Performance of Commercially available Solar and Heat-pump Water Heaters

C.R. Lloyd and A.S.D Kerr
Physics Department, University of Otago, Dunedin, NZ
boblloyd@physics.otago.ac.nz

Abstract

In-situ performance data for solar and heat pump hot water systems are not copious in the literature. Otago University has been testing some systems available in NZ for a number of years. The results obtained are compared to international studies of in-situ performance of solar hot water systems and heat pump hot water systems, by converting the results from the international studies into a single index suitable for both solar and heat pump systems (COP). Variability in the international data is investigated as well as comparisons to model results. The conclusions suggest that there is not too much difference in performance between solar systems that have a permanently connected electric boost backup and heat pump systems over a wide range of environmental temperatures.

1. INTRODUCTION

Solar hot water systems are seen as one step in moving towards a future of self sufficiency in energy supply. Recent criticism, by Monbiot 2007, among others, of the trend to replace traditional consumption with "green consumption" of energy efficient products, however, are emerging and warrant that a careful performance analysis be completed for such products before declaring that they will contribute to saving the planet from resource depletion and global warming. Certainly solar systems permanently connected to electric boost supplies, which typically give between 30% and 70% electricity savings can be criticized on the grounds that reducing hot water consumption by between 30% and 70% will give approximately the same energy savings, for no outlay in terms of cost or embodied energy. Similarly installing energy efficient products of any kind will not produce total energy savings while populations rise and the number of such products proliferate.

Performance testing of solar hot water systems and heat pumps has been carried out for many decades, peaking in the 1980s. Unfortunately much of the testing has been on the absorber panel performance and the heat pump module and in ideal conditions rather than on long term whole system performance where the vagaries of the consumer and the weather are taken into account. In particular the interaction of the active system with the storage system has not been extensively documented.

Shariah and Ecevit 1995, noted for thermo-siphon systems that *"Generally the performance of the thermo-siphon system is given in terms of the instantaneous efficiency on clear days. However this does not give the true long term performance of the system because of varying climatic and radiation conditions".* In terms of the user interaction**,** Prud'homme and Gillet 2001, suggested that current control strategies for solar hot water systems "*do not take into account the evolution of the operational conditions, typically the users' needs in terms of draw off and the weather conditions*". Importantly the implementation of control strategies to manage the electric boost that is typically used on many systems has not been a high priority by either system designers or manufacturers. The priority has been on maximizing energy transfer from solar radiation to the storage tank on a given day. The theory at least is that provided there is good thermal stratification in the storage tank and the boost element and thermostat are placed between half way and a third of the way from the top of the tank, then the energy from the boost element will not interfere with solar collection.

Unfortunately there is some evidence that satisfactory thermal stratification may not be always achieved in practice. Jordan and Furbo 2005, note that the stratification depends "*on the flow rate the* *draw off volume as well as the initial temperature in the storage tank"*. Other factors include the orientation of the tank (either vertical or horizontal) the presence of an effective diffuser on the cold water inlet, the flow rates for circulating pumped systems and the geometry and configuration of the boost element. With little or no thermal stratification, a solar hot water system utilizing a simple thermostat control is likely to perform badly, particularly when draw-off occurs either in the evening or early morning, as the boost will turn on and heat the water in the storage tank by the time the sun is high enough in the sky to allow solar collection. Shariah and Lof 1997, looked at four different daily consumption profiles and found that when water was drawn off during the evening and morning the efficiency of the system was reduced. They also found that randomly timed draw offs over a 24 hour period gave the best overall system performance. It should be noted here that if solar collector panels are retrofitted to existing storage tanks it is unlikely that the positions of the control thermostat, panel return line, the boost element or the cold water intake diffuser can be modified to optimally suit solar energy collection.

