Technical Study on

Improving on Electric Water Heater Efficiency

for the
Australian Greenhouse Office

by

Energy Partners

in association with
Sustainable Solutions Pty Ltd
and
The University of New South Wales

Final Report

May 2000

Executive Summary

This report covers a project to analyse the heat retention performance and scope for improvement in small electric water heaters (ie, under 80 litres) sold in the Australian market. That analysis took five paths:

1. review of a dimensional study and its findings with regard to the ability of outwardly bigger tanks to service the replacement market (this path being not a part of the original brief from the AGO but agreed for inclusion at the project inauguration meeting);
2. survey of current practice and standards in selected comparable countries to establish Australia's relative standing and the scope for implementing improved standards in this country;
3. simulation of the heat loss paths in a tank selected as indicative of current Australian practice to establish their relative importance;
4. simulation and literature searches to establish the potential for performance enhancements of modest cost without an increase in the outer dimensions of the heaters; and
5. simulation and literature searches to establish the performance significance of the pipe connections ignored in the Australian Standard heat loss test and the levels of exposure to the elements (this path being not a part of the original brief from the AGO but agreed for inclusion at the project inauguration meeting).

Dimensional Study

The review of the dimensional study found it to be somewhat misleading due to conceptual errors in its execution. Recommendations were made as to how that may be improved. It is believed that modest increases in tank outer size will be both acceptable to the buying public and in their economic interest.

International Survey

The survey of practice elsewhere found that Australia is not well placed in its energy conservation practices in this particular field. We appear to be on a par with North American practice (but rather inferior to their professional body recommendations) and significantly inferior to the European Union and New Zealand. These exemplars suggest that cost effective improvement is feasible even after the impending change in Australia (already completed in Europe) to a less insulating blowing agent for the commonly used polyurethane foam. As this change does not affect the long term insulation value of the foam, just its value when new (and hence at the time of unit performance testing), this is seen as not being a significant issue in revising Australian performance standards for cost effective long term outcomes.

Heat Loss Paths

Simulation of heat loss paths for a new 50 L tank with current blowing agents revealed that 21.0% of heat loss in current practice results from thermal bridges comprising the anode access plug, inlet, outlet, T&P safety valve and element access panel when tested to AS 1056. The magnitude of the losses from the inlet, outlet and valve are significantly understated by this test which measures performance while disconnected from the tank's relevant pipework. The side walls were found to be the biggest heat loss path in current practice at 44.4% while the bottom at 19.1% and the top at 15.5% were the next most significant.

In the event that no design changes were implemented at the time that mandatory change of blowing agent for the insulating foam comes into effect, these values would

change to 17.1%, 50.8%, 17.2% and 14.9% respectively with an overall increase in heat loss of 20.7% under AS 1056 test conditions.

Potential Enhancements

A range of seven potential enhancements was simulated and/or researched. Those that were found to offer significant potential were: insulate anode access cover, insulate element access cover, insulate T&P valve (or make it from stainless steel), use PVC inlet and outlet connections (instead of brass), relocate the polyester compression wad at the top of the container to the rim where the insulation space is greater, change the outer casing to square in plan and reshape the container bottom like the container top (ie, both concave on the water side). In combination, these reduced standing losses by around 40% relative to our selected base case of 1.915 kWh/24h - current design filled with k=0.035 W/mK foam insulation (in lieu of k=0.024 W/mK as in new units now). Thus it can be seen that even with the change to lower performing foam it is feasible to achieve a heat loss rate of around 1.2 kWh/24h within the currently common outer casing dimensions. See Table 4 for details.

Significance of Pipe Connections

Pipes running up from the container were found to be the worst problem due to the potential for the water in the pipe to convect and increase the effective conductivity of the copper pipe. In this case, each 12.5 mm pipe connection added 20.6% relative to the heat losses of a disconnected tank. Horizontal pipes and those running down from the container (or incorporating a convection trap) add 14.8%. (Both values are increased if exposed to a breeze.) Thus, the worst case for an internally installed unit is for two up-running pipe connections and one down-running (dry) drain from the T&P valve making a total additional loss of around 55%. This situation is representative of the common past practice of installing under a suspended timber floor. Insulating those pipes (or substituting a PVC pipe in the case of the drain) reduces these additional heat losses to around half that. See Appendix 6 for details.

Conclusions and Recommendations

1. The data gathered for the dimensional study should be culled for unreliable values and re-analysed to establish the true importance of dimensional constraints in the replacement market for this size of water heater.
2. It is likely that the corrected dimensional study will confirm that modest increases in casing size can be accommodated in nearly all replacement situations and that the subsequent cost/benefit analysis will confirm that there is no economic reason for the Australian MEPS not emulating European practice or even the New Zealand exemplar.
3. The most cost effective performance enhancement is likely to be had from increases in the thickness of the insulation with the outer case growing a little in size.
4. The most effective improvements that are practical without increasing the dimensions at all are capable of reducing the standing losses to 1.2 kWh/24h even after the switch to the less insulating blowing agents for the polyurethane insulating foam. It should, however, be noted that the change of blowing agent will have a smaller impact on service life heat losses than it will on AS 1056 test results (on new tanks) as the agent migrates out over time to be replaced by air which is less insulating than the agent.
5. The savings to be had from improved installation practices and materials are of the same order of magnitude as those to be had from improving the heat loss performance of the tank itself. These should be the subject of a detailed study similar to this one and subsequent improvement to the installation codes.

Introduction

As part of the Commonwealth's response to the threat of climate change from the enhanced greenhouse effect resulting from the combustion of fossil fuels and other sources, the Australian Greenhouse Office (AGO) has taken up the prior proposals for implementing Minimum Energy Performance Standards (MEPS) for key energy consuming appliances in domestic and commercial use.

As high consumers of coal-fired electricity, electric storage water heaters have been recently improved by co-operation between government and industry to have standing losses reduced to 30% less than those scheduled in the relevant testing standard (AS 1056, 1991). This was implemented on the production lines on or before 1 October 1999 for all units 80 L and over but its implementation for smaller devices was deferred until an appreciation could be established of the impact of such a change on the ability of replacement units to be installed in "confined spaces".

This matter was tackled on two fronts. The first was a "dimensional study" conducted by others under a prior consultancy. The second was the subject of this consultancy to establish the practicality of improving current manufacturing outcomes to cost effectively reduce the standing losses of these smaller heaters without compromising the ongoing replacement needs of existing owners of architecturally "tight" installations.

Project Approach and Work Program

The originally proposed Work Program is set out below (including the optional development, construction and physical testing of prototypes which was not taken up in the acceptance of the proposal).

Week	**Activity or Milestone**
1	Sign contract and initiate project.
2	Commence research of foreign precedents
3	Meet with AGO and Steering Committee
4	Expert brainstorm-workshop to generate and initially cull ideas to be evaluated
5	Commence detailed simulation of conceptual prototypes
6	Detailed simulation of conceptual prototypes
7	Detailed simulation of conceptual prototypes and Interim Report
8	Detailed simulation of conceptual prototypes
9	Detailed simulation of conceptual prototypes
10	Interim Report with cost estimates
11	Commence to fabricate up to 3 prototypes (optional)
15	Test prototypes (optional)
17	Draft Final Report
19	Comment from AGO and Steering Committee
21	Deliver Final Report

By the time of the first meeting with the Steering Committee, however, the results of the Dimensional Study were available and provided to the project team by the AGO (Hood, 1999). A brief critique of that study was offered to that meeting pointing out that its conclusions were essentially misleading due to the excessive margin in insulation thickness assumed as its basis. Accordingly the Steering Committee agreed to some time in this consultancy being diverted to inferring useful data from the survey data. This work is included in this report under the heading *Review of Dimensional Study* (below).

Research of Foreign Precedents

Technologically advanced nations were surveyed for a status report on commercially available efficiencies and the techniques used to attain them to ensure that no proven technique was overlooked. This research was undertaken primarily by a literature search focussed on the OECD-IEA's CADDET[1] network which covers commercially available technologies well but does not have an explicit brief to cover R&D and new products in the pipeline. CADDET Australia provides this sort of service through the CADDET Register and by direct access to their equivalents in other member countries.

The results of this research were very encouraging and are set out in detail in Appendix 1. They can be summarised as follows:

Canada

Canadian practice seems to equate roughly with Australian standards with a lower permitted heat loss but measured at a lower standard hot water temperature. Our contacts advised that the country is in the throes of changing to the United States' Energy Factor method of comparison to eliminate the implied trade barrier in having differing testing standards (see below).

European Union

The European Union has widely varying practices but is moving toward uniformity (SAVE, 1998). Its heat loss test is similar to the AS 1056 but is done with a temperature difference of only 45 K and the container volume is used as the basis of tank size definition rather than rated delivery. On that basis, the range of EU models of a 50 L container capacity has an average performance of 0.880 kWh/24h (called a 'base case' in the report and not to be directly compared with Australian tanks of 50 L rated delivery) and an optimal tank insulation thickness of 6.4 to 9.3 cm (based on EU average electricity costs but depending on tank size and tariff). Actual models vary considerably from this norm and, for example, several German manufacturers offer models with heat losses 33% lower than their mandatory maximum (Ramm, 2000).

The pivotal report on this subject (SAVE, 1998) discusses cost structures, practices and economics and recommends an energy policy mix based on two main strategies:

- Set a minimum energy efficiency standard; and
- Introduce a labelling scheme (subsequently timetabled (Ramm, 2000)).

---

[1] CADDET is the Centre for the Analysis and Dissemination of Demonstrated Energy Technologies.

New Zealand

At first sight, the New Zealand standard seems far more rigorous than its Australian equivalent (ie, it sets much lower maximum standing heat loss rates) but some industry members contend that there is little practical difference between them. To resolve that issue, the AGO has commissioned a testing laboratory to carry out NZS and AS standard heat loss tests on a small selection of Australian small water heaters under the guidance of Energy Efficient Strategies to make reliable empirical comparisons (EES, 2000). As well as recommending several changes to those testing standards (to improve them and/or harmonise them), the draft report concludes that the two tests reach broadly the same numerical results.

Hence it can be confirmed that the New Zealand Standard requires achievement of better than half the standing losses permitted in Australia. Contact with a couple of New Zealand firms has indicated that this is routinely achieved with tank wall insulation thicknesses double those used in current Australian practice.

United States of America

Recent moves to provide a minimum performance standard for small water heaters (under 20 US gallons) have lapsed in the USA but ASHRAE (1999) still has its advisory value for electric water heaters not larger than 12 kW of an Energy Factor minimum of

$$0.93 - 0.005V \text{ (V = volume in litres)}$$

as an indicator of sound practice. The Energy Factor is an efficiency measure under standard service conditions of temperature, connection and draw off patterns over a 24 hour period. It is beyond the scope of this consultancy to make a comparison between the standing loss requirements of the rest of the world and the more holistic testing regime used in the Americas (which apparently has the advantage of ready comparison between electric and fuelled water heaters). From evidence cited in the DOE Final Ruling on small water heaters, however, it is apparent that the ASHRAE “standard” roughly equates to recent practice in the European Union.

Comparisons

Direct comparisons of permitted heat losses for water heaters is complicated by the variety of testing standards and definitions of container size. The latter is commonly denominated by the container volume which is typically 10% greater than the rated delivery as measured under Australian test standards. Foreign tank sizes have accordingly been selected for ease of comparison rather than their market significance in the country concerned.

Apparently, Australia is not well placed in its energy conservation practices in this particular field. We appear to be on a par with North American practice (but rather inferior to their professional body recommendations) and significantly inferior to the European Union and New Zealand. Table 1 sets out the comparison for equivalent models in the countries concerned.

Table 1 Indicative Heat Loss Standards for Key Nations Compared

Country	Nominal Size (L)	Temp. Diff. (K)	Target Losses (kWh/24h)	Status
Australia	50	55	1.900	mandatory; considering 30% reduction, includes an allowance of 0.2 kWh/24h for the T&P valve
Canada	55	45	1.728	mandatory in some provinces, moving to Energy Factor rating to conform with USA practice
European Union	55	45	0.938	average of units sold recently
New Zealand	55	55.6	0.862	mandatory
USA (1980) USA (proposed)	55 55	44.4 38.9	1.032 1.085	ASHRAE recommendation is $5.9 + 5.3\sqrt{V}$ watts for units over 12 kW; smaller units target an Energy Factor of $\geq 0.93 - 0.005V$ (volume in litres)

Review of Dimensional Study

As originally conceived, this review lies outside the scope of this consultancy. However, it critically affects its brief as the effort directed at defining alternatives to increasing insulation thickness (increasing the outer dimensions of the containers) is dependent on the established difficulty and cost of installing improved tanks in “confined spaces”.

The dimensional study had not been completed at the time of the issue of the Request For Tender for this consultancy but, as its findings were a key determinant of the importance of limiting the outer dimensions that would emerge from the application of any MEPS in this size range, it was cited as a key input to its work.

No published report has emerged from that project but the AGO provided a copy of the PowerPoint presentation that encapsulates its findings (Hood, 1999). The project Working Group, later, in response to a request from the project team, agreed to make the data available to this project for the purpose of relating heat loss improvements by the addition of extra insulation thickness with the fraction of households affected. Accordingly, AGO also provided the “raw data” of the full collection of plumbers’ reporting forms and subsequently to that a member of the team contacted the consultants (TNS) for several clarifications and access to the electronic forms of the raw data and are pleased to record the co-operation that was forthcoming. Our critique of the project follows.

Overall, the outcomes of the project are of limited usefulness, because of methodological problems. The market research that was carried out appears to have been misled by the nomination of 80 mm as the increment in insulation thickness to be considered. To put this in perspective, a common insulation thickness of these units at the time was only 12 mm and the Rheem 50 L model recently upgraded to meet the heat loss target set in AS 1056 has only 25 mm of insulation. Thus, a 25 mm increase in casing dimensions has reduced actual heat loss by approximately 25%. The selection of an insulation thickness increment of more than three times that required to achieve the targeted 30% reduction in standing losses seems curious although the increase may have been based on an aim of achieving the NZ Standard, which is much tougher than any proposed Australian MEPS. See Appendix 1 for details.

Based on the survey results, TNS calculated that in 31% of cases the significantly oversized units would not fit into the space available to the tank being replaced and that, of those 31%, the median values for the cost of modification or relocation was $350.

TNS also calculated median values for the clearances above, below and beside the water heaters (for each of the five mainland state capitals) which were not conducive of any conclusion as the three dimensions were not related to the rated delivery of the units and were disconnected in themselves. For example, the two cases of median values of zero clearance below the heaters simply meant that more than half of them were sitting on the floor of the room or cupboard and gave no clue as to the coincident clearance above, nor whether the HWS was located on the floor of a cupboard, or at the room floor level, information which is required to determine if <u>any</u> of the cases is a problem fit.

The survey results were also skewed by mis-definition of the term “sides”. The plumbers were asked to “measure the available space … at the sides of the heater” (as well as above and below, but, curiously, not in front and behind). The plumbers in NSW and Victoria are said by TNS to have interpreted this as the lesser clearance of the two sides, thereby rendering their side measurement data useless. Those in the other three states are said to have interpreted it as the average of the two clearances, potentially understating the available clearance by a factor of two (TNS initially advised that they interpreted the answers the plumbers gave as the sum of the two side clearances but this does not gel with a cursory inspection of the “will/will not fit” data provided later by TNS). The unreliability of the resulting conclusions is obvious.

It is apparent to us that, with the co-operation of TNS, a useful conclusion may be derived from this survey’s raw data but it is also apparent that it will require further work beyond the scope of this consultancy in addition to what is described above.

It is also apparent that those results bear significantly on the purposefulness of the original brief for this consultancy. Despite that, most of the work has proceeded in parallel with this review and its results are set out below.

Proposed Further Work

In order to reach reliable conclusions from this market survey, the following additional work is recommended.

1. Access the raw data in full in electronic form with every individual installation identified with its location, rated delivery and top, bottom and side clearances as recorded by the plumbers and whether they saw the much bigger unit as being able to fit (and the modification cost where it would not).
2. Check each entry for sense – ie, that the fit/not fit decision is consistent with the recorded dimensions.
3. Confirm the meaning of side clearance with each of the inspecting plumbers.
4. Confirm with each of the inspecting plumbers that the front-to-back clearance was never a constraint or, if this is not the case, the extent to which it is a constraint and the extent to which such cases coincide with side or vertical constraints. It may not be possible to obtain a reliable answer from the plumbers’ memories and hence costly reinspection may be required.

5. Eliminate all records that are not reliable (this could require the elimination of all Victoria and NSW records).
6. With all unreliable data sets eliminated, sort the data into sets of will-just-fit specimens in increments of 10 mm in width, depth and height simultaneously to establish the fraction of the sample that will be rendered unworkable by each increment of 5 mm in insulation thickness.
7. Analyse the same data for width, depth and height separately to establish which dimensions are most constraining - to allow manufacturers to design improved tanks in proportions to maximise their utility in the replacement market.

Ideas to be Evaluated

A wide range of potential techniques for efficiency enhancement were considered in the light of our literature search of foreign practices and our parametric analysis (see *Principal Simulation Technique* below) of the standing loss components of a popular 50 litre model: The recently released Rheem 50 L tank which meets the current performance targets set by AS 1056 was chosen as this “base case” due to its high market penetration and the willingness of its manufacturer to provide the level of detail required for this study.

1. Modified pressure vessel
2. New insulation materials
3. Reduce the size of the inner vessel
4. Reduce the thermal bridging
5. Added flexible insulation
6. Reduced storage temperature
7. Phase change material
8. Combinations of the above

The following results were obtained:

1. **Modified pressure vessel**
Modify the shape of the pressure vessel to obtain better insulation coverage within a constrained outer casing.

