Review of Solar Water Heating Technologies – Discussion Document.

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1. Introduction

The Solar Water Heating Industry in New Zealand is steadily progressing towards a sustainable industry providing durable and high performing products. Whilst the total annual sales are relatively static, there has been an emphasis in recent years on implementing quality and performance Standards, improving Building Consent processes and increasing the number of trained installers.

This document is designed to guide the Industry to consider appropriate technologies to be included in the proposed Customer Assurance Scheme. It is intended to cover the main components of solar water heating systems that are widely available in New Zealand at present.

2. Choice of Collectors:

2.1.Flat Panels

Both flat panel collectors and evacuated tube collectors are widely available throughout New Zealand. In recent years, there has been a pronounced shift towards higher performing collectors in the market place, as a direct result of performance modelling of the systems. With flat panels, there are several factors to consider.

- Absorber material
- Absorber surface
- Glass type / reflective properties.

2.1.1. Absorber Material

The absorber surface can be of copper, aluminium or mild steel. Traditionally the absorber has been of copper which has the longest lifespan since it is not susceptible to corrosion. The continuing high cost of copper has led to some manufacturers using aluminium, which has similar performance. Aluminium is likely to be suitable, providing it does not stay wet, putting the onus on ensuring that moisture control within the collector is maintained. Flat panel collectors are prone to condensation occurring under the glass, and cannot be completely sealed otherwise any moisture that did enter the collector would remain trapped.

Mild steel is used for some absorbers and has a track record of degradation in New Zealand. It is unknown if this is still the case.

Most suppliers of flat panel collectors have at least their premium collectors with copper absorbers. The use of aluminium is relatively new the marketplace, and there is no track record of its longevity. It is likely that aluminium collectors will eventually compete with copper based collectors,

2.1.2. Absorber Coating:

Prior to the EECA SWH scheme, many collectors had non selective absorber surfaces in New Zealand. These have almost all been replaced by selective surface absorbers once the TRNSYS modelling showed the benefits of such coatings. There are two types of selective surface coatings – black chrome, and titanium oxide (eg Tinox). There are readily distinguished by colour – the titanium oxide coatings are bluish in colour.

The titanium oxide coatings have the highest performance, and are now used by most of the flat panel suppliers, at least for their premium collectors. There is an approximate 5% improvement in performance over a black chrome collector, all things else being equal. In reality, the difference can be greater as the premium collectors typically are also better insulated, have a higher grade glass etc.

Some of the earlier titanium oxide coatings had longevity problems, largely caused by moisture in the collectors. Anecdotally, this seems to be improving as collector construction improves, at least with the established collector manufacturers.

Concerns about longevity of titanium based absorber needs to be balanced against the higher performance offered by these collectors. On balance, either black chrome or titanium oxide collectors are suitable for at least the warmer half of New Zealand. Non-selective absorbers are not considered suitable for domestic water heating applications in New Zealand, with the possible exception of Northland.

2.1.3. Flat Panel Collector Glazing:

There are two main options to glaze a collector. The most common is low iron solar glass. Normal glass has a considerable iron content, which absorbs some of the incoming solar radiation, significantly decreasing the performance of the collector. Solar glass is used by reputable collector manufacturers for this reason. Some collectors have a polycarbonate glazing. There are real concerns over the UV stability of these products, and as such are not recommended.

The other variable is the anti-reflective surface of the glazing. A proportion (up to 20%) of the incoming solar radiation is reflected from the surface of the glass, and this both decreases performance, and causes a nuisance factor. It is common practice to use a non-reflective (usually prismatic) surface treatment, which also is commonly combined with a 'safety glass' so in the event of breakage, the glass forms small squares as opposed to shards.

It is recommended that only low iron, solar glass glazed collectors be used by the solar water heating industry in New Zealand for domestic applications. An antireflective surface treatment is encouraged.

2.2. Evacuated Tube Collectors

Evacuated tube collectors are manufactured in two commonly available types, and this is to do with the mechanism used to transfer the heat out of the tube and into the circulating fluid.