There are two ways of overcoming the problem of poor storage tank configuration. One is to physically modify the storage tank and booster element arrangement to reduce mixing of hot and cold water; the other is to control the timing of operation of the boost element so that priority is given to solar heating. Solutions relying on reconfiguration can be complex and involve separation of the storage tank into separate compartments or separate tanks (Ragoonanan et al., 2006), resizing or relocating the element inside the tank and resizing or relocating the element outside the main tank. In the latter case the solar system acts as a preheater for an instantaneous electric (or gas) heated system as the boost heater will have no storage attached. All these solutions have been proposed and implemented but they rely on a remanufactured system. Controlling the timing of operation of the boost element can more easily be applied to existing systems with little if any re-engineering. The control system may be a simple on-off timer or a more sophisticated intelligent device that can account for consumer behavior and weather patterns. Prud'homme and Gillet 2001, have proposed optimizing a system including both reengineering the storage tank configuration and by implementing advanced control strategies, including obtaining weather forecasts and automatic prediction of user water draw off. Dennis 2002, has also presented an "*advanced control solution to allow the thermostat to operate with discretion so that less solar energy is displaced by the operation of the auxiliary heater*".

2. METHODOLOGY

The overall performance of a solar or heat pump system that is permanently connected to a (main or backup) non-environmental energy supply can be represented by a variety of indices including the solar fraction and Coefficient of Performance (COP). As the COP is the preferred quantifier for heat pump systems it will be used here, with comparisons to other representations.

The COP for a solar thermal system is defined as the ratio of the thermal energy (referenced to the actual input water temperature) drawn off from the system (Q_{useful_load}) to the non-environmental boost energy input, E_{ne}, to the system. This is expressed by Equation 1.

$$COP = Q_{useful\_load} \;/\; E_{ne} \tag{1}$$

For a heat pump system E_{ne} would be identical to the work input as electricity. Care needs to be taken here to define where Q_{useful_load} is measured. For laboratory measurements (including our own reported in this paper) it is measured at the outlet of the hot water cylinder. Thus losses in the pipe work will reduce the overall COP of the hot water system in a real house.

A COP of greater than one will result if more energy is extracted from the system than the boost energy input, as should be the case with most solar and heat pump water heaters. By the way of comparison, a typical New Zealand standard domestic hot water cylinder (electric resistance heating) would have a COP equivalent of 0.67 (BRANZ, 2005), which means that the standing losses for electric systems are around 33%. This value is a national average measured from around 400 separate systems as part of the BRANZ Housing Energy Efficiency Project (HEEP). The standing losses were measured by monitoring the electricity use in households when there was no draw off of hot water compared to the total energy used for hot water heating.

When there is no environmental energy input, the COP is the same as the efficiency of the system. For a solar system with no boost the COP will be infinite as the denominator is zero. Thus for solar systems the solar fraction (SF) is the more usual defining term and is defined as the proportion of the total load that has been met using solar gain (expressed as a percentage). The solar fraction is given by Equation 2, and represents the percent savings achieved compared to a reference (usually electric) domestic water heater, (Duffie and Beckman 1991). For the same useful energy delivery (Q_{useful_load}) from both the solar and the reference systems:

$$SF\ (\%) = 100^*(Q_{\mathrm{ref}} - E_{ne})/\ Q_{\mathrm{ref}} \qquad (2)$$

And as:

$$Q_{ref} = Q_{useful\_load}/\mathrm{COP}_{ref} \qquad (3)$$

then

$$SF\ (\%) = 100^*(Q_{useful\_load} - E_{ne} * \mathrm{COP}_{\mathrm{ref}})/\ Q_{useful\_load}) \qquad (4)$$

or

$$SF\ (\%) = 100^*(1-\mathrm{COP}_{\mathrm{ref}}/\mathrm{COP})$$

The solar fraction is identical to the percentage savings and as a fraction is given the symbol f_R (Morrison et al 1984) and f_i, (for the i'th month) (Duffie and Beckman 1991).

$$f_R = 1-\mathrm{COP}_{\mathrm{ref}}/\mathrm{COP} \qquad (5)$$

The difficulty of using solar fraction, or percentage savings, as preferred descriptors for solar systems is that these quantities depends on the efficiency of a nominated reference system (this efficiency will be the same as $\mathrm{COP}_{\mathrm{ref}}$) and thus the descriptor will be dependent on environmental conditions including the ambient dry bulb temperature. In Europe the reference system is likely to be a fossil fuel powered boiler system rather than a resistively heated electric system, further complicating the situation (Thur et al., 2006).