No foreign precedents for such a technique were found. The performance improvement available from just making the container more squat (reducing its surface area with volume unchanged) was evaluated by a parametric analysis of the 50 L system in which only the tank dimensions were changed. This approach effectively considered the possibility that the dimensional constraint was real but applied to the casing height only. This technique increased standing losses to 2.309 kWh/24h – a detriment of 13.6%. Apparently this was because in the base case the top and bottom insulation is significantly inferior to the tank wall insulation so that the increase in the poorly insulated areas (the top and the bottom) outweighed the benefit of a lower surface area overall. A modest improvement in standing losses would be expected if the tank insulation were equal to that around the cylinder walls but, even so, the market significance of this technique is highly dependent on the relative importance of the height constraint to that of the diameter constraint. The detailed results are set out in Appendix 6.

The estimated costs of a dual manufacturing change (improve the top and bottom detail and change the height-to-diameter ratio) to achieve a performance advantage were seen as unlikely to be warranted in light of the large improvement available from very modest increases to the thickness of the tank wall insulation without changing the tank shape and with only slight increase to the outer casing diameter.

To consider the possibility that the dimensional constraint was real but applied to the diameter only, a separate analysis was undertaken to evaluate making the container 20 mm narrower within the same outer casing diameter, increasing the insulation thickness by 10 mm. This required the container to be 65 mm taller and the outer casing 85 mm taller if the added insulation thickness was to be applied to the top and bottom as well. This reduced the standard test losses to 1.377 kWh/24h – a saving of 32.2% relative to the base case.

Taking the dimensional constraint as being a rectilinear one impinging on a cylindrical tank, the value in adding extra insulation at the corners of a rectangular outer casing was evaluated and its results included in Appendix 6. Discussion of this approach is included in item 5 *Added flexible insulation* (below) as the geometry of the insulation in the extreme compressed case is essentially the same.

Using an unpressurised thermal store with a heat exchange coil is a radically different approach to this strategy suggested by Ramm (2000). The low pressure in the stored water allows the container to be rectilinear with a much thicker insulation layer. It could never however have a rated delivery more than about 25% of the store's volume and so is impractical in this context.

2. **New insulation materials**
   Apply new cost-competitive insulation materials like the Gas-Filled Panels (GFPs) developed in the USA for appliance insulation (see attached paper by Griffith et al 1995). A GFP uses reflective polymer films and low-conductivity gas to create a very thin, space-saving, flexible insulation panel with high thermal resistance.

Despite their significant potential in applications like this, contact with the developers of this material revealed no commercial development of the concept over the past four years (Griffith, 2000). Since it is most unlikely that such a technological change could be cost effective in this context without having achieved prior mass production in some simpler or larger scale application, no further analysis was undertaken. For illustration purposes, however, the laboratory performance values for such systems is set out in Table 2.

Insulating Material and Gas Fill	**U-value**
	Effective conductivity per 25mm (W/m.K)
Vacuum panels (Glass fibre filled)	0.002 (effectively independent of thickness)
GFP Xenon	0.0074
GFP Krypton	0.0116
GFP Argon	0.0199
GFP Air	0.0281
Polyurethane foam (Australian)	0.7143
Polyurethane foam (European)	1.0417
Polystyrene foam (extruded)	1.1600
Fibreglass	1.4440
Polyester fibre (Tontine)	2.4000 (compressed, as advised by Rheem)

Table 2 - Centre of panel thermal performance of key insulation materials.

It is worth noting that the proponents of this material are actively seeking venture capital to develop the concept into a mass manufactured product and would welcome an approach from any Australian water heater manufacturer(s) interested to pursue this option.

A further literature search for high performance insulations found vacuum panels (effectively a Dewar flask but produced in the flat for glazing and refrigerator applications). While unlikely to offer the robustness and low cost required for the plumbing industry, the insulating value of such systems is included here for completeness.

Several common industrial insulation materials are included in Table 2 along with their published working values (ASHRAE, 1997).

3. **Reduce the size of the inner vessel**
Reduce the size of the inner vessel and increase its operating temperature with a mixing valve near the outlet (required by law in new dwellings now) as a means of increasing insulation thickness within a constrained outer casing.

A potential technique for the efficiency enhancement of a small water heater (in theory) is to increase tank insulation while keeping outside dimensions constant. For this to be effective, the water temperature must be raised in order to supply the same volume of hot water as would the physically larger water heater at a lower temperature. While this may have presented a serious safety hazard in the past, domestic hot water installations are now required to incorporate a fail safe mixing valve to limit the supply temperature to hand basins, baths and showers to 55°C so that the higher temperature water will only go to kitchen and laundry outlets where it may be of practical use.

Accordingly, the effect of reducing container volume and increasing the storage temperature was analysed for its net energy efficiency balance

Figures 1 and 2 show the impact of reducing the container volume for a fixed internal energy, relative to a Rheem 50 L tank operating at 65°C. These results indicate that reducing the container volume to 40 L while maintaining the external casing size will reduce losses by 27%. This assumes that losses through pipe fittings, T&P valve, anode and element access panel do not change. To maintain the same tank energy the tank temperature would have to be increased to 76°C.

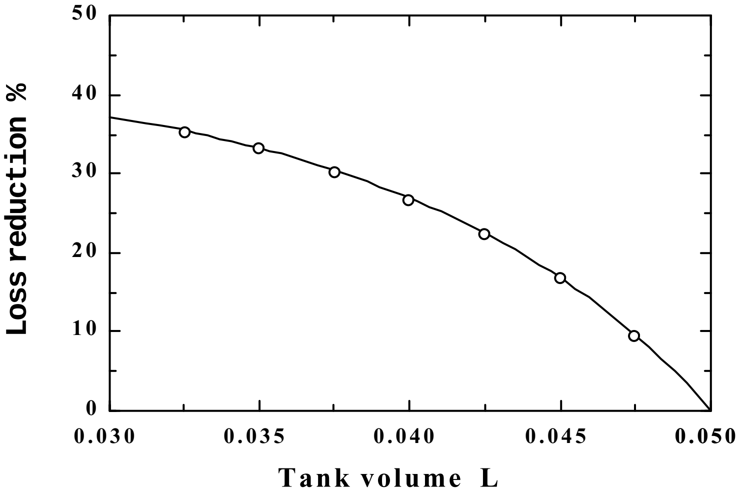


Figure 1. Reduction of tank heat loss for fixed tank energy and reduced container volume.

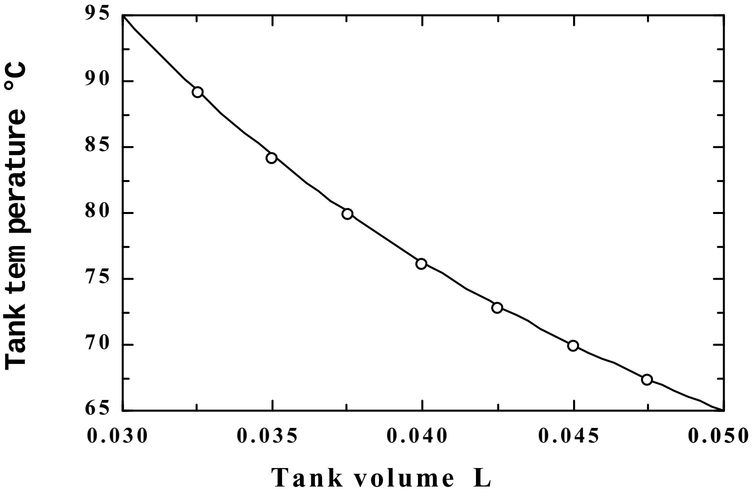


Figure 2. Tank temperature required to maintain constant tank energy as container volume is reduced.

The European experience with this technique, however, is a negative one - concluding that, *"the result of this variation is to increase life-cycle energy losses"* (SAVE, 1998).

That report states, *"The higher water temperature would lead to higher standing losses, but the thicker insulation compensates for this effect to some extent. When additional distribution losses* (ie, pipe losses and "dead-legs")*, the increase in calcification and heat conductivity of the foam and the reduction in the life-span of the domestic electric storage water heater are considered, the total effect is to increase energy losses."* (pages 37–38)

Apparently, in their case, the added distribution losses weigh heavily on the energy outcome. This negative effect can be eliminated by fitting the mixing valve at the container outlet so that the net energy saving is retained in full but that does not avoid the problem of reduced container life. In approximate terms, an increase of 10°C in operating temperature doubles the rate at which vitreous enamel linings dissolve into the water – indicating that a doubling of coating thickness would be required to retain current life expectancies. Given the much higher calcium and chloride contents of Australian reticulated water supplies than their European counterparts and their destructive impact on container life (Rheem, 1998), it may be counterproductive to pursue this theoretical option any further. Although solar systems have been and still are often built to accommodate such high temperatures, using copper or polymer lining of mild steel containers (eg, Coppermatic or Rilsan) or using stainless steel containers, the cost of such a change may exceed the projected benefits in this context. Hence, the effect on the life expectancy or cost of the container of the hotter water may be too detrimental for such an approach to be broadly cost effective in Australia.

Specific analysis of the case of reducing the container size without changing the storage water temperature is dealt with under item 7 *Phase change material* (below).

4. **Reduce the thermal bridging**
   Modify the immediate external plumbing to reduce the thermal bridging by these elements (e.g., by using longer pipes of low-conductivity material encapsulated in locally thickened insulation) while retaining the plumbing layout to suit the replacement market.

Although thermal bridging plays a very minor role in heat losses under AS 1056 standard test conditions, literature search and THERM simulation was used to explore their significance in real applications where the attached pipes, often unlagged, exacerbate the loss rate from those points. The results of this work are set out in Appendix 6 while a discussion of the simulation work itself is set out in the section on modelling (*Principal Simulation Technique*, below).

The points of thermal bridging are itemised in Appendix 5 as the anode, pipe fittings - inlet, pipe fittings - outlet, T&P valve[2] and the element access panel. Together they sum to 21% of the losses in the case of a new Australian tank (foam k=0.024 W/mK) but only 17.2% of the aged Australian tank or a new European tank (foam k=0.035 W/mK, as in Appendix 6). These are the values under AS 1056 testing where the connection point itself is protected by a temporary insulating cover. Actual installed bridging losses are far greater with the "extreme" case being an external but wind-protected installation with both the inlet and outlet pipes being unlagged and running up from the container (as might occur, say, in a subfloor installation) so that convection can occur in the water in the pipe for added wick effect. Here the additional heat loss is about 0.44 kWh/24h for each of the two wet pipes plus about another 0.32 kWh/24h for the drain on the T&P valve making additional losses of around 1.20 kWh/24h. This represents an increase in losses of 63% without allowing for the detrimental effect of wind induced losses.

Modest reductions in these losses can be effected by the use of materials less conductive than brass for the connections themselves (eg, 0.4% saving from stainless steel and 1.3% saving from PVC). The big savings are however to come from lagging the pipe for, say, 1.25 m from the tank and/or using alternative piping materials (eg, the lagging of the outlet pipe in the "extreme" case above would reduce the loss from 0.44 to 0.17 kWh/24h).

It is worth noting that these added losses in the case of the inlet pipe are indicative of performance only under low draw conditions (the standard test is for a 24 hour period with no draw off). With frequent use, the bottom of the container (where the inlet is connected) will often be cold, dramatically reducing the actual losses from this path in real life. Some practical use of this fact to reduce actual in service losses was noted in the European practice, as described, of fitting what they call "mural" units (ie, they are mounted on the wall above the sink or basin) with both the inlet and outlet pipes penetrating the container and insulation at the bottom – but with an internal extension tube to the outlet to ensure that the hottest water is drawn from the top of the container.

While it would be feasible to radically reduce these pipe bridging losses by including a loop of pipe within the thickness of the insulation, this would only be practical in the case of the added thickness available in the square outer casing design unless insulation thicknesses were to significantly increase overall. This possibility should, however, be considered in the work by others to evaluate the energy saving impact of improvements to

---

[2] European practice in container safety obviates the need for the T&P valve in the hot zone (Ramm, 2000) and the New Zealand practice of routinely lagging it both offer significant scope for reduction in standing losses from this bridging point. Similarly, avoiding expansion to waste of hot water would reduce energy demand although that saving will not show up in the AS 1056 testing regime.

the plumbing code and/or regulations to require lagging of connecting pipes. Factory incorporation of such protection in the body of the tank casing will inevitably be more reliable and long lasting and may ultimately be more cost effective than the addition of on site lagging of bare pipes.

The other two areas of thermal bridging are unaffected by pipe connections and are hence simpler to analyse. The anode access plug and the element (and thermostat) access panel account for losses of 18 and 204 Wh/24h respectively. The addition of only 6.4 mm of insulation to these would save around 10 and 66 Wh/24h respectively for a saving of around 3.7% relative to the base case. More radically, in the case of the element cover, a halving of the opening in the wall insulation could be achieved by changing to an internal (immersed) thermostat sensor and the remaining 100 Wh/24h losses further reduced by the addition of modest insulation as described above. Additionally, corset connection of the casing with the container may be an issue with some designs and needs to be evaluated in individual cases.

It is also reasonable to consider the area of polyester fibre insulation at the top of the typical tank as a thermal bridge due to it being more than twice as conductive as the foam insulating the rest of the tank. This area accounts for 157 Wh/24h or around 7.7% of the AS 1056 heat loss. This could be better than halved by substituting foam for the polyester. To provide the capacity to be compressed by the expanding foam to accommodate filling tolerances during manufacture, the same amount of polyester could be included as an annulus in the top rim where the container shape ensures more than double the average insulation thickness and as a result the performance is very insensitive to the reduced insulating value of, say, a quarter of its thickness.

Similarly, the bottom rim can be considered a thermal bridge due to the taking of the container wall very close to the base of the enclosure. Following the New Zealand practice of having the base of the container concave to the water (ie, similar to the top detail) would save 2.3% even if the revised base was no better than the current top detail. If the base was improved to match the enhanced top performance estimated above, that saving would be over 6%. Here however is a case where the AS 1056 test may overstate the significance of a bridging loss as it takes no account of the (sometimes considerable) duration when, under active use, the water at the bottom of the tank is significantly cooler than the thermostat setting would suggest.

It is worth noting too that this configuration allows the element to be located lower such that a smaller volume of container is required to attain a given rated delivery. This factor could be used to advantage by devoting the spare volume to provide added insulation within the current casing dimensions. A similar potential benefit is also available from inlet flow control and stratification control vanes and increased thermostat sensitivity (Ramm, 2000).

5. **Added flexible insulation**
   Added flexible insulation that can be compressed where there are space constraints (model effect of partial compression).

No foreign precedents for such a technique were found in manufacture of tanks. However, at least one New Zealand firm manufactures "tea cosy" style added flexible insulation for sale to the after-market (Pilon, 1999) and such enhancements have been marketed in Australia in the past. Given that this technique requires a change of outer casing material (to, say, a flexible plastic film suitable for external installation) and to the insulation material itself (from the rigid foam now common to a fibrous or flexible celled foam) it is unlikely to be cost effective as a way of increasing insulation thicknesses while allowing installation in a space too small for the uncompressed outer casing. Despite that, the following analysis has been carried out to evaluate the idea in principle.

Data on the thermal performance of compressed foam materials is not readily available but has been estimated for the purposes of this analysis for the example of cross-linked closed-cell polyolefin foam as follows:

Compression	**Nil**	**25%**	**50%**
Conductivity	0.032 W/mK	0.035 W/mK	0.041 W/mK
Conductance (ex-100 mm)	0.320 W/mK	0.467 W/mK	0.820 W/mK
Conductance (ex-50 mm)	0.640 W/mK	0.934 W/mK	1.640 W/mK

Table 3 - Performance Of Compressed Polyolefin Foam

This estimate (Pilon, 1999) is broadly consistent with figures published (ASHRAE, 1997) for polyurethane (presumed rigid cell) and glass fibre insulations of varying densities but not necessarily varying by the compression of a lighter manufactured version of the same material. Using our indicative figure of 1.0 kWh/24h for the side walls of a 50 L tank with 25 mm of foam insulation of similar conductivity we can estimate the effectiveness of increasing its thickness to 50 mm but compressing it on two sides to 50% (ie, to 25 mm thickness). In this example, we would achieve a halving of heat loss over about 70% of the outer casing area saving 0.35 kWh/24h, a reduction of about 0.05 kWh/24h over another 20% and an increase of about 0.03 kWh/24h over the remaining 10% giving an overall estimated reduction of 0.0.37 kWh/24h. This is 37% of the vertical wall heat losses or 22% of AS 1056 standard value for the 50 L size even without allowing for a reduction in losses at the top and bottom rims.

To further evaluate the theoretical merit of a "thick flexible wall" technique, the performance improvement available from just making the tank casing square in plan (increasing its outer surface area and average thermal resistance but with the container volume unchanged) was evaluated by a parametric analysis of the 50 L system. This will approximate to the extreme case of increasing the wall insulation thickness by 200 mm and then constraining it on all four sides to not exceed the rectangular dimensions of current models. The change achieved an improvement in the side wall heat loss coefficient from 1.287 W/m^{2}K for 25 mm thick foam to 1.0155 W/m^{2}K for the square version – a reduction of 21%. With the additional benefit if improved performance at the top and bottom rims we obtained an AS 1056 heat loss reduction of 0.357 kWh/d or 18.7% of the standard base case of a conforming 50 L system. Using a cost of polyurethane of \$0.75 per litre of foam and a cost of prepainted galvanised steel of \$10.00/m^2 this would give an added materials cost of just over \$16 per tank (19.1 L of foam for \$14.35 and 0.187m^2 of sheet steel for \$1.87).

6. Reduced storage temperature

Reduced storage temperature and added instantaneous electric boost to the outlet to bring the supply up to the required temperature.

