Australian Government
Clean Energy Regulator

Heat loss test procedure for solar water heaters with a hot water storage tank greater than 700 L

Renewable Energy (Electricity) Regulations 2001

This document was first published by the Regulator on 29 May 2003 and has been updated applicable from 18 December 2017. It applies to storage tanks in systems that received component certification on or after 18 December 2017.

1. Application

This document sets out a procedure for determining the tank standing heat loss for solar water heater (SWH) system storage tanks that have a volumetric capacity greater than 700 L for the purposes of subparagraph 3A(3)(c)(ii) of the Renewable Energy (Electricity) Regulations 2001 (the Regulations).

The procedure allows heat loss for large tanks to be determined by calculation rather than direct measurement.

The procedure may be applied to SWH system storage tanks that have a volumetric capacity greater than 700 L.

The procedure must not be applied to any SWH system storage tanks that have a volumetric capacity equal to or less than 700 L. These storage tanks must meet the requirements of AS/NZS 4692.1:2005 and AS/NZS 4292.2:2005, as set out in subparagraph 3A(3)(c)(i) of the Regulations.

Note: the version of this document that is applicable to a storage tank in a particular SWH system is the version that was in force at the time an accredited body gave the SWH system component certification to the Australian Standards listed in paragraph 3A(3)(b) of the Regulations. This Version 3.0 applies to storage tanks in SWH systems that received certification on or after 18 December 2017.

2. Procedure

Heat loss of storage tanks for which this procedure may be applied may be estimated based on the tank heat loss area, the thermal conductivity & thickness of the insulation and the number of openings/fittings penetrating the tank insulation. Calculating the heat loss instead of measuring it may be justified for tanks > 700 L due to the fact that the tank heat loss per unit volume for these tanks becomes relatively small and inaccuracies in the tank heat loss have less effect on system performance than for ≤ 700 L tanks.

The heat loss from a tank with a volumetric capacity > 700 L can be estimated in three steps. First, the heat loss from a tank with the insulation covering the entire tank surface area is calculated.

In the second step the heat loss is increased to allow for imperfections and heat bridges in the tank insulation. In the final third step the heat loss is further corrected for extra heat losses from openings in the insulation (e.g. from attached pipes and valves).

Figure 1 shows an idealised cylindrical tank with flat top and base that is covered with insulation of thickness Δx and thermal conductivity k. The tank with flat top and bottom may approximately represent an actual

Renewable Energy Target

tank with curved dome (see Appendix 1 for a drawing) when the insulation thickness Δx for the tank top and bottom is set to the average insulation thickness of the actual tank (see Appendix 2 for calculation). Note the values for Δx and k may be different for the various tank surfaces (cylinder, top and base).

The heat loss from the tank can be estimated by assuming the insulation material provides the only significant resistance to heat flow, i.e. by neglecting the relatively small convective resistances on the inside and outside tank surface and the minor conductive resistances provided by the tank wall and the tank cladding.

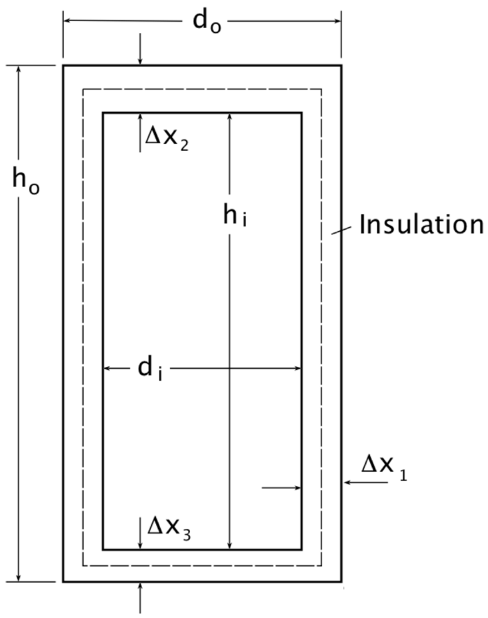

Figure 1. Cross sectional view through an idealised cylindrical tank of inner diameter $\boldsymbol{d_i}$ and height $\boldsymbol{h_i}$ covered with insulation of thickness Δx.