Another descriptor is the "solar contribution to the useful load" f , which is defined as:

$$f = (Q_{\mathrm{useful\_load}} - E_{ne})/\ Q_{\mathrm{useful\_load}} \qquad (6)$$

or

$$f = (\mathrm{COP}-1)/\mathrm{COP} \qquad \text{(e.g. Morrison and Tran., 1984)} \quad (7)$$

.

And thus if the solar contribution to the useful load (f) and the solar fraction, SF (or $f_{R)}$ are known then the $\mathrm{COP}_{\mathrm{ref}}$ can be calculated from:

$$\mathrm{COP}_{\mathrm{ref}} = (1-f_R)/(1-f) \qquad (8)$$

Andersen 1998, working at the Technical University of Denmark, defined the 'solar fraction' as the net utilised solar energy (NUSE) divided by the energy drawn off from the system Q_{useful_load}, where NUSE $=Q_{useful\_load} - E_{ne}$. This quantity is the same as the 'solar contribution to useful load' but different to the Duffie and Beckman 1991 definition of solar fraction.

Carrington et al., 1984 used another term, the 'System Performance Factor' or SPF to categorise heat pump systems. The SPF was defined as the ratio of the equivalent electrical energy input into a resistively heated system to the actual energy used by the heat pump. In our notation this factor would be given by:

$$\mathrm{SPF} = Q_{\mathrm{ref}}/\ E_{ne} \qquad (9)$$

And thus for the test system:

$$\mathrm{COP} = \mathrm{SPF} * \mathrm{COP}_{\mathrm{ref}} \qquad (10)$$

In addition to using COP to characterize short term laboratory based measurements of heat pumps, the long term performances of solar or heat pump systems that are permanently connected to a (main or backup) energy supply can be represented by a coefficient of performance (COP). Here the COP is calculated over the period of concern i.e. day, month or year. It is important to note that COPs cannot be averaged, but the aggregate COP can be calculated for the period of concern by dividing the total energy output over the period divided by the total non-environmental energy input over the period. In the later discussion descriptors used in other internationally published results for solar systems and heat pumps are converted to COPs and compared to our own results using the relationships as given above.

While E_{ne} is well defined and can be measured directly for an electrically boosted system by integrating the electrical power over the time period, Q_{useful_load} is more difficult to measure as it needs to be ascertained by knowing the flow rate of the output water and the temperature difference between the hot water output and the cold water input. As the temperature in the storage cylinder of a solar system is frequently above the thermostat set point due to solar gain during the day, a set volume of water can have a varying Q_{useful_load} on any given day depending on the cold water temperature (T_{cold}) and the actual temperature reached by the system during the day (T_{hot}) .

$$Q_{useful\_load} = mC_p \ (T_{hot} - T_{cold}) \tag{11}$$

Where m is the total mass of water output over the time period and C_p is the specific heat of water at the mean water temperature.

3.COMPARISON OF SYSTEMS

Our experimental results have been reported separately (Kerr and Lloyd 2006). With an annual average solar insolation of 11 MJ/m2 per day or 3 kWh/m2 per day Dunedin has the lowest solar radiation of any of the main centres in NZ. Nevertheless the solar regime is comparable with many parts of Germany and better than most of the UK. The performance of two of the flat plate systems we tested, with COPs of 0.64 and 1.02 were not, however, considered satisfactory. The pumped system with the COP of 0.64, in particular had a COP slightly poorer than the reference restively heated electric storage system and the thermo-siphon system tested could almost be equalled by a either an instantaneous resistively heated electric system (or gas) or a super insulated resistively heated storage system. It might be noted here that the performance for the particular systems is not suggested to be relevant to generic systems of the type described and in fact discussions with the manufacturer's representative has led us to believe that the flat plate thermo-siphon system, at least, was not installed optimally for the latitude of Dunedin and that there were a number of endemic problems with the pumped flat plate system, that if corrected would considerably enhance the performance of that system. In particular this latter system was plumbed to a conventional hot water storage tank with an uncontrolled boost element and a heat transfer system that was non standard. The aim of the present series of tests was, however, not to test optimum systems but to gain some idea of the performance of actual systems as they might be installed in the wider community. Clearly there is room for improvement in this regard. Results by Guthrie et al., 2005 suggested in their paper that the performance of systems in-situ may improve if a large subsided rollout is put in place with recognition given to improved performance. This finding is particularly relevant to the NZ situation as the current (2007) subsidy scheme is strongly performance based.

