

Australian Standard[®]

**Solar water heaters—Domestic and
heat pump—Calculation of energy
consumption**

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Australian and New Zealand Solar Energy Society
Australian Electrical and Electronic Manufacturers Association
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PREFACE

This Standard was prepared by the Standards Australia Committee CS/28 on Solar Water Heaters. The performance evaluation procedure defined in this Standard has been designed to provide a means of evaluating the annual task performance of solar and heat pump water heaters and to provide a means for quickly evaluating the performance of a series of product configurations for a range of locations.

This Standard sets out a method of determining the annual performance of domestic solar and heat pump water heaters using a combination of test results for component performance and a mathematical model to determine an annual load cycle task performance. The Standard also defines a procedure for evaluating the task performance of conventional domestic water heaters so that the energy savings of solar and heat pump water heaters can be evaluated relative to conventional water heaters operated under the same annual task load.

Testing of solar water heating systems under outdoor or indoor solar irradiance conditions has been defined in AS 2984—1987, *Solar water heaters—Methods of test for thermal performance—Outdoor test method*, and AS 2813—1985, *Solar water heaters—Methods of test for thermal performance—Simulator method*. Outdoor testing requires a long test period (8-10 weeks) due to the need to obtain stable inputs for a range of operating conditions. Indoor testing (solar simulator) provides stable input conditions, however, the equipment required and operating costs are very expensive. The major drawback of the outdoor or indoor solar irradiance testing is that the test must be repeated for every variation of system configuration offered by the supplier.

The procedure defined in this Standard overcomes the time and cost limitations of previous water heater performance standards and provides a procedure for calculating the purchased energy consumption of solar and heat pump domestic water heaters.

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the appendix to which they apply. A ‘normative’ appendix is an integral part of a Standard, whereas an ‘informative’ appendix is only for information and guidance.

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Australian Standard

**Solar water heaters—Domestic and
heat pump—Calculation of energy consumption**

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE This Standard sets out a method of determining the annual performance of domestic solar and heat pump water heaters using a combination of test results for component performance and a mathematical model to determine an annual load cycle task performance. The procedure is applicable to solar water heaters with integral boosting or preheating into a conventional water heater and to heat pump water heaters. Solar and heat pump water heater types not covered in the application of this Standard can be tested under AS 2984 or AS 2813 to obtain an annual performance assessment.

1.2 APPLICATION The procedure in this Standard uses a mathematical model to assess annual task performance hence the application of the procedure is restricted by the availability of suitable mathematical models. The analysis required by this Standard shall be based on the TRNSYS simulation model (version 13.1 or later) with modifications to suit typical Australian solar and heat pump water heating products. The software required is included in this Standard together with weather data and typical system description files. The operating conditions to be used for evaluating the performance of a water heater are not defined in this Standard; however a set of typical weather and load conditions are specified in Appendix A.

This Standard defines computer simulation models for the following systems:

- (a) Single tank solar water heaters with electric or gas in-tank boosting.
- (b) Solar pre-heater in series with an instantaneous electric or gas booster.
- (c) Solar pre-heater in series with a conventional storage water heater
- (d) Heat pump water heaters with a flat plate evaporator exposed to ambient air or solar radiation, or both.

The following solar and heat pump water heater configurations are included:

- (i) Solar water heaters with flat plate, concentrating or evacuated tubular solar collectors.
- (ii) Thermosyphon or pumped fluid circulation through the solar collectors.
- (iii) Annular tank in tank heat exchanger in a thermosyphon loop.
- (iv) Horizontal or vertical water storage tanks.
- (v) Storage tanks with dual electric elements.
- (vi) Solar collectors acting as the evaporator in a heat pump circuit.
- (vii) Heat exchangers acting as the condenser in a heat pump circuit.

Other water heater configurations incorporating the above components may also be modelled.