Step 1

Using the tank insulation mid diameter and mid height for the calculation of the heat loss area $\boldsymbol{A}$ (dashed line in Figure1)[1], the steady-state heat loss rate from the tank cylinder wall (index 1 in Eq. 1), the tank top (index 2 in Eq. 1) and the tank base (index 3 in Eq. 1) can be expressed with Fourier's law of conduction as:

$$\dot{\boldsymbol{Q}}_{\boldsymbol{step1}} = \sum_{j=1}^{3} \boldsymbol{A_j}\, \boldsymbol{k_j}\, \frac{\boldsymbol{\Delta T}}{\boldsymbol{\Delta x_j}} \qquad \text{[W]} \qquad (1)$$

$\dot{Q}$ = Heat loss or heat flow rate

where $A_1 = d\,\pi\,h$ [m^2]

$A_2 = A_3 = d^2\,\pi/4$ [m^2]

$d = (d_o + d_i)/2$ [m]

$h = (h_o + h_i)/2$ [m]

---

[1] Note when the insulation thickness $\Delta x = r_o - r_i$ is small relative to the inside tank radius r_i, the numerator in the thermal resistance for a cylindrical wall, $R = \frac{\ln(r_o/r_i)}{2\,\pi\,k\,h_i}$, $\ln(r_o/r_i) \approx \frac{\Delta x}{(r_o+r_i)/2}$ (see also [1]). Substituting this latter approximation into Eq. (1) gives $\dot{Q}_1 = d\,\pi\,h_i\,k_1\,\frac{\Delta T}{\Delta x_1}$, where $d = (d_o + d_i)/2$.

$A_i = {d_i}^2\ \pi/4$ [m^2]

$h_i = Volume/A_i$ [m]

$h_o = h_i + \Delta x_2 + \Delta x_3$ [m]

$\Delta T = T_i - T_o$ [K]

In the above equation ΔT denotes the temperature difference between the inside tank water and the outside ambient air ($\Delta T = 55$ K for the standing tank heat loss of AS/NZS 4692.1:2005). Note in the above equation, the height h and diameter d are used for the heat loss from the tank in place of h_i and d_i to give some consideration also to corner losses.

For the above calculation the insulation thermal conductivity values shown in Table 1 should be assumed, unless the manufacturer can present thermal property data for the tank insulation material. Note air in a convectively stable state (e.g. air trapped inside a ring supporting the tank to the ground – see Appendix 1) may be treated as insulation with the thermal conductivity of still air (approximately 0.028 W/m.K at 47°C= (75+20)/2).

Insulation Material	Thermal conductivity [W/m.K]
Polyurethane	0.025
Fibreglass	0.040
Polystyrene	0.035

Table 1. Thermal conductivities of insulation materials for the tank heat loss calculation of step 1.

Step 2

In the first step it is assumed that the insulation completely covers the inner tank shell. However, an actual tank will have imperfections in the insulation (e.g. voids that have not completely been filled by the insulation) and the insulation may also contain thermal bridges between the inner tank shell and the outer casing (e.g. a stainless steel ring supporting the inner tank shell on the ground – see Appendix 1). The increase in heat loss through imperfections and thermal bridges shall be approximately considered with the below equation:

$$\dot{Q}_{step2} = 0.024 \times 1.3 \times \dot{Q}_{step1} \qquad \text{[kWh/day]} \qquad (2)$$

In the above equation the factor 0.024 (= 24/1000) provides the conversion of the heat loss rate from W to kWh/day, the factor 1.3 represents the assumed increase in the heat loss due to imperfections in the insulation and thermal bridges and $\dot{Q}_{step1}$ is the heat loss rate in W calculated from Eq. (1)

Step 3

In the third step the heat loss rate calculated from Eq. (2) is further corrected, by considering that the tank has several openings in the insulation (e.g. for pipe connections, valves, thermostats and electric elements). The openings in the insulation increase the tank heat loss, particularly when the openings include uninsulated inlet/outlet pipes or valves that act as pin fins.

An opening in the insulation may expose the inner tank shell directly to the ambient environment and heat losses in the order of 20 W/m^2.K may be incurred. For example, for a 0.005 m^2 opening and a 55 K temperature difference to ambient this means a heat loss in the order 0.005 x 20 x 55 = 5.5 W is incurred (or 0.132 kWh over a 24 h period). For an exposed pipe or valve that is connected through the opening to the inner tank shell, the heat loss will be higher than calculated above.

For the correction of the tank heat loss rate of step 2 the tank heat loss shall be increased for each opening and fitting according to Table 2. Note $A_{opening}$ in Table 2 denotes the area of the opening in the insulation in square metres, as it is for example required to house a thermostat. The heat loss increase for an opening shall apply even if the opening is covered on the outside.

The diameter d_{pipe} on the other hand, denotes the outer (uninsulated) pipe or fitting diameter in meters (e.g. for a 1" copper pipe the outer diameter of 0.0254 m).