No foreign precedents for such a product were found but the technique is occasionally used in Europe by combining a storage and instantaneous water heater in series (Ramm, 2000). The performance improvement available from reducing the water temperature by 20 K was evaluated by a parametric analysis of the 50 L system. Under AS 1056 test conditions, this reduces the water:air temperature difference from 55°C to 35°C giving a heat loss saving of approximately 35%. In practice, such a technique would give a greater saving as it would reduce the tank temperature from 60°C (a common setting) to 40°C and this reduces the water:air temperature difference from 40°C to 20°C giving a heat loss saving of approximately 50%.

Tanks of rated delivery in the range 25 L to 125 L are required to deliver at the rate of 9 to 10 litres per minute (AS 1056, 1991).[3] To raise the temperature of that delivered water by 20 K as it exits would take a power input of 837 kJ/minute or 13.95 kW. This is not manageable for a domestic connection even if the main element is controlled to not energise at the same time as the after-heater. For units with a 15 Amp (3.6 kW) connection, a boost of 5 K is possible. For units with the standard 10 Amp connection (elements of 2.4 kW or less) the achievable temperature rise is only about 3.5°C. This represents a saving of only 12.5% and 8.8% respectively in the practical case, and even less in the standard test case.

An alternative but technically similar approach is to not reduce the temperature of the stored water but reduce its volume instead with the after-heater acting to lift the system's rated delivery relative to the container volume. The potential savings of around 25% are discussed in section 3 above.

Even in the uncommon situation where adequate power is available to support a 20 K boost at the outlet, the theoretical merits of this approach are overshadowed somewhat by the practical and economic limits of its application. Firstly, the device must be failsafe as the energising of the element in excess of the power appropriate for the water flow rate will result in a slug or even a continuous flow of dangerously hot water to emerge from the tap – potentially as flash steam[4]. Secondly, the power of the device must modulate reliably with the water flow rate and in practice that will mean the control will be in response to the water temperature immediately downstream from the device – while this is not a big technical problem, reliable versions of such controls are prohibitively expensive for this context. Thirdly, storing water at 40°C promotes bacterial growth (eg, Legionella) which can be a health hazard - so the after-heater would need to be reliably bactericidal (eg, by holding the water hot enough long enough). The combined result of these problems is to effectively preclude this approach despite its very promising theoretical potential.

---

[3] This is a demanding requirement. At the standard test temperature of 75°C this would deliver hot water mixed to shower temperature of around 25 L/minute. See Appendix 2 for comment.

[4] This is a lesser safety hazard in new homes than in the past as domestic hot water installations are now required to incorporate a fail safe mixing valve to limit the supply temperature to hand basins, baths and showers to 55°C. Consequently, the dangerously hotter water will only go to kitchen and laundry outlets – presumed to be away from children but still presenting an unacceptable hazard to adults.

7. **Phase change material**
Addition of modules of phase change material to allow the volume of water stored to be reduced while maintaining stored heat capacity.

No foreign precedents for such a technique were found. The performance improvement available from reducing the water volume by, say, 10 L and increasing the tank insulation foam by the same amount (about an extra 10 mm over a surface area of about 1 m^2) was evaluated by a parametric analysis. Detailed results are set out in Appendix 6. The improvement was found to be about 24% making the concept theoretically worth pursuing.

The physical change to the tank design is the same as described under item 3 *Reduce the size of the inner vessel* (above). In this case, however, the total stored heat is retained at the rated level not by lifting the temperature of the stored water but by the incorporation of some encapsulated phase change material (PCM) which has an energy storage capacity significantly greater than the water it displaces (Lane, 1983). The concept is well known in the literature of energy research (Garzoli, 1999) but no working examples exist in commercial production. This was confirmed by two Australian companies active in the field who offer PCM's with appropriate melting temperatures.

Dussek Campbell imports a paraffin wax 150/155 (referring to its melt temperature in °F, it melts at 66.1°C and is presumably an impure form of triacontane) from Nippon Seiro Co. Ltd. of Japan.

In 1995, Thermal Energy Group built and tested a 250 L horizontal water heater tank with three concentric annular cylinders of 40 mm thickness filled with sodium acetate trihydrate ($NaCH_3COO.3H_2O$) which they give the trade name TH58 due to its melt temperature of 58°C (Trinh, 1999). The 150 kg of this inorganic hydrated salt displaced about 100 L of water and stores about 34 MJ of heat (latent heat of fusion 226 kJ/kg) theoretically able to heat 200 L of water by 40 K. Over the longer term draw off test of AS 2984 which spaces the daily load over an eleven hour period it was able to deliver about 250 L (some of it heated less than 40 K) in addition to the 155 L of water in the container. Clearly, a large surface area per kg of PCM is required for the sort of recovery rate required for small tanks.

Considering the TH58, about 7.5 kg of the material is required to substitute for 10 L of water (ie, 1675 kJ for a temperature rise of 40 K) and at 1.28 kg/L in the liquid state that material will displace 5.86 L of water and only 5.18 L when solidified (ie, exhausted of its heat of fusion it occupies 11.6% less volume than when fully charged). Hence about 15 kg is required to reduce the container volume by 10 L to achieve the increase of insulation wall thickness of 10 mm on all surfaces. In this case, the material will expand from around 10.4 L when exhausted to 11.6 L fully melted – displacing 1.2 L of heated water in the process. This represents an energy dissipation of around 200 kJ per charge/discharge cycle as in most jurisdictions, such expansion is not permitted to be accommodated by displacement of cold water back to the town supply.

To give the sort of effect needed to substitute for water volume in such a small tank, the PCM must deliver most of its heat to the first 10 L of make-up water as it enters – ie, in the space of one minute or at a rate of around 14 kW. At a surface thermal film coefficient of 80 W/m^2K on the water side and an average temperature difference of 20 K (ie, 1.6 kW/m^2), this will require a surface area of over 8.75 m^2 which is impractically large even without considering the thermal coefficient on the side of the solidifying PCM which is expected to be significantly lower despite its thickness of only about 1.1 mm.

Hence, although PCM's may be a practical way of extending the storage capability of tanks whose draw down and recovery cycles are spread over many hours (like solar and off peak water heaters) they appear to offer no practical advantage in adding to the thermal efficiency of small electric systems.

8. Combinations of the above.

Several of the above possibilities could be used in combination with the potential savings under AS 1056 test conditions set out in Table 4 below. Additionally, increasing the operating temperature and reducing the container size to allow a greater insulation thickness while fitting a mixing valve at the outlet offers an effective but more expensive method of achieving lower standing losses (efficiency improvement) in the order of 25%.

Possible Modification	Loss, Wh/24h	Saving, Wh/24h	%
Insulate anode access cover	18.0	10	0.5%
Insulate element access cover	203.9	66	3.3%
Insulate T&P valve (or make from SS)*	132.2	42	2.2%
PVC inlet and outlet connections*	75.4	48	2.5%
Relocate polyester compression wad	152.7	80	4.1%
Change outer casing to square in plan	968.0	357	17.4%
Reshape tank bottom like tank top	482.7	180	9.4%
Total		**783**	**39.4%**

Table 4 – Combined Savings Under AS 1056 Heat Loss Test from Potential Improvements within the Dimensional Constraint
(* actual losses/savings are greater when connected to conductive pipes)

Principal Simulation Technique

Computer modelling was used as the method to test the various hypotheses to reduce the energy losses from the hot water heater system.

The computer modelling was used to replicate the test process described in AS 1056.1 (Standards Australia, 1991) for a 50 litre hot water heater. In the physical test process heat loss is determined over a twenty-four hour period with the hot water in the heater held at constant temperature of 75°C in a test room maintained at 20°C (both within tolerances set out in the standard). During the standard test, the tank is full of water but no pipes are connected. The safety temperature and pressure valve is fitted but without a drain line and the two or more sockets for water connection are plugged and covered with 12.5 mm of hair felt insulation or equivalent.

The physical test process can be analysed using steady-state heat transfer. The steady state analysis makes provision for conduction, convection and radiation heat exchange but does not accommodate natural convection in the water in the heater container and fittings. The inability to model natural convection in the water in the heater was not considered a problem due to the size of the tank and the expected uniformity of the water temperature in the container during a standard heat loss test.

One-dimensional steady-state heat transfer analysis is a standard technique described in all basic thermodynamic textbooks. Extension of the technique to two and three dimensions for irregular shaped bodies is more complex and is best carried out using computational techniques.

In one dimensional and two dimensional analyses the dimensions not being analysed (that is the second and third dimensions in one dimensional analysis and the third dimension in two dimensional analysis) are considered to be of one unit of length deep in the non analysed dimension. ASHRAE (Fundamentals, 1997, Chapter 25) shows the type of application in the analysis of heat losses through building walls where two dimensional (2D) heat transfer analysis is required.

Modelling Validation

Two computational methods available for use are the two dimensional (2D) analysis program THERM 2.0 (LBNL, 1998) and the three dimensional (3D) analysis program WATSIM (EPRI, 1992). Originally, WATSIM was proposed for the generalised simulation and THERM was proposed for analysis of specific elements of the water heater.

The general design of a 50 L electric water heater currently in production was provided by Rheem (Southcorp Australia Pty. Ltd.). A layout of the heater is provided in Appendix 3. Rheem tested the heater and measured the heat loss at 1.67 kWh per 24 hours under standard conditions.

A component of the tank is the safety temperature and pressure valve. The design of a typical valve was generously provided by RMC (Reliance Manufacturing Company Ltd) in CAD file format. This is the valve used in Rheem's 50 L model and so is a suitable basis for our analysis.

By using the tank and valve designs we prepared 2D models of sections of the heater. In the case of the tank the sections were accurately replicated in the modelling. For the valve the model was simplified as the valve shape is non-uniform in three dimensions and so it becomes more difficult to model in two dimensions. A simplified model was used as an approximation because the losses from the valve, whilst significant, are only of the order of 6-7% of the total losses (see the Table following) and so such an approximation will not adversely affect the overall results of the analysis. The approximate model will affect any studies on the valve itself but if these studies are limited to a comparative basis then the approximate model is still valid.

To verify the validity of the 2D method of analysis, each of the key sections of the heater was modelled for heat loss using THERM 2.0 and the results extrapolated to three dimensions for the whole heater. The extrapolation comprised determining the conduction heat transfer coefficients in two dimensions with THERM 2.0 and then using these coefficients and three dimensional geometry to estimate the heat loss in three dimensions.

The 2D drawing provided by Rheem was divided into sections so that these sections could be individually analysed. Simulation models of the tank sections were practically identical with the cross-sectional drawings provided by Rheem. Choosing sections to reflect the adiabatic boundary conditions assumed by THERM also improves the accuracy of the analysis (see Appendix 4 for the detailed sections and their locations in the water heater vessel).

Rheem use three types of insulation in the heater, the details of which were provided for analysis. The insulation materials are expanded polyurethane for the sides and top and bottom rims, polystyrene for the cast bottom sections and polyester fibre for the top as an infill to finish off the section not able to be filled with expanded polyurethane.

The insulation properties used in the modelling are as follows:

Polystyrene foam	k = 0.038 W/mk.
Polyurethane foam	k = 0.024 W/mK (new) and
Polyester fibre	k = 0.060 W/mK.

Applying these insulation values to each of the relevant sections and interpreting the 2D results into a 3D heat flow as set out in Appendix 5, we obtain the modelled heat losses itemised by heat loss path as set out in Table 5 below.

Tank Section	Section No.	Loss, Wh/24h	%
Anode	1	18.0	1.1%
Top Pad - a	2	22.1	1.3%
Top Pad - b	3	69.1	4.1%
Top Pad - c	4	66.5	3.9%
Top Rim	5	93.8	5.5%
Side less sections 12, 12a, 13 &14	6	707.5	41.7%
Bottom Rim - a	7	136.1	8.0%
Bottom Rim - b	8	59.0	3.5%
Bottom - c	9	79.2	4.7%
Bottom - b	10	40.1	2.4%
Bottom - a	11	6.3	0.4%
Pipe Fittings – inlet	12	37.2	2.2%
Pipe Fittings – outlet	12a	37.2	2.2%
Temperature & Pressure Safety Valve	13	129.4	7.6%
Element access panel	14	194.4	11.5%
		1695.8	

Table 5 - THERM Modelled Heat Loss for a 50 Litre Tank
See Appendix 4 for graphical definition of each of the sections.

The overall heat loss test carried out by Rheem on a (presumably) new heater showed a total heat loss of only 1.67kWh / 24 hours. The value derived from the modelling, 1.70 kWh / 24 hours, is within 2% of the measured heat loss. This confirms that our technique of modelling 2D sections using THERM and applying the results in three dimensions provides a reliable method to study the heat loss characteristics of such a heater and parametrically varied versions of it.

Additionally, our literature search for foreign equivalents uncovered some recent and relevant empirical work in New Zealand (Donald, 1996) that concerned itself with the losses in real installations, paying particular regard to the losses resulting from common arrangements of piping connections for both cold water inlet and hot water outlet configurations.

This work provided a basis to extend the application of THERM 2.0 to the analysis of piping sections and insulation. In hot water filled piping, natural convection movement in the hot water considerably affects the overall heat transfer in the water and as a consequence the heat losses from the piping. THERM has no capacity to model convection in water but, by adjusting the conduction properties of the piping and using a higher conduction rate for the water in the pipe, the heat loss rate for a pipe section can be estimated.

The THERM results were then matched against the experimental results described by Donald to confirm their validity before applying them to other circumstances. With adjusted properties the effect of insulation and material properties of pipe connections can be compared providing the modified properties are not changed. The availability of the NZ test results enabled the 2D results of THERM 2.0 to be extended so that comparative analyses could be made without needing to carry out complex 3D modelling.

In the New Zealand study the heat loss from a horizontal pipe of 12.5mm diameter and 1.1m long was determined as approximately 0.4 kWh / 24hours. The results of modelling a similar pipe configuration (we were not sure of how the pipe was connected to the heater in the NZ experimental study) using THERM 2.0 and adjusted thermal properties for the pipe provided an estimated heat loss of 0.39 kWh / 24hours, within 3% of the NZ study results.

These two confirmations of the accuracy of the 2D modelling applied in both the standard test and real installation contexts, was such as to make the application of 3D modelling redundant. Consequently all of the modelling analysis was carried out using the THERM 2D modelling program and our validated techniques for extrapolating those sectional results to the full apparatus performance.

Parametric Analysis

The modelling technique described above was then applied to a range of parametric changes of interest to this project, the results of which are described below as to their overall impact on system standing heat losses. Details of the section-specific heat losses are summarised in Appendix 5.

Higher Polyurethane Conductivity

The polyurethane conductivity used in the European study on electric water heaters was 0.035W/mK. The report stated that whilst it was possible to achieve a conductivity of 0.027WmK in manufacture there was no evidence to show that the conductivity would be stable at this level over the lifetime of the domestic hot water heater[5].

---

[5] The decay of insulation values over time is believed to result from the slow migration of the foaming gas to the atmosphere and its replacement by the less insulating air – a process which is effectively complete well within the first half of the unit's projected service life. This important factor is ignored by the AS 1056 test which applies to new units rather than specimens exposed to accelerated aging techniques. Apparently,

The polyurethane conductivity at 0.035W/mK is higher than that expected for new material in the current manufacture of heater tanks in Australia (eg, Rheem advise that their material, supplied by Orica, is rated at k=0.022 to 0.024W/mK when installed). Australian performance is expected to decay (ie, heat losses rise) in the near future to align roughly with the European experience by the adoption of more environmentally benign blowing agents in Australian manufacture. In any event it is more indicative of the service performance of the heater over its life even with current insulation foaming practice.

Using THERM and the 3D interpretation technique described above, the performance of the same tank insulated with this lower performing foam was estimated as set out in Table 6 below.

Tank Section	Section No.	Loss, Wh/24h	%
Anode	1	18.0	0.9%
Top Pad - a	2	22.1	1.1%
Top Pad - b	3	69.1	3.4%
Top Pad - c	4	65.3	3.2%
Top Rim	5	131.8	6.5%
Side less sections 12, 12a, 13 &14	6	968.0	47.6%
Bottom Rim - a	7	161.8	8.0%
Bottom Rim - b	8	59.0	2.9%
Bottom - c	9	79.2	3.9%
Bottom - b	10	40.1	2.0%
Bottom - a	11	6.3	0.3%
Pipe Fittings – inlet	12	37.7	1.9%
Pipe Fittings – outlet	12a	37.7	1.9%
Temperature & Pressure Safety Valve	13	132.2	6.5%
Element access panel	14	203.9	10.0%
		2032.1	

Table 6 - THERM Modelled Heat Loss for a 50 Litre Tank
See Appendix 4 for graphical definition of each of the sections.

These results estimate that the heat loss from the heater under standard conditions is 2.03 kWh per 24 hours. This suggests an increase of almost 20% in standing losses relative to our current practice case (as modelled) which in turn is 8% (11%) under the current Australian Standard target for this size of heater of 1.7 kWh / 24 hours (or 1.9 kWh / 24 hours including the allowance for the T&P valve).

Parametric Base Case

Because Australian manufacturers are likely to change to the use of foams of similar performance to their European equivalents before the contemplated MEPS of 30% lower losses than the current target in AS 1056.1 comes into effect, we have adopted this system as the parametric base case. That is, we have analysed ways to improve the performance

---

concern expressed by Australian manufacturers about the impact of the scheduled banning of HCFC blowing agents is a concern about test ratings more than about long term service performance.

of this notional system from 2.03 kWh / 24 hours to be 30% better than the current standard – to have standing heat losses of less than 1.19 kWh / 24 hours (1.33 kWh / 24 hours) when tested under standard conditions. The result of this work is included and discussed in the section on *Ideas to be Evaluated* above where the effect of pipe connections is consciously ignored. Below is a brief analysis of the losses of a tank and associated pipework in real service conditions.