1.3 REFERENCED DOCUMENTS

AS

1056 Storage water heaters

1056.1 General requirements

2535 Solar collectors with liquid as the heat-transfer fluid—Method for testing thermal performance

2813 Solar water heaters—Methods of test for thermal performance—Simulator method

2984 Solar water heaters—Methods of test for thermal performance—Outdoor test method

ISO

9806.3 Thermal performance test for solar collectors
Part 3: Unglazed liquid heating collectors

AG

102 Approval requirements for gas water heaters

ASHRAE

23—93 Methods of testing for rating positive displacement refrigerant compressors and condensing units

1.4 DEFINITIONS For the purpose of this Standard, the definitions below apply.

1.4.1 Absorber—device within a collector for absorbing radiant energy and transferring this energy as heat into a fluid.

1.4.2 Angle of incidence—angle between the direct radiation and the outward normal from the plane considered (e.g. from the collector aperture).

1.4.3 Angle of inclination—angle between the absorbing surface of the collector and the horizontal.

1.4.4 Close-coupled solar water heater—unit where the collector abuts the container on a common chassis or cradle.

1.4.5 Collector—device containing an absorber.

1.4.6 Collector aperture—net area measured parallel to the plane of the collector available to admit, reflect or refract solar radiation to the absorber. The aperture width for different collector types is illustrated in AS 2535.

1.4.7 Container—vessel (including fittings) in which the heated water is stored; sometimes referred to as a storage container, cylinder or tank.

1.4.8 Electricity tariffs

1.4.8.1 Continuous tariff—tariff for continuously available electricity supply.

1.4.8.2 Off-peak tariffs—tariffs that are available at off-peak times, as follows:

- (a) Off-peak one (OP1)—electricity supply at restricted or night hours. (See Appendix A for typical off-peak boost times.)
- (b) Off-peak two (OP2)—electricity supply during extended hours. (See Appendix A for typical off-peak boost times.)

1.4.8.3 Combined tariff (off-peak and continuous)—tariff used by systems having an upper level, continuous tariff element and a lower-level, off-peak tariff element.

1.4.9 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 the surface (W/m^2).

1.4.10 Irradiation—the incident energy per unit area of a surface, found by integration of irradiance over a specified time interval, often an hour or a day (MJ/m^2).

1.4.11 Solar water heater—system normally consisting of a solar collector and a container which may be integral, close-coupled or remote, and which heats water by means of radiant energy from the sun. It is normal for solar water heaters to be either fitted with or connected to a supplementary heating source.

1.4.12 Load—amount of thermal energy drawn from the system as hot water. Energy is computed relative to the cold water temperature.

1.4.13 Heat pump water heater—a system incorporating a compressor (vapour compression), a flat plate evaporator exposed to ambient air or solar radiation, or both, and a wrap around or immersion coil condenser.

1.5 NOTATION Symbols used in this Standard are listed below.

a, b, c	= correlation coefficients for solar collector efficiency
B_c	= annual auxiliary energy used by a conventional water heater (MJ/year)
B_s	= annual auxiliary energy for a solar or heat pump water heater (MJ/year)
E	= Energy consumed (kWh)
f_R	= energy savings relative to a conventional water heater = $(B_c - B_s)/B_c$
G_T	= total solar irradiance on the collector aperture (W/m^2)
G_b	= beam irradiance on the collector aperture (W/m^2)
G_L	= relative long wave irradiance ($\lambda > 4 \mu\text{m}$) = $G_s - \sigma T_a^4$ (W/m^2)
G_s	= long wave thermal irradiance ($\lambda > 4 \mu\text{m}$) (W/m^2)
H	= heat loss (kWh/day)
$K\tau\alpha$	= solar collector angle modifier
K_{NS}, K_{EW}	= bi-axial incidence angle modifiers
t	= duration of test (h)
T	= collector fluid temperature
T_a	= ambient temperature ($^{\circ}\text{C}$)
$\bar{T}$	= mean air temperature during the test ($^{\circ}\text{C}$)
$\bar{T}_w$	= mean temperature of water in the storage tank ($^{\circ}\text{C}$)
$\bar{T}$	= mean collector fluid temperature ($^{\circ}\text{C}$)
T_{set}	= manufacturer's recommended thermostat setting or 75°C
u	= surrounding air speed over the solar collector (or evaporator) (m/s)
UA	= heat loss coefficient $\times$ area product (W/K)
α	= unglazed collector hemispherical absorber absorptance, short wave
ϵ	= unglazed collector hemispherical absorber emittance, long wave
η	= solar collector efficiency
θ	= incidence angle relative to the collector aperture normal (deg.)

