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Solar heating — Domestic water heating systems —

Part 2:
Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems

Chauffage solaire — Systèmes de chauffage de l'eau sanitaire —
Partie 2: Méthode d'essai en extérieur pour la caractérisation de la performance des systèmes "tout solaire" et la prédiction de leur performance annuelle

Reference number
ISO 9459-2:1995(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 9459-2 was prepared by Technical Committee ISO/TC 180, *Solar energy*, Subcommittee SC 4, *Systems — Thermal performance, reliability and durability*.

ISO 9459 consists of the following parts, under the general title *Solar heating — Domestic water heating systems*:

— *Part 1: Performance rating procedure using indoor test methods*

— *Part 2: Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems*

— *Part 3: Performance test for solar plus supplementary systems*

— *Part 4: System performance characterization by means of component tests and computer simulation*

— *Part 5: System performance characterization by means of whole-system tests and computer simulation*

Annex A forms an integral part of this part of ISO 9459. Annexes B, C and D are for information only.

Introduction

International Standard ISO 9459 has been developed to help facilitate the international comparison of solar domestic water heating systems. Because a generalized performance model which is applicable to all systems has not yet been developed, it has not been possible to obtain an international consensus for one test method and one standard set of test conditions. It has therefore been decided to promulgate the currently available simple methods while work continues to finalize the more broadly applicable procedures. The advantage of this approach is that each part can proceed on its own.

ISO9459 is divided into five parts within three broad categories, as described below.

Rating test

ISO 9459-1:1993, *Solar heating — Domestic water heating systems — Part 1: Performance rating procedure using indoor test methods*, involves testing for periods of one day for a standardized set of reference conditions. The results, therefore, allow systems to be compared under identical solar, ambient and load conditions.

Black box correlation procedures

ISO 9459-2 is applicable to solar-only systems and solar-preheat systems. The performance test for solar-only systems is a "black box" procedure which produces a family of "input-output" characteristics for a system. The test results may be used directly with daily mean values of local solar irradiation, ambient air temperature and cold water temperature data to predict annual system performance.

ISO 9459-3 applies to solar plus supplementary systems. The performance test is a "black box" procedure which produces coefficients in a correlation equation that can be used with daily mean values of local solar irradiation, ambient air temperature and cold water temperature data to predict annual system performance. The test is limited to predicting annual performance for one load pattern.

Testing and computer simulation

ISO 9459-4, a procedure for characterizing annual system performance, uses measured component characteristics in the computer simulation program "TRNSYS". Procedures for characterizing the performance of system components other than collectors are also presented in this part of ISO 9459. Procedures for characterizing the performance of collectors are given in other International Standards.

ISO 9459-5 presents a procedure for dynamic testing of complete systems to determine system parameters for use in a computer model. This model may be used with hourly values of local solar irradiation, ambient air temperature and cold water temperature data to predict annual system performance.

The procedures defined in ISO 9459-2, ISO 9459-3, ISO 9459-4 and ISO 9459-5 for predicting yearly performance allow the ouput of a system to be determined for a range of climatic conditions.

The results of tests performed in accordance with ISO 9459-1 provide a rating for a standard day.

The results of tests performed in accordance with ISO 9459-2 permit performance predictions for a range of system loads and operating conditions, but only for an evening draw-off.

The results of tests performed in accordance with ISO 9459-3 permit annual system performance predictions for one daily load pattern.

The results of tests performed in accordance with ISO 9459-4 or ISO 9459-5 are directly comparable. These procedures permit performance predictions for a range of system loads and operating conditions.

System reliability and safety will be dealt with in ISO 11924:—, *Solar heating — Domestic water heating systems — Test methods for the assessment of reliability and safety.*

Solar heating — Domestic water heating systems —

Part 2:
Outdoor test methods for system performance characterization and yearly performance prediction of solar-only systems

1 Scope

This part of ISO 9459 establishes test procedures for characterizing the performance of solar domestic water heating systems operated without auxiliary boosting, and for predicting annual performance in any given climatic and operating conditions, but only for an evening draw-off. A "black box" approach is adopted which involves no assumptions about the type of system under test; the procedures are therefore suitable for testing all types of systems, including forced circulation, thermosiphon, freon-charged and integrated collector-storage systems.

This part of ISO 9459 is not intended to be used for testing solar heating systems which have an auxiliary heater as an integral part of the system, since the operation of the auxiliary input may influence the performance of the solar heating system. To quantify the interaction between the energy inputs, the test procedure described in ISO 9459-3 is recommended.

This part of ISO 9459 applies to solar-only domestic water heating systems designed to heat potable water to be supplied for domestic water usage and is not intended to be applied to other systems. The test procedures are applicable only to systems of 0,6 m^3 of solar storage capacity or less.

The test procedures in this part of ISO 9459 do not require the solar water heating system to be subjected to freezing conditions. Consequently, the energy consumed or lost by a system while operating in the freeze-protection mode is not determined.

This part of ISO 9459 is not generally applicable to concentrating systems.

It is not intended to be used for testing the individual components of the system, nor is it intended to abridge any safety or health requirements.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 9459. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 9459 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 9060:1990, *Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation.*

ISO 9459-3:—[1], *Solar heating — Domestic water heating systems — Part 3: Performance test for solar plus supplementary systems.*

ISO 9846:1993, *Solar energy — Calibration of a pyranometer using a pyrheliometer.*

ISO 9847:1992, *Solar energy — Calibration of field pyranometers by comparison to a reference pyranometer.*

ISO/TR 9901:1990, *Solar energy — Field pyranometers — Recommended practice for use.*

ISO 11924:—[1], *Solar heating — Domestic water heating systems — Test methods for the assessment of reliability and safety.*

World Meteorological Organization, *Guide to Meteorological Instruments and Methods of Observation,* No. 8, 5th edition, WMO, Geneva, 1983, Chapter 9 — World Radiometric Reference, known as the WRR.

3 Definitions

As stated in the Introduction, each part of ISO 9459 has been conceived as a self-contained document. Therefore, some of the terms with their definitions given in this clause may also appear in other part(s) of ISO 9459.

For the purposes of this International Standard, the following definitions apply.

3.1 absorber: Device within a solar collector for absorbing radiant energy and transferring this energy as heat into a fluid.

3.2 accuracy: Ability of an instrument to indicate the true value of the measured physical quantity.

3.3 ambient air: Air in the space (either indoors or outdoors) surrounding a thermal energy storage device, a solar collector, or any object being considered.

3.4 angle of incidence (of direct solar radiation)**:** Angle between the solar radiation beam and the outward-drawn normal from the plane considered.

NOTE 1 Angle of incidence is often termed "incidence angle" or "incident angle". The use of these terms is deprecated.

3.5 aperture area: Maximum projected area through which the unconcentrated solar radiation enters a collector.

3.6 aperture plane: Plane at or above the solar collector through which the unconcentrated solar radiation is admitted.

3.7 auxiliary energy: See auxiliary (heat) source.

3.8 auxiliary (heat) source: Source of heat, other than solar, used to supplement the output provided by the solar energy system.

3.9 collector: Device containing an absorber.

3.10 collector tilt angle: Angle between the aperture plane of a solar collector and the horizontal plane.

3.11 components: Parts of the solar hot water system including collectors, storage, pumps, heat exchanger, controls, etc.

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1) To be published.

3.12 concentrating collector: Solar collector that uses reflectors, lenses or other optical elements to redirect and concentrate the solar radiation passing through the aperture onto an absorber, the surface area of which is smaller than the aperture area.

3.13 differential temperature controller: Device that is able to detect a small temperature difference, and to control pumps and other electrical devices in accordance with this temperature difference.

3.14 domestic: For use in residential and small commercial buildings.

3.15 draw-off rate; water draw-off rate: Rate at which water is withdrawn from a water heating system.

3.16 draw-off temperature: Temperature of hot water withdrawn from the system.

3.17 evacuated tube [tubular] collector: Solar collector employing transparent tubing (usually glass) with an evacuated space between the tube wall and the absorber.

The absorber may consist of an inner tube or another shape, with means for removal of the thermal energy. The pressure in the evacuated space is usually less than 1 Pa.

3.18 flat plate collector: Non-concentrating solar collector in which the absorbing surface is essentially planar.

3.19 fluid transport: Transfer of air, water, or other fluid between components.

3.20 gross collector area: Maximum projected area of a complete solar collector, excluding any integral means of mounting and connecting fluid pipework.

For an array or assembly of flat plate collectors, evacuated tubes or concentrating collectors, the gross area includes the entire area of the array, i.e. also borders and frame.

3.21 heat exchanger: Device specifically designed to transfer heat between two physically separated fluids.

Heat exchangers can have either single or double walls.

3.22 heat transfer fluid: Fluid that is used to transfer thermal energy between components in a system.

3.23 irradiance: Power density of radiation incident on a surface, i.e. the quotient of the radiant flux incident on the surface and the area of that surface, or the rate at which radiant energy is incident on a surface, per unit area of that surface.

It is expressed in watts per square metre.

NOTE 2 Solar irradiance is often termed "incident solar radiation intensity", "instantaneous insolation", "insolation" or "incident radiant flux density"; the use of these terms is deprecated.

3.24 irradiation: Incident energy per unit area of a surface, found by integration of irradiance over a specified time interval, often an hour or a day.

It is expressed in megajoules per square metre.

NOTE 3 Solar irradiation is often termed "radiant exposure" or "insolation"; the use of these terms is deprecated.

3.25 load: Heat supplied to the user, for example in the form of hot water.

NOTE 4 Because of heat losses in the distribution system, the location of the heat delivery must be specified.

3.26 long-wave radiation: Radiation at wavelengths greater than 3 μm, typically originating from sources at terrestrial temperatures (e.g. ground and other terrestrial objects); sometimes called "thermal radiation".

3.27 precision: Measure of the closeness of agreement among repeated measurements of the same physical quantity.

3.28 pyranometer: Radiometer for measuring the irradiance on a plane receiver surface which results from the radiant fluxes incident from the hemisphere above, within the wavelength range 0,3 µm and 3 µm.

3.29 pyrgeometer: Instrument for determining the irradiance on a plane receiving surface which results from the radiant fluxes incident from the hemisphere above, within the wavelength range 3 µm to 50 µm.

NOTE 5 The given spectral range is similar to that of atmospheric long-wave radiation and is only nominal. Depending on the material used for the domes which protect the receiving surface of a pyrgeometer, the spectral limits of its responsivity meet more or less accurately the limits mentioned above.

3.30 pyrheliometer: Radiometer for measuring the irradiance which results from the solar radiant flux incident from a well-defined solid angle whose axis is perpendicular to the plane receiver surface.

NOTE 6 Pyrheliometers are used to measure direct solar irradiance at normal incidence. Typical field-of-view angles of pyrheliometers range from 5° to 10°.

3.31 radiant energy: Energy in the form of electromagnetic waves.

3.32 radiant flux: Power emitted, transferred or received in the form of radiation.

3.33 radiation: Transfer of radiant energy in the form of electromagnetic waves.

3.34 radiometer: Instrument for measuring radiant energy.

Its output can be either irradiance or irradiation.

3.35 solar (thermal) collector: Device designed to absorb solar radiation and to transfer the thermal energy so gained to a fluid passing through it.

NOTE 7 Sometimes called a solar "panel". This term is deprecated to avoid potential confusion with photovoltaic panels.

3.36 solar energy: Energy emitted by the sun in the form of electromagnetic radiation (primarily in the wavelength range of 0,3 µm to 3 µm) or any energy made available by the reception and conversion of solar radiation.

3.37 solar contribution: Heat supplied by the solar part of a system.

3.38 solar noon: Local time of day at which the sun crosses the observer's meridian.

NOTE 8 For the solstices, solar noon occurs when the sun is at its highest altitude for that day.

3.39 solar radiation: Radiation emitted by the sun, practically all of which is incident at the earth's surface at wavelengths less than 3 µm.

NOTE 9 It is often termed "short-wave radiation". Use of the term "insolation" to mean solar radiation is deprecated.

3.40 solar irradiance simulator: Artificial source of radiant energy simulating solar radiation, usually an electric lamp or an array of such lamps.

3.41 solar storage capacity: Quantity of sensible heat that can be stored per unit volume of store for every degree of temperature change.

3.42 solar hot water system: Complete assembly of subsystems and components necessary to convert solar energy into thermal energy for the heating of water; may include an auxiliary heat source.

3.43 storage device (thermal): Container(s) plus all contents of the container(s) used for storing thermal energy.

NOTE 10 The transfer fluid and accessories such as heat exchangers, flow switching devices, valves and baffles which are firmly fixed to the thermal storage container(s) are considered a part of the storage device.

3.44 surrounding air speed: Air speed measured in a specified location near a collector or system.

3.45 tank capacity: Measured volume of the fluid in the tank when full.

3.46 temperature, ambient air: Temperature of the air surrounding the thermal energy storage device or solar collectors being tested.

NOTE 11 Significant differences in ambient air temperature can occur over short distances; therefore, in a particular application the method of measurement should be specified.

3.47 time constant: Time required for a system, whose performance can be approximated by a first-order differential equation, to change output by 63,2 % of its final change in output, following a step change in input.

3.48 thermopile: Set of thermocouples connected in series which can measure small temperature differences by means of enhancement of the voltage signal per unit temperature change.

4 Symbols

The symbols given in ISO 9459-1 and the following symbols apply.

a_1, a_2, a_3	coefficients used in equation (2) (system performance)
b_1, b_2, b_3	coefficients used in equation (3) (water temperature increase)
c_{pw}	specific heat capacity of water, in joules per kilogram kelvin [J/(kg·K)]
$f(V)$	normalized draw-off temperature profile, dimensionless
$g(V)$	normalized mixing draw-off temperature profile, dimensionless
H	daily solar irradiation (radiance exposure) in the collector aperture, in megajoules per square metre
H_d	daily diffuse solar irradiation in the collector aperture, in megajoules per square metre
H_h	monthly average daily solar irradiation on a horizontal plane, in megajoules per square metre
H_{tilt}	monthly average daily solar irradiation on a tilted plane, in megajoules per square metre
Q	useful energy extracted from the system, in megajoules
Q_c	energy contained in a volume of water V_c, in megajoules
Q_{LOS}	thermal loss from the store, in megajoules
Q_R	energy remaining in the store, in megajoules
t_a	ambient or surrounding air temperature, in degrees Celsius
$t_{a,s}$	ambient air temperature adjacent to the store, in degrees Celsius
t_d	water temperature of load drawn off, in degrees Celsius
t_f	final water temperature [equation (1)], in degrees Celsius
t_h	required hot water temperature, in degrees Celsius
t_i	initial water temperature [equation (1)], in degrees Celsius
t_{main}	cold water supply temperature, in degrees Celsius
t_n	average ambient air temperature during the night, in degrees Celsius
t_s	average temperature of water in the store, in degrees Celsius

u	surrounding air speed, in metres per second
U_s	storage tank heat loss coefficient, in watts per kelvin
V_c	volume of daily hot water consumption, in litres
V_d	volume of water drawn off, in cubic metres
V_s	fluid capacity of the store, in litres
Δt	time interval, in seconds
ρ_w	density of water, in kilograms per cubic metre

Subscripts

(av)	average (mean) value of parameter
(day)	average (mean) value of parameter during the period 6 h before solar noon to 6 h after solar noon
(max)	maximum value of parameter

5 System classifications

Solar domestic hot water systems are classified by seven attributes, each divided into two or three categories. The categories of each attribute are defined as shown in table 1.

5.1 Attribute 1

a) **Solar only** — system designed to provide solar heated domestic water without use of supplementary energy other than that required for fluid transport and control purposes.

b) **Solar preheat** — system not incorporating any form of supplementary heating and installed to preheat cold water prior to its entry into any other type of household water heater.

c) **Solar plus supplementary** — system which utilizes both solar and auxiliary energy sources in an integrated way and is able to provide a specified hot water service independently of solar energy availability.

Table 1 — Classification of solar domestic hot water systems

Attribute	Category		
	a	b	c
1	Solar only	Solar preheat	Solar plus supplementary
2	Direct	Indirect	
3	Open	Vented	Closed
4	Filled	Drainback	Draindown
5	Thermosiphon	Forced	
6	Circulating	Series-connected	
7	Remote storage	Close-coupled collector storage	Integral collector storage

5.2 Attribute 2

a) **Direct** — system in which the heated water that will ultimately be consumed passes through the collector.

b) **Indirect** (heat exchange) — system in which a heat transfer fluid other than the heated water ultimately consumed passes through the collector.

5.3 Attribute 3

a) **Open** — system in which the heat transfer fluid is in extensive contact with the atmosphere.

NOTE 12 In the USA the term "open system" encompasses both open and vented systems as herein defined.

b) **Vented** — system in which contact between the heat transfer fluid and the atmosphere is restricted either to the free surface of a feed and expansion cistern or to an open vent pipe only.

c) **Closed** (sealed or unvented) — system in which the heat transfer fluid is completely sealed from the atmosphere.

5.4 Attribute 4

a) **Filled** — system in which the collector remains filled with the heat transfer fluid.

b) **Drainback** — system in which, as part of the normal working cycle, the heat transfer fluid is drained from the collector into a storage vessel for subsequent reuse.

c) **Draindown** — system in which the heat transfer fluid can be drained from the collector and run to waste.

5.5 Attribute 5

a) **Thermosiphon** — system which utilizes only density changes of the heat transfer fluid to achieve circulation between collector and storage.

b) **Forced** — system in which heat transfer fluid is forced through the collector either by mechanical means or by externally generated pressure.

5.6 Attribute 6

a) **Circulating** — system in which heat transfer fluid circulates between the collector and a storage vessel or heat exchanger during operating periods.

b) **Series-connected** — system in which the water to be heated passes directly from a supply point through the collector to a storage vessel or to a point of use.

5.7 Attribute 7

a) **Remote storage** — system in which the storage vessel is separate from the collector and is located at some distance from it.

b) **Close-coupled collector storage** — system in which storage vessel abuts the collector, and is mounted on a common support frame.

c) **Integral collector storage** — system in which the functions of collection and storage of solar energy are performed within the same device.

6 Requirements

6.1 System requirements

6.1.1 System type

Before applying the test procedure to a system with an auxiliary heater the following must be considered.

6.1.1.1 Systems with separate auxiliary heating

Only the solar part of the system shall be tested using the test procedure. The solar performance of systems which have an auxiliary heater separated from the solar-heated storage tank will not be influenced by the auxiliary heater. However, the load size will be influenced by the presence of the auxiliary heater. Therefore, if the system is to be tested with both the solar preheater and separate auxiliary heater considered as part of the same system, the test procedure described in ISO 9459-3 shall be used.

6.1.1.2 Systems with manual auxiliary heater control

Systems which have an auxiliary heater integrated in the solar-heated storage tank, and in which the auxiliary heater is provided only for irregular intermittent operation (manually operated switch), shall be tested with the auxiliary heater switched off.

6.1.1.3 Systems with integrated auxiliary boosting

The test procedure does not apply to systems which have a continuous or nighttime-use auxiliary heater integrated in the solar-heated storage tank. Such systems should be assessed using the test procedure defined in ISO 9459-3 or other suitable International Standard.

6.1.2 Test system installation

Tests shall be performed with the system components installed in accordance with the manufacturer's installation instructions. Any controller included in the system shall be set in accordance with the manufacturer's instructions. In the absence of specific instructions from the manufacturer, the system shall be installed as follows.

The system shall be mounted in a manner such as to ensure safety to personnel. Due consideration shall be paid to the likelihood of glass failure and the leakage of hot liquids. Mountings shall be able to withstand the effects of wind gusts.