- Heat-pipe collectors
- U-tube collectors

The most common, and lowest cost is the heat-pipe collector. This consists of a thin copper tube inserted down the length of the evacuated tube, with heat conducting material interfacing the inner walls of the tube with the heat-pipe. The tube is sealed, and contains a working fluid under a partial vacuum (usually an alcohol or distilled water), which boils at a suitable temperature. The heated fluid rises as a vapour to the top of the pipe to a condenser bulb that is embedded in the manifold at the top of the collector. The solar fluid removes the heat from the condenser bulb, and the fluid condenses, falls to the bottom of the pipe where the process starts over. The ability to maintain a vacuum in the tube is the most contentious part of the evacuated tube heat-pipe collector. Should the vacuum in the heat-pipe be reduced, the efficiency of the collector will steadily decrease.

The recent testing / monitoring of the evacuated tube collectors uncovered that a significant proportion of the collectors had poorly performing heat-pipes. The affected suppliers have either addressed the concerns with the manufacturers or have changed products, and the new collectors in these cases have been retested with in most cases, significantly improved results.

Almost all heat-pipe evacuated tube collectors are installed as open circuit systems, which they are well designed for, and is the recommended installation approach.

The alternative approach for evacuated tube collectors is the U-tube. In this configuration, the fluid in the manifold at the top of the collector is piped through thin copper tubes inside the glass tube, in a U-configuration. This approach overcomes the issues with heat-pipes, and also leads to a slightly more efficient collector (as the heat-transfer is more direct).

The downside of this approach is cost. The manufacture of the collectors is more expensive and the collector cannot be disassembled which increases transportation costs. This is countered by the use of CPC style reflectors behind the tubes to maximise the solar gain available to each tube. This helps to reduce costs as fewer tubes are required for the same energy output, when compared with heat-pipe collectors.

The other cost is installation costs. The U-tube pipes have a small internal diameter, and are prone to blocking through calcification (or other sediments) and also tend to result in steam 'bumping' when installed as open circuit systems. Steam bumping occurs when water that is over 100°C within the U-tube and staying liquid due to the system operating pressure (eg mains pressure), suddenly flash boiling when the user turns on a hot tap (which decreases the system pressure temporarily). As a result, these systems are usually installed as closed circuit systems which increase installation costs.

The recommendation is to accept open circuit heat-pipe systems and closed circuit U-tube systems. The cost of replacing heat-pipes is approximately $NZ15 per tube, which for a whole collector is about the cost of a single change of the glycol. It is difficult to justify excluding heat-pipe evacuated tubes on this basis. U-tube systems usually use water, not glycol as the working fluid.

2.3. Performance of Evacuated Tube Collectors versus Flat Panel Collectors:

This was an area of considerable debate within the industry, which the testing / modelling of the systems has gone a long way to addressing. As a result, it is now generally accepted that a class leading flat-panel of 4.0 m^2 has about the same annual savings as a class leading heat-pipe evacuated tube collector of 30 tubes, and a U-tube collector of 21 tubes (47 mm CPC version) and 15 tubes (58 mm CPC version).

The best way to compare the relative collector performances is to compare test reports for the same tank and modelled at the same load. The AS/NZS4234 test reports provide a valid approach for doing this.

2.4. Energy Star:

For a system to achieve Energy Star labelling, the solar fraction is required to be greater than 70% for the modelled load. Due to EECA grant influences, a number of systems that should be modelled at the large system load are modelled at the medium load to increase the solar fraction to achieve Energy Star. Systems achieving Energy Star status are considered to have oversized collectors, when installed at optimum slopes and orientations. This is compounded by the routine practise of installing the collectors at the slope of the roof, not at 40° as modelled. This further increases summertime solar gain (at the expense of winter) and the likelihood of overheating. For these reasons, selecting systems based on Energy Star I consider is flawed, and a 65% solar fraction requirement would provide a more useful alternative. There is a considerable difference in the risk of overheating between a solar fraction of 65% and 70%.