SECTION 2 PERFORMANCE EVALUATION PROCEDURE

2.1 INTRODUCTION The procedures in this Standard define a means of evaluating the task performance of domestic solar and heat pump water heaters using a short time step mathematical model of the system and hour-by-hour environmental conditions for the area of interest.

For continuous electric or gas storage water heaters acting as boosters the procedure builds on data obtained from Standards AS 1056.1 and AG 102.

For off-peak electric storage water heaters the temperature stratification in the storage tank is evaluated throughout the day to quantify variation of tank heat loss with time, due to cooling of the bottom of the tank. Mixing during load draw off and conduction between the hot and cold layers in the tank is also included.

For solar water heaters this procedure is limited to systems capable of being separated into a solar collector component and a storage vessel component. The performance of these components is evaluated under Standards AS 2535 and AS 1056.1.

The performance of heat pump water heaters with flat plate evaporators is evaluated using test results for the evaporator evaluated under AS 2535 and test results for the compressor evaluated under ASHRAE 23-93.

2.2 COMPONENT TESTING

2.2.1 Electric boosted storage vessels The standing heat loss and the rated delivery of storage vessels with bottom booster elements shall be evaluated using AS 1056.1.

2.2.2 Electric storage vessels with raised elements Electric boosters in solar water heaters may be located above the bottom of the tank to separate the function of solar heating and auxiliary boosting. Evaluation of the standing loss and rated delivery of such tanks requires a special test to avoid thermal stratification below the electric element. A revised test procedure for this type of tank is given in Appendix B.

2.2.3 Gas boosted storage vessels The combustion efficiency, pilot consumption, maintenance rate and the rated delivery of gas storage tanks shall be evaluated using the test methods in AG 102.

2.2.4 Heat pump storage water heaters The heat pump compressor thermal capacity and power consumption shall be evaluated for evaporator temperatures from -5°C to 30°C (at least four temperatures) and condenser temperatures of 30°C to 70°C (at least four temperatures) following the test procedure in ASHRAE 23-93. The standing loss and rated delivery of the storage tank in a heat pump water heater shall be evaluated using AS 1056.1 if a bottom electric booster is fitted or the procedure defined in Appendix B of this Standard if an electric booster is not fitted to the bottom of the tank.

2.2.5 Solar collector efficiency The efficiency of glazed solar collectors shall be evaluated using AS 2535. The efficiency of unglazed solar collectors (or solar boosted heat pump evaporators) shall be evaluated using ISO 9806.3.

The collector efficiency characteristic shall be specified by one of the following equations:

$$\text{Glazed flat plate collectors} \quad \eta = a_1 - a_2 \frac{(\bar{T} - T_a)}{G_T} - a_3 \frac{(\bar{T} - T_a)^2}{G_T} \quad \dots 2.2.5(1)$$

($G_T = G_b$ for concentrating collectors)

Evacuated collectors:
$$\eta = b_1 - b_2 \frac{(\bar{T} - T_a)}{G_T} - b_3 \frac{(\bar{T}^4 - T_a^4)}{G_T} \quad \dots 2.2.5(2)$$

where $\bar{T}$ and T_a are absolute temperatures

Unglazed collectors:
$$\eta = c_1 - (c_2 + c_3 u) \frac{(\bar{T} - T_a)}{G_T + \frac{\epsilon}{\alpha} G_L} \quad \dots 2.2.5(3)$$

2.3 WATER HEATER CONFIGURATION The simulation model requires knowledge of the component performance and interconnection data listed in Appendix C.