Whenever possible the system shall be mounted on the mounting structure provided by the manufacturer. If no mounting is provided then, unless otherwise specified (for example when the system is part of an integrated roof array), an open mounting system shall be used. The system mounting shall in no way obstruct the aperture of the collectors and the mounting structure shall not significantly affect the back or side insulation of the collectors or storage vessel.

Except for systems where the storage vessel is fixed to the collectors in some way (for example integral collector-storage systems and close-coupled thermosiphon systems), the store shall be installed in the lowest position allowed in the manufacturer's installation instructions.

For systems where the hot water store is separate from the collectors, the total length of the connecting pipes between the collector and store (pumped circulation systems) shall be 15 m. The diameter and insulation of the pipes shall be in accordance with the manufacturer's installation instructions.

6.1.3 Collector installation

The collector shall be mounted in a fixed position facing the equator to within $\pm$ 10°.

The collector shall be located such that a shadow will not be cast onto the collector at any time during the test period.

The collector shall be located where there will be no significant solar radiation reflected onto it from surrounding buildings or surfaces during the tests, and where there will be no significant obstructions in the field of view.

The performance of some collectors is sensitive to air speeds over the collector in the range 0–3 m/s. In order to maximize the reproducibility of results, collectors that are sensitive to surrounding air speed shall be mounted such that air with a mean speed of between 3 m/s and 5 m/s will freely pass over the aperture, back and sides of the collector.

Warm currents of air, such as those which rise up the walls of buildings, shall not be allowed to pass over the system. Systems tested on the roof of a building shall be located at least 2 m away from the edge of the roof.

Collectors designed for integration into a roof may have their backs protected from the wind, though this shall be reported with the test results.

6.1.4 Liquid flow system

A test loop of the type shown in figure 1 shall be used. The piping material used in the loop shall be appropriate to the fluid used in the system and suitable for operation at temperatures up to 95 °C. Pipe lengths should be kept short. In particular, the piping between the outlet of the cold water (inlet) temperature controller and the inlet to the storage vessel shall be minimized, to reduce the effects of the environment on the inlet temperature of the water. This section of pipe shall be insulated to ensure a rate of heat loss of less than 0,2 W/K and be protected by a reflective weatherproof coating.

Pipework between the temperature-sensing points and the store (inlet and outlet) shall be protected with insulation and reflective weatherproof covers extending beyond the positions of the temperature sensors, such that the calculated temperature gain or loss along either pipe does not exceed 0,01 K under test conditions. Flow mixing devices such as pipe bends are required immediately upstream of temperature sensors.

The flow controller and flow meter shall be installed on the cold water inlet pipe, so that readings are not affected by temperature changes.

A draw-off bleed pipe shall be installed on the cold water pipe just before the store inlet.

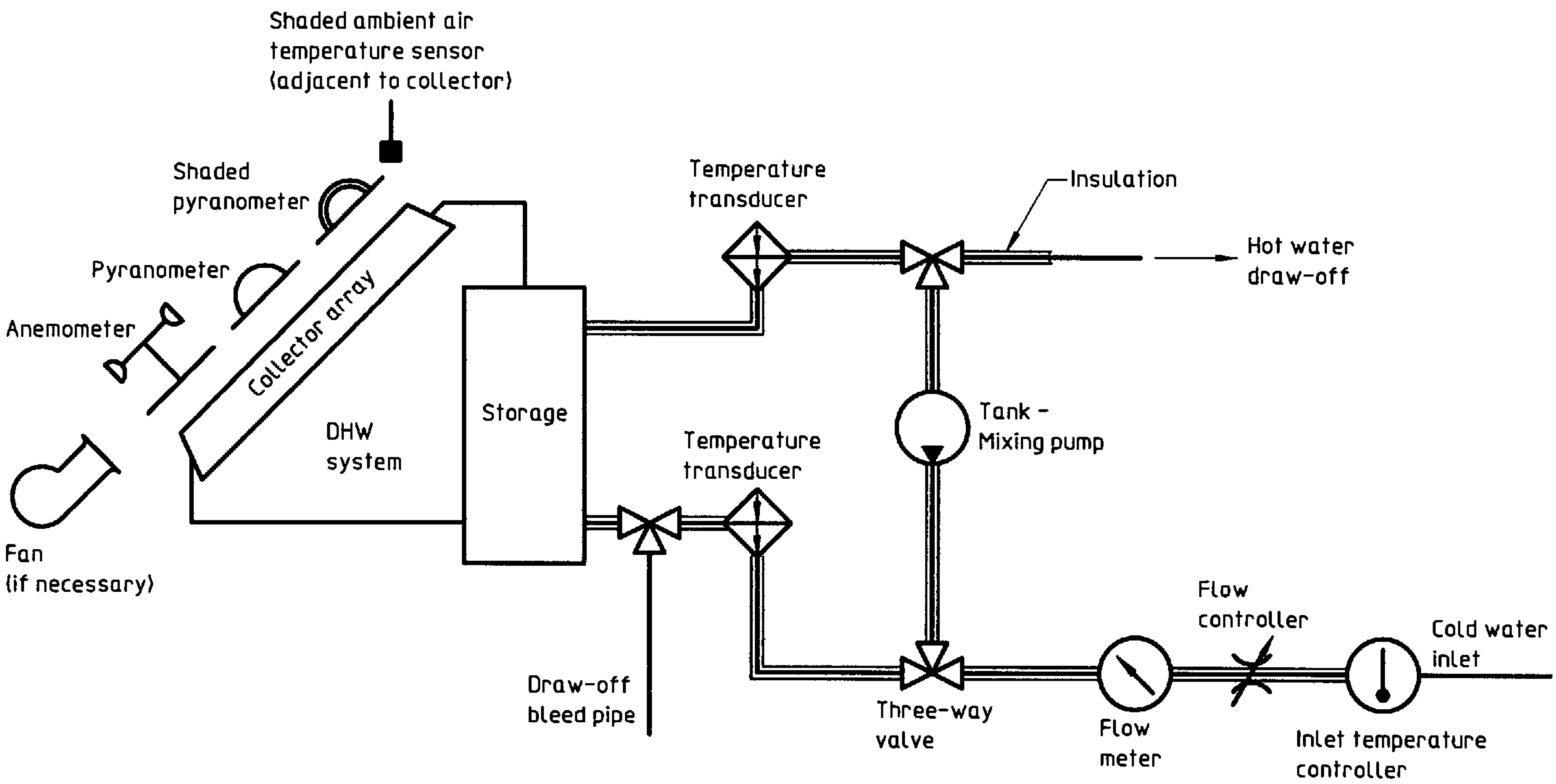


Figure 1 — Schematic representation of experimental apparatus for daily system performance test

The solar domestic water heating system shall be installed with the collector tilted at the specified tilt angle, and the tilt angle used for testing shall be reported with the test results. The specified tilt angle shall remain constant throughout the test.

The heat transfer fluid used in the system during testing shall be the fluid recommended by the manufacturer. When testing forced-circulation systems, the fluid flowrate recommended by the manufacturer shall be used. If the solar collector loop is designed to be used with non-freezing fluids (antifreezing inhibitors), the test procedures in this standard must be carried out with these fluids, according to the manufacturer's requirements.

6.2 Measurement requirements

6.2.1 Solar radiation

Pyranometers shall be used to measure the solar global irradiance and the solar diffuse irradiance. Pyranometers shall be first class (or better) pyranometers as specified in ISO 9060. The recommended practice included in ISO/TR 9901 should be observed.

The pyranometers shall be calibrated using either a standard pyrheliometer in accordance with ISO 9846 or a reference pyranometer in accordance with ISO 9847. Any change in the responsivity of more than ± 1 % over a one-year period shall warrant the use of more frequent calibration or replacement of the instrument if the instability is permanent. If an instrument is damaged in any significant manner, it shall be recalibrated to check the stability of the calibration factor and the time constant. In case of replacement of one of the domes, the cosine response should also be verified.

6.2.2 Temperature

6.2.2.1 Accuracy, precision and response time

The accuracy and precision of the instruments for temperature measurement including their associated readout devices, shall be within the limits given in table 2. The response time shall be less than 5 s.

6.2.2.2 Ambient temperature

The ambient air temperature shall be measured using a shaded aspirated sampling device approximately 1 m above the ground, not closer than 1,5 m to the collector and system components and not further away than 10 m from the system. The temperature of surfaces adjacent to the system should be as close as possible to that of the ambient air. For example, the field-of-view of the system shall not include chimneys, cooling towers or hot exhausts.

NOTE 13 The use of radiation shields with forced ventilation is recommended during ambient air temperature measurements.

6.2.2.3 Input water temperature

The temperature of the water supply to the system, t_{main}, shall be controlled to give the values specified in 7.2 for the test conditions.

Table 2 — Accuracy and precision of instruments for temperature measurement

Parameter	Instrument accuracy	Instrument precision
Temperature, ambient air	± 0,5 °C	± 0,2 °C
Temperature, cold water inlet	± 0,1 °C	± 0,1 °C
Temperature difference across hot water system (cold water inlet to hot water draw-off)	± 0,1 K	± 0,1 K

If an in-line temperature controller is used at the inlet to the storage vessel, then this will require a high power due to the high flowrate used during the test. Alternatively, temperature regulation may be achieved by the controlled mixing of water from a hot water reservoir and cold water reservoir, both held at constant temperatures. The temperature controller or mixing valve shall be able to control the drift in temperature of the inlet fluid to within 0,2 K in the period between the start and the end of the draw-off when the flowrate is 600 l/h. Fluctuations in the inlet fluid temperature of ± 0,25 K are permitted if these are caused by the hysteresis in the temperature controller, and provided that they do not result in additional drift.

6.2.3 Liquid flow

The accuracy of the liquid flowrate measurement shall be equal to or better than ± 1,0 % of the measured value in mass units per unit time.

When testing systems with pumped circulation, a flow meter shall be installed in the collector loop to measure the fluid flowrate to an accuracy of ± 5 %.

6.2.4 Mass

Mass measurement shall be made to an accuracy of ± 1 %.

6.2.5 Elapsed time

Elapsed time measurements shall be made to an accuracy of ± 0,20 %.

6.2.6 Surrounding air speed

The surrounding air speed shall be measured with an instrument and associated readout device that can determine the integrated average surrounding air speed for each test period to an accuracy of ± 0,5 m/s.

6.2.7 Data recorders

Analog and digital recorders used shall have an accuracy equal to or better than ± 0,5 % of the full scale reading and have a time constant of 1 s or less. The peak signal indication shall be between 50 % and 100 % of full scale.

Digital techniques and electronic integrators used shall have an accuracy equal to or better than 1,0 % of the measured value.

The input impedance of recorders shall be greater than 1 000 times the impedance of the sensors or 10 MΩ, whichever is higher.

In no case shall the smallest scale division of the instrument or instrument system exceed two times the specified precision. For example, if the specified precision is ± 0,1 °C, the smallest scale division shall not exceed ± 0,2 °C.

7 Test procedure

7.1 Principle

This test involves a series of one-day outdoor tests (see 7.6) on the complete system (at least six one-day tests), together with a short test (see 7.7) to determine the degree of mixing in the storage tank during draw-off, and an overnight heat loss test (see 7.8) to determine the heat loss coefficient of the storage tank. An optional test (annex C) with a midday draw-off is included.

The test procedure consists of a number of one-day tests which are independent of each other. On each day of the test, the system is allowed to operate outdoors and a single draw-off is applied at the end of day. At the start of each day of the test, the system is preconditioned by flushing it with water at a known temperature. The input, (i.e. the irradiation incident on the system), and the output, (i.e. the energy contained in the hot water draw-off), are measured for each test day and plotted on an input/output diagram. The test days shall cover a range of irradiation values and values of $(t_{a(day)} - t_{main})$ so that the dependence of the system performance on these parameters can be established.

7.2 Range of test conditions

Results shall be obtained for at least four different days with approximately the same values of $[t_{a(day)} - t_{main}]$ and irradiation values evenly spread over the range 8 MJ/m^2 to 25 MJ/m^2. Results shall also be obtained for at least two additional days with values of $[t_{a(day)} - t_{main}]$ at least 9 K above or below the values of $[t_{a(day)} - t_{main}]$ obtained for the first four days. The value of $[t_{a(day)} - t_{main}]$ shall be in the range − 5 K to + 20 K for each test day.

7.3 Preconditioning of the test system

Visually inspect the system and record any damage. Thoroughly clean the collector aperture cover.

At the beginning of each test day, before the start of the test, shield the collector from direct sun and precondition the system by circulating cold water at temperature t_{main} through the system at a flowrate of at least 600 l/h so that the whole system is brought to a uniform temperature.

Where the collector loop employs forced circulation, use the pump to bring the collector loop to the preconditioning temperature. Where a special means of preconditioning is needed, then the test report shall include details of the methods employed. Unless the system is one in which the hot water delivered to the taps is heated by being passed through a heat exchanger, the system is assumed to have reached a uniform temperature when the difference in the temperature of water at the outlet of the system and the inlet of the system is less than 1 K for a period of at least 15 min.

When the system has reached a uniform temperature, stop the circulation, but (in the case of forced circulation systems) leave the pump of the solar collector loop running.

The values of t_{main} to be used for each test day are determined as in 7.2. The cold water temperature shall be maintained at t_{main} by means of a temperature controller as specified in 6.2.2.3. Stop the circulation just before the beginning of the test period and isolate the bypass loop by means of a valve to inhibit natural circulation.

7.4 Surrounding air speed

The average speed of the air flowing over the collector shall lie between 3 m/s and 5 m/s when measured in the plane of the collector at a distance of 50 mm from the surface of the cover, and at no point over the collector aperture shall the speed deviate from the mean by more than ± 25 %. Artificial wind generators shall be used as necessary to achieve these wind speeds. The speed at any point over the collector aperture shall remain steady and the temperature of the air leaving the wind generator shall lie within ± 1 °C of the ambient air temperature.

7.5 Measurements during test period

The following measurements, made in accordance with the requirements given in clause 6, shall be recorded on an hourly average basis during the test period, from 6 h before solar noon to 6 h after solar noon:

a) global solar irradiance on the collector aperture;

b) diffuse solar irradiance on the collector aperture;

c) ambient air temperature adjacent to the collectors;

d) surrounding air speed (if a ventilator is used, a single measurement may be used as the daily average value);

e) electric energy consumed by circulation and control apparatus of the system (pumps, controls, solenoid valves, etc.).

7.6 Determination of daily system performance

The system shall be allowed to operate for 12 h, from 6 h before solar noon until 6 h after solar noon. At 6 h after solar noon the collector shall be shielded, and water drawn off from the store at a constant flowrate of 600 l/h. The cold make-up water shall be at the temperature t_{main} defined during the preconditioning of the system.

A short time (10 min – 20 min) before water is drawn off from the system (at 6 h after solar noon) some cold inlet water shall be discharged through the bleed-off pipe to ensure that the water in the pipework between the cold water inlet temperature controller and the inlet to the store is at the desired temperature t_{main}. The flowrate from the store through the bleed pipe shall be zero.

The temperature of the water being drawn off (t_d) shall be measured at least every 15 s and an average value recorded at least every time a tenth of the tank volume is drawn off. The temperatures shall be used to construct a draw-off temperature profile as shown in figure 2. Measurements of water temperature entering the storage tank and water drawn off from the storage tank shall be made in accordance with the requirements of clause 6.

A volume of water equal to three times the tank volume shall be drawn off. If the temperature difference between the water drawn off and the cold water entering the store is greater than 1 K after three tank volumes, then the draw-off shall be continued until the temperature difference is less than 1 K.

During the draw-off, the temperature of the cold water entering the storage tank shall not fluctuate by more than ± 0,25 K and shall not drift by more than 0,2 K during the draw-off period.

The flowrate during the draw-off of hot water from the store is very important, and can greatly influence the draw-off temperature profile. The flow controller must therefore maintain a constant flowrate through the storage vessel at 600 l/h ± 50 l/h.

7.7 Determination of the degree of mixing in the storage vessel during draw-off

7.7.1 General

This test shall be carried out in addition to the daily system performance tests specified in 7.6. The test is designed to determine the amount of mixing between hot water in the tank and cold water entering the tank, during a hot water draw-off. The "mixing" draw-off profile can be obtained by drawing off water from a tank which has been preheated to a uniform high temperature.

NOTE 14 This may be achieved by filling the storage tank with hot water, or by allowing it to heat up by operating the system with no draw-off, as necessary.

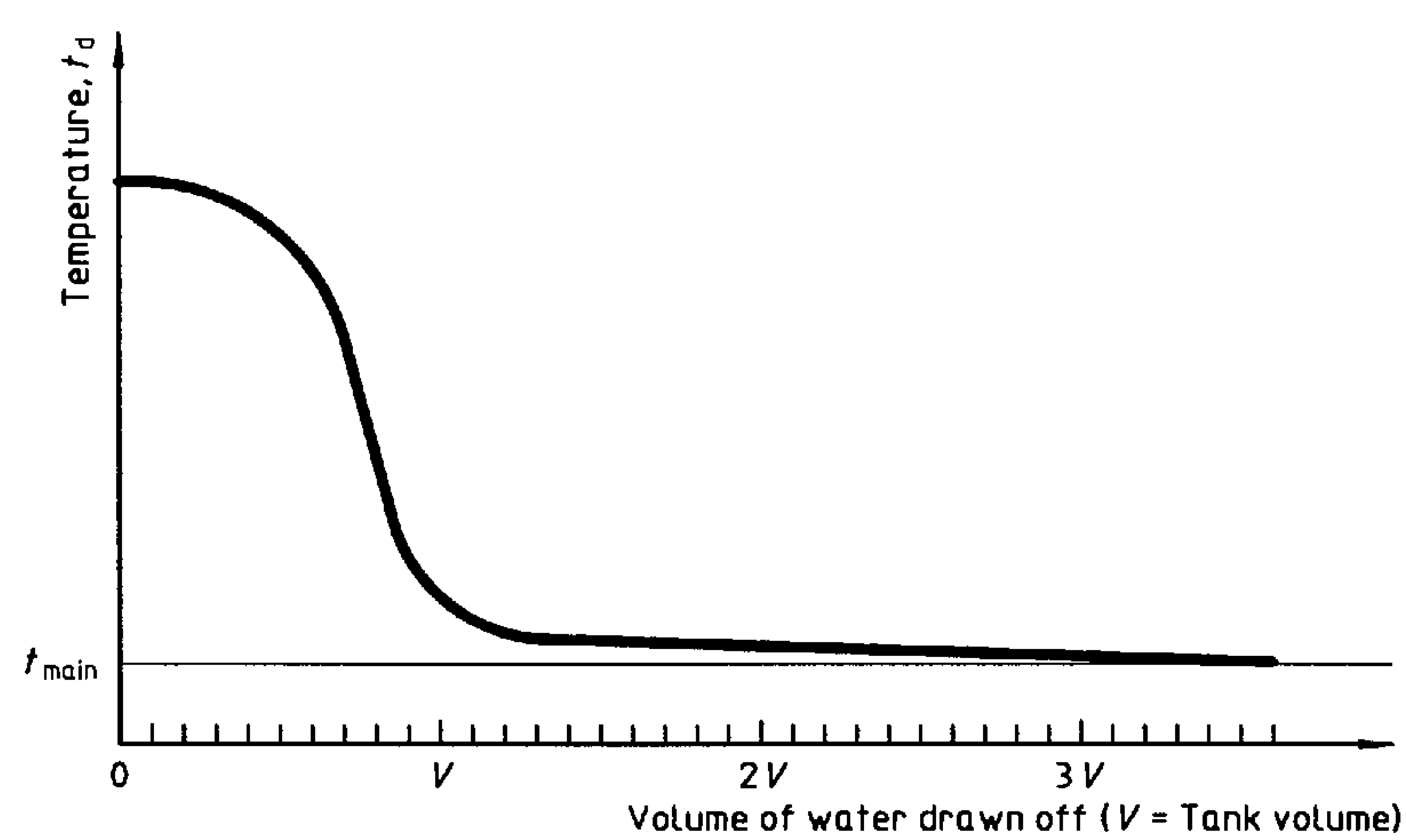


Figure 2 — Draw-off temperature profile

7.7.2 Test method

The test may be performed with the system mounted indoors or outdoors. If the test is performed outdoors, then the collector shall be shaded from the sun. The storage tank shall be preconditioned by being uniformly heated to a temperature above 60 °C.