It is recommended that the specification requires a solar fraction of greater than 65% for Zone 5 (Auckland) when modelled to AS/NZS4234:2008, at a load based on the household occupancy.

2.5. AS/NZS2712:2007

The main component quality Standard for solar water heating systems in New Zealand is AS/NZS2712, and is a requirement of the Acceptable Solution, G12/AS2. AS/NZS2712 is similar in scope to EN12975,1:2006, however it has been adapted to some of the conditions more applicable to New Zealand and Australia. Of most significance is the no-load test, where the ability of the system to withstand several days of no draw-off without releasing large amounts of hot water, or over-heating the tank is determined. This test, due to the predominance of open circuit systems in New Zealand is important.

2.6. Recommended Systems:

The following collector configurations are recommended:

a) Flat panel solar collector with selective surface absorbers with tempered anti-reflective glass, or
b) Heat-pipe evacuated tube collector, or
c) U-tube evacuated circuit collector,

Collectors should be of a sufficient size and performance to achieve a minimum solar fraction (% savings) of 65% for Zone 5 when modelled at the suitable load for the number of household occupants. All systems are to be compliant with AS/NZS2712:2007.

3. Heat-Transfer:

There are several main system designs used for solar water heating in New Zealand.

- Open circuit system
- Closed circuit with glycol (or water with evacuated tubes)
- Closed circuit (drain-back)
- Heat-store systems
- External heat-exchanger designs (dual pump or thermosiphon)

These systems can be either pumped or thermosiphon (except the latter design).

3.1. Open circuit systems

The lowest cost design is the open circuit system. Water is drawn from the bottom of the tank and directly heated within the solar collector, and returned to a point further up the tank. This system design is simple, but requires to have active frost protection during cold clear nights to prevent frost damage occurring. The frost prevention system usually requires an operating pump, so is a risk during power cuts. Flat panel collectors are much more susceptible to freezing damage than are evacuated tube collectors.

Auckland, and areas to the North have a generally mild winter, with relatively few nights during winter requiring active frost protection with flat panel systems. The greater risk, however, is if either the collector sensor or pump fails resulting in the collector to lose its frost protection system.

For the areas south of Auckland, the incidence of frost increases depending on both altitude and latitude. Areas in the central North Island District, and the South Island tend to have substantial frost risk during the winter months. This applies in particular to the inland areas of the South Island. Open circuit, flat panel systems are not appropriate in these locations.

Open circuit, flat panel systems are the most likely systems to undergo frost damage over the long term, which when it occurs, usually destroys the panel. Evacuated tube collectors have a greatly reduced risk of failing due to frost in New Zealand climate, even with electricity, pump or sensor failure, and therefore it is unjustified to exclude them on this basis. Flat panel systems ideally should be installed as indirect systems.

3.2. Closed Circuit, Glycol Based Systems.

It is common practise to install flat panels as closed circuit systems with glycol as the working fluid. Glycol, however has a limited lifespan before it deteriorates and acidifies. As a result, the glycol should be replaced periodically. Manufacturers of glycol for solar water heating applications add stabilisers to their product to extend the lifespan. The expected life varies however, based on product and the temperature the glycol is exposed to. The more frequently the glycol is exposed to higher temperatures, the more rapidly it degrades. Therefore systems that frequently enter stagnation conditions will require more frequent replacement of the glycol. It is for this reason that glycol is not recommended for evacuated tube systems. . A typical lifespan for glycol would be 5 years in a flat panel collector application. The cost of replacing the glycol however, is approximately equivalent to a year of electricity savings from the solar system.

U-tube evacuated tube systems routinely use water as the working fluid as frost protection is not an important drawback with this system design in Auckland.