Water Heaters as Typically Connected in Service

Although not formally a part of this brief, the modelling technique has been applied to estimate the significance of differences between heat losses as measured in the standard test and those that might be expected in real applications. The differences analysed are set out below.

When Installed with all Pipe Connections

Under the same ambient conditions that apply in the standard test (75°C water and 20°C still air) the analysis technique described above was used to estimate the standing heat losses when connected with 1.25 m x 12.5 mm diameter copper piping to the inlet, outlet and PTR valve drain. This was found to increase the standing losses by 25% where the pipes are lagged to the equivalent of 12.7 mm of expanded rubber (ie, R = 0.32 m^2K/W) and by 58% with bare pipes where there was no immediate upward slope on the connecting pipe at the point of connection. Where there was unimpeded convection possible in the outlet pipe the increased loss was further increased to be 27% for a lagged pipe and 66% for the unlagged case. Details of these results are set out in Appendix 6.

When Installed in Enclosed Spaces

It has been argued that these small water heaters often have significantly lower losses than the standard test implies when they are installed in confined spaces like cupboards under sinks. To estimate this impact, we looked at the losses to a higher ambient temperature. At a cupboard temperature of 30°C the losses from a connected tank with lagged and non-convecting outlet pipe were found to be 33% more than standard heat loss test value. Conversely, the enclosure effect saved 18% for the unconnected tank. Details of these results are set out in Appendix 6.

When Installed "Outside"

Similarly with the savings available for tanks in enclosed spaces, there is an expected heat loss increase associated with installation "outside" (in a roof or ventilated subfloor space). The standard test conditions of 20°C air is indicative of the annual average air temperature for Brisbane (Szokolay, 1988). For Melbourne the relevant temperature is 15°C. In the latter case the heat losses were increased by 13%.

This value is not a worst case, however, as it assumes full sheltering from breezes and the advective heat losses associated with such exposure. Assuming a sheltered suburban situation with little or no rain reaching the tank and the wind speed cut down by, say, a third of the mean wind speed measured in the clear at 10 m above the ground (the weather data standard), the heat losses for a tank connected with lagged and non-convecting pipes is increased by 10.0% for Brisbane (ie, by breeze effects alone, mean clearwind speed of 10.8 km/h 3 m/s with average air temperature of 20.7°C) and 20.0% for Melbourne where both the breeze (12.3 km/h or 3.6 m/s) and the lower average air temperatures (15.2°C) impact on the result.

A broader perspective on HWS performance

The context within which all hot water services are used is very varied, and is changing. For example:

- Increasing use of water-efficient showerheads means that the rate of hot water draw off for a shower may now be 4 litres/minute or less, compared with a traditional rate of around 9 litres/minute: this may justify testing at lower draw-off rates.
- Many small electric HWS units are installed in commercial facilities where daily draw-offs may be low, so standby losses are disproportionately significant.
- A HWS is just one part of an overall hot water delivery system: losses from pipework, as well heat loss from the tank via the pressure-temperature valve and attached pipework, could potentially be reduced at costs comparable to or cheaper than that of reducing tank heat losses beyond a certain point.
- There will be increasing pressure in coming years to achieve significant reductions in greenhouse gas emissions from HWS units. Compatibility with solar boosting may become a significant criterion in larger tanks.
- Day-rate electric water heaters are significant contributors to peak electricity demand: this is being increasingly reflected in electricity tariffs. It may become increasingly important to design/select them to be compatible with load management controls.

Appendix 2 is a paper presented at the recent Solar '99 conference (Pears, 1999). This provides a useful perspective on the broader issues affecting hot water demand and appliance characteristics and the appropriateness of current methods of test for evaluation of actual efficiency in the installed systems as a whole.

References

ASHRAE-90A, 1980, *Energy Efficient Design of New Buildings Except Low Rise Residential Buildings*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Tullie Circle N.E, Atlanta, GA 30329, USA.

ASHRAE-90.1, 1989, *Energy Efficient Design of New Buildings Except Low Rise Residential Buildings,* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Tullie Circle N.E, Atlanta, GA 30329, USA.

ASHRAE-90.1, 1999, *Energy Standard for Buildings Except Low Rise Residential Buildings,* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Tullie Circle N.E, Atlanta, GA 30329, USA.

ASHRAE 118.2, 1993, *Methods of Testing for Rating Residential Water Heaters*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Tullie Circle N.E, Atlanta, GA 30329, USA.

ASHRAE, 1997 - *ASHRAE Handbook of Fundamentals*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Tullie Circle N.E, Atlanta, GA 30329, USA.

Donald, William J, *Hot Water Storage Tanks – Standing Losses With Appendages*, Project Number 36, Bachelor of Engineering Project Report 1996, University of Canterbury, Christchurch, New Zealand.

EES, 2000, *Hot Water Service Testing for MEPS 1999*, Energy Efficient Strategies for AGO, draft report, unpublished.

EPRI, 1992, *WATSIM 1.0 Simulation Model*, Electric Power Research Institute, Palo Alto, CA 94304, USA.

Garzoli, K, 1999, *Personal Communication*, Deputy-Head, Energy Research Centre, Australian National University, Canberra.

Griffith, B, 2000, *Personal Communication*, Laurence Berkeley National Laboratory, Berkeley, CA 94720, USA.

Griffith et al, 1995 - Brent T. Griffith, Dariush Arasteh, and Daniel Türler, *Energy Efficiency Improvements for Refrigerator/Freezers Using Prototype Doors Containing Gas-Filled Panel Insulating Systems,* Proceedings of the 46th International Appliance Technical Conference, 15-17 May, 1995, at the University of Illinois at Urbana-Champaign, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA.

Griffith et al, 1998 - Brent Griffith, Elizabeth Finlayson, Mehrangiz Yazdanian and Dariush Arasteh (1998). *The Significance of Bolts in the Thermal Performance of Curtain-Wall Frames for Glazed Facades*, ASHRAE Transactions., **104**, Pt.1.

Hood, M, 1999, *Implications of Further Insulating Small Hot Water Heaters*, Report to Australian Greenhouse Office, unpublished, Taylor Nelson Sofres (Australia) Pty Ltd, Sydney.

Lane, GA, *Solar Heat Storage: Latent Heat Materials*, Volumes 1 and 2, CRC Press, Boca Raton, Florida, USA.

LBNL, 1998 - *THERM 2.0 – A PC Program for Analyzing Two-Dimensional Heat Transfer Through Building Products*, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA.

LBNL 2000 – *gfp.lbl.gov/,* Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA.

Pears A, 1999, *Cost-effective Renewable-energy Sourced Hot Water for Australian Homes: Issues and Opportunities*, Proceedings of Solar ’99 Conference “Opportunities in a Competitive Marketplace”, Australian and New Zealand Solar Energy Society, Geelong.

Pilon, 1999, *Personal Communication*, G Zinoviev of Pilon Plastics Pty Ltd, Sydney.

Ramm SJ, 2000, *Review of the Draft Final Technical Report, January 2000, "Improving on Electric Water Heater Efficiency"*, Unpublished report to AGO, Sydney.

Rheem, 1998, *Hot Water Manual*, Southcorp Water Heaters Australia, Sydney.

Sakulin M, 2000, *Personal Communication*, Professor Manfred Sakulin, Technische Universitaet Graz, Austria.

SAVE, 1998 (March), *Analysis of Energy Efficient Domestic Electric Storage Water Heaters (DESWHs), Study for the Directorate General for Energy (DGXVII) of the Commission of the European Communities Final Report*, SAVE, Vienna: Directorate General for Energy (DGXVII) of the Commission of the European Communities Contract No. -4.1030/E/95-013, Final Report, Vienna, Austria.

Standards Australia, 1990 – *AS 3500.4, "National Plumbing and Drainage Code – Part 4: Hot Water Supply Systems"*, Sydney NSW.

Standards Australia, 1991 – *AS 1056.1, "Storage Water Heaters – Part 1: General Requirements"*, Sydney NSW.

Standards Australia, 1998 – *AS/NZS 1056.4, "Storage Water Heaters – Part 4: Daily Energy Consumption Calculations for Electric Types"*, Sydney NSW.

Standards New Zealand, 1996, *NZS 4305:1996 "Energy Efficiency – Domestic Type Hot Water Systems*", (1996), Wellington, New Zealand.

Standards New Zealand, 1989, *NZS 4606:Part 1:1989 "Storage Water Heaters – General Requirements"*, Wellington: New Zealand.

Szokolay, S, 1988, *Climatic Data and its Use in Design*, Royal Australian Institute of Architects, Canberra.

Trinh, D, 1995, *Personal Communication*, Thermal Energy Group, Perth, Western Australia.

U S Department of Energy, 1998 (May 11) - *Final Rule: "Energy Conservation Program for Consumer Products: Test Procedure for Water Heaters"*, Washington DC: Department of Energy, USA.

U S Department of Energy, 1999 (November), *About Water Heater Efficiency*, Available http://www.eren.doe.gov/buildings/consumer_information/water/waterabout.html

US Department of Energy (1999, November)*, Energy Star, The Symbol for Energy Efficiency,* Available http://www.energystar.gov/.

Williamson A, 1999, *Personal Communication*, Professor and Managing Director of Thermocell Ltd, Christchurch, New Zealand.

Appendices

1. ***Survey of Performance Standards and Requirements in Comparable Countries***
2. ***Cost-effective Renewable-energy Sourced Hot Water for Australian Homes: Issues and Opportunities***
3. ***Section of a Typical Small Electric Water Heater***
4. ***Detailed Tank Sections Showing Isotherms***
5. ***Developing 3D Results from 2D Simulations***
6. ***Summary of Simulation Results***

Appendix 1

Survey of Performance Standards and Requirements in Comparable Countries

A survey of the European Union, Canada, the USA, and New Zealand was completed to determine the commercially available efficiencies of small electric storage water heaters and the techniques used to obtain them. The literature search focussed on the OECD-IEA's CADDET network.

European Union

The report *"Analysis of Energy Efficient Domestic Electric Storage Water Heaters (DESWHs), Study for the Directorate General for Energy (DGXVII) of the Commission of the European Communities, Contract No. SAVE-4.1030/E/95-013, Final Report, March1998"* was obtained and is the source document for the following notes.

In the EU, electric water heater test standards are issued by:

1. The IEC (International Electrotechnical Commission), which is the relevant international standards authority; and
2. CENELEC (Comite Europeen deNormalisation Electrotechnique), the European standards organisation.

The relevant IEC energy measurement standard is IEC 379 (3rd edition 1987, replacing the 2nd edition of 1982), *'Methods for measuring the performance of electric storage water heaters for household purposes'*.

According to IEC 379, Rated Capacity is defined as
"The water heater is filled in the normal way and then the water supply is cut off. It is then emptied through the water inlet or through the drain plug if necessary. The water withdrawn is measured and the result stated in litres to the nearest one-tenth litre."

The energy test under IEC 379 includes the following steps:

1. Starting and ending at the period the thermostat cuts out, the energy consumed is measured over a period of not less than 48 hours.
2. Energy consumption per 24 hours is calculated.
3. The mean water temperature of 65 ± 2 °C is calculated.
4. Standing losses per 24 hours at an ambient temperature of 20 ± 2°C with temperature of cold water supply 15 ± 2 °C are calculated and expressed in kilowatt-hours per 24 hours related to a temperature rise of 45 K and expressed to the nearest 0.01 kWh.

During the test, any connecting pipes are either heavily lagged or disconnected as is the case in Australia (Sakulin, 2000).

This standard is covered at the European level in the CENELEC standard HD 500 S1 (1987), *'Methods to be used for measuring energy consumption of thermal storage water heaters and for the purpose of informing consumers on it.'*

There are no reported significant differences between these two standards.

Mural vertical (>50 L – 1000 L), horizontal (>50 L – 300 L) and small-capacity (5 L – 50 L) DESWHs account for nearly three-quarters of existing EU models.

An analysis of the CECED database, carried out to define DESWH categories, or groups of water heaters that can be considered homogeneous with respect to their technical characteristics and therefore comparable regarding their standing losses/energy efficiency, led to the assignment of DESWH groups into three categories:

Small DESWHs, with a capacity of 5 – 50 litres
Horizontal DESWHs, with a capacity of more than 50 litres
Vertical DESWHs, with a capacity of more than 50 litres

Based on the data supplied by CECED for 1995, which covers about 80% of the European DESWH market, the average ‘standard’ (according to IEC 379) standing losses were calculated and used to define the ‘base case’ for their following technical/economic analyses. The base case for standing losses ($L_{St,BC}$) is the approximated mean of weighted/unweighted averages and can be described as shown in the following table (V = rated capacity of the DESWH in litres).

Type of DESWH	Capacity (L)	Base case for standing losses ($L_{St,BC}$)
Vertical	> 50 L	$0.20 + 0.0510 * V^{2/3}$
Small	5 – 50	$0.13 + 0.0553 * V^{2/3}$

Table 7 - Average DESWH standing losses as a function of rated capacity

Using this formula, the base case standing losses for small – capacity DESWHs is as follows:

Capacity (L)	Base case standing losses kWh/d
55	*0.938*
50	0.880
25	0.602
10	0.386
5	0.291

Table 8 - Small DESWH (≤ 50 L) base case standing losses

In order to identify the relevant parameters influencing standing losses, a sensitivity analysis was conducted. A mathematical simulation model was developed that describes the standing losses of DESWHs with a series of physical parameters:

H:R	the boiler’s height:radius ratio
s, s_t	insulation thickness of the boiler: on the side and top, respectively
	thermal conductivity of the insulation material
s:λ	ratio of insulation thickness at the side to thermal conductivity
s_t:s	ratio of insulation thickness on top and at the sides
P_{fix}	fixed losses due to heat bridges (connections, flanges, etc.).

The variation in the magnitude of these parameters likely to be found on the EU market showed that the main contributor is sλ. No other parameter – single or combined – can explain the large differences in standing losses.

Using the thermal conductivity of PU foam (0.035 W/m K) and using average values for all parameters, the simulation model gave an insulation thickness of 4-5 cm for the base-case standing losses. This thickness was determined as valid for the whole capacity range from 50 to 1000 litres for vertical DESWHs.

Life-cycle costs were calculated for the sum of the cost of the insulation of a DESWH and its discounted real standing loss costs during the lifetime of the DESWH.

The life-cycle cost analysis showed an optimal insulation (related to the lowest life-cycle costs) between 5 cm and 11 cm depending on the electricity tariffs in the different EU member states. For the 'EU case' (average of electricity tariffs) the optimal insulation thickness is between 6.4 cm and 9.3 cm.

Compared to real storage losses, it can be shown that increasing insulation thickness relative to current practice decreases not only standing losses but also life-cycle costs. The main factors influencing the level of optimal insulation are the additional insulation costs and the price of electricity. The discount rate, ambient temperature and usage conditions (f_{real}) are of minor importance.

Further options for improving DESWH efficiency were outlined:

- Improvement of insulation material – no insulation materials better than PU foam (λ = 0.035 W/m K) were available on the market. Vacuum insulated panels should be considered in future R&D activities.
- Changes in DESWH shape (height:radius ratio).
- Changes in insulation thickness at sides/top of the boiler.
- Avoidance of heat bridges – R&D efforts should explore this potential.
- Use of optimal hot water temperature for a given DESWH capacity.
- Use of DESWHs with capacity adapted to household size.
- Increasing insulation but keeping outside dimensions constant – total life-cycle effect of this was found to increase energy losses.
- Use of intelligent control devices – should be a focus of R&D efforts.
- Use of water-saving devices.
- Reduction of distribution losses with short pipe lengths, good pipe insulation and small pipe diameters.
- Use of heat pumps for hot water production in DESWHs – may be cost effective in higher-tariff conditions.
- Use of solar collectors – may be cost effective in areas of combined high solar radiation and high electricity tariffs.

The Report recommended an energy policy mix based on two main strategies:

- Set a minimum energy efficiency standard.
- Introduce a labelling scheme.

Canada

It is understood that Ontario Hydro's old Research Division previously did some developmental studies with regard to domestic water heaters (20 to 60 gallons). These apparently were mainly with dual elements.

Advice obtained from the Energy Consultancy Department - Ontario Power Technologies indicated they did not have any recent developmental studies on water heater efficiency that they felt would be of use to this consultancy.

Canada uses the Canadian Standards Association (CSA) Standard C191 for the specification of water heater efficiency. This standard contains a stand-by loss test for rating the energy efficiency of water heaters. The allowable loss from the water heater is related to the volume of the container and is not to exceed the values calculated as follows:

for container sizes 50 to 270 litres, $W = 61 + 0.20V$ and
for container sizes 270 to 454 litres $W = 0.472\ V - 12.5$

where V is actual container capacity in litres (only about 90% of which is deliverable hot water) and W is standby loss in watts.

On the basis that our 50 L tank would be considered a 55 L tank in the Canadian Standard, this equates to a standing loss of 61 + 11 = 72 W standing loss or 1.728 kWh/24h. This standard is curiously little related to size (eg, a 110 L tank is permitted a standing loss of 61 + 22 = 83 W or 1.992 kWh/24h – only 15% more for a tank double the size).

They are, however, in the process of converting to the American "Energy Factor" rating as a result of the North American free trade agreement. The CSA standard was adopted by many of Canada’s provinces as a mandatory standard, but it is expected that they will now switch to the U.S. standard, which in many ways is inferior to the CSA standard. Currently, Ontario Hydro, Quebec Hydro and New Brunswick Power still use the CSA standard to specify water heaters that they purchase for their rental program.

Advice was requested, but not received, from the Canadian Office of Energy Efficiency.