Before the start of test, mix the water in the storage tank by using a small pump to circulate the water from the top to the bottom of the store. Circulate the water at a rate of at least five times the tank volume per hour. The water in the store is assumed to be at a uniform temperature when the temperature of the water at the outlet of the store varies by less than 1 K for a period of 15 min. Then stop the circulation and close the valves to the pipework containing the tank mixing pump.

Draw off water from the store at a constant flowrate of 600 l/h. The cold water entering the store shall be at a constant temperature of less than 30 °C, shall not fluctuate by more than ± 0,25 K and shall not drift by more than 0,2 K during the draw-off period. Measure the temperature of the water being drawn off frequently enough to permit a curve like that shown in figure 3 to be constructed. Measure the temperature at least every 15 s and record an average value at least every time a tenth of the tank volume is drawn off. The measurements of the temperature of water entering the storage tank and water drawn off from the storage tank should be made in accordance with the requirements of clause 6.

Draw off a volume of water equal to three times the tank volume. If the temperature difference between the water drawn off and the cold water entering the storage tank is greater than 1 K after three tank volumes have been drawn off, then the draw-off shall be continued until the temperature difference is less than 1 K.

7.8 Determination of storage tank heat losses

7.8.1 General

This test shall be carried out in addition to an overall system performance test. The heat loss coefficient of the storage tank shall be determined with the system installed and mounted as specified in clause 6. This is to ensure that an appropriate value for the heat losses is determined for use in system performance calculations, including, for example, heat losses caused by reverse flow in the collector loop. This coefficient shall be used for prediction of the long-term performance of the system.

The test may be performed with the system mounted indoors or outdoors. If the test is performed indoors, a radiative shield at a temperature of 20 K below ambient shall be placed in front of the collectors.

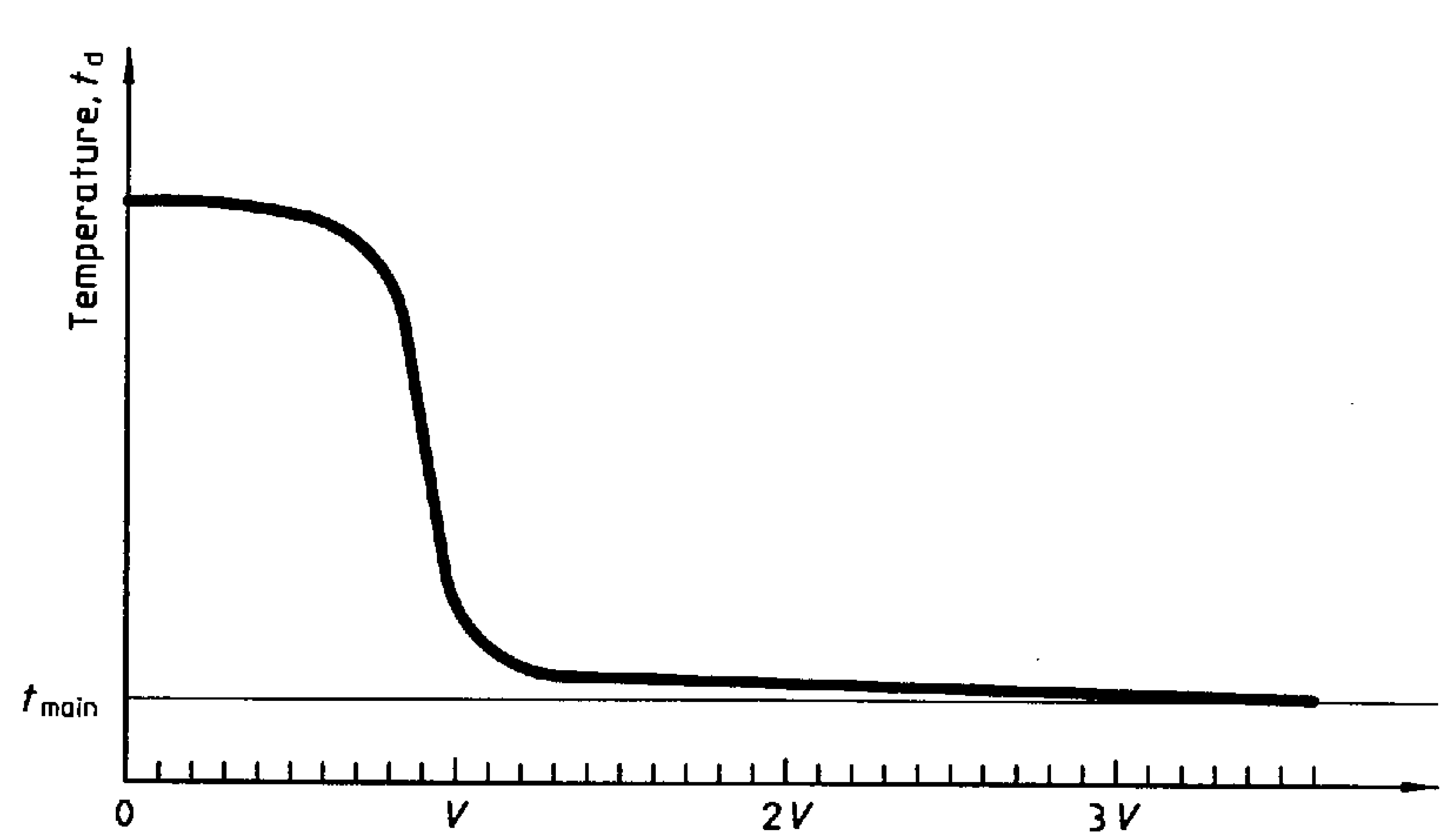


Figure 3 — Mixing draw-off profile

If the test is performed outdoors, then it shall be performed at night, with the collectors exposed to clear sky. Some early morning and late evening daylight hours may be used provided that the whole system is shielded from solar irradiation during these periods.

The storage tank water shall be preconditioned by being uniformly heated to a temperature above 60 °C.

NOTE 15 This may be achieved by filling the storage tank with hot water, or by allowing it to heat up by operating the system with no draw-off as necessary.

7.8.2 Test method

Before the start of the test, turn off the auxiliary heater and mix the preconditioned water in the store by using a pump to circulate the water from the top to the bottom of the store. Circulate the water at a rate of at least five times the tank volume per hour. The water in the store is assumed to be at a uniform temperature when the temperature of the water at the outlet of the store varies by less than 1 K for a period of 15 min. The average temperature over these 15 min is to be taken as the initial temperature of the tank. Then stop the circulation, close the valves to the pipework containing the tank mixing pump and leave the tank to cool for a period of between 12 h and 24 h.

During the cooling period, air with a mean wind speed of between 3 m/s and 5 m/s shall pass freely over the aperture, back and sides of the collector and over the storage vessel if this is designed to be mounted outdoors, following the requirements of clause 6 and 7.4.

Measure the ambient temperature in the locality of the storage tank every hour during the test period.

At the end of the test period, recirculate the water in the storage tank so that it reaches a uniform temperature. The temperature is assumed to be uniform when the temperature at the outlet of the tank varies by less than 1 K for a period of 15 min. The average temperature during this 15-min period shall be taken as the final temperature of the tank.

Carry out a second, identical test to determine the heat loss coefficient of the storage tank with the collector loop disconnected (i.e. with no flow in the collector loop). Before performing this test, the system should be modified as necessary to ensure that there is no flow in the collector loop (i.e. also eliminating the possibility of reverse flow).

7.8.3 Calculation of the heat loss coefficient of the storage tank

The heat loss coefficient U_s of the tank, in watts per kelvin, shall be calculated using the following relationship:

$$U_s = \frac{\rho_w c_{pw} V_s}{\Delta t} \ln \left[\frac{t_i - t_{as(av)}}{t_f - t_{as(av)}} \right] \qquad \ldots (1)$$

where Δt is the duration of the cooling period (in seconds), taken as the time between the moment when the circulation of water through the tank is stopped and the moment when it is restarted, and other symbols are as defined in clause 4.

8 Analysis and presentation of results

8.1 Introduction

The experimental results from the system test shall be reported using the format sheets shown in annex A. The input-output diagram, the temperature increase diagram and draw-off profiles described in 8.2 to 8.4 shall also be represented.

The experimental results shall not be used to make statements about the performance of the system under test. They are an intermediate stage in the test method and shall only be used as inputs to the calculation procedures described in clause 9.

The test results consist of the daily energy output of the system for various values of H and $t_{a(day)} - t_{main}$. The performance of a domestic solar-only water heater system can be represented by the equation:

$$Q = a_1 H + a_2 (t_{a(day)} - t_{main}) + a_3 \qquad \ldots (2)$$

The coefficients a_1, a_2 and a_3 for the system are determined from the test results using the least-squares fitting method. Q refers to the net solar energy gained by the storage tank during the day. Q is taken as the energy contained in the total volume of hot water drawn off according to the test procedure defined in 7.6.

In addition, test results consisting of the temperature increase $(t_{d(max)} - t_{main})$ of the water for various values of H and $(t_{a(day)} - t_{main})$ shall be represented by the following equation:

$$t_{d(max)} - t_{main} = b_1 H + b_2 (t_{a(day)} - t_{main}) + b_3 \qquad \ldots (3)$$

The coefficients b_1, b_2 and b_3 for the system are determined from the test results using the least-squares fitting method. $t_{d(max)}$ in the equation refers to the maximum temperature of the water being drawn off.

8.2 Input-output diagram

The experimental results shall be presented graphically as shown in figure 4. The experimental points and the system performance characteristics predicted by equation (2) for $(t_{a(day)} - t_{main}) = -10$ K, 0 K, 10 K, 20 K shall be plotted. If these values of $(t_{a(day)} - t_{main})$ do not cover the range of test values of $(t_{a(day)} - t_{main})$, then additional characteristic lines shall be plotted.

8.3 Temperature increase $(t_{d(max)} - t_{main})$ diagram

The experimental results shall be presented as shown in figure 5. The experimental points and the system temperature increase predicted by equation (3) for $(t_{a(day)} - t_{main}) = -10$ K, 0 K, 10 K, 20 K shall be plotted. If these values of $(t_{a(day)} - t_{main})$ do not cover the range of test values of $(t_{a(day)} - t_{main})$, then additional curves shall be plotted.

8.4 Draw-off temperature profiles

8.4.1 Measured draw-off temperature profiles

For all systems, hot water draw-off profiles shall be presented for test day conditions (1) and (2), as shown in table 3. Draw-off profiles for test day (3) conditions may also be presented if a midday draw-off is being considered (see annex C).

8.4.2 Normalized draw-off temperature profiles $f(V)$

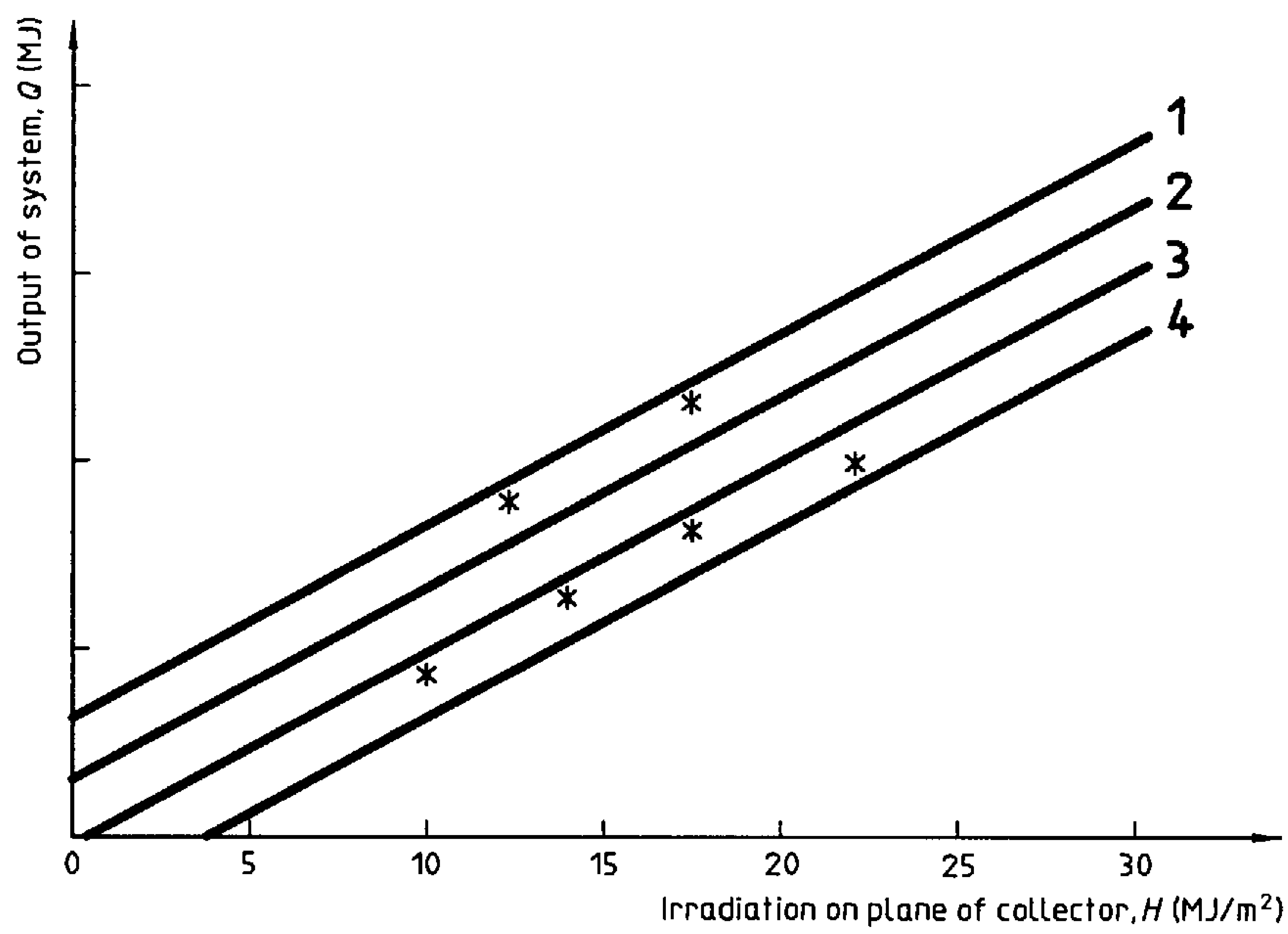
By using the measured values, the energy Q_i contained in any one-tenth of the tank volume ΔV_i which has been drawn off shall be calculated as follows:

$$Q_i = \Delta V_i \rho_w c_{pw} [t_{di}(V_i) - t_{main}] \qquad \ldots (4)$$

where $t_{di}(V_i)$ is the average temperature of the volume of water ΔV_i drawn off, and V_i is the total volume of water drawn off.

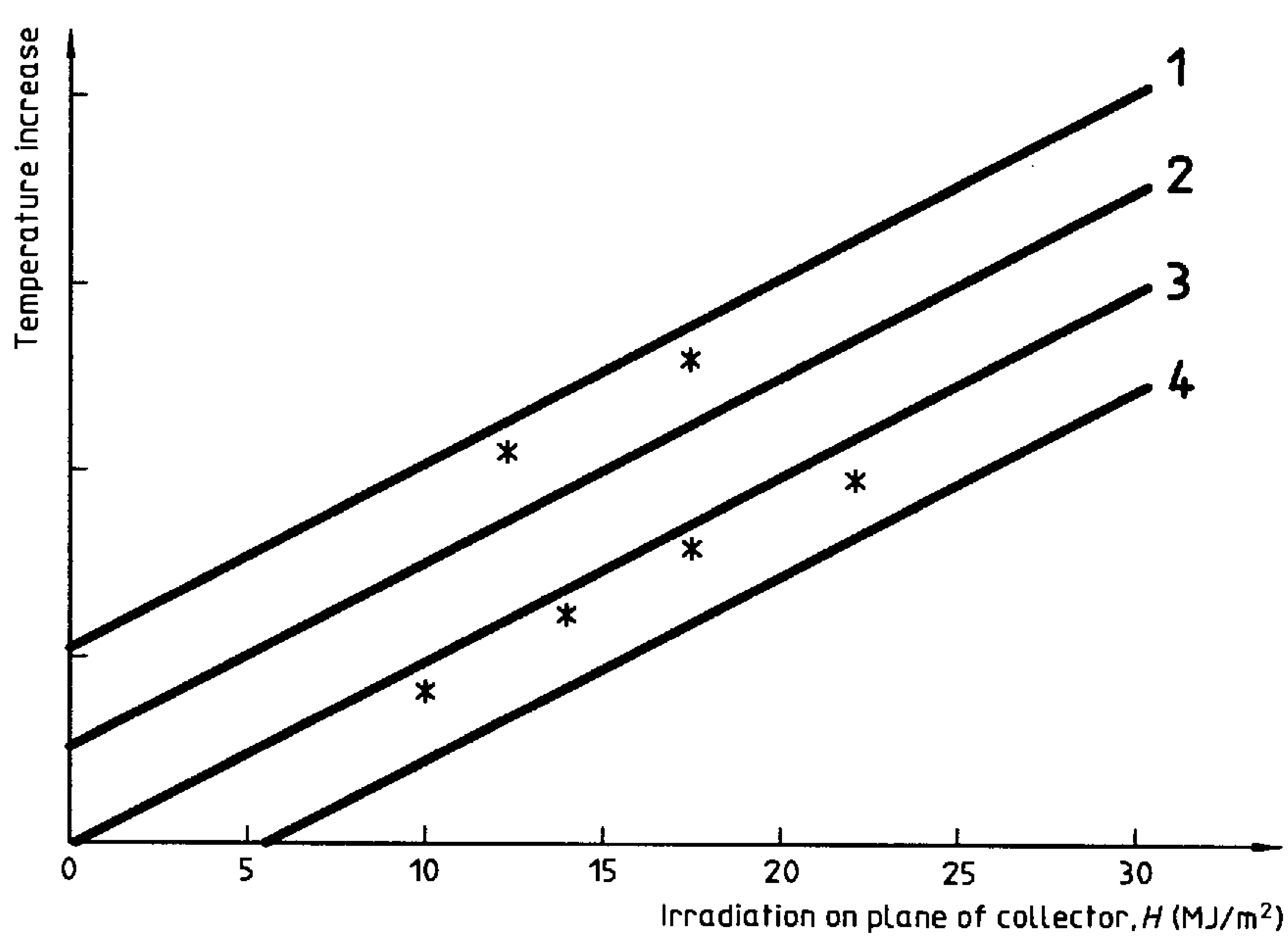
Energy Q_i shall be calculated for each ΔV_i (one-tenth of the tank volume) for which a temperature was recorded (either up to a draw-off volume of $3V_s$ or up to the volume at which $(t_d - t_{main}) \leqslant 1$ K. The total energy contained in the hot water drawn off from the tank is the sum of all Q_i, i.e.:

$$Q = \sum_{i=1}^{n} Q_i \qquad \ldots (5)$$



1 $t_{a(day)} - t_{main} = 20$ K
2 $t_{a(day)} - t_{main} = 10$ K
3 $t_{a(day)} - t_{main} = 0$ K
4 $t_{a(day)} - t_{main} = -10$ K

Figure 4 — Energy output Q of the system as a function of irradiation



1 $t_{a(day)} - t_{main} = 20$ K
2 $t_{a(day)} - t_{main} = 10$ K
3 $t_{a(day)} - t_{main} = 0$ K
4 $t_{a(day)} - t_{main} = -10$ K

Figure 5 — Temperature increase ($t_{d(max)} - t_{main}$) of the system as a function of irradiation

Table 3 — Hot water draw-off temperature profiles

Period	Solar irradiation MJ/m^2	Hot water draw-off volume	Time
Test day (1)	8 - 16	$3{,}0V_s$	Solar noon + 6 h
Test day (2)	16 - 25	$3{,}0V_s$	Solar noon + 6 h
Test day (3)	16 - 25	$0{,}5V_s$	Solar noon
Test day (3)	16 - 25	$1{,}5V_s$	Solar noon + 6 h

The value F_i of the normalized draw-off temperature profile $f(V)$, which is associated with each volume ΔV_i, is derived from the ratio of the energy Q_i extracted in each small volume of water drawn off to the total energy extracted Q, i.e.:

$$F_i = \frac{Q_i}{Q} \qquad \ldots (6)$$

Normalized draw-off temperature profiles $f(V)$ shall be derived for test days (1), (2) and (3) (when applicable) and shall be included in the format sheets (values and diagrams).