The overall tank standing heat loss rate in kWh/day therefore is estimated as:

$$\dot{Q} = \dot{Q}_{step2} + \{\text{extra heat losses due to openings in the tank insulation and fittings}\} \tag{3}$$

where $\dot{Q}_{step2}$ is the heat loss in kWh/day calculated from Eq. (2) and the term in brackets is the sum of extra heat losses due to tank insulation openings and fittings calculated with the aid of Table 2.

Tank insulation opening	**Heat loss increase [kWh/24 h @ ΔT = 55 K]**
Tank opening (e.g. thermostat pocket)	$A_{opening} \times 27$
Uninsulated pipe or fitting (e.g. PTR valve)	$d_{pipe} \times 5$
Insulated pipe or fitting	$d_{pipe} \times 3.5$

Table 2. Tank heat loss increase in kWh/day per insulation opening of area $A_{opening}$ (m^2) or per connecting pipe or fitting of diameter d_{pipe} (m).

Application to tanks with domed ends

Tanks with domed ends (appendix 1) shall be analysed using equation (1) and the simplified tank (Figure 1) having the same inner tank diameter and total water volume as the actual tank. The average tank insulation thickness for the top and base of the simplified tank shall be calculated with Eq. (6) of Appendix 2.

3. Example

Consider a 1000 L tank of 800 mm inner diameter with 0.05m thick polyurethane insulation thickness for the cylinder, top and base ($\Delta x_1 = \Delta x_2 = \Delta x_3$). The tank has one exposed PTR valve of 35 mm diameter, three insulated 2" pipe connections of 50.8 mm diameter and one thermostat pocket requiring a 35 mm opening in the insulation.

With the inner tank shell height $h_i = 4\,Vol/{d_i}^2\,\pi = 4\,Vol/0.8^2\,\pi$ = 1.99 m, the tank mid insulation diameter $d = (d_o + d_i)/2 = (0.90 + 0.80)/2$ = 0.85 m and the tank height between insulation mid points $h = (h_o + h_i)/2 = (2.09 + 1.99)/2$ = 2.04 m, the approximate tank heat loss area is:

$$A = 2 \times d^2\pi/4 + d\,\pi\,h$$

$$= 2 \times 0.85^2\pi/4 + 0.85\,\pi\,2.04 = 1.135 + 5.447 = 6.58\,m^2$$

Using the above area in Eq. (1) and the thermal conductivity for polyurethane of 0.025 W/m.K from Table 1 then gives:

$$\dot{Q}_{step1} = A\,k\,\frac{\Delta T}{\Delta x} = 6.58 \times 0.025 \times \frac{55}{0.050} = 181\ \mathrm{W}$$

or 181 × 0.024 = 4.344 kWh per day at 55 K temperature difference to ambient.

Converting the rate of heat loss to kWh/day and correcting the heat loss for insulation imperfections and heat bridges using Eq. (2) yields:

$$\dot{Q}_{step2} = 0.024 \times 1.3 \times 181 = 5.647\ \text{kWh/day}$$

Finally also including extra heat losses through tank openings and fittings gives with Eq. (3) a standing heat loss rate:

$\dot{Q}$ =Tank wall loss + PTR valve loss + Pipe heat loss x number of pipes+ Thermostat pocket heat loss

$$\dot{Q} = 5.647 + 0.035 \times 5 + 0.0508 \times 3.5 \times 3 + \frac{0.035^2\,\pi}{4} \times 27$$

$$= 6.381\ \text{kWh/day}$$

at 55 K temperature difference to ambient.

4. Report

A report must be prepared in relation to each storage tank for which this document is used to determine heat loss. The report must set out:

- the calculations carried out in accordance with Section 2 for the storage tank, and
- a labelled and dimensioned drawing of the inner tank shell for the storage tank showing all openings to the tank insulation and the outer casing.

If the manufacturer uses thermal conductivities for an insulation material other than those shown in Table 1, these need to be supported by reference to insulation data sheets in the report.

5. References

[1] Spiegel, M. R. and Liu, J., Mathematical Handbook of Formulas and Tables, 1st term of Eq. 22.19 of Taylor series for ln(x), 2nd edition, McGraw Hill, 1999. Note using only the first term of Eq. 22.19 approximates ln(x) for 1 ≤ x ≤ 1.2 to an accuracy of better than 0.3%.

6. Appendix 1

Figure A1 shows a partial cross section view of a large hot water tank.