3.3. Drainback Systems.

These systems are a solution as an alternative to using glycol. During either freezing conditions, or stagnation conditions, the working fluid drains back into a small drain-back tank located on the collector circuit. The increased initial cost of the system is recovered through a lower operating cost (since the glycol is not required to be replaced). There is a small reduction in performance of these systems (compared with a glycol system) due to the heat-loss of the additional drain-back tank. This is partially recovered through using water as the working fluid, which has a higher heat-transfer capacity than glycol. The disadvantage of drain back systems is increased initial cost, and that of ensuring the collector does actually drain back when the pump is not operating. Collectors need to be able to withstand the elevated collector temperatures during stagnation.

3.4. Heat-store systems

Heat-store systems differ to conventional systems in that the solar working fluid occupies the volumne of the tank, and the potable water is in the coil. This enables low pressure on the solar circuit, and mains pressure service hot water. The advantage is that the solar circuit can readily boil, without causing damage to the tank. There is also no requirement for legionella control. In addition, a wetback heater can be readily added to the system. The disadvantage is that the rate of heat-exchange into the potable water coil limits the hot water delivery of these systems. The higher the temperature of the solar fluid, the greater the flow rate that can be achieved.

3.5. Dual Pump, External Heat-Exchanger Designs.

These systems are mostly an attempt to retrofit an existing tank to a closed circuit solar collector. They are not generally recommended due to the added complexity, and the risks of the heat exchanger fouling over time.

3.6. Thermosiphon Systems (tank above collector)

Thermosiphon systems are the most simple, and one of the most common of system designs, with the tank located above the collector. As the fluid in the collector heats, the decrease in density causes it to rise, and displace cooler fluid from the tank, which is then drawn into the collector to be heated. The downsides with these systems are:

- Horizontal tanks exhibit poor thermal stratification. Some systems have the tank inside the house, and vertically orientated, and these perform much better.
- Storage tank is located outside, and exposed to the elements. The heat-loss of thermosiphon tanks can be considerable, especially if they are designed for hotter climates than New Zealand.

- Over temperature control. These systems have a history of dumping large quantities of very hot water onto house roofs, and into gutters. Installers are now required to plumb the TPR waste to a safe location. Some systems now use effective heat dissipation devices. It is difficult to prevent the tank overheating with these designs since heat transfer into the tank cannot be prevented.

Thermosiphon systems can work well as preheater systems, with, for example, a gas califont providing supplementary heating. It is recommended, however, that thermosiphon systems be excluded on the basis that the vast majority of these systems use in-tank electric boosting, and have horizontal tanks. It is possible to design an effective thermosiphon system using a vertical, NZ-MEPS compliant tank, however these systems are relatively rare.

4. Solar Pump

The pump used for solar water heating applications needs to be both bronze bodied and suitable for high temperature operation. The manufacturers of these pumps typically offer only limited duration warranties on them. This is because how the system is installed has a considerable impact on the longevity of the pump. Factors to be considered are pump orientation, water quality and operating temperatures / pressures.

5. Storage Cylinder

The most appropriate material for a solar water heater storage tanks is duplex stainless steel. Other grades of stainless steel can suffer corrosion problems. Steel tanks with an enamel lining are susceptible to corrosion, both through the port connections, and through operation at the elevated temperature commonly attained with solar water heating systems. Low pressure copper tanks (or heat-store tanks) have high rates of thermal destratification, due to the exceptionally high rate of conductivity of copper. The initial cost of a stainless steel tank is worth the investment in the long term, and the extra cost is generally not much more than the cost of replacing the anode once. Usually householders are not aware of the need to replace anodes, and this leads to premature failure of the tank. In addition, many tanks are installed in such a way that replacing the anode requires removal of the tank, which generally prevents the anode being replaced.

5.1.Sizes:

New Zealand tanks are manufactured in a range of sizes. Suggested sizes for new installations are 250 L for up to 4 people, and 300L or more for larger households. The insulation requirements of AS/NZS4692:2005 are more than sufficient for New Zealand applications, and is significantly higher than that required in Australia. The MEPS requirements for New Zealand and Australia is currently under review but it is considered unlikely that it will be considered cost effective to increase insulation levels above the NZ-MEPS level. Al the current level, the heat-loss from attached pipework and valve sets dominates the thermal losses of the tank, and increasing tank insulation will have minimal effect on total thermal storage loss.