8.4.3 Computed draw-off temperature profiles

The normalized draw-off temperature profile $f(V)$ (8.4.2) can be used to determine the draw-off temperature profile for any combination of:

— daily solar irradiation at collector aperture H^*;

— average ambient temperature $t^*_{a(day)}$;

— cold water temperature t^*_{main}.

The solar energy gained during such a day is calculated by equation (2):

$$Q^* = a_1 H^* + a_2 (t^*_{a(day)} - t_{main}) + a_3 \qquad \ldots (7)$$

and the temperature of the water is found from the following equation:

$$t_{di}(V_i) = t_{main} + \frac{Q^* F_i}{0{,}1\ V_s \rho_w c_{pw}} \qquad \ldots (8)$$

Draw-off temperature profiles shall be computed and presented in the format sheets for the conditions shown in table 4.

8.5 Mixing draw-off temperature profile

8.5.1 Measured mixing draw-off temperature profile

The mixing draw-off temperature profile, obtained as described in 7.7, shall be presented in the format sheets, together with the temperature of the cold water entering the storage tank.

8.5.2 Normalized mixing draw-off temperature profile $g(V)$

The normalized mixing draw-off temperature profile shall be derived using the procedure outlined in 8.4.2 and shall be included in the format sheets (values and diagrams).

Table 4 — Conditions for computed draw-off temperature profiles

H MJ/m^2	$t_{a(day)}$ °C	t_{main} °C	$t_{a(day)} - t_{main}$ K	**Comments**
10 20	25 25	20 20	5 5	Spring or summer day
10 20	10 10	10 10	0 0	Winter or spring day

9 Prediction of long-term performance

9.1 General

The results of the test are given in the form of system performance characteristics which are independent of the climatic conditions under which they were derived. The system characteristics are used to determine the monthly and annual solar energy output from the system for the required climatic conditions and load demand.

The method is able to predict the long-term output of the system for various values of:

— solar irradiation;

— ambient air temperature;

— mains cold water temperature;

— load volume;

— hot water demand temperature.

The goal of the method is to predict long-term system performance to an accuracy of about $\pm$ 5 %.

9.2 Day-by-day calculation method

The performance of the system is calculated for each day of the year based on climatic data for the day and volume of hot water consumption for the day, taking into account energy in the storage tank carried over from the previous day. Energy may be carried over from one day to the next either because only a small volume of water has been drawn off during the day, or because mixing has taken place in the tank during the draw-off. Part of this energy will be lost during the night as a result of tank heat losses, but it is still likely to cause the system storage to start the next day with an initial temperature above that of the mains cold water.

The only assumption made in the day-by-day calculation procedure is that if the water in the storage tank is at a temperature higher than the cold water temperature at the beginning of the day (due to the carryover of energy from the previous day), then this energy is mixed over the tank volume at the start of the new day, so that the storage tank is always at a uniform temperature at the start of each day.

The calculation procedure employs the data obtained from the system performance test described in clause 7, hence the predictions apply only for a single draw-off at six hours after solar noon. The long-term performance of the system is found by summing the performance of the system for each day over the period of days under consideration.

9.3 Calculation procedure

The data required for the calculation procedure are listed in 9.4 and the steps involved in the calculations are presented in 9.5 and 9.6.

The system output for any given period is the sum of the daily energy outputs calculated in 9.5 and 9.6.

$$Q = Q_{c(1)} + Q_{c(2)} + \dots + Q_{c(n)} \qquad \dots (9)$$

The predicted long-term performance should be reported using the format sheets in annex A. A computer program for performing the calculations is described in annex B.

In 9.4 to 9.6, the draw-off temperature profiles and the mixing draw-off temperature profile are represented by the functions $f(V)$ and $g(V)$ respectively. This is used as a convenient form of notation only, and it is not necessary to derive analytical expressions for the draw-off temperature profiles and the mixing draw-off temperature profile as a function of volume. It is only necessary to know the value of $f(V)$ and $g(V)$ at regular intervals of every tenth of a tank volume (see A.4.4).

9.4 Data required for the calculation

9.4.1 Test results

The following test data is necessary:

a) the total energy output characteristics of the system determined from the test as a function of the daily irradiation and the difference between the ambient temperature and the cold water temperature:

$$Q = a_1 H + a_2[t_{a(day)} - t_{main}] + a_3 \qquad \dots (10)$$

b) the draw-off temperature profile expressed as a function of volume, $f(V)$, and normalized so that the area under the draw-off profile is equal to 1 (see 8.4.2 and A.4.4).

$$\int_0^\infty f(V)\, dV = 1 \qquad \dots (11)$$

The value of $f(V)$ is known at volume intervals of every tenth of a tank volume.

Two draw-off temperature profiles shall be determined for differing ranges of irradiance, e.g. 9 MJ/m^2 to 15 MJ/m^2 and 16 MJ/m^2 to 25 MJ/m^2.

c) the mixing draw-off profile expressed as a function of volume, $g(V)$, and normalized so that the area under the draw-off profile is equal to 1 (see 8.5.2 and A.4.4).

$$\int_0^\infty g(V)\, dV = 1 \qquad \dots (12)$$

The value of $g(V)$ is known at volume intervals of every tenth of a tank volume.

d) the heat loss coefficient of the storage tank, U_s, in watts per kelvin (see 7.8.3 and A.4.4).

9.4.2 Climatic data

The following climatic data is necessary:

a) the daily solar irradiation on the collector plane H, in megajoules per square metre;

b) the average ambient temperature over the period from 6 h before solar noon to 6 h after solar noon for each day, $t_{a(day)}$;

c) the average ambient temperature during the night for each night, t_n.

9.4.3 System usage data

The following data on system use is necessary:

a) the volume of daily hot water consumption, V_c, or the minimum useful temperature limit for the hot water consumption;

b) the cold water inlet temperature, t_{main}, for each day.

9.5 Calculation steps for day 1

9.5.1 Data input for day 1

The conditions for day 1 are:

— irradiation = $H(1)$;

— daytime average ambient temperature = $t_{a(day)}(1)$;

— cold water temperature = $t_{main}(1)$;

— draw-off volume $V_c(1)$ or temperature limit for draw-off = $t_h(1)$.

The system begins the day at the temperature of the mains cold water, $t_{main}(1)$. A draw-off of volume $V_c(1)$ is made at 6 h after solar noon.

9.5.2 Step 1 — Energy available at 6 h after solar noon

The total energy contained in the system at 6 h after solar noon, $Q(1)$, is calculated using equation (2), with $t_{main} = t_{main}(1)$, $t_{a(day)} = t_{a(day)}(1)$ and $H = H(1)$, i.e.:

$$Q(1) = a_1\, H(1) + a_2\, [t_{a(day)}(1) - t_{main}(1)] + a_3 \qquad \ldots (13)$$

9.5.3 Step 2 — Draw-off volume to meet minimum temperature limit

NOTE 16 This step is required only if the hot water demand is temperature-limited. For a hot water demand which is volume-limited, omit step 2 and continue with step 3.

The temperature profile of the hot water drawn off, as a function of the volume, is calculated using equation (8), which gives the instantaneous energy balance during the hot water draw-off, i.e.:

$$t_d(V) = t_{main}(1) + \frac{Q(1)\, f(V)}{0{,}1 V_s \rho_w c_{pw}} \qquad \ldots (14)$$

The volume consumed $V_c(1)$ is calculated by determining the maximum volume at which t_d, as calculated in equation (14), remains higher than $t_h(1)$.

9.5.4 Step 3 — Energy drawn off

The energy $Q_c(1)$ contained in a draw-off volume of $V_c(1)$ (which may not equal the total energy contained in the system) is calculated using the function $f(V)$ integrated from $V = 0$ to $V = V_c(1)$.

$$Q_c(1) = Q(1) \int_0^{V_c(1)} f(V)\, \mathrm{d}V \qquad \ldots (15)$$

9.5.5 Step 4 — Energy left in tank

The energy remaining in the tank, Q_R, can be calculated.

$$Q_R(1) = Q(1) - Q_c(1) \qquad \text{... (16)}$$

9.5.6 Step 5 — Energy lost overnight

The energy lost overnight can be calculated using the tank heat loss coefficient. Hence the energy remaining in the tank the next morning can be determined. It is assumed that by the morning, the tank has returned to a fully mixed state and the water is at a uniform temperature t_s. This temperature t_s can be calculated.

$$t_s(2) = t_{main}(1) + \frac{Q_R(1) - Q_{LOS}}{\text{tank heat capacity}} \qquad \text{... (17)}$$

where Q_{LOS} is the loss from the store overnight.

The night tank losses, Q_{LOS}, may be calculated as:

$$Q_{LOS} = V_s \rho_w c_{pw} [t_i - t_{a(night)}] \left[1 - \exp\left(- \frac{U_s \Delta_t}{V_s \rho_w c_{pw}} \right) \right] \qquad \text{... (18)}$$

where t_i is the average temperature of the tank at the beginning of the night and $t_{a(night)}$ is the average ambient temperature during the night. t_i can be calculated from the value of Q_R determined in equation (16).

$$t_i = \frac{Q_R(1)}{V_s \rho_w c_{pw}} + t_{main}(1) \qquad \text{... (19)}$$

9.6 Calculation steps for day 2 and subsequent days

9.6.1 Data input for day 2 and subsequent days

The conditions for day 2 are:

— irradiation $= H(2)$;

— daytime average ambient temperature $= t_{a(day)}(2)$;

— cold water temperature $= t_{main}(2)$;

— draw-off volume $= V_c(2)$ or temperature limit for draw-off $= t_h(2)$.

The system starts the day at the temperature $t_s(2)$ as calculated in step 5 of day 1. $t_s(2)$ may be greater than $t_{main}(2)$. Volume $V_c(2)$ is drawn off at 6 h after solar noon.

9.6.2 Step 1 — Energy available at 6 h after solar noon

One part of the energy available is that which would have been collected if the system had been refilled during the hot water draw-off at 6 h after solar noon with water at the initial temperature $t_s(2)$. This energy is calculated using equation (7), with $t_{main} = t_s(2)$, $t_{a(day)} = t_{a(day)}(2)$ and $H = H(2)$.

$$Q(2\text{:part 1}) = a_1 H(2) + a_2 [t_{a(day)}(2) - t_s(2)] + a_3 \qquad \text{... (20)}$$

The other part of the energy available is due to the fact that the system has been filled with water at $t_{main}(2)$ which is lower than $t_s(2)$. This energy is given by the product of the solar part of the tank volume and the difference between $t_s(2)$ and $t_{main}(2)$.

$$Q(2{:}\text{part } 2) = V_s \rho_w c_{pw} [t_s(2) - t_{main}(2)] \qquad \dots (21)$$

Hence the total energy available is:

$$Q(2) = Q(2{:}\text{part } 1) + Q(2{:}\text{part } 2) \qquad \dots (22)$$

9.6.3 Step 2 — Draw-off volume to meet minimum temperature limit

NOTE 17 This step is required only if the hot water demand is temperature-limited. For a hot water demand which is volume-limited, omit step 2 and continue with step 3.

The temperature profile of the hot water as a function of the volume is calculated using equation (23). In calculating the temperature profile, it is necessary to consider the two energy contributions $Q(2{:}\text{part } 1)$ and $Q(2{:}\text{part } 2)$.

$$t_d(V) = t_{main}(2) + \frac{Q(2{:}\text{part } 1) \cdot f(V)}{0{,}1 V_s \rho_w c_{pw}} + \frac{Q(2{:}\text{part } 2) \cdot g(V)}{0{,}1 V_s \rho_w c_{pw}} \qquad \dots (23)$$

The volume consumed $V_c(2)$ is calculated by determining the maximum volume at which t_d, as calculated in equation (23), remains higher than $t_h(2)$.

9.6.4 Step 3 — Energy drawn off

One part of the energy contained in a draw-off volume of $V_c(2)$, is the energy $Q_c(2{:}\text{part } 1)$ which would be delivered if the system were refilled with water at the initial temperature $t_s(2)$. It is based on the available energy which was determined in step 1 and is calculated using the function $f(V)$ integrated from $V = 0$ to $V = V_c(2)$.

$$Q_c(2{:}\text{part } 1) = Q(2{:}\text{part } 1) \int_0^{V_c(2)} f(V)\, dV \qquad \dots (24)$$

The proportion of the carried-over energy which is extracted in the volume consumed $V_c(2)$ can be calculated by using the mixing profile curve, $g(V)$:

$$Q_c(2{:}\text{part } 2) = Q(2{:}\text{part } 2) \int_0^{V_c(2)} g(V)\, dV \qquad \dots (25)$$

The total energy extracted in volume $V_c(2)$ is the sum of the two energies given above:

$$Q_c(2) = Q_c(2{:}\text{part } 1) + Q_c(2{:}\text{part } 2) \qquad \dots (26)$$

9.6.5 Step 4 — Energy left in tank

The total energy left in the tank at the end of day 2 is [equations (22) and (26)]:

$$Q_R(2) = Q(2) - Q_c(2) \qquad \dots (27)$$

9.6.6 Step 5 — Energy lost overnight

The energy lost overnight can be calculated using the tank heat loss coefficient, and hence the energy remaining in the tank the next morning is known. It is assumed that by the morning, the tank has returned to a fully mixed state and the water is at a uniform temperature t_s. This temperature t_s can be calculated.

$$t_s(3) = t_{main}(2) + \frac{Q_R(2) - Q_{LOS}}{\text{tank heat capacity}} \qquad \dots (28)$$

The night tank losses, Q_{LOS}, may be calculated as:

$$Q_{LOS} = V_s \rho_w c_{pw} \left[t_i - t_{a(night)} \right] \left[1 - \exp \left(- \frac{U_s \Delta_t}{V_s \rho_w c_{pw}} \right) \right] \qquad \ldots (29)$$

where t_i is the average temperature of the tank at the beginning of the night and $t_{a(night)}$ is the average ambient temperature during the night. t_i can be calculated from the value of Q_R calculated in equation (27):

$$t_i = \frac{Q_R(2)}{V_s \rho_s c_{pw}} + t_{main}(2) \qquad \ldots (30)$$

9.6.7 Step 6 — Subsequent days

The procedure may be continued by starting again at step 1 of day 2.

Annex A
(normative)

Format sheets for test and annual performance prediction for solar domestic water heating systems

System reference: ....

Testing laboratory:		
....		
Address:		
....		
Tel.:	Fax:	
Accredited laboratory:	☐ Yes	☐ No
Date of issue:		

A.1 Description of the solar domestic hot water system (complete as applicable)

A.1.1 Manufacturer

Name of manufacturer: ....

Address: ....

....

A.1.2 Model

System model: ....

Serial number: ....

A.1.3 System classification

thermosiphon ☐	forced ☐	
direct ☐	indirect ☐	
open ☐	vented ☐	closed ☐
filled ☐	drainback ☐	draindown ☐
remote storage ☐	close-coupled collector storage ☐	
integral collector storage ☐		

Other (specify): ....

A.1.4 Heat transfer fluid

Type:

☐ water/glycol mixture, concentration of glycol: .... %

☐ oil

☐ chlorofluorocarbon

☐ air

other (specify): ....

Specifications: ....

Total fluid content: .... kg

Alternative acceptable fluid: ....

System reference: ....

A.1.5 Antifreeze

Antifreeze protection Yes ☐ No ☐

Other: ....

A.1.6 Collector system

Number of collectors in the system: ....

Total collector gross area: .... m²

A.1.7 Collector design

Type:

☐ flat plate ☐ evacuated tube

other (specify): ....

Gross area: .... m²

Aperture area: .... m²

Absorber area: .... m²

Number of covers: ....

Cover material(s): ....

Cover thickness(es): .... mm

Insulation material(s): ....

Insulation thickness(es): .... mm

Casing material: ....

Weight of collector without fluid: .... kg

Gross dimensions: .... mm

A.1.8 Absorber

Material(s): ....

Construction type: ....

....

....

Surface treatment: ....

Number of tubes or channels: ....

Tube diameter or channel dimensions: .... mm

Distance between tubes or channels: .... mm

System reference: ....

A.1.9 Storage tank

Manufacturer: ....

Model: ....

Volume: l

Outside tank diameter: .... m

Outside tank length: .... m

Insulation material: ....

Insulation thickness: .... mm

Heat exchanger type:

- ☐ spiral pipe
- ☐ straight pipe
- ☐ double jacket

other (specify): ....

A.1.10 Pump

Manufacturer: ....

Model: ....

Rating: .... W

Speed: .... r/min

A.1.11 Controller

Manufacturer: ....

Model: ....

A.1.12 Schematic diagram of the system

System reference: ....

A.1.13 Connecting piping between the collector(s) and the tank

Diameter: .... mm

Length: .... m

Insulation material: ....

Insulation thickness: .... mm

A.1.14 System data

Collector tilt angle: .... degrees

Flowrate in collector loop: .... l/s

Controller setting: ....

....

....

A.1.15 Comments on the system design

....

....

....

....

A.1.16 Photograph of the system

System reference: ....

A.2 System performance test

A.2.1 Schematic diagram of test loop

A.2.2 Photograph of the test rig

System reference: ....

A.2.3 System performance test results and derived data

Test results and derived data shall be presented in table A.1.

Test location latitude: .... , longitude: ....

Collector azimuth: ....

Table A.1

Date	During 12-h test						Draw-off				Output
YYMMDD	H MJ/m^2	H_d MJ/m^2	$t_{a(day)}$ °C	t_{main} °C	(4) – (5) K	u m/s	V_d l	$t_{d(av)}$ °C	$t_{d(max)}$ °C	(10) – (5) K	Q MJ
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)

NOTE — Symbols are defined in clause A.6.

System reference: ....

A.2.4 System performance curves

The measured data points shall be entered on a graph as in figure A.1, and fitted by least squares regression to equation (A.1). Straight-line graphs shall be drawn for values of $[t_{a(day)} - t_{main}] = -10$ K, 0 K, 10 K, 20 K, using the derived coefficients a_1, a_2 and a_3, and labelled to indicate the values of $[t_{a(day)} - t_{main}]$ mentioned.