United States of America

Part B of Title III of the Energy Policy and Conservation Act established the Energy Conservation Program for Consumer Products other than Automobiles.

The following information is extracted from the so called Final Rule: *"Energy Conservation Program for Consumer Products: Test Procedure for Water Heaters"*, Federal Register, May 11, 1998.

In amendments published by the Department of Energy (DOE) in 1995, it was proposed that coverage for testing storage-type water heaters with rated storage capacities less than 20 gallons (76 litres) be included.

To cover these water heaters, DOE proposed to adopt the draw rate and the schedules in the ANSI/ASHRAE Standard 118.2-1993, *"Method of Testing for Rating Residential Water Heaters"* to be used in the first-hour rating test and the 24-hour simulated use test.

The draw schedules are as follows:
For units with rated storage less than 10 gallons (38 litres), a total volume of 9 gallons (34 litres) shall be withdrawn, and for units with rated storage greater than or equal to 10 gallons (38 litres) but less than 20 gallons (76 litres), a total volume of 24 gallons (91 litres) shall be withdrawn. The draw rate for both draw schedules shall be 1.0 gallons ± 0.25 gallons per minute (3.8 litres ± 0.95 litres per minute). DOE also requested comments and data on its proposal to extend test procedure coverage to storage-type water heaters of less than 20 gallons (76 litres).

The thermostat setting of the water heater is 135°F ± 5°F (57.2°C ± 2.8°C). The DOE test procedure specifies supply water temperature to be 58°F ± 2°F (14.4°C ± 1.1°C).

Several commenters objected to one or more of these proposals.

Although the Department believed the stand-by loss measurement for water heaters less than 20 gallons (76 litres) proposed by the commenters might have been feasible, DOE reserved consideration of this proposal for a future revision of the test procedure.

The reasons for this decision were:
- Absence of data to determine the appropriate daily hot water consumption; and
- DOE's need to develop and evaluate the stand-by loss procedure.

Therefore, DOE withdrew its proposal for small water heaters in the Final Rule: *"Energy Conservation Program for Consumer Products: Test Procedure for Water Heaters"*, Federal Register, May 11, 1998.

Reference is made by the DOE's Energy Efficiency and Renewable Energy Clearinghouse (EREC) regarding an Energy Factor (EF) expected of appliances, including water storage heaters. The Energy Factor for water heaters is defined as the measure of overall efficiency of an appliance. Any new or amended standard must achieve the maximum improvement in energy efficiency that DOE determines is technologically feasible and economically justified.

For water heaters, the energy factor is based on three factors:
1. the recovery efficiency - how efficiently the heat from the energy source is transferred to the water;
2. stand-by losses – the percentage of heat lost per hour from the stored water compared to the heat content of the water; and
3. cycling losses.

EREC quotes the EF for electric water heaters as:

0.93 - (0.00132 X rated storage volume in gallons)

in which the rated storage volume equals the water storage capacity of a water heater, in gallons, as specified by the manufacturer.

EREC notes the higher the EF, the more efficient the water heater, with electric resistance water heaters having an EF between 0.7 and 0.95. (Gas heaters have an EF between 0.5 and 0.6, with some high-efficiency models around 0.8; oil heaters range from 0.7 to 0.85; and heat pump water heaters range from 1.5 to 2.0.) Product literature from manufacturers usually gives the appliance's EF rating.

While it is understood that EF's would apply to the larger water heater units in accord with the focus of the DOE's Final Rule above, this for small capacity water storage heaters would theoretically be calculated as follows:

Table 9 - Small water heaters (≤ 50 L) theoretical Energy Factor

Capacity (L)	Energy Factor
80	0.90
50	0.91
25	0.92
10	0.93
5	0.93

'Energy efficiency features' that consumers are encouraged by the EREC to consider prior to the purchase of a water heater include noting the amount of insulation, ie, "look for are tanks with at least 1.5 inches (3.8 centimeters) of foam insulation" (sic) and energy efficiency ratings shown on the US consumer oriented EnergyGuide labels.

The U.S. government established a mandatory compliance program in the 1970s requiring that certain types of new appliances bear a label to help consumers compare the energy efficiency among similar products. In 1980, the Federal Trade Commission's Appliance Labelling Rule became effective, and requires that EnergyGuide labels be placed on all new refrigerators, freezers, **water heaters**, dishwashers, clothes washers, room air conditioners, heat pumps, furnaces, and boilers. Similarly, ASHRAE proposed maximum standby losses in its energy conservation standards of the time (ASHRAE, 1980), setting 43 W (1.032 kWh/d) as the key value over a temperature difference of 80°F (44.4°C) for a system under 20 gallons (76 L). ASHRAE (1989) recommended maximum losses of 1.9 W/ft^2 (down from 4 W/ft^2) for units over 120 US gallons after 1992; with smaller units having a target of an Energy Factor of $\geq$ 0.95 – 0.001332V (in US gallons) after 1990.

Subsequently, ASHRAE (1999) has changed to categorising water heaters by their rated power rather than storage or delivery volume. Units up to 12 kW have a required Energy Factor of $\geq$ 0.93 – 0.005V (in litres) but, unlike the case for the larger units, with no improvement slated for October 2001.

The DOE's Energy Efficiency and Renewable Energy Network (EREN) notes that although many consumers make water heater purchase decisions based only on the size of the storage tank, the first-hour rating (FHR), provided on the Energy Guide label, is actually more important. The FHR is a measure of how much hot water the heater will deliver during a busy hour. The FHR is required by law to appear on the unit's Energy Guide label. Therefore, consumers are advised, before they buy a water heater, to estimate the household's peak-hour demand and look for a unit with an FHR in that range.

Water heaters are not included in the US Energy Star labelling program that is promoted within the broader home appliance sector.

New Zealand

The New Zealand Standard NZS 4305:1996 *"Energy Efficiency – Domestic Type Hot Water Systems"* was obtained and is the source document for the following notes.

The requirements of the standard are based on a practical and economic analysis of insulation costs and energy savings and common sense. Energy efficient systems provide economic, comfort and health benefits to the nation and the householder by reducing overall energy consumption while retaining or improving on the existing levels of service. These benefits are particularly marked in the colder zones.

Acceptable methods of test are:

- The Australian Gas Association AG 102;
- The US Department of Energy (DOE) Federal Register 10 CFR Part 430 Energy Conservation Program for Consumer Products: Final rule regarding test procedures and energy conservation standards for water heaters.

Electric storage water heaters are tested according to NZS 4606:Part 1 or NZS 4602, shall achieve a 24-hour standing heat loss not greater than the value specified in the following table:

Capacity (L)	**Maximum heat loss (kWh/d)**
135	1.4
180	1.6
200	1.7
225	1.8
270	2.0
300	2.2
360	2.5
450	2.9

Table 10 – Permissible Heat Losses for Larger Tanks

For electric water heaters of smaller sizes, the maximum permitted 24 hour standing heat loss is determined according to the following

Capacity (L)	**Maximum heat loss (kWh/d)**
> 90	0.0048 L + 0.72
=/< 90	0.0084 L + 0.40

Table 11 – Permissible Heat Loss Formulae for Large and Small Tanks

Using this formula, the maximum permitted 24 hour standing heat loss for smaller units would be as follows

Capacity (L)	**Maximum heat loss (kWh/d)**
80	**1.072**
70	0.988
60	0.904
50	**0.82**
40	0.736
30	0.652
25	**0.61**
20	0.568
10	**0.484**
5	**0.442**

Table 12 - Permissible Heat Losses for Small Tanks

Note that storage capacity refers not to rated delivery in New Zealand but to the actual volume of the container (Williamson, 1999). Note also that the test is undertaken with a temperature difference of 55.6°C (100°F).

As well as the heater itself, the NZ Standard requires minimum performance of installation to ensure that the benefits of improved tank insulation are not dissipated by bare and internally convecting pipe connections as cited below:

“Pressure relief valves and temperature and pressure relief valves shall be thermally insulated. Where a pressure relief valve is not fitted directly to the water heater, the connecting pipe-work shall not exceed 1 metre, and shall be thermally insulated.

“Hot water distribution pipes shall be thermally insulated for a distance between the storage hot water and one or more of the following points:

- for horizontal pipe, to not less than 2 metres
- to the end of the first continuous 2 metres of horizontal pipe
- to the first pipe drop of at least 250mm, i.e. heat trap. The insulation shall extend at least 150 mm past the top of the heat trap.”

These factors are amplified by drawings of suitable installations in the standard itself.

Appendix 2

Cost-Effective Renewable-Energy Sourced Hot Water for Australian Homes: Issues and Opportunities

Alan PEARS

Director, Sustainable Solutions Pty Ltd, Senior Research Associate, Centre for Design
RMIT
2/78 William Street Brighton Vic 3186

ABSTRACT

Around 55% of Australian households now consist of only one or two people, and 30% of new homes are not traditional detached houses. Water-efficient equipment and improving detergents mean less hot water is needed for each task. Ever improving solar and electric heat pump hot water services, 'continuous' gas units, better-insulated storage tanks, intelligent controls and metering, heat recovery systems and other technology changes offer new ways of satisfying household hot water requirements. Yet new HWS units are sold using marketing slogans that promise a never-ending flood of hot water.

This paper reviews trends in household demand for hot water, and proposes several technology packages that could cost-effectively satisfy future requirements in environmentally-sound ways. It raises a number of issues to be confronted by manufacturers of all types of hot water services, the building industry and policymakers.

Key Words: energy efficiency; hot water service; greenhouse gas emissions.

INTRODUCTION

Analysis of water heating energy use tends to focus on technical aspects of water heater design. In practice, the water heater is just one component of a complex system that responds to user behaviour and is intended to satisfy household requirements for cleaning of bodies, clothes and dishes, as well as contributing to quality of life. Too often, we see solar HWS units with poorly insulated pipes, storing water held in under-insulated tanks, and supplying showers fitted with water-guzzling showerheads. If renewable energy is to cost-effectively contribute to household hot water supply, it will be important to optimise the overall system.

This paper reviews the overall context within which water heating systems function. It indicates some directions for system design.

THE DEMAND FOR HOT WATER

Household and housing characteristics

- Around 55% of Australian households are now comprised of one or two people, but more houses have varying numbers of occupants (eg part-time parents, holiday homes). So standby consumption is increasingly important, but peak hot water supply capacity can’t be sacrificed. And, for smaller households with lower hot water consumption, the economics of low greenhouse impact water heating solutions can be problematic

- An increasing share of new housing is medium-density apartments/townhouses (30% now, up from 20% a decade ago). This has implications for types of water heating units and hot water consuming appliances and fittings, eg smaller hot water service (HWS) units, flueing issues, access to roof area for solar panels, etc. Also, developers, builders and designers (who have little interest in ongoing operating costs) have an increasing role in making decisions about appliances for new housing.

Contextual issues

Environmental factors

- Pressures to reduce the environmental impacts of household energy use are increasing as a result of international climate change agreements. This is being reflected in programs encouraging solar water heating at both state and national levels
- Water-efficiency is becoming increasingly important, so total demand for hot water should be declining - but HWS marketing promotes wasteful use of hot water as a desirable thing

Political and market factors

- State and Commonwealth governments have been reluctant to take a strong position on fuel and appliance choices for hot water, partly because the electricity and gas industries are both very protective of their hot water market shares, and are sensitive to any possibility of intervention. However, recent studies (eg Energy Efficient Strategies, 1999) and new policies (eg NGS, 1998) have highlighted the reality that greenhouse gas emissions from household hot water comprise almost 30% of total household energy-related emissions, so pressure for action is increasing.
- Local government is becoming increasingly active on energy and environmental issues, including environmental impacts of household hot water - eg NSW Energy Smart Homes policy.
- There may be growth of integrated gas/electricity suppliers, who will promote options that minimise their total costs, not just one energy source. The implications of this for households are not yet clear
- There will be increasing tensions between the developer/builder/tradesperson/installer focus on low up-front cost, and the home occupant's interest in low ongoing costs and high quality indoor environment. Governments may regulate for information on lifecycle costs and operating costs - for example, ACT now requires a House Energy Rating to be made available to prospective home buyers. How long before past energy bills and ratings of water heater greenhouse emissions must also be made available to prospective buyers and tenants? Remember, market theory requires all market participants to be fully-informed and empowered: this is not the case at the moment.

Priorities and practicalities

- Almost 85% of emissions from hot water supply result from use of electricity for water heating, even though less than 60% of households use electric water heating. And around 15% of Australian households use expensive-to-run day-rate electric HWS units. So the pressure is on electric water heating to lift its environmental performance. Yet existing gas storage water heaters can hardly claim to be high in efficiency, particularly at low draw-offs
- The economics of water heaters other than electric units are coming under pressure. Lower hot water consumption extends the payback period for higher capital investments

in equipment. And, in small, energy efficient households, low levels of consumption mean that the fixed supply charges levied by gas suppliers are becoming a significant barrier to connection to and use of gas. It is also likely that, when households become contestable customers, electricity suppliers will try to block competition from gas and other competitors by raising fixed supply charges and reducing marginal unit prices.

- Since large reductions in greenhouse gas emissions are likely to be required in the medium term, it will be important to ensure that each new HWS installed achieves maximum greenhouse emission savings (including minimum standby losses), has potential to utilise solar boosting either when installed or as a simple retrofit and, for gas units, offer compatibility with gas from renewable sources. This is doubly important because new models are designed for longer lives
- Since average HWS life is 7-15 years (and new models may last longer), less than half of existing HWS units may be replaced before the Kyoto target date of 2010, so consideration must be given to retrofit opportunities.

SCOPE FOR COST-EFFECTIVE REDUCTION IN GREENHOUSE EMISSIONS

To evaluate potential for reduction of emissions, it is necessary to consider the overall system used to deliver hot water, as well as the end-use requirements of users. These elements include:

- supply water temperature (which varies seasonally and geographically)
- user behaviour
- tap and shower fittings, and hot water-consuming appliances
- distribution pipes
- hot water service (including fuel selection)
- utilisation of waste heat

Unless all of the elements of this system are optimised, savings may fall short of predictions, as discussed in the previous section. Lets look at these issues, apart from supply water temperature, which is not easily controlled - although global warming will be playing its part in raising the average temperature.

User Behaviour

Usage patterns

There is little public information on hot water usage by activity. One Perth survey (reported in Wilkenfeld 1991) suggested that 59% of hot water usage was in the bathroom, 28% in the laundry, and 13% for dishwashing. There is wide variation in household water consumption, both between households and from day to day, as shown in Figure 1. Also, occupancy of a given home varies over time, leading to long term variation in hot water requirements. And the possibility of running out of hot water is a major concern for many households.

An important aspect of user behaviour is the length of showers. Anecdotal information about the lengths of showers taken by teenagers suggests that there is a serious issue here, while significant numbers of adults seem to enjoy the relaxing effect of a long shower or large bath. Other factors influencing shower length include hair length (which affects washing requirements), developments in shampoos (does combined shampoo-conditioner reduce showering time?), popularity of shaving under the shower, etc. Of course, shower length could be limited by an automatic cut-off after a specified period of showering, but this may be seen as draconian by some. Many people run the shower while undressing, further increasing hot water wastage. Further sociological research is needed here to develop energy and water saving strategies that have some chance of success.

The range of hot water requirements can be expected to widen, as some households continue to use to water wastefully, while others adopt leading edge techniques to minimise hot water requirements. The extremes might be characterised by:

- A requirement for up to 100 MJ/day (approx 500 litres) of hot water, with up to 300 litres requirement within a half hour period at a flow rate of 10-15 litres/minute. This would apply if two showers are available and four people each use standard flowrate showerheads for 10 minute showers before going out at about the same time. This assumes a supply temperature of around 60C - more volume would be required if supply temperature was lower.
- A requirement of 5MJ/day (approx 25 litres) of hot water, with peak demand of 15 litres over 5 minutes for a single person using water-efficient showerhead and appliances: this requirement could be reduced if heat recovery captures heat from waste shower water. Maximum flow rate might be 4 litres/minute, or even less. And if a very water efficient showerhead is used in conjunction with a heat recovery system, the hot water flow for a shower might be as little as 1-2 litres per minute.

To satisfy this spectrum of user requirements is indeed a challenge. Manufacturers would prefer to sell one flexible product, and householders may want satisfactory performance across this range of activity.

