", have been used to distinguish between different approaches the definition of the phenomena. But each discipline appears to attach a different definition to each suffix.

Here, the suffix "ance" is used for the four quantities which are all dimensionless and defined as ratios in the following ways:

$$\text{emittance} \quad \epsilon = \frac{E}{E_b}\left(\text{or } \frac{M_s}{M_{sb}}\right)$$

$$\text{absorptance} \quad \alpha = \frac{\phi}{\phi_i}$$

$$\text{reflectance} \quad \rho = \frac{\phi}{\phi_i}$$

$$\text{transmittance} \quad \tau = \frac{\phi}{\phi_i}$$

where E and ϕ are the radiant flux densities that are involved in the particular processes. As these are the values that are measured for most surfaces used in solar equipment, it is sufficient to recommend these names.

The use of α for absorptance and diffusivity is usual, as is the use of ρ for reflectance and density. Neither case should give much concern.

Table 5. Recommended symbols for radiation quantities

PREFERRED NAME	SYMBOL List 1	SYMBOL List 2	UNIT
radiant energy	Q	Q	J
radiant flux	Φ	Φ	W
radiant flux density	ϕ	ϕ	Wm^{-2}
irradiance	E	H	Wm^{-2}
radiosity or radiant exitance	M	J	Wm^{-2}
radiant emissive power or radiant self-existance.	M_s	E	Wm^{-2}
radiant intensity or radiance	L	I	$Wm^{-2}\ sr^{-1}$
irradiation or radiant exposure	H	...	Jm^{-2}
<u>Solar Radiation or Insolation</u>			
global irradiance or solar flux density	G	G	Wm^{-2}
beam irradiance	G_b	G_b	Wm^{-2}
diffuse irradiance	G_d	G_d	Wm^{-2}
global irradiation	H	...	Jm^{-2}
beam irradiation	H_b	...	Jm^{-2}
diffuse irradiation	H_d	...	Jm^{-2}
<u>Atmospheric Radiation*</u>			
irradiation	$\phi\downarrow$	$\phi\downarrow$	Wm^{-2}
radiosity	$\phi\uparrow$	$\phi\uparrow$	Wm^{-2}
exchange	ϕ_N	ϕ_N	Wm^{-2}

*Unsubscripted—solar and thermal. Subscript s—solar (or short wave). Subscript t—thermal (or long wave).

Sun and related angles (see Table 2). Greek letters have been preferred for these symbols. Several systems of sign convention for the angles are in use, with quite divergent approaches to azimuth and hour angle. The system recommended appears to be the most usual.

Miscellaneous quantities (see Table 3). These values seem to have general agreement.

Subscripts (see Table 4). Lower case letters have been preferred. As a result, the subscript b is recommended for beam (or direct) radiation. There should be little confusion with the use of the same letter for "black-body".

There is a need to distinguish between solar (or short wave) and thermal (or long wave) radiation, so subscripts s and t are recommended. Some conflict arises with the use of t for total radiation, but it is felt that there should be no need to subscript the total radiation.

Radiation Quantities (see Table 5). Considerable differences exist between various systems of definitions and symbols for radiation quantities. The most comprehensive approach is that recommended by the Commission Internationale d'Eclairage (CIE) and the International Electro-technical Commission (IEC)[3]. But there are direct conflicts with the symbols and definitions accepted by heat-transfer authorities. Thus two lists are suggested, though the first list is recommended as being more comprehensive and self consistent. Generally, this first list is also consistent with the recommendations being studied by the World Meteorological Organisation.

Major conflicts have occurred with the definition of radiant intensity. But in the case of radiant energy, it has been felt that a unit in terms of power per unit solid angle is not needed. The other conflict that could not be resolved was the use of the symbol E to mean radiant emissive power in one system and irradiation in the other.

Note

The authors of this technical note welcome any comments or suggestions on this paper, as there should be a continuing effort to achieve standardization. Correspondence should be addressed to N. R. Sheridan, Chairman, ISES Committee on Education and Standardization, Department of Mechanical Engineering, University of Queensland, Brisbane, Australia, 4068.

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