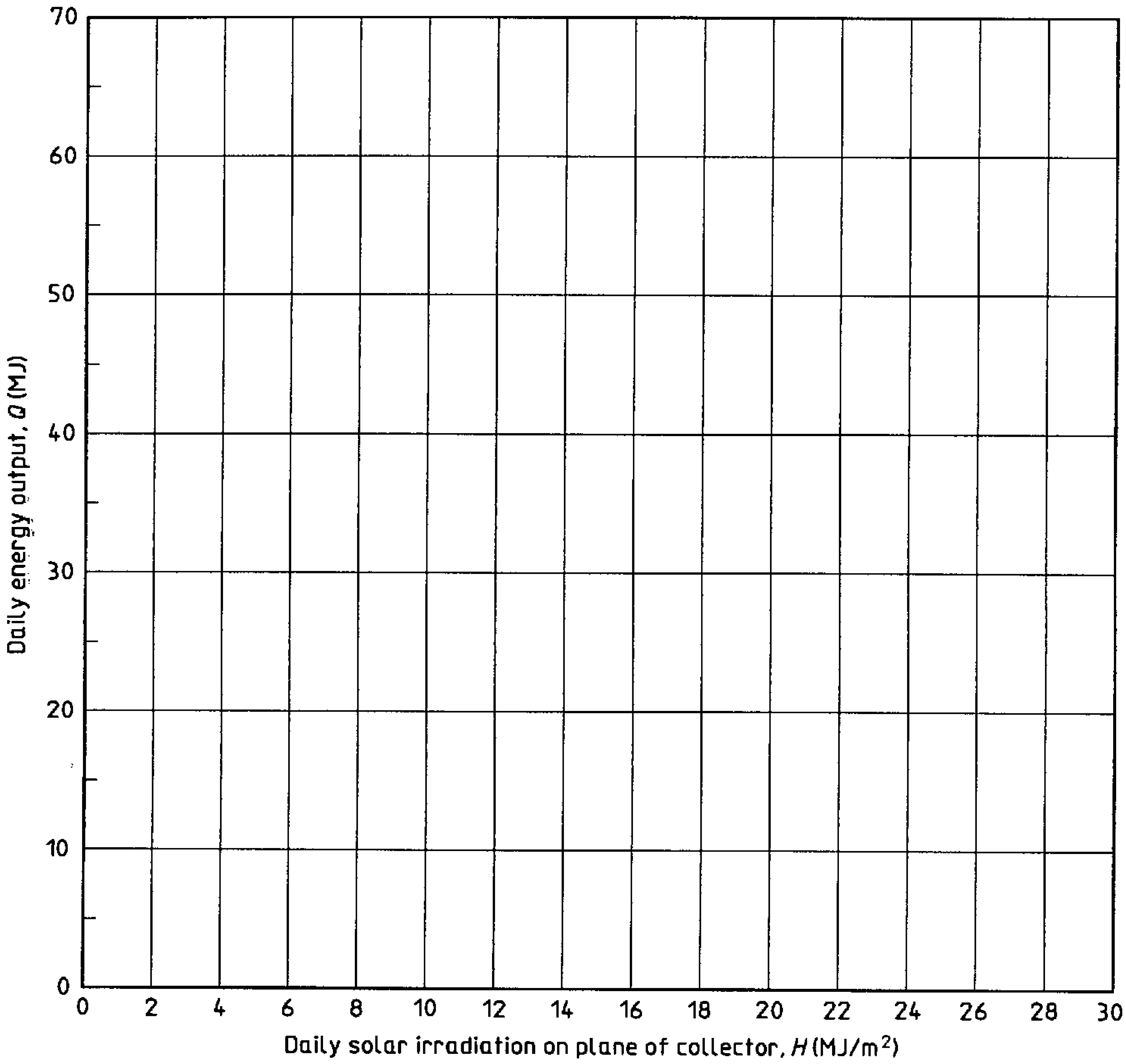


Figure A.1

Linear fit to data of the daily energy output of the system:

$$Q = a_1 H + a_2 [t_{a(day)} - t_{main}] + a_3 \quad \ldots (A.1)$$

where

a_1 = ... m^2

a_2 = ... MJ/K

a_3 = ... MJ

System reference: ....

A.2.5 System temperature increase [$t_{d(max)} - t_{main}$] curves

The measured data points shall be entered on a graph as in figure A.2, and fitted by least squares regression to equation (A.2). Straight-line graphs shall be drawn for values of [$t_{a(day)} - t_{main}$] = – 10 K, 0 K, 10 K, 20 K, using the derived coefficients b_1, b_2 and b_3, and labelled to indicate the values of [$t_{a(day)} - t_{main}$] mentioned.

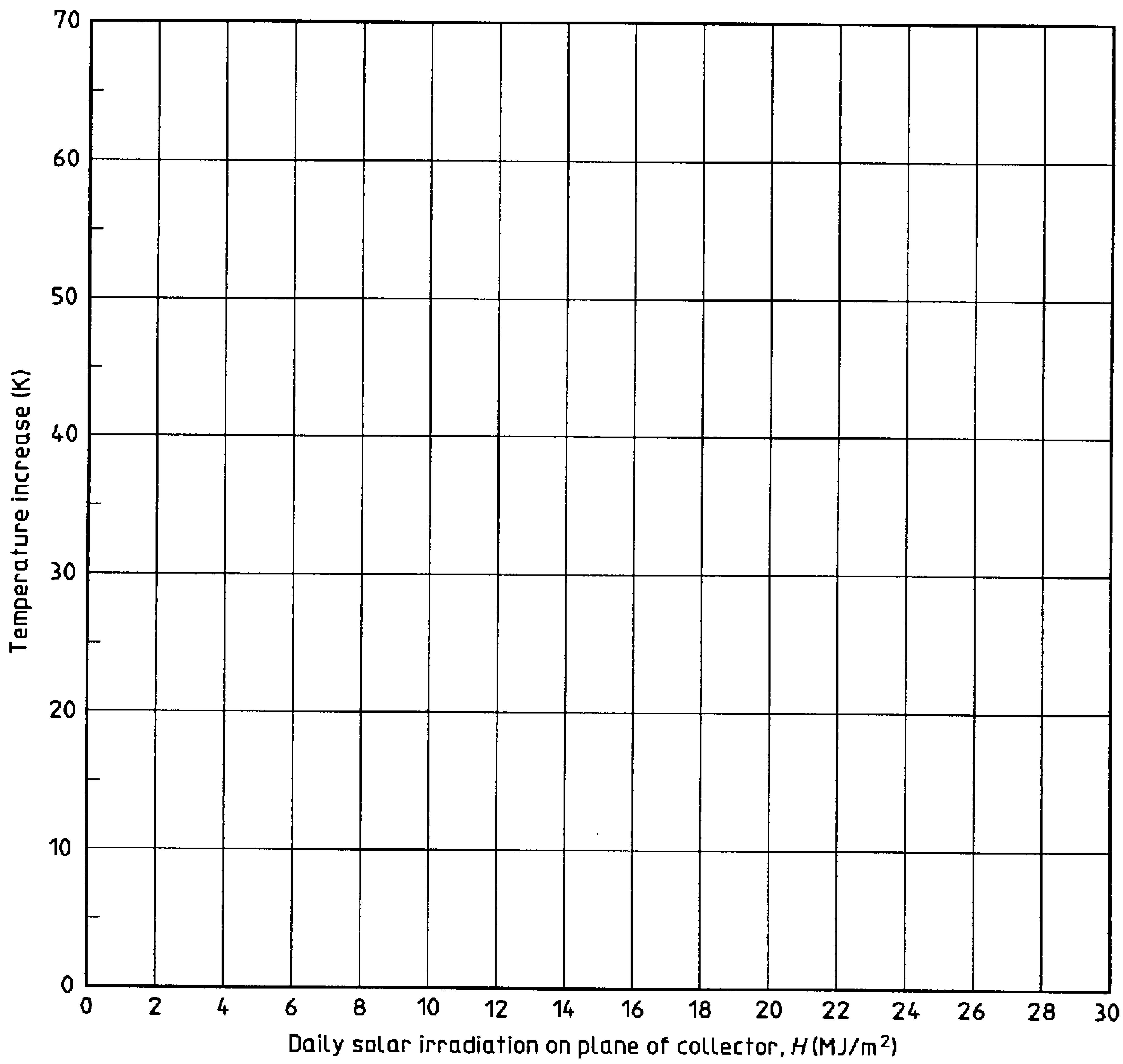


Figure A.2

Linear fit to data of the temperature increase:

$$t_{d(max)} - t_{main} = b_1 H + b_2 [t_{a(day)} - t_{main}] + b_3 \quad \ldots (A.2)$$

where

b_1 = ... m^2 K/MJ

b_2 = ...

b_3 = ... K

System reference: ....

A.3 Storage tank heat loss coefficient

A.3.1 Collector loop connected

Test performed: ☐ outdoors ☐ indoors

Tank volume (V_s): l

Initial average temperature of water in tank (t_i): .... °C

Final average temperature of water in tank (t_f): .... °C

Average ambient air temperature adjacent to store during test [$t_{a,s(av)}$]: .... °C

Average wind speed over collector: .... m/s

Average wind speed over tank: .... m/s

NOTE — Wind speeds should lie between 3 m/s and 5 m/s.

Duration of test (Δt): .... s

Deduced value of mean storage heat loss coefficient (U_s): .... W/K

$$U_s = \frac{4180 V_s}{\Delta t} \ln \left(\frac{t_i - t_{a,s(av)}}{t_f - t_{a,s(av)}} \right) \quad \ldots (A.3)$$

The coefficient U_s is used in equation (A.3) to determine the final tank water temperatures t_f in table A.2, considering the initial tank water temperatures t_i, and the average ambient air temperature $t_{a,s(av)}$ in a 12-h period given in table A.2.

Table A.2

Temperatures in degrees Celsius

Initial water temperature	Final tank water temperature			
	Average ambient air temperature around the tank during 12 h			
	0	5	10	15
70				
60				
50				
40				
30				

System reference: ....

A.3.2 Collector loop disconnected

Test performed: ☐ outdoors ☐ indoors

Tank volume (V_s): l

Initial average temperature of water in tank (t_i): .... °C

Final average temperature of water in tank (t_f): .... °C

Average ambient air temperature adjacent to store during test [$t_{a,s(av)}$]: .... °C

Average wind speed over collector: .... m/s

Average wind speed over tank: .... m/s

NOTE — Wind speeds should lie between 3 m/s and 5 m/s.

Duration of test (Δt): .... s

Deduced value of mean storage heat loss coefficient (U_s): .... W/K

$$U_s = \frac{4180 V_s}{\Delta t} \ln \left(\frac{t_i - t_{a,s(av)}}{t_f - t_{a,s(av)}} \right)$$

NOTE — During this test no reverse flow is allowed and the storage tank heat loss coefficient is expected to be equal (if no reverse flow is present in the system) to or smaller (if reverse flow exists in the system) than that determined with the collector loop connected (see A.3.1).

System reference: ....

A.4 Draw-off temperature profiles

A.4.1 Draw-off temperature profile for test day with a daily irradiation H in the range 8 MJ/m2 to 15,99 MJ/m2

Date: ....

Draw-off flowrate: .... l/h

Tank volume (V_s): l

Daily irradiation on collector plane (H): .... MJ/m²

Ambient air temperature [$t_{a(day)}$]: .... °C

Cold water supply temperature (t_{main}): .... °C

Temperature difference [$t_{a(day)} - t_{main}$]: .... K

A graph shall be prepared as shown in figure A.3. The graph shall include the temperature of the water drawn off and the temperature of the cold water supply.

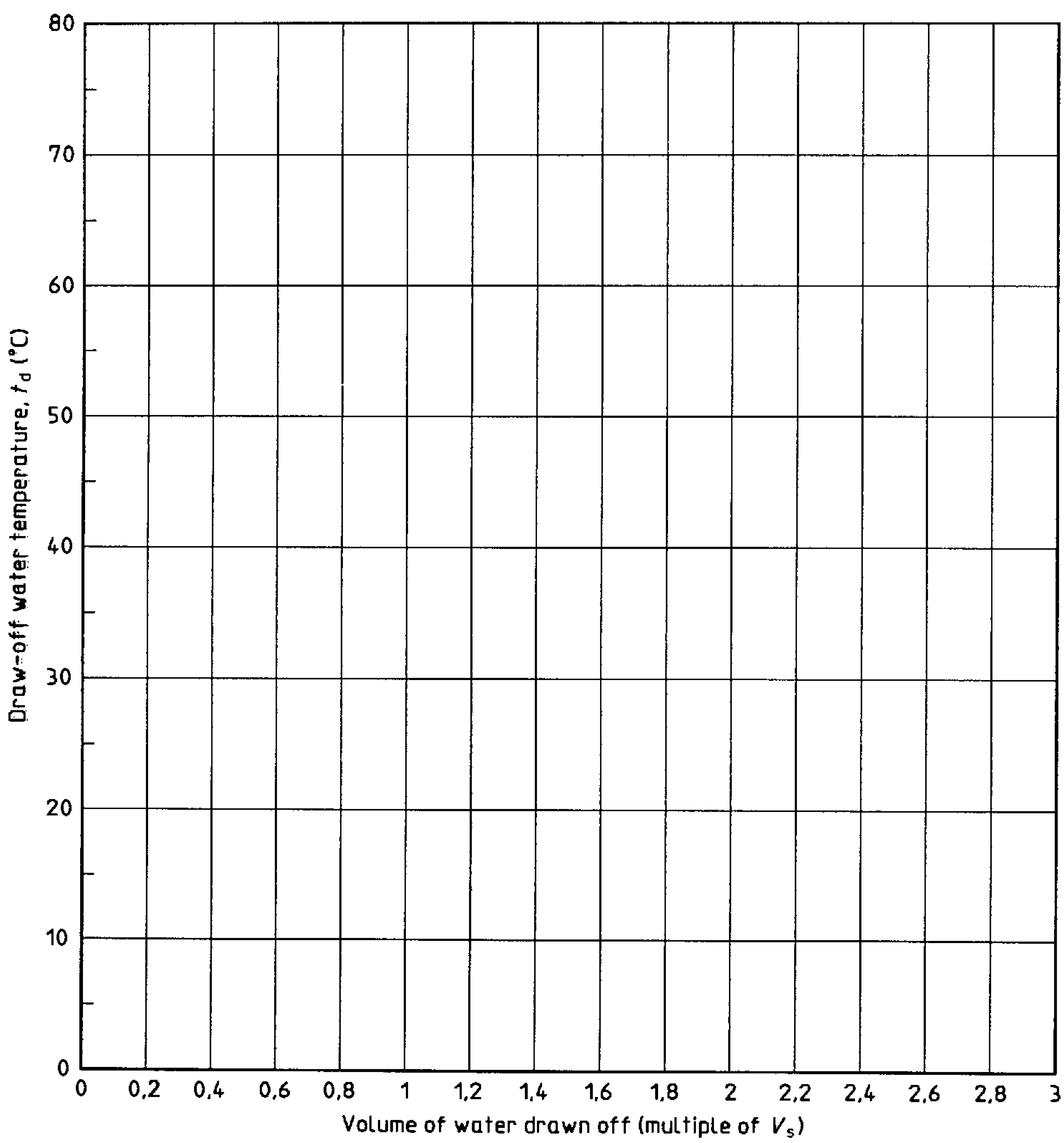


Figure A.3

System reference: ....

A.4.2 Draw-off temperature profile for test day with a daily irradiation H in the range 16 MJ/m^2 to 25 MJ/m^2

Date: ....

Draw-off flowrate: .... l/h

Tank volume (V_s): l

Daily irradiation on collector plane (H): .... MJ/m^2

Ambient air temperature [$t_{a(day)}$]: .... °C

Cold water supply temperature (t_{main}): .... °C

Temperature difference [$t_{a(day)} - t_{main}$]: .... K

A graph shall be prepared as shown in figure A.4. The graph shall include the temperature of the water drawn off and the temperature of the cold water supply.

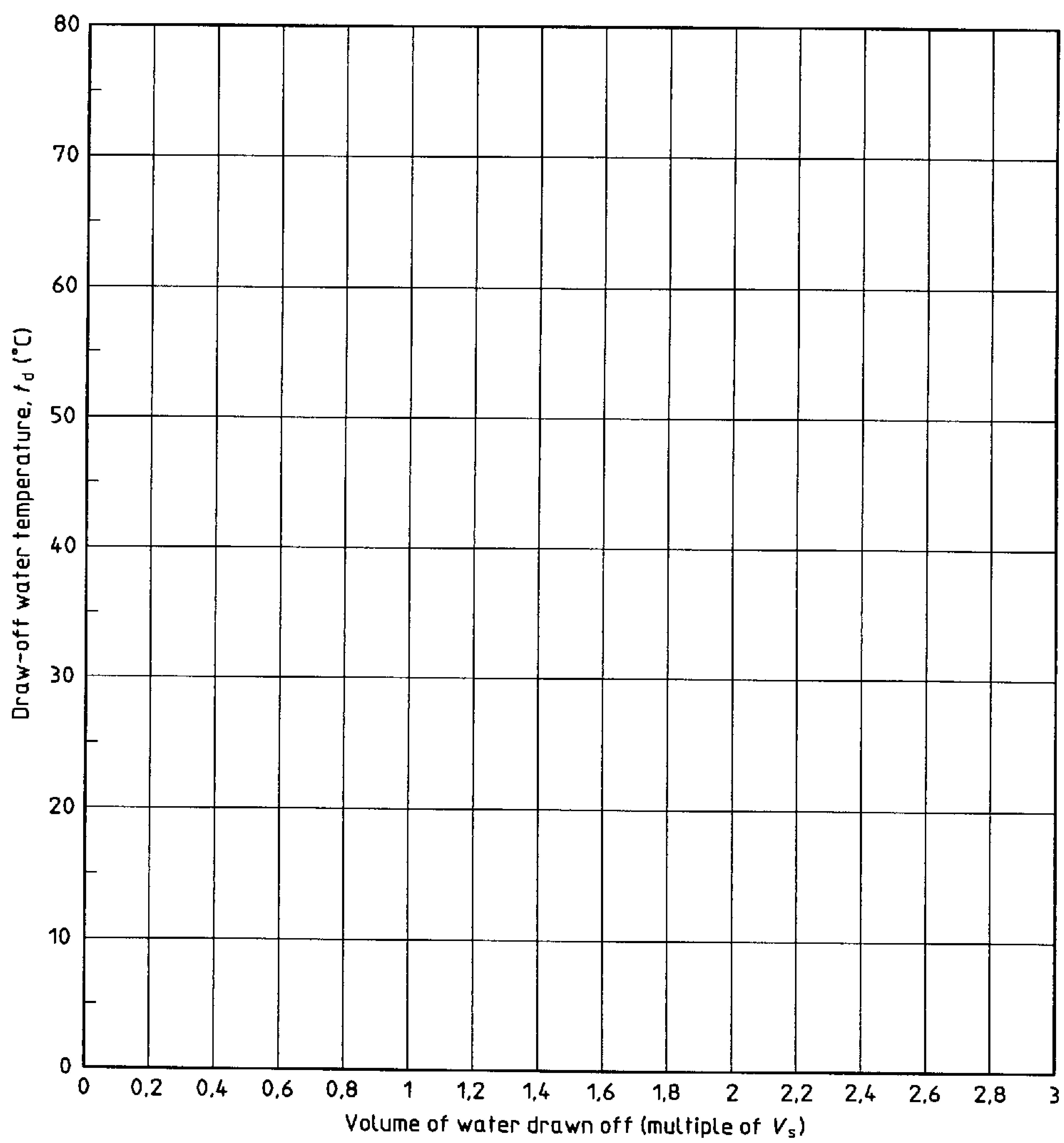


Figure A.4

System reference: ....