Figure 1a. Daily quantity of hot water usage per person for 13 households (Allwood et al 1995)

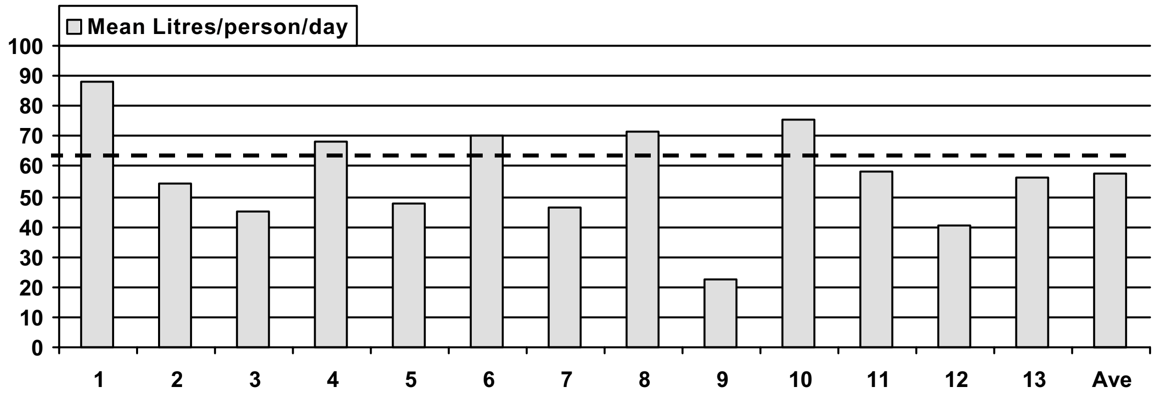
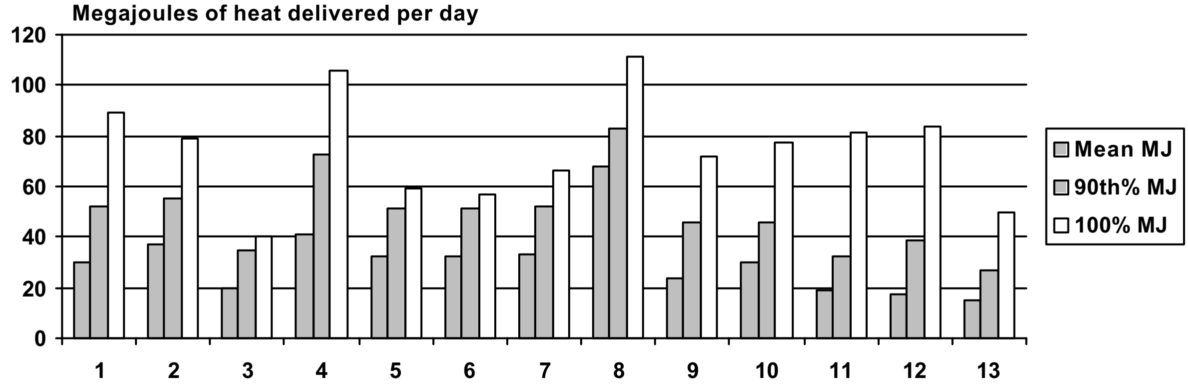


Figure 1b. Daily average and peak heat supplied by HWS for a sample of households (Allwood et al 1995)



Tap and Shower Fittings, and Hot Water Consuming Appliances

The hot water consumption of major hot water consuming appliances is declining for reasons including:

- Washing temperatures are declining with improving washing machine design, development of low temperature detergents, changing fabrics and cultural change
- The quantity of water (and hence hot water) per wash program for clothes and dishwashers is declining. While a traditional top-loading washing machine uses over 150 litres of water per wash, the best top loaders now use as little as 60 litres and the best front loaders use even less water: for a hot wash, about a quarter of this would be hot water. The best dishwashers now use less than 18 litres of water, of which around half would be either heated within the appliance or supplied from the HWS: older dishwashers use more than 40 litres.

While early water-efficient showerheads were criticised for poor comfort and lack of user satisfaction, modern AAA rated showerheads now achieve high levels of user satisfaction. For example, in a recent *Choice* study, testers were not told that the showerheads they were evaluating were water-efficient, but several models were well-regarded (ACA 1998).

This improved user satisfaction has been accompanied by a redefinition of the meaning of an AAA rating. Originally, this rating was equivalent to a maximum flow rate of around 6.8 litres per minute. Now it means a maximum flow rate of less than 9 litres per minute! So the water savings being achieved are not as great as some may think. It should also be noted that few people run their showers at maximum flow, so savings from switching showerheads are further reduced by this effect.

This situation raises the question of whether there is further scope for improving the water-efficiency of showerheads or showers as systems. The answer, of course, is yes. Several years ago, a project carried out at the RMIT Centre for Design led to construction of a prototype showerhead that seemed to work well at a flow rate of around 6 litres per minute. Other experiments with fine mist sprays (which can be supplemented by conventional hand-held showerheads for rinsing shampoo from hair) showed they could provide pleasant showering experiences - although very different from a conventional shower.

It should also be noted that heat from shower water plays an important role as a heating system in cold bathrooms (Pears 1997). The hot water warms the cold surfaces of the shower recess, and condensing steam warms the walls and ceiling of the bathroom. This is a possible reason why water-efficient showers have gained lower acceptance in colder areas - they do not provide as much heat. But improving building thermal performance should help overcome this problem.

Another key factor affecting acceptance of water-efficient showerheads is whether an exhaust fan is installed over the shower recess. The cooling effect as cold air is drawn over a wet body is a serious challenge for a water-efficient shower. Of course, it is relatively simple to leave the fan switched off until after a shower. But if the fan is linked to the room light, there can be a serious discomfort problem.

Water-efficient taps are also proving to be practicable. Aerators and precision design allow effective function with low water consumption. However, a serious problem is emerging in the form of mixer taps, which are becoming increasingly popular. In the default position, that is with the lever pointing directly at the user, these taps deliver 50% cold water and 50% water from the hot supply. To block off the supply of hot water, the lever on the tap must be pushed to the extreme right of its available range of movement. Since most people seem to like symmetry, they frequently use these taps with the lever in the 'straight ahead' position. This wastes large amounts of hot water. And, because small draw-offs only draw 'dead water' which has cooled in the supply pipe, users are generally not aware that this behaviour is increasing their hot water bills. There is an obvious solution: make the 'straight ahead' position the 100% cold supply path, and require the user to move the lever to the left to add hot water.

Poor maintenance, which leads to dripping and leaking taps and pipes, can also increase energy losses from fittings. At a dripping rate of 20 drips per minute (approx 4 millilitres/minute), a tap can leak over 2,000 litres per annum, over 100 kWh electricity (or 0.5 GJ of gas) per annum energy loss.

Overall, effective hot water-efficiency measures could reduce household hot water requirements by half to two-thirds. This has dramatic implications for the design of the rest of the hot water supply system.

Pipework

As showerheads and taps become more water-efficient, the time delays before hot water reaches outlets are increasing, while the temperature drop along long lengths of pipe is also becoming a bigger issue.

For example, 10 litres of standard 15 mm (actually 12.7 mm OD) pipe holds almost a litre of water. When a showerhead delivers 15 litres of water per minute (that is, 7.5 litres/minute of hot water), this means the delay before hot water is received via 15 metres of pipe is less than 15 seconds. But for a shower running at 6 litres per minute (3 litres/minute hot water), the delay would be more than 30 seconds. This problem is even more annoying where low flow-rate taps are used for small draw-offs.

The temperature drop as hot water flows along long lengths of uninsulated hot water pipes is also becoming more of an issue, as water moves more slowly when water-efficient fittings are used. With water-efficient fittings, temperature drops can be up to three times those that occurred when conventional fittings were installed. This problem is being exacerbated by recently introduced safety requirements for lower supply temperature water for showers and baths, which mean the initial hot water temperature is already lower than in the past.

Energy losses from pipes can be a surprisingly large component of water heating energy. They include:

- Removal of heat from the HWS via copper pipes connected to the inlet, outlet and pressure/temperature valves. This occurs both through a 'fin effect' and through convection of water in the pipes. Use of plastic pipes near the HWS, improved pipe insulation, and convection suppression devices reduce this loss
- 'Dead water' losses as water that has cooled in the delivery pipes must be flushed out by hot water. While it is usually assumed that these losses comprise only around 5% of hot water usage (Rheem 1992), they are increasing where many small draw-offs occur (when mixer taps are installed, or water consuming appliances draw off several amounts of hot water at intervals through their programs). Further, as overall water efficiency improves, these losses become a larger proportion of total consumption. Use of smaller diameter, insulated pipes (see below) would reduce dead water losses by reducing the volume of water in the pipes and keeping remaining water hot for longer, so later users may find it is still hot enough to use, and less energy will be required to re-heat the pipes.
- Heat loss from pipes under steady state conditions. According to Rheem (1992), losses from standard 15mm pipes running at a 40C temperature differential are around 28 watts/metre. If showers and taps run for a total of 40 minutes per day, and typical pipe length is 15 metres, annual steady-state energy loss is over 100 kWh pa of electricity or 0.5 GJ of gas. If the pipes were insulated, residual heat would be maintained for longer so, in addition to saving much of this energy, dead-water losses would also be reduced

The use of smaller diameter pipes raises the issue of whether pressure drops would be too great. However, lower flow rates for water-efficient fittings limit this problem. For example, the pressure drop along 10mm (nominal) pipe at 4 litres per minute is about the same as for 15mm (nominal) pipe at a flow rate of 10 litres per minute (Rheem 1992). In any case, larger pipe could be used to supply the shower, while less critical uses could switch to smaller diameter pipe.

When we look at the real world, we find the potential significance of pipe losses is greater than is often assumed. The reality is that poor practices can lead to serious energy wastage. For example, where old HWS units have been replaced, plumbers may leave unnecessarily long lengths of pipe in place or, where a gravity fed unit has been replaced by a mains pressure one, 20mm pipe may not have been replaced by 15mm pipe, which holds half as much water. Often when new external HWS units are installed, they will be located near existing wiring or an existing gas meter, rather than in the most appropriate location from an efficiency perspective. In one extreme case, the author found that unnecessary pipework was doubling one household’s hot water bill and leading to frustrating delays in delivery of hot water to outlets.

Hot Water Services

Just under 60% of Australian households have electric HWS units which contribute an average of 3.0 tonnes of CO_2 each year. Almost 35% of households have gas HWS units (up from 25% a decade earlier), which generate on average 1.3 tonnes of CO_2 each year, while 5% have solar HWS units and 2% have other types (most likely wood) (Pears 1998a). This mix gives an overall average of 2.2 tonnes of CO_2 per year per household for hot water. Greenhouse gas emissions from household hot water total around 15 million tonnes of carbon dioxide each year - around 5% of all energy-related emissions. Clearly fuel choice has a major impact on greenhouse emissions from water heating. Table 1 shows the broad options for hot water supply, and their associated greenhouse gas emissions.

Table 1. Hot water service options and associated greenhouse gas rating (the darker the shading the higher the greenhouse intensity - with the highest being 3 to 5 tonnes per annum)

SUPPLY SIDE		ON-SITE FEATURES		
	Energy source	Conversion technology	HWS type	With solar
Fossil fuel[1]	gas	combustion	Instantaneous	░
Renewable[2]			Instantaneous	
Fossil fuel	gas	combustion	Storage	░
Renewable			Storage	
Fossil fuel	gas	Cogeneration or fuel cell	Storage	░
Renewable			Storage	
Fossil fuel[3]	electricity	Resistive	Instantaneous	▒
Renewable[4]			Instantaneous	
Fossil fuel	electricity	Resistive	Storage	▒
Renewable			Storage	
Fossil fuel	electricity	Heat pump	Storage	░
Renewable			Storage	

1. Natural gas or LPG
2. Biogas, wood gas or hydrogen
3. Average Australian electricity
4. Green Power tariff, grid-interactive renewables or renewables supplying a RAPS or remote grid

Resistive electric hot water services are the highest greenhouse intensity hot water sources when using fossil fuel-generated electricity. To significantly reduce their emissions involves minimising standby losses, reducing the greenhouse intensity of the electricity used and/or utilising solar energy. For households with low water usage, resistive electric HWS with minimum standby losses running on a Green Power tariff could well be a cost-effective zero greenhouse emission option. For larger users, other options shown in Table 1 are likely to be more cost-effective.

A key issue to consider when considering cost-effectiveness is the potential for increasing scale of production to reduce the cost of low greenhouse impact options. For example, in 1993, high efficiency instantaneous gas units cost around $1850. Today builders can buy them for around $850. Today, electric heat pump HWS units are quite expensive. But the cost of a small room airconditioner, which uses similar electric and mechanical components, is under $500, so the mass-produced cost of a heat pump HWS should eventually be much lower than today's prices.

In looking to the future, it will also be important to consider the system level impacts of fuel selection. For example, in many regions, electricity demand from off-peak electric HWS units actually creates the daily peak demand and drives investment in expansion of supply capacity. Day-rate electric HWS units are not only costly for users, but contribute to peak electricity demand and thus add to infrastructure cost. Gas water heaters often play a critical role in underpinning investment in expansion of the gas grid by providing a base load. Particularly for electric HWS units, flexible load management controls will be important to minimise both operating costs and greenhouse gas emissions.

Energy-efficient HWS Design

Key factors in design of a HWS unit from an energy and cost-effectiveness perspective include:

- low standby losses
- low cycling losses (especially for instantaneous units)
- high efficiency conversion of input energy to useful heat
- use of low greenhouse impact energy sources
- scope for conversion to low greenhouse impact energy sources
- compatibility with solar boosting
- compatibility with water-efficient showers and taps, and heat recovery from showers etc (that is, ability to deliver hot water at very low flow rates without temperature variation)
- low probability of running out of hot water when water-efficient showerheads are used (and possibly capacity to satisfy high peak hot water demand for existing houses)
- very rapid recovery time (or, alternatively, sufficient storage capacity while avoiding increased standby losses)
- for gas units, relatively simple burner and electronics
- suitability for integrated space and water heating, and/or clothes drying
- relatively compact
- compatibility with existing electrical wiring and gas supply
- for gas units, simple flueing
- cost-effectiveness

It is not possible to deal with all these issues in this short paper, so the reader is directed to Pears (1994, 1997, 1998a and 1998b) for further discussion. Nevertheless a few comments are particularly relevant.

Around a third of the greenhouse gas emissions from water heating result from heat losses from storage tanks and, for those with gas storage units or small households with large electric units, these losses can exceed 60% of water heating energy. Figure 2 shows the impact of standby losses on overall task efficiency over a range of daily consumption for a standard gas storage HWS, the same HWS with electronic ignition and upgraded insulation, and a high efficiency concept HWS proposed in Pears (1998b). Clearly there is substantial scope for improvement.

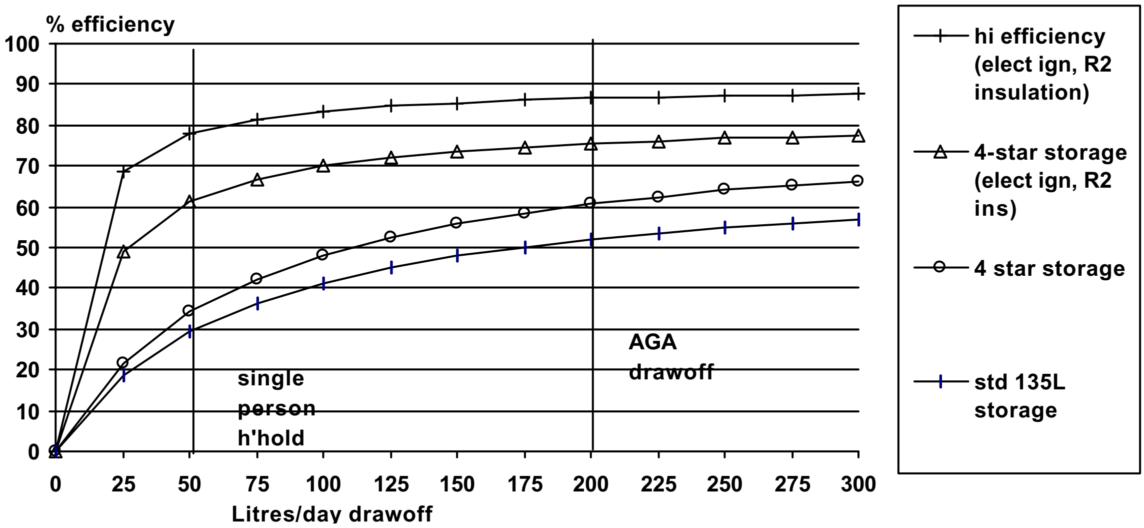
As average household size declines (and water efficiency hopefully improves), losses will comprise an increasing proportion of average water heating energy, unless different design philosophies are pursued.

The introduction of Minimum Energy Performance Standards for electric units larger than 80 litres in October 1999 is a step in the right direction: MEPS requires a reduction in standby heat loss of around 30% from the previous Australian Standard guidelines. But further improvements are needed. And gas HWS units are due for serious attention: removal of energy wasteful pilot lights is long overdue.

Attention should also be given to retrofit measures to improve HWS efficiency of existing units. In some cases, such improvements could deliver savings comparable with those gained from solar boosting at lower cost. This strategy will be important if rapid reduction in greenhouse gas emissions is to be achieved. Possibilities include:

- additional tank insulation for electric HWS units
- retrofit electronic ignition and upgraded insulation for gas units (if the pilot light is not removed when insulation is upgraded, the HWS may overheat)
- external retrofit gas burners for electric HWS units
- solar pre-heaters or retrofit heat pump units (already commercially available) - but tank insulation should also be upgraded
- installation of pressure relief valves on the cold supply, so less water is dumped from the pressure-temperature valve: ideally, insulated P/T valves should be installed

Figure 2. Comparison of task efficiencies of standard, 4-star rated and high efficiency HWS described in text. The significance of effective insulation is shown by two different options for the high efficiency model and the 4-star model. (Pears 1998b)



Heat Recovery

Heat recovery from shower water has the potential to reduce total hot water requirements by up to 30% in moderate climates but, depending on the technique used, may require installation of automatically-adjusting mixer controls in showers, to maintain constant temperatures. This could be promoted as a safety device, to limit temperatures to safe levels for children and the elderly. A variety of heat recovery systems, such as the GFX system, have been developed (Vasile 1997, Proskiw 1998) which recover waste heat from shower water either to pre-heat water being used for showering, or to preheat water flowing into the HWS. Heat recovery could potentially halve the energy required for showering. (Note that the colder the supply water temperature, the larger the potential savings from heat recovery: that is why studies in Canada and other cold regions have identified large savings potential.)

There is also scope to recycle water (or heat) from showers. For example, a scavenging pump could collect, say, a third of the water running to waste from a shower, and mix it with incoming water. The user could cancel this feature when rinsing.