5.2. Retrofitting to an Existing Cylinder. :

Retrofitting solar water heaters to an existing electric storage water heater is the most contentious issue within the industry. If done to best practise and the storage tank is appropriately sized, then a cost effective outcome can be obtained. Much more frequently, however, the tank is too small, and the electric element competes with the solar collector, with poor savings as a result. It is not recommended to include these systems, unless the existing tank is a stainless steel tank with solar ready connections, or some other suitable tank design (such as a heat-store tank).

The main problem with retrofit systems is that the existing tank is usually sized for the typical household demand. For solar water heating to be effective, the electric supplementary heater needs to be disabled so cold water is circulated through the panels, rather than already heated water. Whist disabling the electric element is readily achieved through the use of a timer or similar device, this generally will significantly reduce the amount of hot water available. There is therefore a conflict between having an effective solar water heating system and maintaining hot water delivery for use.

Retrofit systems can work well however where the existing tank is of excess capacity (either one or two occupants with a 180 l tank, or a 280 L or greater tank with up to 6 occupants), or where there is no in-tank supplementary heating. This can be achieved using an instantaneous gas heater, so that the solar collector works as a preheater. Some households which are willing to manually control the electric element usage, and adjust their hot water consumption accordingly can have effective retrofit systems.

6. Piping Insulation

The insulation required for the pipes to and from the collector needs to be heat-stable and UV stable. Unfortunately, the material commonly used that is heat stable has poor UV stability, and vice versa. Therefore, the internal pipe insulation should be that which is heat stable, and the exterior insulation should be UV protected, and heat-stable.

7. Solar controller: Recommendation

The controller for the solar water heater is to display, as a minimum, system operating temperatures for the collector, the bottom of the storage tank and the upper region of the storage tank. Tank sensors are to be positioned internally within the tank, in sensor pockets or thermostat housings.

8. General comments.

8.1. The BRANZ Report:

There is considerable comment about what the BRANZ Report on the performance of SWH shows. Project Solar, as an EECA funded project, modelled using TRNSYS as many systems as possible that BRANZ monitored, and as a result gained a very good understanding of the systems involved. The main conclusions that can be drawn from this report were:

- A large proportion of the systems had poor performance
- The root cause of the poor performance was poor control of the element, when positioned at the bottom of the tank, and
- Thermosiphoning at night between tank and collector, and

- High heat-loss of on-roof thermosiphon tanks.
- Systems with mid-positioned elements performed as expected in TRNSYS modelling,
- Some systems with uncontrolled bottom elements performed as expected in TRNSYS modelling,
- TRNSYS provided close correlations to observed performance with many systems, and in particular, with systems that were performing well, or simply had uncontrolled bottom elements.
- Of the 35 or so systems that BRANZ monitored, only 19 systems had datasets that were sufficiently complete that they could be modelled. Of those 19, 10 systems had modelled savings with 10% of monitored savings. Seven of those systems had very close correlations between monitored and modelled tank temperatures.
- It needs to be realised that weather data was not recorded on site for any system, nor did Project Solar have access to any system to determine if, for example, a tree shaded the collector etc. Therefore it is not surprising that there were some discrepancies between the modelling and the monitoring. Weather data was obtained from the closest NIWA monitoring station to the installation, and converted from the horizontal to the installed angle and orientation of the collector.

Monitoring of the systems began prior to the advent of AS/NZS4234 modelling, or at least, before the impact of the modelling resulted in the industry responding to it with new collectors, and widespread use of dual element tanks. The BRANZ Report reads as a cautionary tale to the solar water heating industry of Government subsidies that are not backed up with performance standards. The Industry has generally responded to this, and risen to the new paradigm.