A.4.3 Mixing draw-off temperature profile

Date: ....

Draw-off flowrate: .... l/h

Tank volume (V_s): l

Cold water supply temperature (t_{main}): .... °C

A graph shall be prepared as shown in figure A.5. The graph shall include the temperature of the water drawn off and the temperature of the cold water supply.

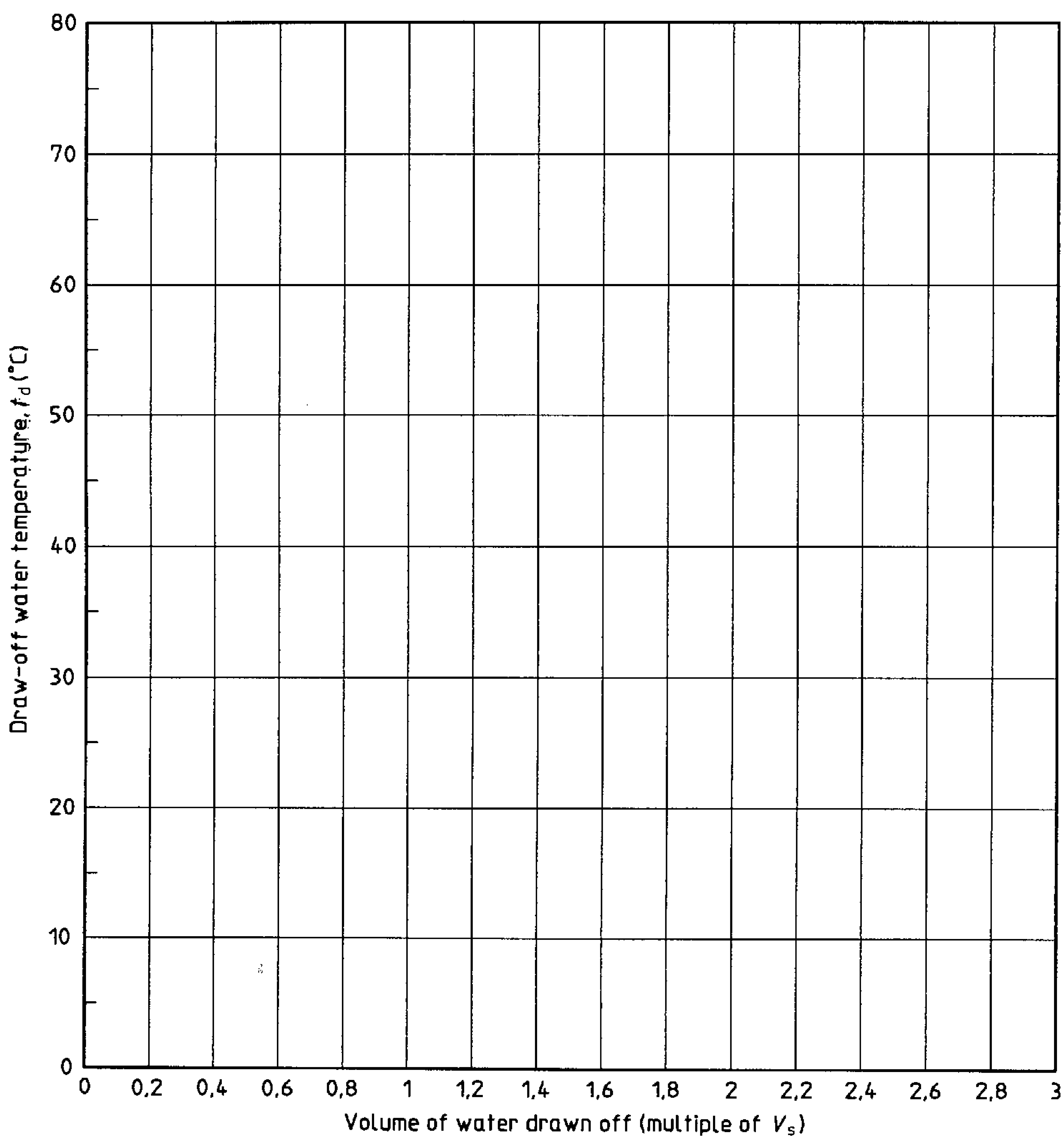


Figure A.5

System reference: ....

A.4.4 Normalized temperature profiles (see table A.3 and figures A.6 and A.7)

A.4.4.1 Values of normalized draw-off and mixing temperature profiles $f(V)$ **and** $g(V)$, based on the test data of A.4.1, A.4.2 and A.4.3.

Table A.3

Multiple of total tank volume	$f(V)$ %		$g(V)$ %	Multiple of total tank volume	$f(V)$ %		$g(V)$ %
	$H < 16$ MJ/m²	$H \geqslant 16$ MJ/m²			$H < 16$ MJ/m²	$H \geqslant 16$ MJ/m²	
0 - 0,1				1,5 - 1,6			
0,1 - 0,2				1,6 - 1,7			
0,2 - 0,3				1,7 - 1,8			
0,3 - 0,4				1,8 - 1,9			
0,4 - 0,5				1,9 - 2,0			
0,5 - 0,6				2,0 - 2,1			
0,6 - 0,7				2,1 - 2,2			
0,7 - 0,8				2,2 - 2,3			
0,8 - 0,9				2,3 - 2,4			
0,9 - 1,0				2,4 - 2,5			
1,0 - 1,1				2,5 - 2,6			
1,1 - 1,2				2,6 - 2,7			
1,2 - 1,3				2,7 - 2,8			
1,3 - 1,4				2,8 - 2,9			
1,4 - 1,5				2,9 - 3,0			
0 - 1,0				0 - 3,0			

System reference: ....

A.4.4.2 Graphs of normalized draw-off temperature profiles $f(V)$ ($H < 16\ MJ/m^2$ and $H \geqslant 16\ MJ/m^2$)

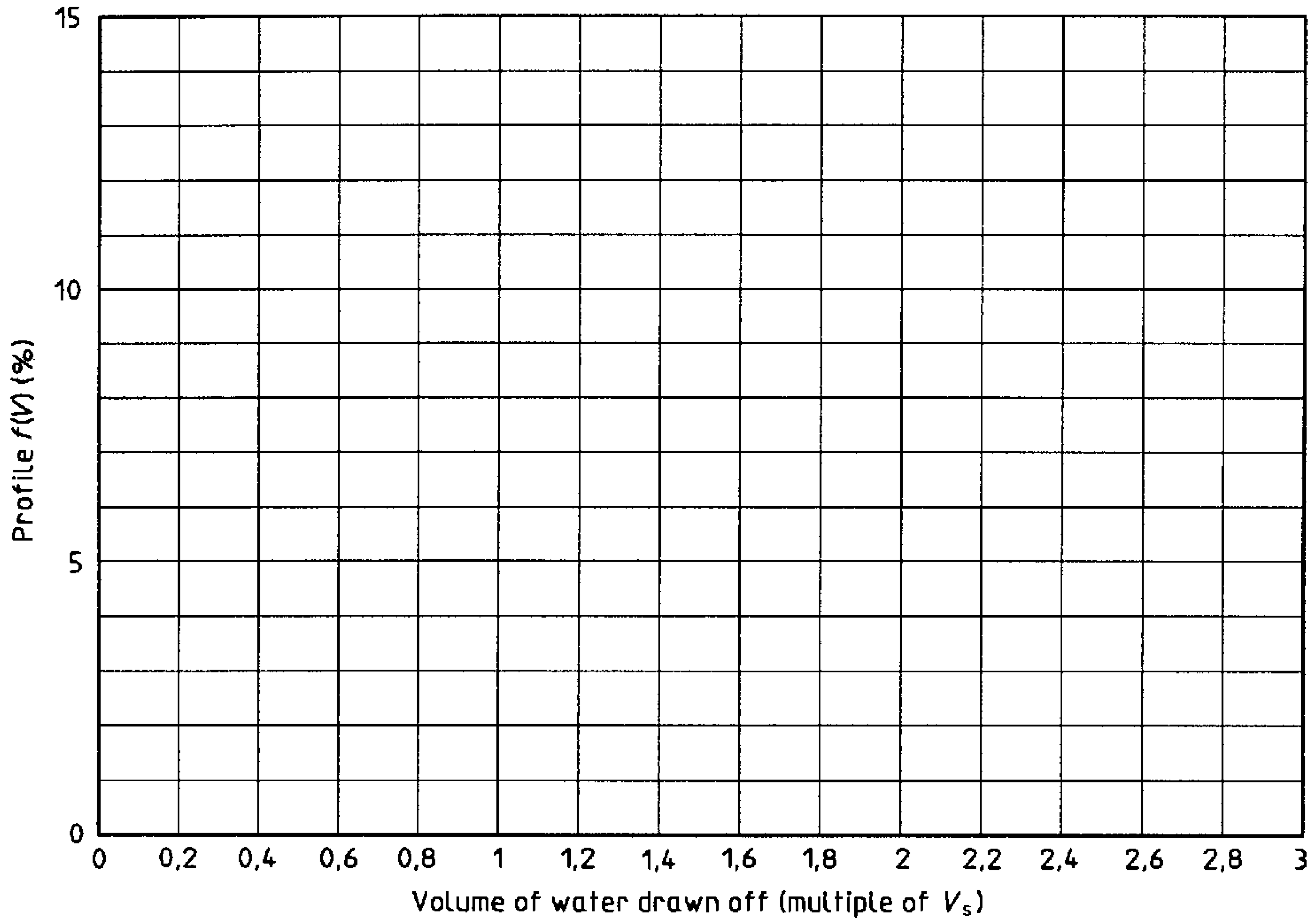


Figure A.6

System reference: ....

A.4.4.3 Graph of normalized mixing draw-off temperature profiles $g(V)$

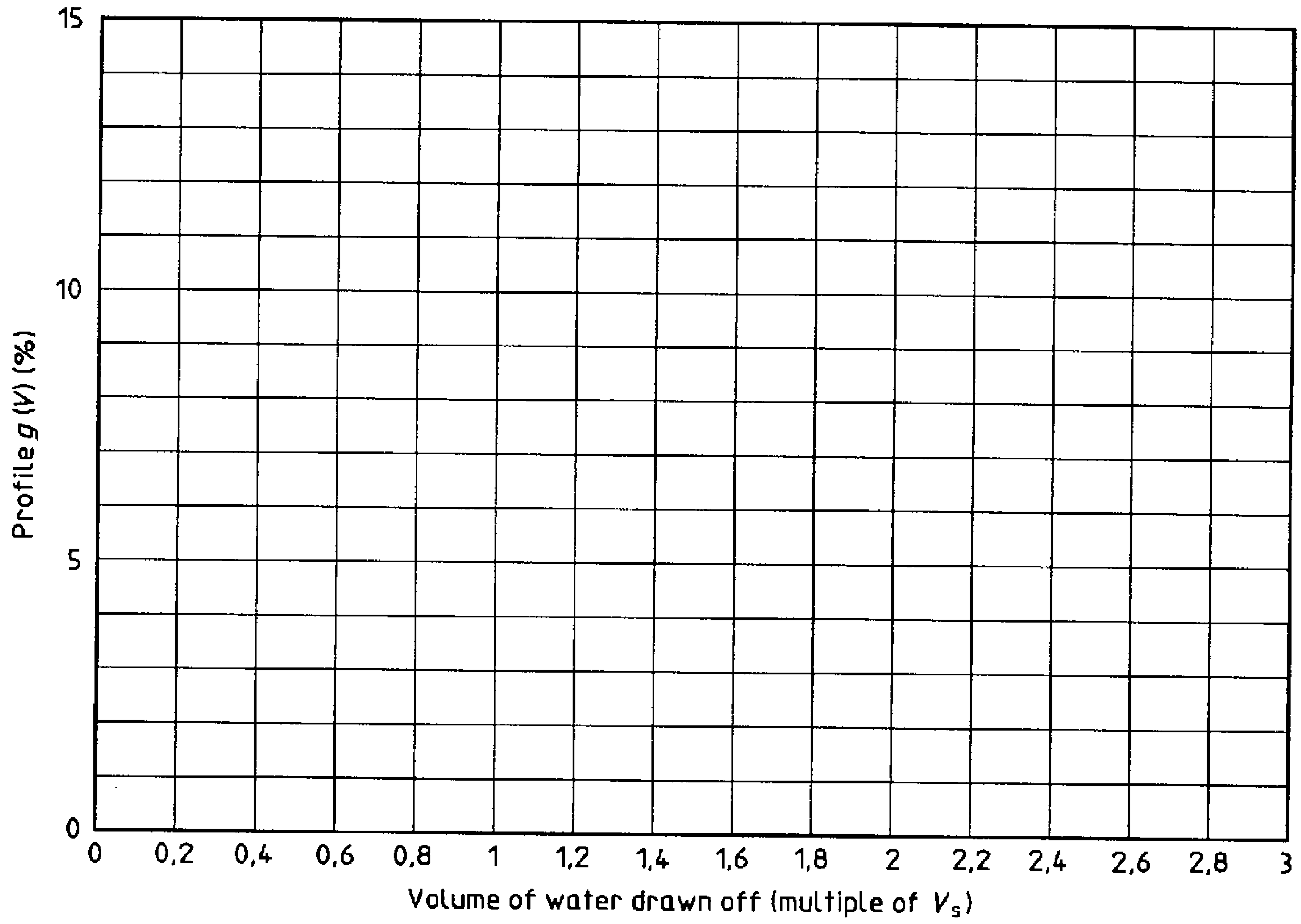


Figure A.7

System reference: ....

A.4.5 Computed draw-off profiles (see figures A.8 to A.11)

NOTE — In figures A.8 to A.11 include graph for t_{main}.

A.4.5.1 Draw-off temperature profile for $H = 20$ MJ/m^2, $t_{a(day)} = 25$ °C and $t_{main} = 20$ °C

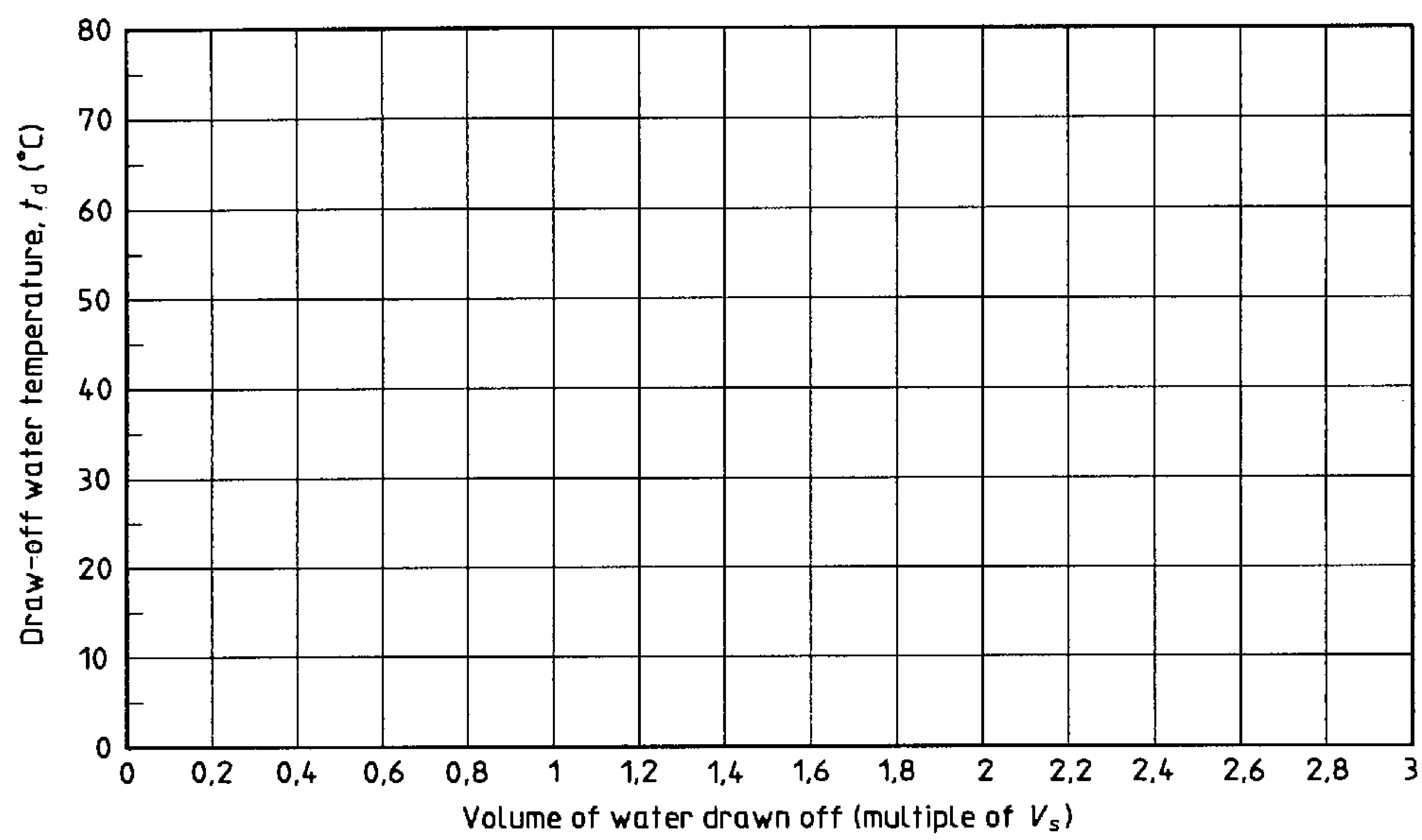


Figure A.8

A.4.5.2 Draw-off temperature profile for $H = 10$ MJ/m^2, $t_{a(day)} = 25$ °C and $t_{main} = 20$ °C

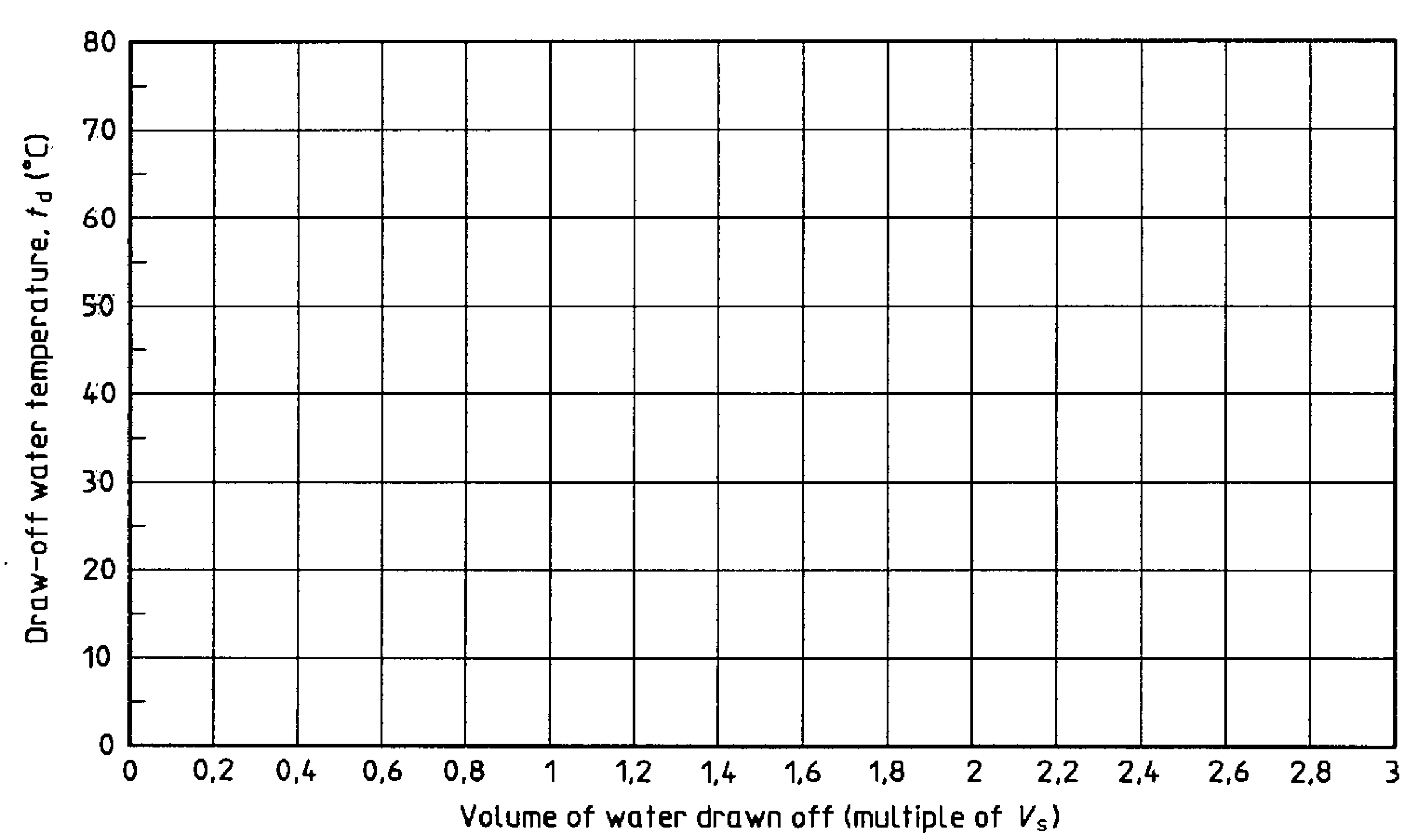


Figure A.9

System reference: ....