In terms of international comparisons, as mentioned, there is a relative dearth of reliable data for complete systems, especially in-situ testing. Carrington et al.,1984 measured laboratory performance of a specific design of hot water heat pump (separate condenser and evaporator with pumped flow to an existing storage tank) with COP results ranging from 2.39 to 2.95 for an output water temperature of 55 ^{o}C and ambient temperatures between 5 ^{o}C and 20 ^{o}C. The same group measured in-situ results for seven heat pump hot water heaters located in residential households in Dunedin and Auckland, finding 'System Performance Factors' ranging from between 1.6 and 2.6. These SPF values would correspond to COPs ranging from 1.06 to 1.7 using a reference COP (COP_{ref}) of 0.67, suggesting that in-situ results for complete systems may be somewhat lower than laboratory measurements. The in-situ measurements were for heat pump systems retrofitted to existing storage tanks, which at that time were relatively poorly insulated. The tank standing losses reported by Carrington et al., 1984 were given as 2.63 kWh/day for a 180 litre tank at 55 ^{o}C. The BRANZ 2004 standing losses for the 2004 HEEP study were comparable and were measured between 2.2 kWh/day for well insulated 180 litre storage tanks and 2.7 kWh/ day for the same size less well insulated tanks and measured at actual storage temperatures experienced in-situ.

Morrison et al., 2004 tested both solar systems and heat pumps. For heat pumps they found that in Sydney, Australia a COP of 2.3 was possible for a heat pump system in a laboratory situation with an integral condenser and 1.8 for systems with an external condenser. Lloyd, 2001 found exactly the same value (2.3) for the COP of heat pump hot water systems (integral condenser) used in-situ in

Aboriginal communities in central Australia. Our present results indicate COPs of just under 2 could be obtained in Auckland, which has a somewhat cooler climate than Sydney). Merrigan and Parker 1990 found in Florida USA that *"Heat pump water heaters have a system efficiency roughly twice that of an electric resistance heater and operate at a load factor of 52%"*. This would correspond to a COP of 1.64 given that in Florida the reference electric heaters had an average COP of 0.82.

For solar systems Prud'homme and Gillet, 2001 found with advanced control technologies that COPs of between 1.5 and 1.7 were possible for flat plate solar domestic systems in Switzerland. Knudsen, 2002 at the Technical University of Denmark found that consumer behaviour had a great influence on performance and that: "*A previous investigation showed that the thermal performances of small Danish SDHW systems are much lower than expected and that the thermal performances of systems in practice are lower than the thermal performances of similar systems tested in the laboratory*.. Andersen, 1998, working at the same institution in Denmark, measured the laboratory performance of 18 different systems (with collector areas from 4-6 m^2 and tank volumes ranging from 200l to 300l) and in addition measured the in-situ performance of a further 32 systems. The results for both the laboratory tests and the in-situ testing were reported using annual NUSE and the annual solar fractions (figure 1).