OVERALL HOT WATER SAVINGS

Decisions made during house design and construction, and when a HWS is being replaced have the greatest impact on emissions from water heating. These determine the fuel source and appliance efficiency, types of fittings installed, and lengths and diameters of pipes. Householders have limited involvement in many of these decisions, which are often made by builders, plumbers or designers. These decisions have long-term implications. For example, an electric HWS may generate over 60 tonnes of CO_2 over its life, compared with 25 tonnes for a gas HWS, or less for a solar HWS. And the existence of the wiring and metering, combined with the probability that gas supply will not be available near the location of the HWS, means that the replacement HWS is more likely to be an electric unit. If greenhouse gas emissions are to be minimised, these market failures will have to be addressed.

By adopting water-efficiency improvement options and best technology gas HWS units, Australian households could reduce their average annual greenhouse gas emissions to around half-a-tonne of CO_2 per year using gas HWS (and to below a quarter of a tonne with solar-gas), while resistive electric HWS units could cut emissions to less than two tonnes per year. If resistive electric HWS units were replaced by heat pumps, solar or gas HWS units, or were run on Green Power, their emissions could also fall to below half-a-tonne of CO_2 per year. Total emission savings could exceed 10 million tonnes CO_2 pa.

CONCLUSION

There is tremendous potential to improve the efficiency of and reduce greenhouse gas emissions from domestic hot water supply technologies, and to improve their contribution to quality of life. But 'best technology' energy-efficient system solutions are needed, not systems and products with mediocre efficiency and environmental performance. And an overall systems-oriented approach is needed, not a piecemeal one that focuses just on some aspects of HWS energy efficiency or use of solar energy.

REFERENCES

Allwood P, Pham T and Guthrie K (1995) *Matching water heaters to the load* **Transactions of International Symposium on Energy Environment and Economics,** University of Melbourne Nov.

Australian Consumers Association (1998) *Water-efficient Shower Heads* **Choice** Dec, Sydney

Energy Efficient Strategies (1999) *Australian Residential Building Sector Greenhouse Gas Emissions 1990-2010* Australian Greenhouse Office, Canberra

Pears, A. (1994) *Getting out of Hot Water: Scenarios for Residential Water Heating, Energy Use and Greenhouse Gas Emissions* in **Energy Use and Greenhouse Gas Emissions Scenarios: Three Sectoral Studies** No.11 in A Series of Greenhouse Studies Dept of the Environment, Sport and Territories, AGPS Canberra

Pears, A. (1997) *The Challenge for Efficient Active Heating Systems* pp.39-41 **Hot Stuff Final Report** Centre for Design at RMIT, Melbourne

Pears, A. (1998a) *Strategic Study of Household Energy and Greenhouse Issues* unpublished report for Home Greenhouse Action unit, Australian Greenhouse Office, Canberra

Pears, A. (1998b) *Energy-Efficient, Environmentally-Preferable Gas Appliances For A Sustainable World* Australian Gas Association Annual Convention Nov 1998, Adelaide

Proskiw, G (1998) *Technology Profile: Residential Greywater Heat Recovery Systems* Report for CANMET Energy Technology Centre Energy Technology Branch, Energy Sector, Dept of Natural Resources Canada, Ottawa, Ontario and Manitoba Hydro Electrical Board Winnipeg, Manitoba

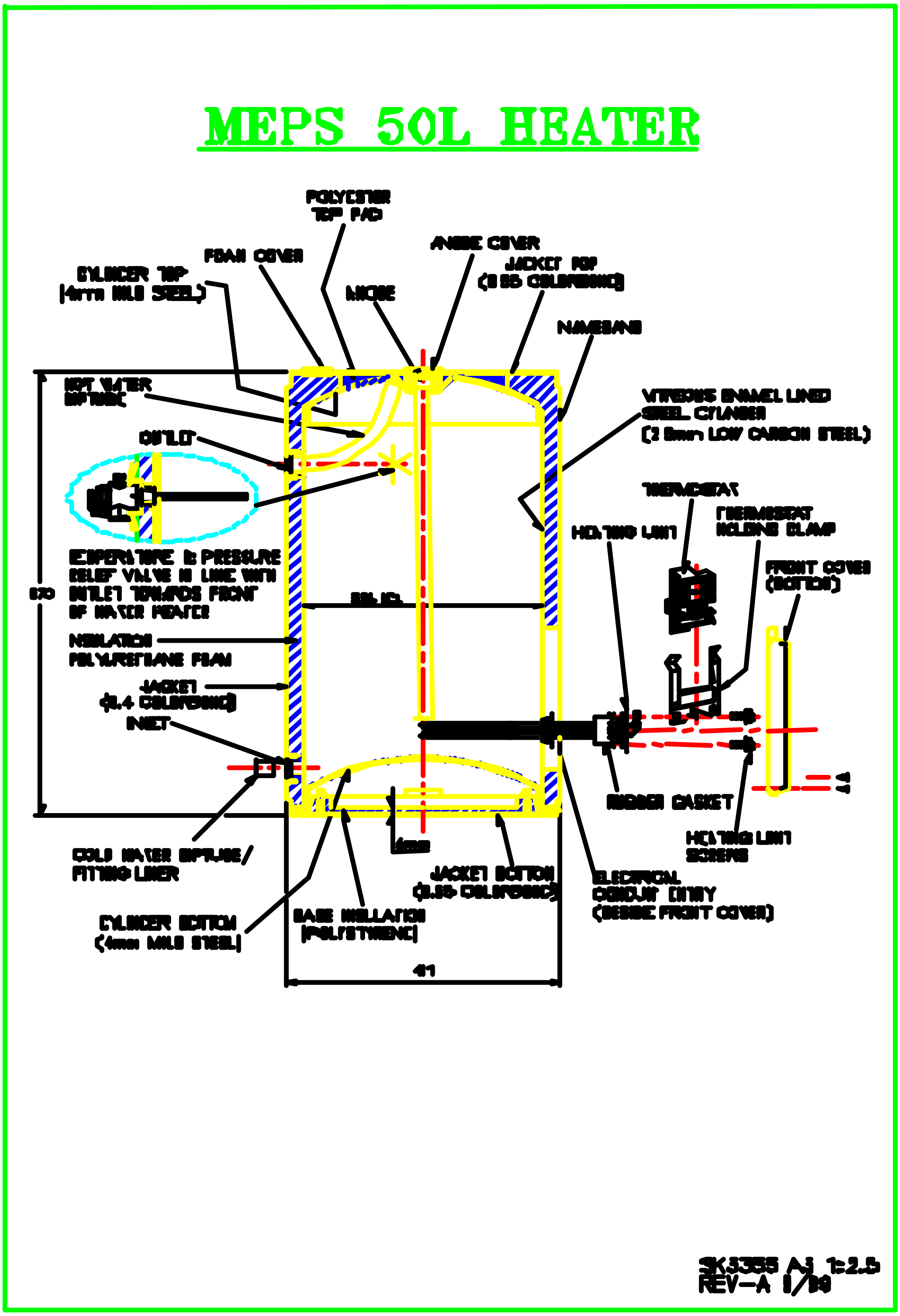
Rheem (1992) *Hot Water Manual* Sydney

Vasile, C. (1997) *Residential waste water heat-recovery system: GFX* CADDET Energy Efficiency Newsletter No 4, December, OECD/IEA Novem B.V., Sittard, the Netherlands

Wilkenfeld, G. (1991) *Residential Appliances in Australia: an assessment of market and technology developments with particular reference to energy-efficiency* Report prepared for the State Electricity Commission of Victoria Demand Management Unit, Melbourne

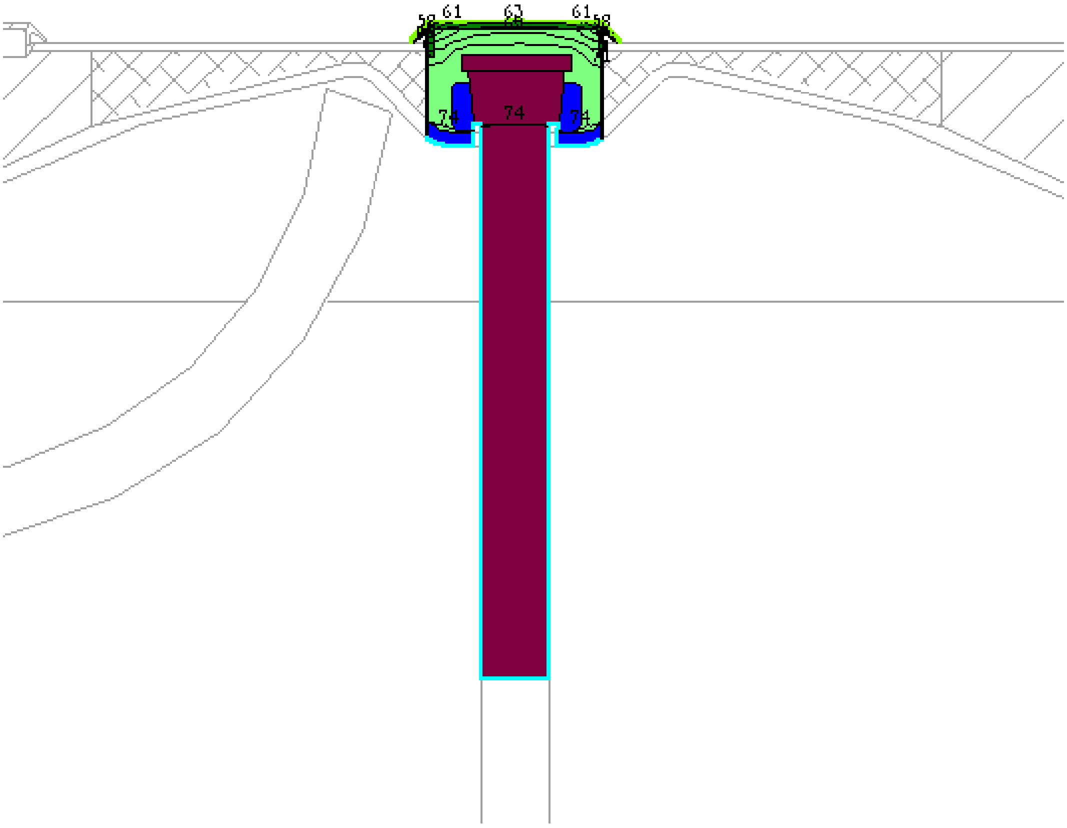
Appendix 3 - Section of a Typical Small Electric Water Heater

The following heater design was provided by Rheem. The detail has been reproduced from a Rheem drawing but it is not to scale.

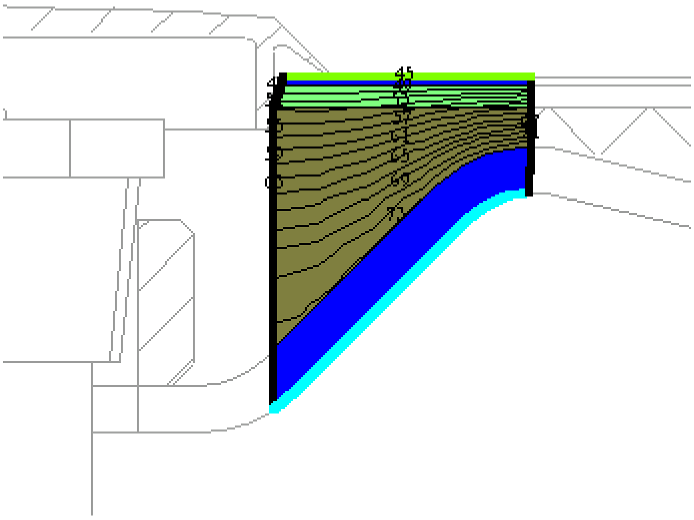


APPENDIX 4 - DETAILED TANK SECTIONS SHOWING ISOTHERMS

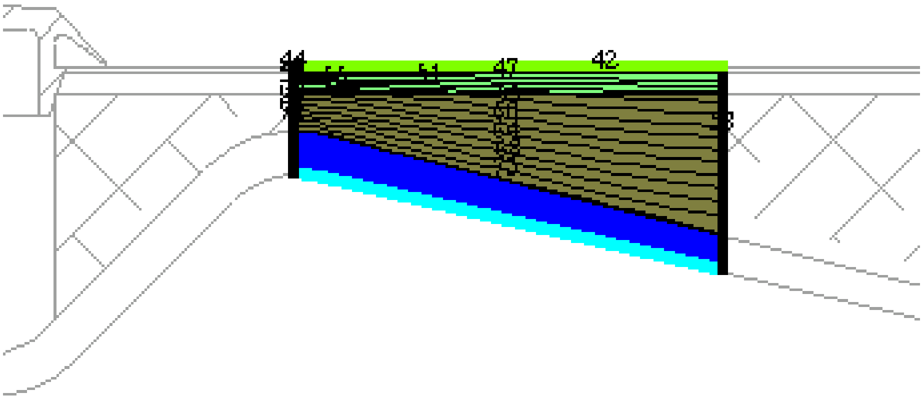
The following graphics shown the 2D isotherms developed by THERM 2.0 in calculating the conductivity of the section.



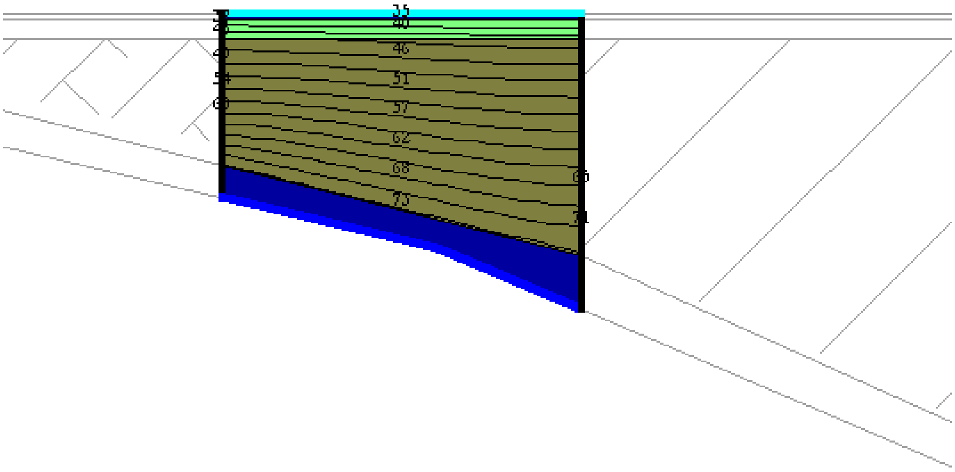
Section No.1 – Anode (shortened)



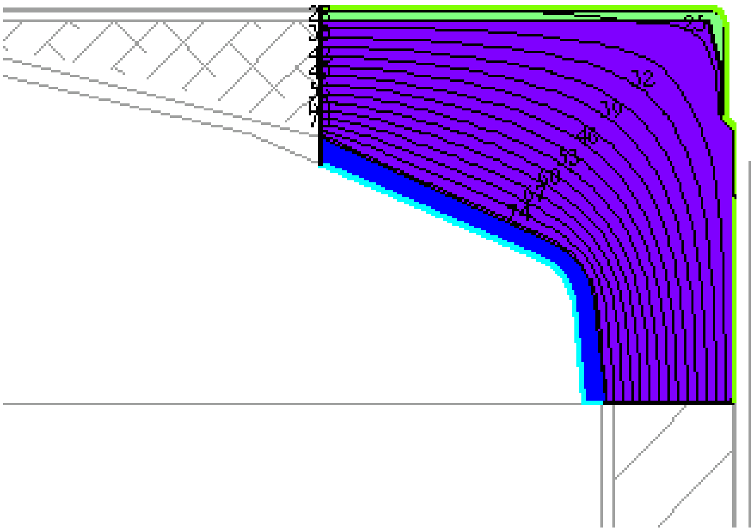
Section No.2 – Top Pad (a)



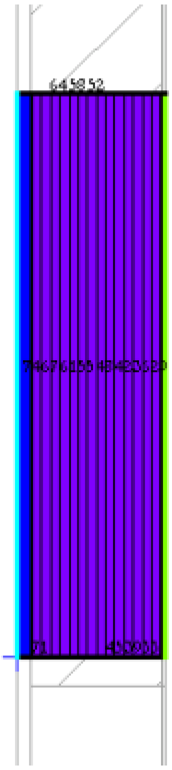
Section No.3 – Top Pad (b)



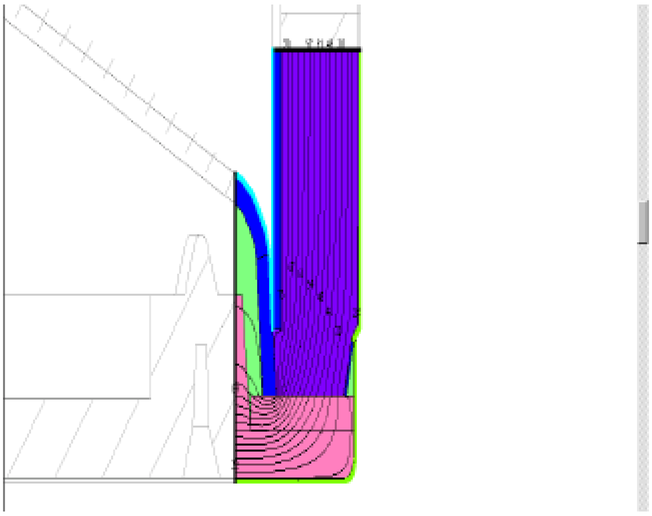
Section No.4 – Top Pad (c)