A.4.5.3 Draw-off temperature profile for $H = 20$ MJ/m^2, $t_{a(day)} = 10$ °C and $t_{main} = 10$ °C

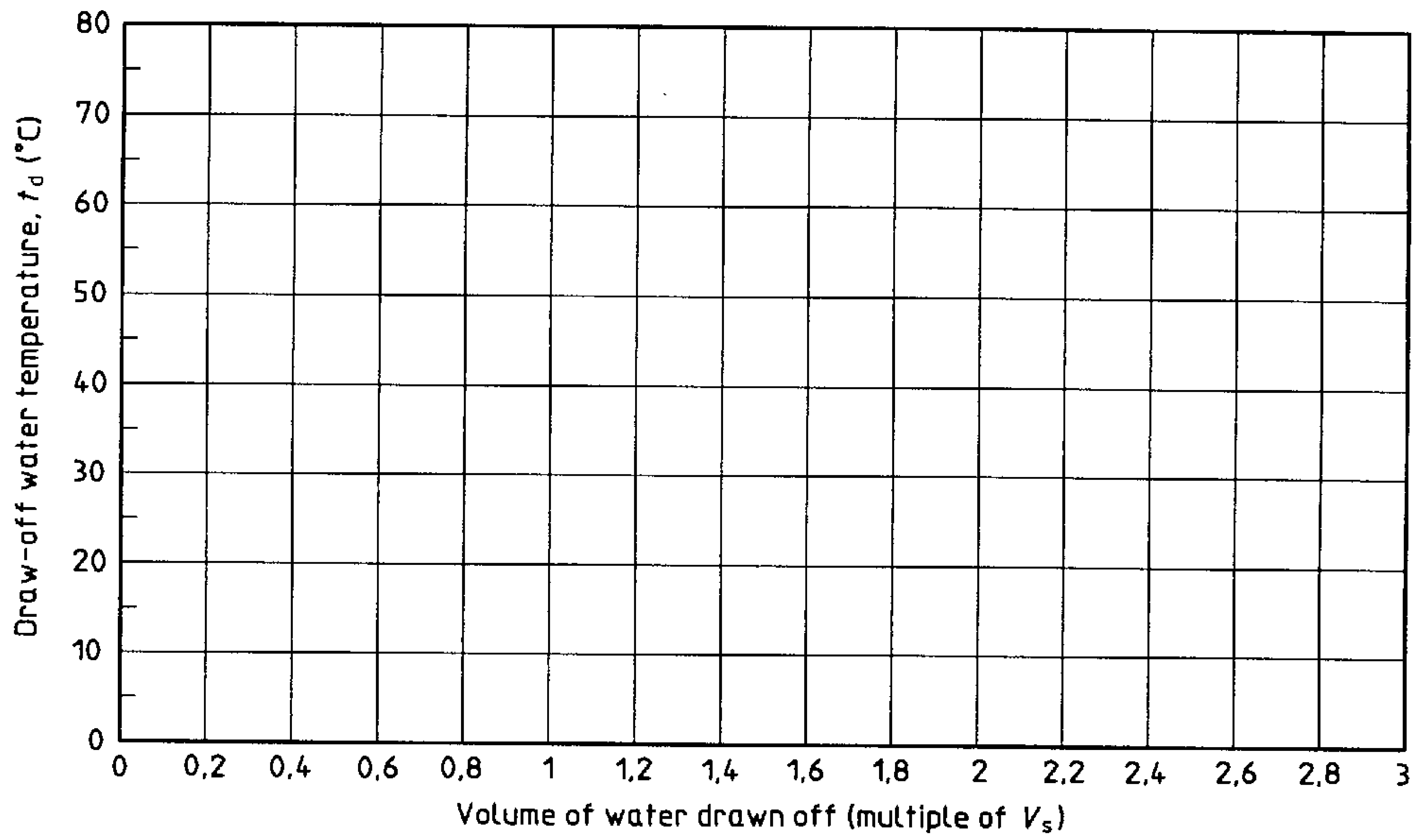


Figure A.10

A.4.5.4 Draw-off temperature profile for $H = 10$ MJ/m^2, $t_{a(day)} = 10$ °C and $t_{main} = 10$ °C

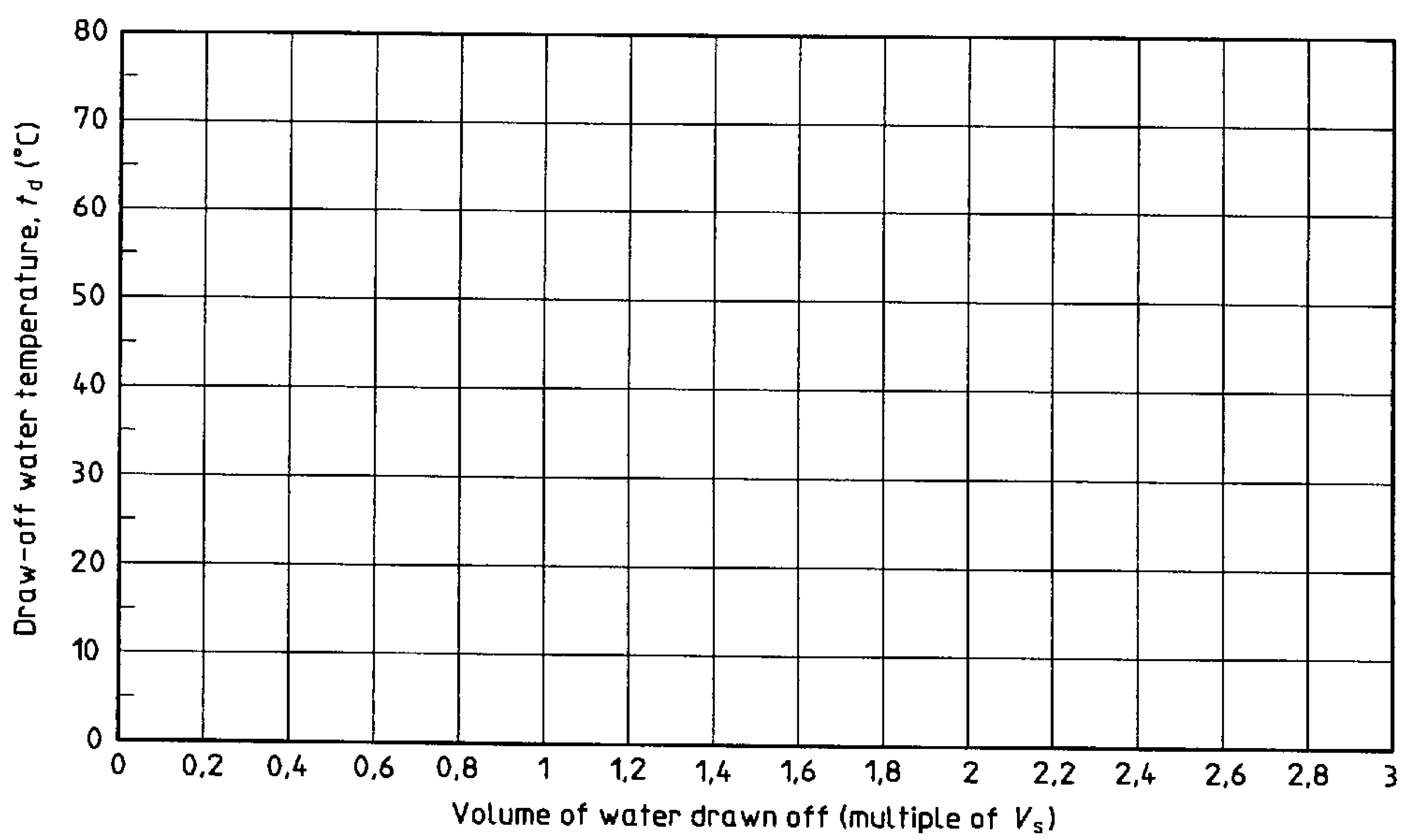
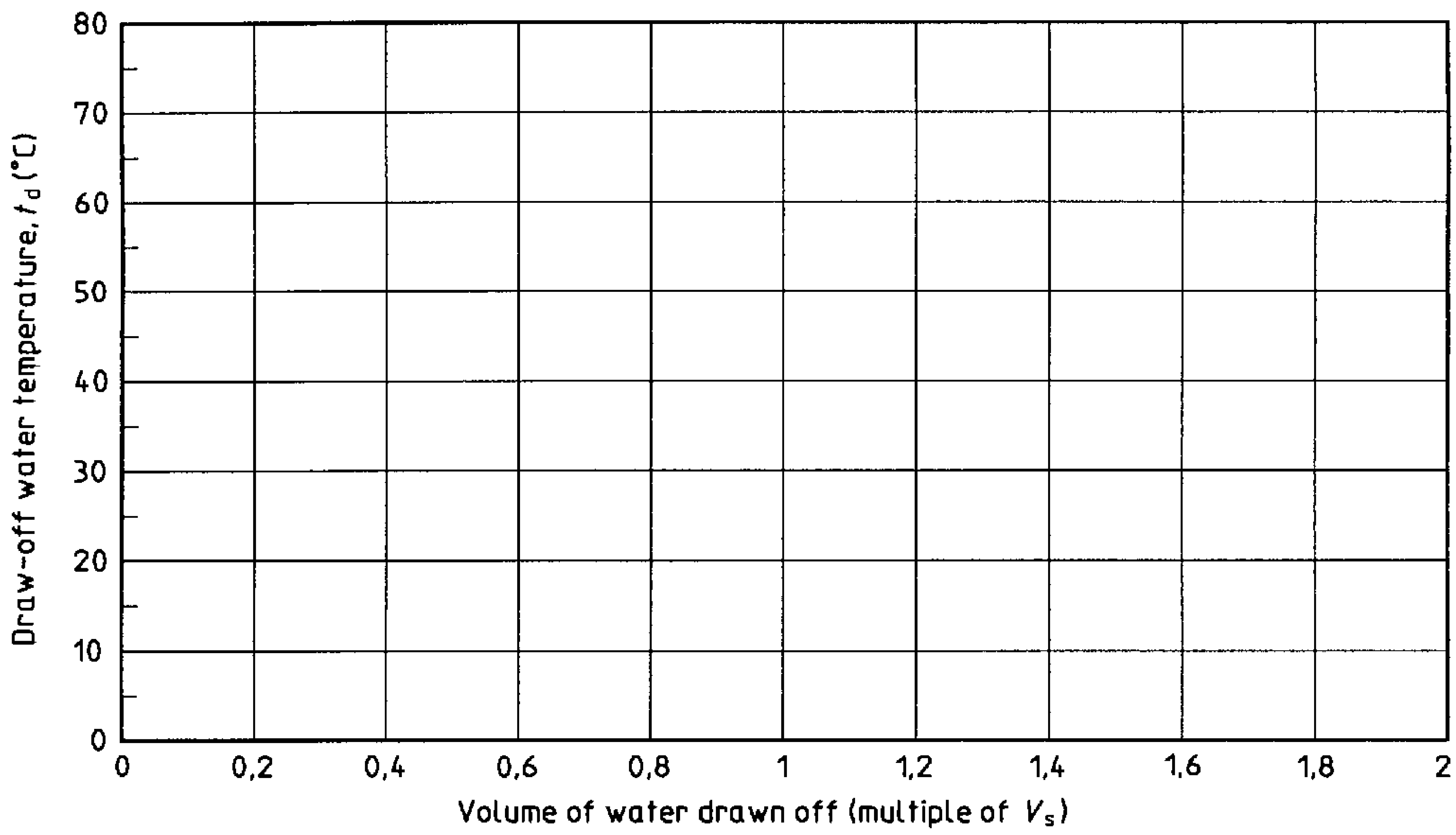


Figure A.11

System reference: ....

A.4.6 Direct comparison of draw-off ($H \geqslant 16$ MJ/m^2) and mixing temperature profiles (see figure A.12)



NOTE — Do not include the graph of the cold water supply temperature (t_{main}).

Figure A.12

System reference: ....

A.5 Annual performance prediction

A.5.1 Climatic data assumed in annual prediction (fill in as applicable)

Reference for climatic data: ....

Location 1: Name .... , latitude .... , longitude ....

Month	1	2	3	4	5	6	7	8	9	10	11	12
H_h (MJ/m^2)												
H_{tilt} (MJ/m^2)												
t_{main} (°C)												
$t_{a(day)}$ (°C)												
t_n (°C)												

Location 2: Name .... , latitude .... , longitude ....

Month	1	2	3	4	5	6	7	8	9	10	11	12
H_h (MJ/m^2)												
H_{tilt} (MJ/m^2)												
t_{main} (°C)												
$t_{a(day)}$ (°C)												
t_n (°C)												

Location 3: Name .... , latitude .... , longitude ....

Month	1	2	3	4	5	6	7	8	9	10	11	12
H_h (MJ/m^2)												
H_{tilt} (MJ/m^2)												
t_{main} (°C)												
$t_{a(day)}$ (°C)												
t_n (°C)												

NOTE — Symbols are defined in clause A.6.

System reference: ....

A.5.2 System usage data (fill in as applicable)

Location 1												
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
V_c (l)												
t_h (°C)												

Location 2												
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
V_c (l)												
t_h (°C)												

Location 3												
Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
V_c (l)												
t_h (°C)												

NOTE — Symbols are defined in clause A.6.

System reference: ....

A.5.3 Predicted solar energy output Q (MJ) of system under the load conditions defined in A.5.2, as calculated in clause 9

Month	**Consumed volume V_c**			**Minimum temperature limit t_h**		
	Location			**Location**		
	1	**2**	**3**	**1**	**2**	**3**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
Year (total) (MJ)						
Year[1] (MJ/m^2)						

1) Predicted annual energy output per square metre of collector aperture area.

System reference: ....

A.5.4 Predicted solar energy output Q, under standard usage conditions ($V_c = V_s$, t_h = 35 °C, t_h = 40 °C) as calculated in clause 9

Month	$V_c = V_s$			t_h = 35 °C			t_h = 40 °C		
	Location			Location			Location		
	1	2	3	1	2	3	1	2	3
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
Year (total) (MJ)									
Year[1] (MJ/m^2)									

NOTE 1 — Prediction based on climatic data included in A.5.1.

1) Predicted annual energy output per square metre of collector aperture area.

System reference: ....

A.5.5 Predicted average daily quantity of hot water (litres) per month under standard conditions (t_h = 35 °C and t_h = 40 °C) as calculated in 9.5.3 and/or 9.6.3

Month	t_h = 35 °C			t_h = 40 °C		
	Location			**Location**		
	1	**2**	**3**	**1**	**2**	**3**
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

System reference: ....

A.6 Symbols

The following symbols apply in the test format sheets.

$f(V)$	normalized draw-off temperature profile, dimensionless
$g(V)$	normalized mixing draw-off temperature profile, dimensionless
H	daily solar irradiation (radiance exposure) in the collector aperture, in megajoules per square metre
H_d	daily diffuse solar irradiation in the collector aperture, in megajoules per square metre
H_h	monthly average daily solar irradiation on a horizontal plane, in megajoules per square metre
H_{tilt}	monthly average daily solar irradiation on a tilted plane, in megajoules per square metre
Q	useful energy extracted from the system, in megajoules
t_a	ambient or surrounding air temperature, in degrees Celsius
$t_{a,s}$	ambient air temperature adjacent to the store, in degrees Celsius
t_d	water temperature of load drawn off, in degrees Celsius
t_f	final water temperature, in degrees Celsius
t_h	required hot water temperature, in degrees Celsius
t_i	initial water temperature, in degrees Celsius
t_{main}	cold water supply temperature, in degrees Celsius
t_n	average ambient air temperature during the night, in degrees Celsius
u	surrounding air speed, in metres per second
U_s	storage tank heat loss coefficient, in watts per kelvin
V_c	volume of daily hot water consumption, in litres
V_d	volume of water drawn off, in cubic metres
V_s	fluid capacity of the store, in litres

Subscripts

(av)	average (mean) value of parameter
(day)	average (mean) value of parameter during the period 6 h before solar noon to 6 h after solar noon
(max)	maximum value of parameter

Annex B
(informative)

Computer programs for long-term performance prediction

B.1 General

The calculation method is presented in detail in clause 9. As the method requires that the same procedure be repeated for each day of the period under consideration, a computerized version of the calculations has been developed. The program runs on an IBM-compatible PC, under an MS-DOS operating system.

The day-by-day computer calculation program DAY-B-D.BAS is applicable to solar systems without an integral auxiliary heater. The program is written in BASIC for the GW-BASIC compiler. The program listing is given in B.4 and a diskette is available (contact the secretariat of ISO/TC 180, *Solar energy*, for details).

B.2 Input data for long-term calculation program

B.2.1 System parameters

The system parameters required for the program are the following:

— the storage tank volume, in litres;

— the storage tank heat loss coefficient, in watts per kelvin;

— the coefficients a_1, a_2 and a_3 of the total solar energy available at 6 h after solar noon, i.e. of equation (2), as follows:

a) one selection of the reference temperature difference, $(t_{a(day)} - t_{main})$ for the linear regression,

b) (for this reference temperature difference) the values of the daily system thermal output for daily solar radiation values of 0 MJ/m^2 (even if the energy ouput value is negative) and of 25 MJ/m^2,

c) the sensitivity of the system thermal output as a function of $(t_{a(day)} - t_{main})$ (coefficient a_2 of the equation), in megajoules per kelvin;

— two draw-off curves (one representing the shape of the outlet temperature during consumption for a cloudy day [$H < 16$ MJ/m^2] and a second for a sunny day [$H \geqslant 16$ MJ/m^2] and one "mixing" curve. These curves should be input in normalized form, should be given per one-tenth of the storage tank volume and are the functions $f(V)$ and $g(V)$ (see 8.4.2, 8.5.2 and A.4.4).