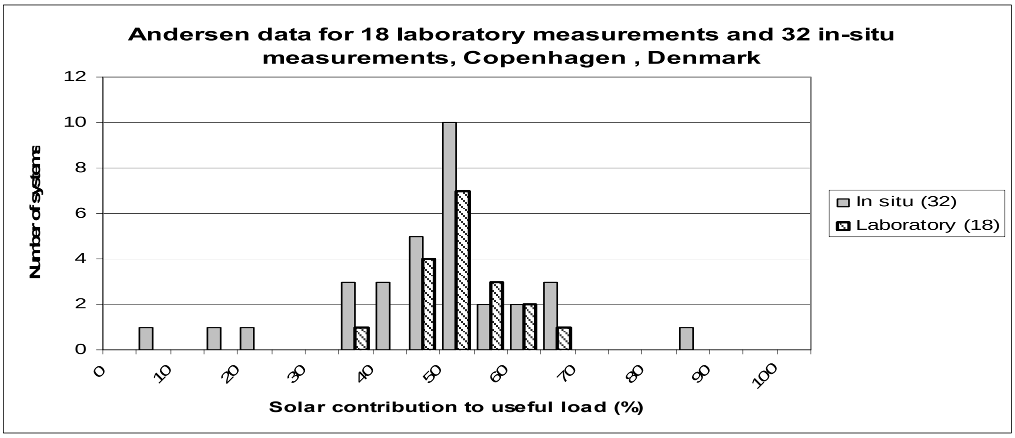

Figure 1: Solar system performance data from Andersen, 1998

These results show a much higher variability for the in-situ measurements, as might be expected considering a much wider range of draw of volumes that occur in real household. When the reported solar fractions and 'net utilised solar energy' (NUSE) were converted to COPs they gave an aggregate COP for the 18 laboratory measurements of 1.9. The corresponding value for the in-situ results was found to be 1.7, suggesting that the in- situ results were around 12% lower than the laboratory results. The annual average insolation for Copenhagen is close to the Dunedin value of 3 kWh/m2/day and the annual average temperature is also close to the Dunedin annual average of 11 degrees.

Tully, 1995, working in South Africa, found that the back up element size had a marked effect on the COPs of solar thermo-siphon systems. This researcher found for a horizontal tank and a 1kW element, a COP of 2.1. Using a vertical tank, which enables a higher degree of thermal stratification, the COP improved dramatically to 3.9 for a 1kW element and 3.0 for a 6 kW element. Morrison and Tran, 1984 measured COPs for thermo-siphon systems of around 2.3 and Lloyd, 2001 found a COP of around 1.7 for thermo-siphon systems monitored in-situ, but this was for Aboriginal communities in central Australia where the daily draw off rates were extremely variable and often very high. Van Amerongen and Bergmeijer 1991, found energy savings of between 23% and 51% for a series of domestic solar hot water systems in the Netherlands. These researches also suggested that their work showed "*clearly that the actual energy savings of a SDHW heavily depend on the performance of the total combination of SDWS and auxiliary heater.*

Guthrie et al., 2005 reviewed a Victorian state government subsidy program which resulted in the installation of some 9507 solar hot water systems. These researchers obtained annual electricity consumption data both before the installation of the solar systems and after, for a subset of 31 of 500 systems surveyed as part of the subsidy program. The results gave an average annual savings of 54% corresponding to an aggregate COP for the systems of 1.51 using a reference COP (COP_{ref}) for Melbourne of 0.7. In addition these researchers compared the savings for each system to that obtained using the TRNSYS modelling program. The draw-off rates and other input data for the computer simulation were as for AS4234. The Guthrie et al., 2005 results are reproduced as a frequency distribution below in figure 2 showing the percentage differences between the actual annual savings and the savings predicted by the TRNSYS simulation configured to AS4234. On average the simulation over predicted the actual savings by around 11%.