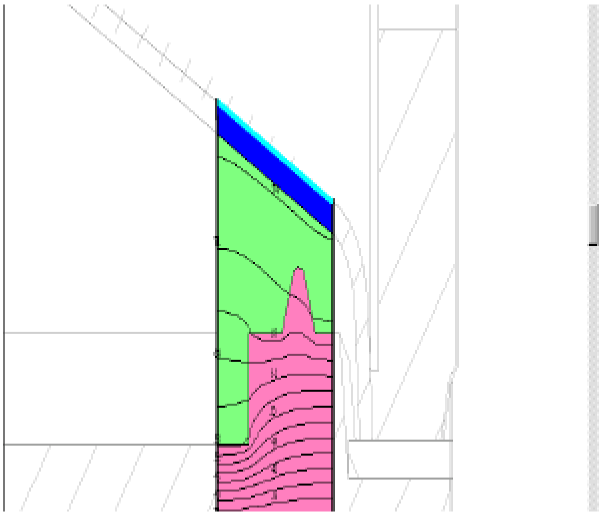
Section No.5 – Top Rim



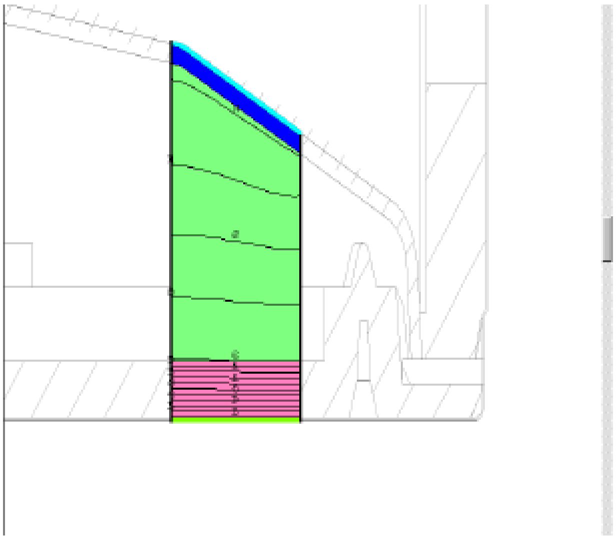
Section No.6 – Tank Side



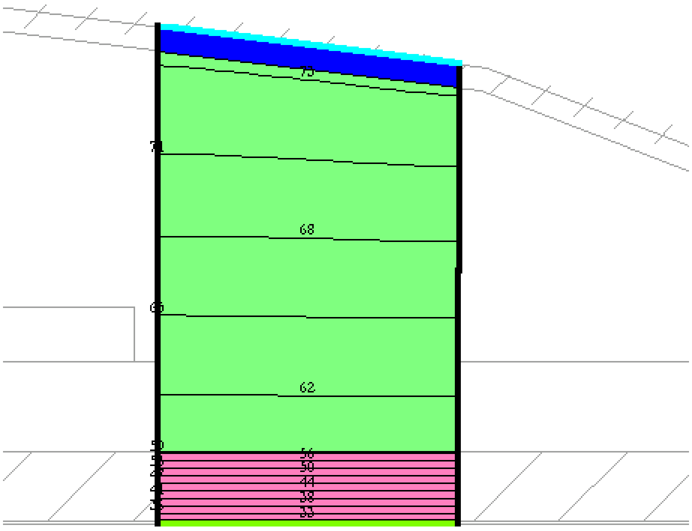
Section No.7 – Bottom Rim (a)



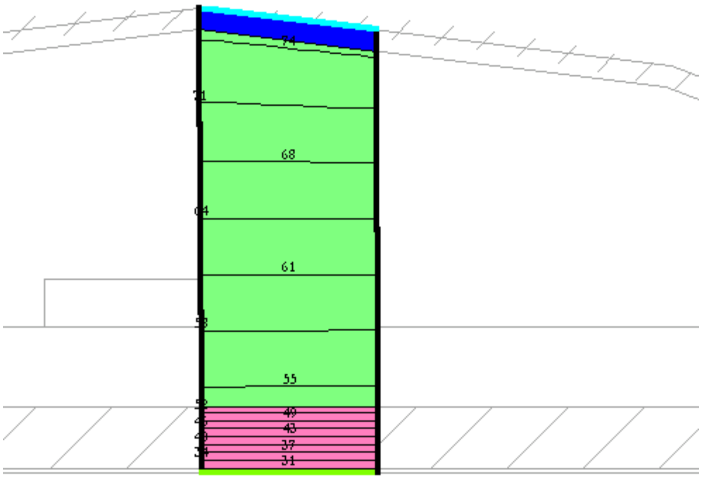
Section No.8 – Bottom Rim (b)



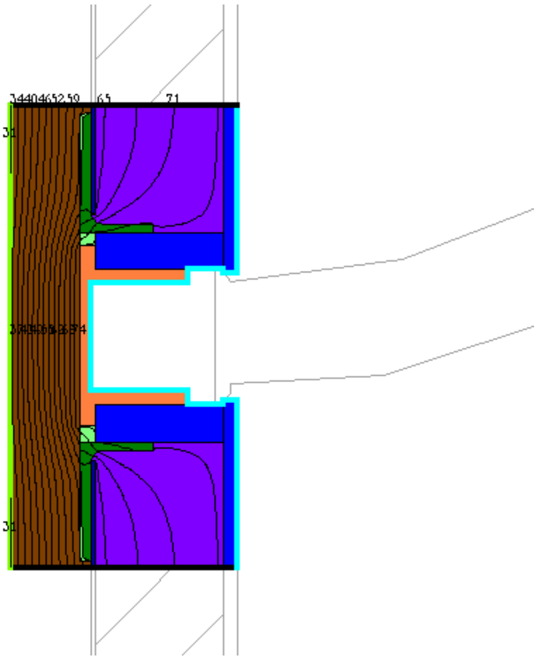
Section No.9 – Bottom (c)



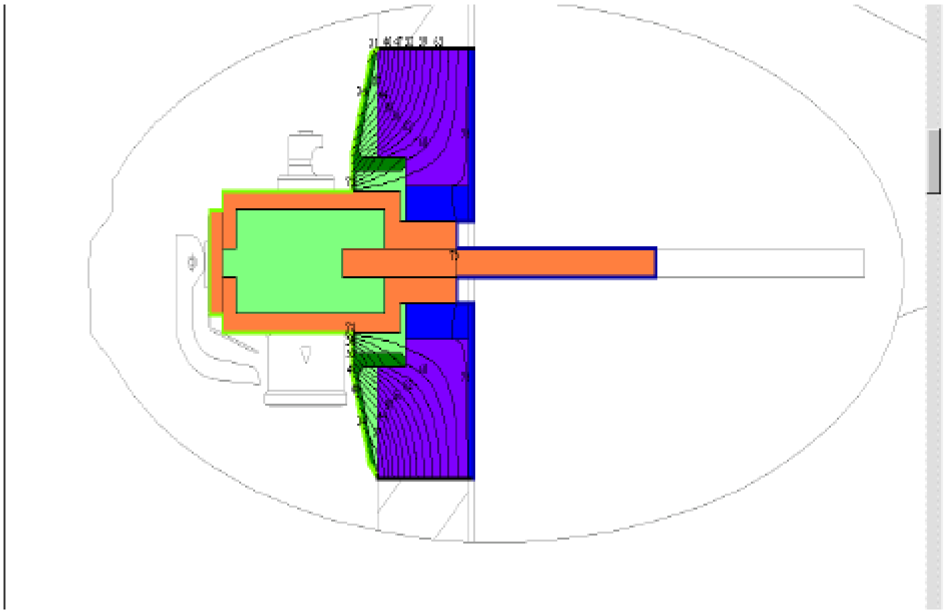
Section No.10 – Bottom (b)



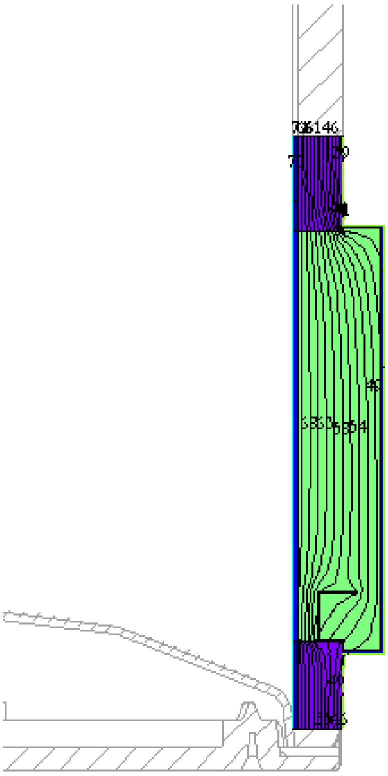
Section No.11 – Bottom (a)



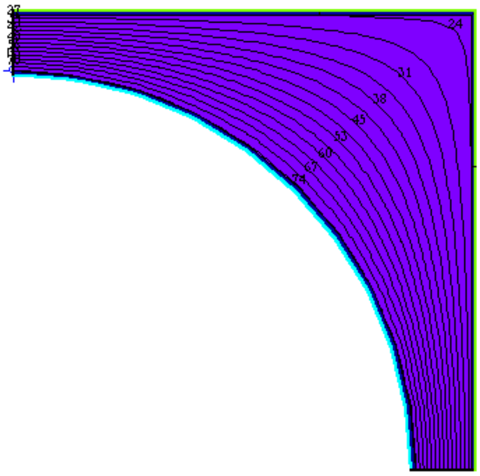
Section No.12 / 12a – Pipe Fitting – Inlet / Outlet (insulated water connection)



Section No.13 – Temperature & Pressure Safety Valve



Section No.14 – Electric Heater Cover



Heat Transfer Through a Square Tank Casing (plan)

APPENDIX 5 -
DEVELOPING 3D RESULTS FROM 2D SIMULATIONS

The following table shows the results of the extrapolation of the 2D THERM 2 heat loss calculations to estimates of 3D heat loss.

RHEEM TANK DESIGN WITH THEIR K VALUE FOR POLYURETHANE

ΔT (K) = 55.0

Polyurethane foam, k (W/mK) = 0.024

Note: all Ux & Uy are equivalent factors based on the composite of the materials.

Tank Section	Section No.	Inner Dia.	Outer Dia.	Hx Length	Ux	Area(x)	Hy length	Uy	Equiv. ky	Area(y)	Loss(x), W	Loss(y), W	Total Loss, W	%	Loss,Wh /24h
Anode	1		51.2	27.5	6.675	0.002		2.119				0.8	0.8	1.1%	18.0
Top Pad	2	51.2	95.4	22.1	3.277	0.005	18.6	3.889		0.004	0.9	0.9	0.9	1.3%	22.1
	3	95.4	175.3	40.0	3.079	0.017	8.9	13.776		0.004	2.9	2.9	2.9	4.1%	69.1
	4	175.3	249.3	37.0	2.040	0.025	11.4	6.614		0.008	2.8	2.8	2.8	3.9%	66.5
Top Rim	5	246.0	356.0	55.0	1.368	0.052	46.2	1.628	0.090		3.9	3.9	3.9	5.5%	93.8
Side less sections 12, 12a,13 &14	6	356.0	411.0	27.5			530.8	0.904	0.025			29.5	29.5	41.7%	707.5
Bottom Rim	7	333.6	356.0	11.2	8.483	0.012	40.6	2.346	0.026		5.7	5.7	5.7	8.0%	136.1
	8	264.1	333.6	34.8	1.370	0.033	13.4	3.545		0.013	2.5	2.5	2.5	3.5%	59.0
Bottom	9	164.1	264.1	50.0	1.784	0.034	18.1	4.930		0.012	3.3	3.3	3.3	4.7%	79.2
	10	64.0	164.1	50.0	1.691	0.018	6.2	13.685		0.002	1.7	1.7	1.7	2.4%	40.1
	11	0.0	64.0	32.9	1.441	0.003	4.1	11.659		0.000	0.3	0.3	0.3	0.4%	6.3
Pipe Fittings - inlet	12	83.8		26.3	5.119		83.8	1.605		0.006		1.6	1.6	2.2%	37.2
Pipe Fittings - outlet	12a									0.006		1.6	1.6	2.2%	37.2
T & P Valve	13	106.7		69.8	16.750		106.7	10.963		0.009		5.4	5.4	7.6%	129.4
Electric heater section	14							5.708		0.026		8.1	8.1	11.5%	194.4
											23.8	70.6	70.7		1695.8

APPENDIX 6 - SUMMARY OF SIMULATION RESULTS

a) RHEEM TANK DESIGN WITH ADJUSTED K VALUE FOR POLYURETHANE

ΔT (K) = 55.0
Polyurethane foam, k (W/mK) = 0.035

Note: all Ux & Uy are equivalent factors based on the composite of the materials.

Tank Section	Section No.	Inner Dia.	Outer Dia.	Hx Length	Ux	Area(x)	Hy length	Uy	Equiv. ky	Area(y)	Loss(x), W	Loss(y), W	Total Loss, W	%	Loss,Wh /24h
Anode	1		51.2	27.5	6.675	0.002		2.119				0.8	0.8	0.9%	18.0
Top Pad	2	51.2	95.4	22.1	3.277	0.005	18.6	3.889		0.004	0.9	0.9	0.9	1.1%	22.1
	3	95.4	175.3	40.0	3.079	0.017	8.9	13.776		0.004	2.9	2.9	2.9	3.4%	69.1
	4	175.3	249.3	37.0	2.005	0.025	11.4	6.503		0.008	2.7	2.7	2.7	3.2%	65.3
Top Rim	5	246.0	356.0	55.0	1.918	0.052	46.2	2.283	0.126		5.5	5.4	5.5	6.5%	131.8
Side less sections 12, 12a,13 &14	6	356.0	411.0	27.5			530.8	1.237	0.034			40.3	40.3	47.6%	968.0
Bottom Rim	7	333.6	356.0	11.2	10.084	0.012	40.6	2.788	0.031		6.7	6.7	6.7	8.0%	161.8
	8	264.1	333.6	34.8	1.370	0.033	13.4	3.545		0.013	2.5	2.5	2.5	2.9%	59.0
Bottom	9	164.1	264.1	50.0	1.784	0.034	18.1	4.930		0.012	3.3	3.3	3.3	3.9%	79.2
	10	64.0	164.1	50.0	1.691	0.018	6.2	13.685		0.002	1.7	1.7	1.7	2.0%	40.1
	11	0.0	64.0	32.9	1.441	0.003	4.1	11.659		0.000	0.3	0.3	0.3	0.3%	6.3
Pipe Fittings - inlet	12	83.8		26.3	5.193		83.8	1.628		0.006		1.6	1.6	1.9%	37.7
Pipe Fittings - outlet	12a									0.006		1.6	1.6	1.9%	37.7
T & P Valve	13	106.7		69.8	17.111		106.7	11.199		0.009		5.5	5.5	6.5%	132.2
Electric heater section	14							5.986		0.026		8.5	8.5	10.0%	203.9
											14.4	84.6	84.7		2032.1

b) IDEAS FOR CHANGE (ABRIDGED)

The following table provides a summary of the analyses undertaken to study various effects on the heater construction.

The reference to “base” refers to the heater with polyurethane with k=0.035W/mK.

With the “”base” design the fittings were assumed to be brass. Changes were made to other materials to examine the effect on heat loss.

	Loss, kWh/ 24h	Change relative to base
Tank Shape		
- tank diameter set equal to height	2.309	+13.6%
Tank insulation thickness increased by 10mm		
- Tank outer casing remains at 411mm but height is increased to 755mm	1.377	-32.2%
- Tank outer casing increased to 431mm and height increased to 690mm	1.550	-23.7%
- Top Pad of tank only	1.974	-2.9%
Electric Heater Section		
Addition of 6.3mm insulation	1.966	-3.3%
Square Tank Casing	1.679	-17.4%
Fittings		
- Bronze temperature & pressure valve	2.020	-0.05%
- Stainless steel temperature & pressure valve	2.009	-1.2%.

c) EFFECT OF ENCLOSURE TEMPERATURE

The following table shows the effect of a change in enclosure temperature on heat loss. The relativity is the change in heat loss relative to that at 55K.

Space Temp, °C	ΔT, K	Loss, Wh/24h	Relativity
15	60	2216.8	109%
20	55	2032.1	100%
25	50	1847.3	91%
30	45	1662.6	82%
35	40	1477.9	73%

d) EFFECT OF PIPING LOSSES

The following table provides an estimate of the heat loss from a section of 12.5 mm diameter x 1.25 m long hot water piping connected to the hot water heater. Values listed as "Internal" are in still air at 20°C (as though the pipes are added in an AS 1056 test) while those listed as "External" are exposed to a 2 m/s breeze but still in an air temperature of 20°C. For comparison purposes, each value is also expressed as a percentage increase over the base case disconnected tank. Again, for comparison purposes, values to three significant figures are shown whereas the accuracy of any individual value will be only two significant figures.

The effect of changing the pipe connection fitting is evaluated under "pipe bridging".

	Pipe Loss, kWh/ 24h	Change relative to base
Vertical Piping – Internal		
- Un-insulated	0.394	+19.4%
- Insulated (12.7mm expanded rubber)	0.169	+8.3%
Vertical Piping – External		
- Un-insulated	0.442	+21.8%
- Insulated (12.7mm expanded rubber)	0.174	+8.6%
Horizontal Piping - Internal		
- Un-insulated	0.285	+14.0%
- Insulated (12.7mm expanded rubber)	0.159	+7.8%
Horizontal Piping - External		
- Un-insulated	0.321	+15.8%
- Insulated (12.7mm expanded rubber)	0.1640	+8.1%
Pipe Bridging **Vertical Un-insulated Piping - Internal**		
- Stainless steel connection	0.387	+19.0%
- PVC connection	0.370	+18.2%

e) EFFECT OF INTERNAL vs. EXPOSED LOCATION

The following shows the effect of locating the "base" hot water heater outside the building where the average wind velocity is 2 m/s. These are "tank only" figures with no pipe losses included - as though an AS1056 test was undertaken outdoors over a full year in the two locations.

	Loss, kWh/ 24h	Change relative to base
Tank externally located - Brisbane	2.236	+10.0%
Tank externally located - Melbourne	2.439	+20.0%