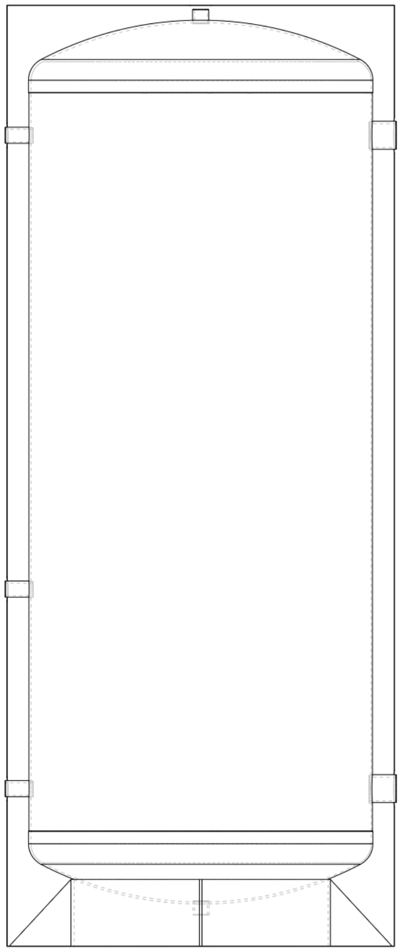

Figure A1. Large hot water tank resting on a ring that supports the tank on the ground. The inside of the supporting ring contains air, which substitutes for the insulation on the tank underside.

7. Appendix 2

This appendix provides a calculation of the area weighted average insulation thickness of above an ellipsoidal[2] tank dome (see Figure A2).

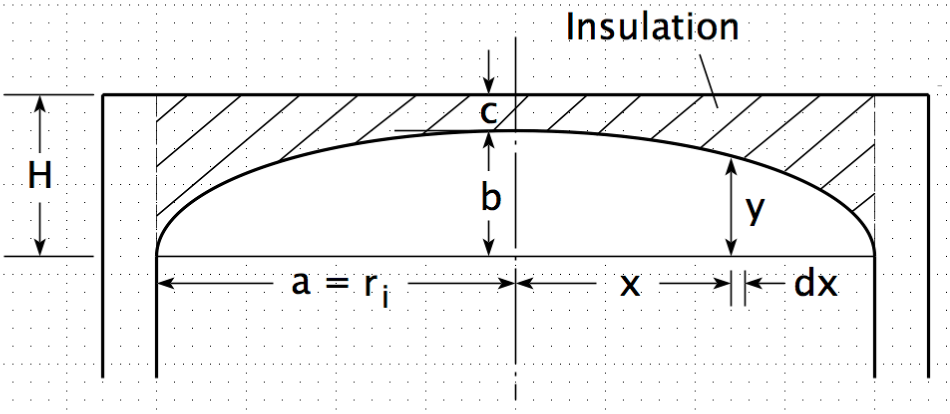

Figure A2. Schematic diagram of the top section of a hot water tank with an ellipsoidal dome, where a and b are one-half of the ellipse's major and minor axes respectively. The average insulation thickness above the tank dome can be determined by calculating the volume of the insulation above the dome and dividing the volume by the circular area below the dome.

The volume below the tank dome in Figure A2 can be expressed as:

$$Vol = \int_0^{r_i} y\, 2\,\pi\, x\, dx$$

Substituting $y = \frac{b}{a}\sqrt{a^2 - x^2}$, where a and b are the one-half of the ellipse's major and minor axes for the dome, then gives:

$$Vol = 2\,\pi\,\frac{b}{a}\int_0^{r_i} \sqrt{a^2 - x^2}\; x\, dx$$

with the substitution $u = a^2 - x^2$ and $du/dx = -2x$ the volume under the dome between 0 and $r_i = a$ then becomes:

$$Vol = -\frac{1}{3}\, 2\,\pi\,\frac{b}{a}\left[(a^2 - x^2)^{\frac{3}{2}}\right]_0^{r_i} = \frac{2}{3}\,\pi\, b\, a^2 \qquad (4)$$

[2] It is assumed that an elliptical dome also approximates other dome shapes such as a torispherical dome.

Now the volume of the insulation above the dome between 0 and $r_i = a$ can be obtained with $H = b + c$ by writing:

$$Vol_{insul} = H\,\pi\,a^2 - Vol = \left(\frac{1}{3}\,b + c\right)\pi\,a^2 \qquad (5)$$

and therefore the average insulation thickness above the tank dome between 0 and r_i is:

$$\Delta x_2 = \frac{Vol_{insul}}{\pi\,a^2} = \frac{1}{3}\,b + c \qquad (6)$$

A similar calculation of the average insulation thickness may be performed for the bottom dome. Note using the average dome insulation thickness Δx_2 and Δx_3 in Eq. (1) only provides an approximation for the dome heat transfer rate, as the rate of heat transfer in Fourier's law does not change linearly with Δx. However, the error involved in this approximation should be small, particularly when it is considered that typically around 80% of the tank heat loss is through the cylinder wall.