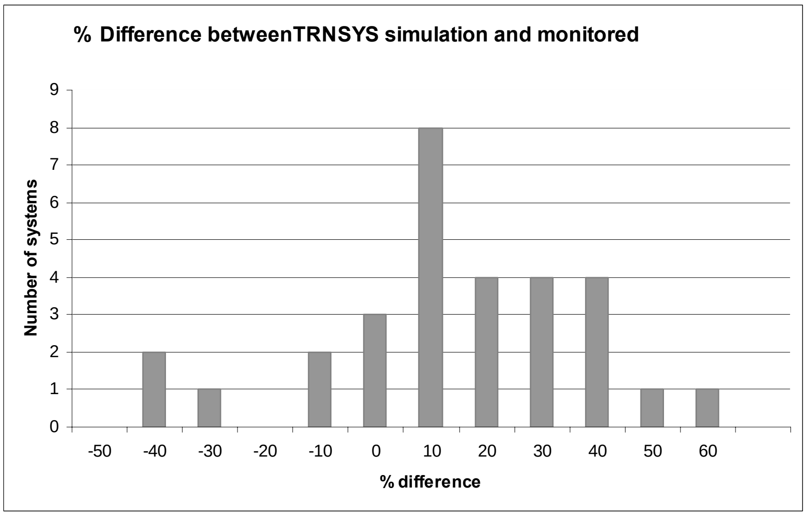

Figure 2: 30 solar systems in situ: data from Guthrie et al 2005

Figures 3, 4 and 5 show results from the literature research converted to COP values of actual operational solar systems and heat pumps (figure 12 only) of various types plus our own results for Dunedin as a function of both average annual solar radiation (kWh.m2/annum) and average annual ambient temperature. As can be seen, average ambient temperature with an R^2 value of 0.4296 is a better predictor of system performance than solar radiation for solar systems. Note that the trend lines are not to be interpreted as assuming a linear relationship between COPs and either ambient temperature or solar insolation but as a means of comparing solar system performance with heat pump system performance.

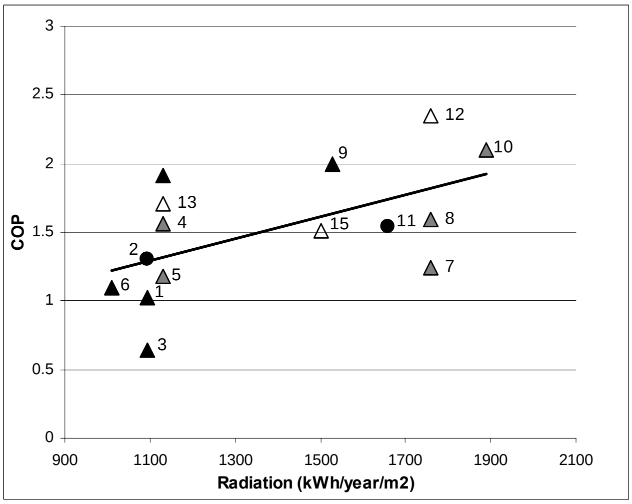

Figure 3: COP versus solar insolation, solar systems.

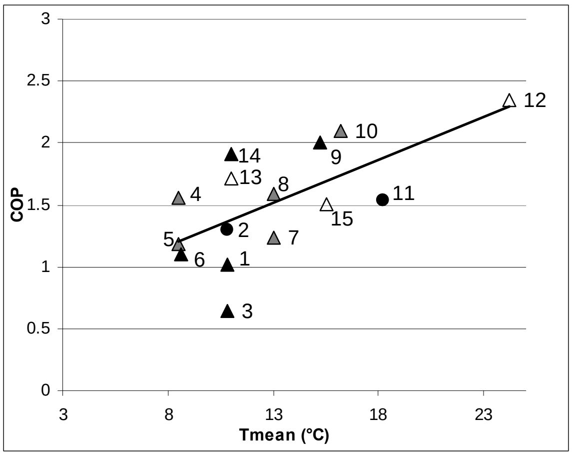

Figure 4: COP versus ambient temperature, solar systems.

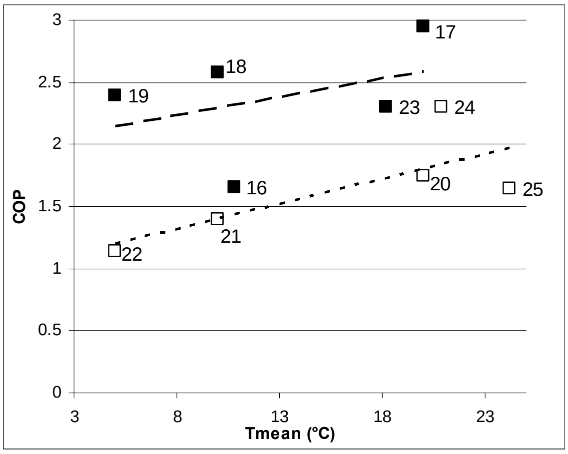

Figure 5: COP versus ambient temperature, heat pump.