The BRANZ Report is not a rationale for discounting the EECA programme since 2008.

In saying that, there are still system designs that are known to be causing problems within the Industry.

- Open circuit, retrofits to existing non-solar ready tanks
- System with bottom element tanks,
- Thermosiphon systems with high heat-loss from tanks.

8.2.Overheating of Evacuated tube collectors

"Evacuated tubes over perform. They can emit boiling water onto the roof, melting plastic gutters and scalding people"

Evacuated tube systems can have excellent performance, as can flat panel collectors. Systems that are compliant with AS/NZS2712:2007 are unable to emit boiling water onto the roof, and if they do, the quantities are minimal and certainly not sufficient to melt gutters.

Prior to AS/NZS2712, the use of TPR valves on collectors was common on both flat panel collectors and evacuated tube collectors. In both applications, the TPR valve had a short service life since they were not designed for such applications. Installations configured this way using evacuated tubes simply failed quicker due to the higher temperatures generated. The solution that is now widely used is to use a caleffi air vent on the collector, and rely on the non-return valves to allow the collector to safely stagnate. As such, the boiling water issue has been overcome with systems compliant to AS/NZS2712:2007.

8.3. Reliability of Evacuated Tubes

The reliability of evacuated tubes is frequently used in discussions regarding their use. There are two main types of evacuated tube construction, widely available on the New Zealand market.

- Dewar double walled evacuated tubes (most common type)
- Single walled evacuated tube with a glass / metal seal.

The Dewar type has the vacuum entirely enclosed by glass, so only the space between the two walls contains the vacuum. The entire tube is evacuated in the single walled type, and this type relies on the glass / metal seal at the top of the tube to maintain the vacuum. In both cases, the vacuum is maintained through the use of a pure barium 'getter' coating at the bottom of the tube. This is the same technology that was used in older tube style TV sets.

Aside from mechanical damage (eg through bumping, or thermal shock) the incidence of tubes breaking is very low by all accounts, with installations at the University of Otago now 8 years old without a degraded barium getter (indicating that the tube is still evacuated). The systems with the glass/metal seal were considered to be of greater risk, but this risk does not appear to be manifesting itself.

8.4. European State of the Art

The performance of most major suppliers of solar water collectors is listed on the Switzerland based SPF website, and is accessible to the public. The test methodology used to list the performance of these systems is equivalent to AS/NZS2535, which is used for the modelling of the systems in New Zealand to AS/NZS4234. In fact, the only real difference between AS/NZS4234 and that used by SPF is that New Zealand weather data, cold water temperatures and load (hot water demand) profiles are used. The hot water demand profile was determined by BRANZ, as a result of monitoring over 250 houses throughout New Zealand as part of their HEEP Study. Polysun, Tsol and TRNSYS have all been shown to give very similar results when the same systems are modelled. TRNSYS is considered the benchmark thermal simulation software package, and is widely used in research settings.

In terms of system performance, the best systems in New Zealand readily compete with the best systems available in Europe. In terms of system design, there are differences between New Zealand and much of Europe. They are:

- Europe is subject to continental climate influences during winter, and northern Europe is 10° further north than Auckland is south. Therefore, the winter frost issue is much more of a problem in Europe, so open circuit systems have more limited scope.
- Europe often has a high dissolved calcium content in the water, which is not the case in New Zealand's main cities.
- Evacuated tube collectors with glycol as the working fluid are known to have on-going operation costs, due to the deterioration of the glycol. This is a reason for the decline in the prevalence of evacuated tubes in Europe.
- Solar water heating is often combined into central heating system in Europe. In New Zealand, the systems are generally installed as stand-alone systems.

The Standard AS/NZS2712:2007 is very similar in scope and practise to EN12975,1:2006 to which European systems are generally tested. The test methodology in New Zealand is almost identical to that in Australia. There is limited scope for a conclusion that New Zealand Standards are insufficient, when compared to EN12975,1:2006, Solar Keymark, etc.

9. References

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