2.3.1 Solar collector orientation The solar collector inclination and azimuth shall be as specified in the manufacturer's installation instructions. If no specific collector orientation is required the collector inclination and azimuth angles specified in Appendix A are recommended.

2.3.2 Solar storage tank auxiliary input The position of the auxiliary booster in the storage tank of a solar water heater may be varied to suit different boosting modes. With continuous boosting, the auxiliary element may be located towards the top of the tank. With off-peak boosting, the auxiliary element may be located low in the tank to achieve a satisfactory load delivery on days of low solar irradiation.

The following auxiliary boost modes and control options may be specified:

- (a) Electric in-tank boosting (continuous or off-peak tariffs).
- (b) Dual electric elements operated on different tariffs
- (c) User override of the thermostat in combination with any electric tariff.
- (d) Gas in-tank boosting
- (e) Separate auxiliary tank or in-series booster with the solar heater operating as a preheater. The separate auxiliary input may be a storage water heater or an instantaneous electric or gas heater.
- (f) Intelligent solar controller that overrides the thermostat operation in response to solar radiation conditions (usually with additional user override).

SECTION 3 PERFORMANCE EVALUATION

3.1 ANNUAL TASK PERFORMANCE The mathematical model to be used for the annual task performance evaluation shall be the TRNSYS simulation program (version 13.1 or later) with modifications outlined in Appendix C. The software and example data files are provided with this Standard (Appendix D). The application conditions recommended in Appendix A may be adopted, or the user may develop appropriate load and environment conditions for each application.

3.1.1 Solar Water Heaters The performance of solar water heaters shall be determined using the modified TRNSYS simulation model (time step of 30 minutes or less) to determine the annual auxiliary inputs for the selected load and environmental conditions (Appendix E).

3.1.2 Heat pump water heaters The performance of heat pump water heaters shall be determined using the modified TRNSYS simulation model (time step of 15 minutes or less) to determine the annual electrical energy used by the compressor motor and auxiliary heater (if used).

3.2 WEATHER DATA The weather data required for the simulation consists of one year of records of hourly or half-hourly values for the following variables:

Global horizontal radiation	(all systems)
Ambient temperature	(all systems)
Wet bulb temperature	(heat pump only)
Wind speed	(unglazed collector only)
Cloud cover	(unglazed collector only)

To facilitate comparison of different simulations, weather data for the four zones listed in Appendix A are recommended.

3.3 THERMAL ENERGY LOADS The average daily thermal energy load and hourly and seasonal variation of load must be specified for the simulation model; typical load patterns are shown in Appendix A. The average load is distributed within each day using the hourly load pattern and the daily load is varied each month using the seasonal load pattern. Two typical load sizes are recommended in Appendix A. Any load may be specified provided the auxiliary system can satisfy the minimum delivery temperature in typical winter conditions (see Clause 3.6). The TRNSYS simulation deck shall be configured so that the load is specified in terms of energy withdraw in the manner shown in the example data files (Appendix D).

3.4 COLD WATER TEMPERATURE The monthly cold water temperature profile over a year must be specified. Typical water temperatures for the four recommended climate zones in Australia are given in Appendix A.

3.5 LOAD CAPACITY Solar water heaters commonly use only a small auxiliary boost volume (boost element above the bottom of the tank) in order to separate the solar preheating and auxiliary energy inputs. As a result, the daily delivery capacity of a solar water heater under no-solar conditions may be limited, particularly if off-peak electric boosting is used.

To quantify the auxiliary heating system capacity, the solar water heater performance shall be assessed by simulating the task performance with the solar irradiation set to zero over a period of five or more days until stable operation is obtained.