All the data are stored on a data-file on disk, for which a name is requested by the program.

B.2.2 Climatic data

The climatic data required for each day are as follows:

— the daily solar irradiation in the collector plane, in kilojoules per square metre;

— the 24-h average ambient temperature, in degrees Celsius.

NOTE 18 The program assumes that:

$t_{a(day)} = t_{a(24h)} + 2,5$ K

$t_n = t_{a(24h)} - 2,5$ K

The data file consists of as many lines as days, and each line consists of 30 characters, composed as (see program line 1210):

— characters 1-10: number of the day in the year (1 to 365);

— characters 11-20: daytime average ambient temperature;

— characters 21-30: daily solar radiation.

B.2.3 System usage data

The system usage data required are:

— the daily hot water consumption, V_c, or the minimum useful temperature limit for the hot water consumption, t_h;

— the cold water temperature, t_{main}, data (the program assumes that this temperature varies according to a sinusoidal profile over the year, and requires as inputs the average value during the year, which is assumed to occur on the 21st of March and the 21st of September, and the amplitude of the annual variations for the appropriate locality.)

B.3 Results

The results of the calculations are averaged or integrated on a monthly basis and printed. They include either the useful solar energy of the system or the daily available quantity of hot water at the specified minimum demand temperature t_h. All daily values (weather and energy output data) remain available in the program on lines 2110 to 2180 with the index (J) referring to the number of the day in the year.

B.4 Computer calculation program listing

```
10  ' ****************************** 30 / 9 / 1988 ******************************** *
20  ' *                                                                            *
30  ' * Day-by-day calculation program to determine the long-term                  *
32  ' * thermal performance of solar water heating systems based on                *
34  ' * MEASUREMENTS carried out according to the test procedure                   *
36  ' * described in this part of ISO 9459 and in Chapter A 5 of the publication: *
38  ' * Recommendations for thermal performance and durability                     *
40  ' * tests of solar collectors and water heating systems                        *
42  ' * (CEC, Joint Research Centre, 21020 Ispra, Italy).                          *
50  ' *                                                                            *
54  ' * The essential part of the calculation procedure as described in this      *
55  ' * part of ISO 9459 and in table A 6.3 of the CEC publication corresponds    *
57  ' * to lines 1570 to 1930 in this computer program.                           *
58  ' *                                                                            *
60  ' * ************************************************************************** *
70  '
90   OPTION BASE 1
110  DIM Filedata(42),Solar(366),Tamb(366),Date(366),Enout(366),Tcoldin(366)
115  DIM Cons(366),Description[80]
120  DIM Enpercmix(30),Enperc20(30),Enperc10(30)
125  DIM Percenmix$(30),Percen20$(30),Percen10$(30)
130 '
140  print "Give name of file where system parameters are stored"
142  print "(optionally adding DISK name: e.g. A:SYSPARA)"
144  print "**** if file does not exist, then TYPE : NEW "
145  input Filepar$
150  IF LEFT$(Filepar$,1)="N" OR LEFT$(Filepar$,1)="n" THEN GOTO 3000
155 '
157 ' ********** File does exist ***************
159 '
165  open "R",#1,Filepar$,82
170  field #1,60 as Comment$,20 as value$
172  get #1,5
174  Tankvolume=val(value$)                                        '[ L ]
180 '
183  get #1,6
186  Hlctank=val(value$)                                           '[ W / K ]
190 '
193  get #1,7
196  Enout0=val(value$)                                            '[ MJ ]
200 '
203  get #1,8
206  Enout25=val(value$)                                           '[ MJ ]
210 '
213  get #1,9
216  Reftemp=val(value$)                                           '[ K ]
220 '
223  get #1,10
226  Senstemp=val(value$)                                          '[ MJ / K ]
230 '
232  field #1,62 as Comment$,6 as Perc20$ ,6 as Perc10$ ,6 as Mix$
240  for I=1 to 30
```

```
242  GET #1,14+I
245  Enperc20(I)=VAL(Perc20$)
247  Enperc10(I)=VAL(Perc10$)
249  Enpercmix(I)=VAL(Mix$)
252  NEXT I
300  CLOSE #1
800 '
820  PRINT;CHR$(15)
825  Description$="**** Calculation program version 30 / 9 / 1988 **********"
830  PRINT Description$
840 '
950  B=Enout0
960  A=(Enout25-B)/25.
970 '
1100 ' SHELL "DIR *.dat"
1102 print "  "
1103 print "  "
1105 PRINT;"Give file name of weather data (optionally adding DISK name (e.g. A:))
1107 PRINT;"AND the first and last day to be considered "
1109 PRINT;"( for example :  A:CARPTR.DAT ,1,365 )"
1112 INPUT Weatherfile$,Firstday,Lastday
1113 print "  "
1114 PRINT;"Consumption at Solar noon + 6 hours : "
1116 PRINT;" If LIMIT is Volume then input quantity in units of TANK VOLUME "
1117 PRINT;"             (e.g. : 192 l/day for 160 l tankvolume , then type : 1.2 )"
1118 PRINT;" If LIMIT is Minimum outlet TEMPERATURE then input value in degrees C"
1135 INPUT Help
1136 IF Help<5 THEN GOTO 1140
1137 PRINT "You have selected a TEMPERATURE limit "
1138 Toutlimit=Help
1139 GOTO 1148
1140 PRINT;"You have selected a VOLUME limit "
1142 Consvolume=Help
1144 Toutlimit=0
1148'
1149 PRINT "Specify the cold water inlet temperature as follows :"
1151 PRINT "  the temperature varies according to a sinusoidal profile over"
1152 PRINT "  the year ; Tcold = Taverage + Tamplit. * SIN (Day nr - 90 )"
1153 PRINT "  *** 21 march and 21 september  Tcold = Taverage   *****   "
1154 INPUT "input the VALUES FOR Taverage and Tamplitude :",Tcoldbas,Tcoldampl
1156'
1160 OPEN "R",#1,Weatherfile$,32
1180'
1190 FOR I=Firstday TO Lastday
1210 FIELD #1,10 AS Day$,10 AS Tamb$,10 AS Solar$
1310     GET #1,I
1320     Date(I)=VAL(Day$)                                      ' Day number
1330     Tamb(I)=VAL(Tamb$)+2.5
         ' Tamb. daytime = Tamb. 24h + 2.5 degrees
1340     Solar(I)=VAL(Solar$)/1000.                             ' [ MJ ]
1360     Tcoldin(I)=Tcoldbas+Tcoldampl*SIN(2*3.1415*(I-80)/365.)
1380 NEXT I
1390'
1400 LPRINT;CHR$(12) '                                          New page
1410 LPRINT;Description$
1420 LPRINT;"          "
```

```
1425 LPRINT;"System parameters file  : ";Filepar$
1430 LPRINT;"Weather file  :";Weatherfile$
1440 IF Toutlimit=0. THEN LPRINT;"Daily Cons. volume :";Consvolume;" times the
     'tank volume at Solar Noon + 6 h"
1445 IF Toutlimit>0. THEN LPRINT;"Consvolume is limited by a minimum water
     'OUTLET temperature of ";Toutlimit; "[ C ]"
1450 LPRINT;"Tank characteristics : Volume ";Tankvolume;" liters Heat loss
     'coeff.";Hlctank;" W/K"
1460 LPRINT;"ref. energy output :";Enout0;" MJ at 0 AND ";Enout25;" MJ at 25
     'MJ/m2.day    ***    (Tamb - Tcold )ref. =";Reftemp;" K"
1470 LPRINT; " Temp. correction for system output "; Senstemp;" MJ/K for
     '(Tamb.- Tcold)"
1560'
1570 FOR I=Firstday TO Lastday
1590'
1600 IF I=Firstday THEN Ttank=Tcoldin(I)  ' 1st day : initial tankt. = Tcold-in
1610'
1620 Enout3v=(A*Solar(I)+B)+Senstemp*((Tamb(I)-Ttank)-Reftemp) ' Energy in R/R test
     'conditions
1630 IF Enout3v<0. THEN GOTO 1660 ' If energy output is negative then only tank
     'heat losses during the day
1635 GOTO 1700
1660 Tankhl=Tankvolume*4.18*/Ttank-Tamb(I))*(1-EXP(-Hlctank*12*3.6/ (Tankvolume
     '*4.18)))                                                   ' [ K ]
1670    Ttank=Ttank-Tankhl/(Tankvolume*4.18)
1680    Enout3v=0.
1700'
1710 Percrr=0.      ' part of the energy output in R/R test conditions .. f ( V )
1715 Percmix=0.     '  "     "   "     "    for the carry - over .... g ( V )
1718 Enmixing=Tankvolume*(Ttank-Tcoldin(I))*4.18/1000. 'Energy available from
     'previous day in [ MJ ]
1719'
1720' Calculation of the water OUTLET temperature and DRAW-OFF volume in
     'case of a Temperature LIMIT
1721 IF Toutlimit=0. THEN GOTO 1737  ' limit is expressed in VOLUME
1722    FOR J=1 TO 30.
1723    IF SOLAR(I)>=15. THEN HLP=Enperc20(J) ELSE HLP=Enperc10(J)
1727    Enout=Enout3v*HLP/100.+Enmixing*Enpercmix(J)/100.          ' [ MJ ]
1728    Tout=Tcoldin(I)+Enout*1000./((Tankvolume/10.)*4.18)         ' [ K ]
1729    Consvolume=(J-1)/10.
1731    IF Tout< THEN GOTO 1737
1733    NEXT J
1734'
1735 Consvolume=3.  '
1737 FOR J=1 TO Consvolume*10.  'Steps of 0.1 tankvolume
1740 IF Solar(I)>=15 THEN Percrr=Percrr+Enperc20(J) ELSE Percrr= Percrr+
     'Enperc10(J)
1750 Percmix=Percmix  +Enpercmix(J)
1760 NEXT J
1780'
1790 Enout(I)=Enout3v*Percrr/100.+Enmixing*Percmix/100.
1800 Rest=Enout3v*(1-Percrr/100.)+Enmixing*(1.-Percmix/100.)
1810'
1820 Ttank=Tcoldin(I)+Rest*1000./(Tankvolume*4.18)                  ' [ C ]
1830 'Night heat losses
```

```
1840 Tankhl=Tankvolume*4.18*(Ttank-(Tamb(I)-5.))*(1-exp((-Hlctank*12*3.6)/
         '(Tankvolume*4.18 )))                                          ' [ kJ ]
1850 Ttank=Ttank-Tankhl/(Tankvolume*4.18 '[ C ] ; Temperature in the tank at
       'Solar noon + 6 hours
1870'
1930 NEXT I
1940'
1960' **********  Printout of RESULTS  **********
1982'
1983 LPRINT "  "
1984 LPRINT "  ********** Results averaged on a monthly basis  ***************
1985 LPRINT "  "
1990 LPRINT "  from to Solar on coll. Tamb. during Supply water average energy
1994 LPRINT "  day  day plane daytime  temperature  output "
1996 LPRINT "       [ MJ / m2.day ]     [ C ]     [ C ]          [ MJ / day ] "
1997 LPRINT "  "
1998'
2002 FOR I=1  TO 331  STEP 30   ' LPRINT out of results per month
2004 IF Firstday>I+29 OR Lastday<1 THEN GOTO 2012
2006    IF Firstday>I AND Firstday<=I+29 THEN Day1=Firstday ELSE Day1=I
2009    IF Lastday>=I AND Lastday<I+29 THEN Day2=Lastday ELSE Day2=I+29
2011 GOSUB 2026  ' LPRINT results month per month
2012 NEXT I
2013'
2014 LPRINT "-------------------------------------------------------------"
2015 Day1=Firstday
2016 Day2=Lastday
2018 GOSUB 2026  ' LPRINT results for the whole period
2019 GOTO 2253
2022'
2026 Solarav=0.
2028 Tambav=0.
2030 Enoutav=0.
2040 Tcoldav=0.
2050 Consav=0.
2095'
2100    FOR J=Day1 to Day2
2105    Dif=Day2-Day1+1
2110    Solarav=Solarav+Solar(J)/Dif   'Solar rad. on collector plane
2130    Tambav=Tambav+Tamb(J)/Dif      'Ambient temp. during daytime
2150    Enoutav=Enoutav+Enout(J)/Dif   'Energy output for given draw-off volume
2170    Tcoldav=Tcoldav+Tcoldin(J)/Dif 'cold water temperature
2180 IF Toutlimit>0. THEN Consav=Consav+Enout(J)/(0.00418*(Toutlimit-Tcoldin(J)))
     'hot water volume (in case of minimum temperature limit
2190 ' LPRINT;J; Tamb(J),Solar(J),Enout(J),Tcoldin(J)
2200 NEXT J
2210 LPRINT USING  " ###.  ###.      ######.#     #####.#       ####.#
        #######.#";Day1,Day2,Solarav,Tambav,Tcoldav,Enoutav
2215 IF Toutlimit> 0. THEN LPRINT "Total water consumption (for the whole period):
        'equivalent to ",Consav," liters AT ",Toutlimit," deg. C (each day at Solar noon
        '+ 6 h)"
2230 LPRINT    "  "
2235 RETURN
2250'
2253 PRINT "Finished"
2255 BEEP
```

```
2257 BEEP
2258 STOP
2259'
3000 '********** introduction of system parameters. **********
3005 '******************************************************
3010 print chr$(12)
3020 print "give name of file where system parameters have to be stored "
3030 print " (optionally adding DISK file name : e.g. A:SYSPARA )       "
3035 input Filepar$
3037 OPEN "R",#1,Filepar$,82
3038 FIELD #1,80 AS Text$,2 as Crlf$
3039 LSET Crlf$=chr$(13)+chr$(10)
3040'
3050 print "The 3 first lines are for reference or comments "
3060 FOR I=1 TO 3
3070 PRINT "Line nr :";I;"  max. 80 characters "
3080 INPUT Help$
3085 LSET Text$=Help$
3090 PUT #1,I
4000 NEXT I
4005'
4010 Help$="          System parameters :"
4020 PRINT Help$ : LSET Text$=   Help$
4030 PUT #1,4
4040'
4045 FIELD #1, 65 AS Comment$ , 15 AS Value$,2 AS Crlf$
4047'
4050 Help$="Tank volume                                           [ liters ] :    '
4060 I=5 : GOSUB 4500
4080'
4090 Help$="Tank heat loss coefficient                            [ W / K ] :     "
4100 I=6 : GOSUB 4500
4110'
4112 PRINT "          ------------------------------          "
4113 PRINT "The following values correspond to the LINEAR regression "
4116 PRINT "                                                     *
4120 Help$="Energy output for test conditions of  0 MJ/m2         [ MJ ] :    "
4130 I=7 : GOSUB 4500
4140'
4150 Help$= "  "      "  "  "     "      25 MJ/m2              [ MJ ] :    "
4160 I=8 : GOSUB 4500
4170'
4180 Help$="Reference temp. diff. (Tc - Ta) for these results     [ K ] :    "
4190 I=9 : GOSUB 4500
4200'
4210 Help$="Temperature sensitivity of the energy output           [ MJ / K ] :
4220 I=10 : GOSUB 4500
4230 GOTO 4540
4455'
4500 PRINT Help$ : INPUT  VA$
4505 LSET Comment$ = Help$
4510 LSET VALUES = VA$
4520 PUT #1,I
4530 RETURN
4540'
5000 Help$="Temperature profiles in dimensionless form (in steps of 0.1 tankvolumes)"
```

```
5010 PRINT Help$ : LSET Text$ = Help$ : PUT #1,11
5020 Help$=" - : draw-off profile for days 16 - 25. MJ / m2 "
5030 PRINT Help$ : LSET Text$ = Help$ : PUT #1,12
5040 FOR I=1 TO 30
5050 PRINT "Value from ";(I-1)/10.;" to ";I/10.;" tankvolumes IN [ % ]"
5060 INPUT Percen20$(I)
5070 NEXT I
5080'
5100 Help$=" + : draw-off profile for days  0 - 15.99 MJ / m2 "
5110 PRINT Help$ : LSET text$ = Help$ : PUT #1,13
5120 FOR I=1 TO 30
5130 PRINT *Value from ";(I-1)/10.;" to ";I/10.;" tankvolumes IN [ % ]"
5140 INPUT Percen10$(I)
5150 NEXT I
5160'
5170 Help$="  " : mixing draw-off profile "
5180 PRINT Help$ : LSET Text$ = Help$ : PUT #1,14
5190 FOR I=1 TO 30
5200 PRINT "Value from ";(I-1)/10.;" to ";I/10.;" tankvolumes IN [ % ]"
5210 INPUT Percenmix$(I)
5220 NEXT I
5230'
5235 FIELD #1,62 AS Profile$ ,6 AS *S20$, 6 AS S10$ AS SMIX$,2 AS Crlf$
5237'
5240 FOR I = 1 TO 30
5250 A = INT(VAL (Percen20$(I)) * 4.)+ 6.
5255 IF A>61 THEN A=62
5260 B = INT(VAL (Percen10$(I)) * 4.)+ 6.
5265 IF B>61 THEN B=62
5270 C = INT(VAL (Percenmix$(I))* 4.)+ 6.
5275 IF C>61 THEN C=62
5280 Help$="                                                              "
5290 MID$(Help$,A) = "-"
5300 IF B=A THEN MID$(Help$,B)="o" ELSE MID$(Help$,B)="+"
5310 IF C=B OR C=A THEN MID$(Help$,C)="o" ELSE MID$(Help$,C)="*"
5320 PRINT Help$
5325 LSET Profile$ = Help$
5330 LSET S20$ = LEFT$(Percent20$(I),5)
5340 LSET S10$ = LEFT$(Percen10$(I),5)
5350 LSET SMIX$= LEFT$(Percenmix$(I),5)
5360 PUT #1,(14 + I)
5370 NEXT I
5380'
5390 CLOSE #1
5400 GOTO 165
5500'
6000 END
```

Annex C
(informative)

Test for systems with a midday draw-off

C.1 Introduction

In some countries there may commonly be a large hot water consumption at midday. In order to determine the ability of a system to deliver a volume of water at a high temperature at midday, a one-day test shall be performed where a load of half the tank volume is drawn off at midday, and a load of one and a half times the tank volume at the end of the day.

C.2 Test conditions

The system shall be preconditioned as described in 7.3. The test day shall have a total irradiation H of greater than 20 MJ/m^2, with an irradiation of greater than 10 MJ/m^2 in the period between 6 h before solar noon and solar noon, and an irradiation of greater than 10 MJ/m^2 between solar noon and 6 h after solar noon. The temperature t_{main} of the cold water used to precondition the tank shall be ($t_{a(day)}$ – 5 K).

C.3 Test method

The preconditioning of the system as described in 7.3 shall be stopped at 6 h before solar noon and the system allowed to operate for 12 h. Measurements shall be made during this period as described in 7.6. At solar noon, a volume of water equal to half the volume of the tank shall be drawn off from the store at a constant flowrate of 600 l/hr. Water replacing this shall be at the temperature t_{main} defined during the preconditioning of the system.

The temperature of the water drawn off at solar noon and at 6 h after solar noon shall be measured as specified in 7.7. Draw-off temperature profiles as shown in figure 2 shall be recorded for the two hot water draw-offs.

Annex D
(informative)

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