Key for figures 3, 4 and 5.

	Model only	Laboratory	In-situ
Flat plate	▲ (grey)	▲	Δ
Evacuated tube		●	○
Heat pump		■	□

	Location	References	Notes
1 - 3	Dunedin (New Zealand)	Present results	Laboratory but based on whole systems
4, 5	Switzerland	Prud'homme and Gillet, 2001	Model based on whole systems
6	The Netherlands	Van Amerongen and Bergmeijer 1990	Laboratory but based on whole system
7, 8	Canberra (Australia)	Dennis, 2002	Model based on whole system
9	Auckland (New Zealand)	Present results	Inferred result from laboratory in Dunedin
10	South Africa	Tully, 1995	Model based on whole system
11	Sydney (Australia)	Morrison and Tran,1984	Laboratory but based on whole system
12	Florida	Merrigan and Parker, 1990	In-situ measurements in family residences
13, 14	Denmark	Anderson, 1998	Laboratory tests and in-situ measurements
15	Melbourne (Australia)	Guthrie et al., 2005	In-situ measurements
16	Dunedin (New Zealand)	Present results	Laboratory based on whole system
17-19	New Zealand	Carrington et al.,1984	Laboratory tests with no storage
21-22	New Zealand	Carrington et al.,1984	In-situ tests of complete systems
23	Sydney (Australia)	Morrison et al., 2004	Laboratory but based on whole system
24	Alice Spring (Australia)	Lloyd, 2001	In-situ measurements in 4 remote aboriginal communities
25	Florida	Merrigan and Parker,1990	In-situ measurements in family residences

Source of climate data: RETScreen® International. Clean Energy Project Analysis Software. Version 3.1. Minister of Natural Resources Canada 1997-2005. CTEC-Varennes (RETScreen, 2005).

The COP values for heat pump hot water systems and direct solar systems with a permanently connected boost showed considerable overlap for most temperature regimes. Heat pump systems are less likely to experience poor performance due to variations in draw off times or a lack of control strategy but solar systems on the other hand have the potential to produce hot water without any non-environmental energy. The heat-pump system tested had a thermostat set temperature of 55ºC, with typical outlet temperatures recorded in the range of 48-52ºC. These temperatures, however, do not meet the local building requirements for Legionella control.

4. CONCLUSIONS

Reliable data is needed on the performance of solar and heat pump systems to allow informed policy decisions to be made, especially where government funds may be used to promote deployment of such systems. The results reported here suggest that solar hot water systems are at best marginal in the lower parts of the South Island in NZ in terms of performance, if the systems do not have some control of the boost element activation. The results also suggest that heat pump systems compete over all temperature regimes with direct solar systems. This conclusion is in some disagreement with a simulation study undertaken by Aye et al., 2002 at Melbourne University, Australia where it was found that direct solar systems outperformed heat pump systems for the warmer cities in Australia but heat pump systems were better performers in the cooler environs of Melbourne and Hobart. It might be noted here that most population centres in NZ are cooler on average than Melbourne. The present results, however, did not have access to results for solar systems operating in very high sunshine conditions.

In terms of the product type tested, the evacuated tube product gave the best results for a direct solar system giving savings of 1.25 times that of the (selective surface collector) flat plate thermo-siphon system on a square metre of collector area basis. This result is consistent with other research; Morrison and Tran, 1984 for instance found that the efficiency of evacuated tube collectors was about 1.8 times that of a non selective surface flat plate collector and 1.3 times that of a selective surface flat plate collector per collector area when measured in Sydney, Australia.

There was, however, a substantial spread in performance between the products as tested as found by Andersen, 1998. In NZ heat-pump technology is likely to result in a better match between security of supply, GHG emissions and reduced peak transmission loading compared to the solar option and therefore should be considered as a part of a strategy to reduce household energy consumption.

The research also found that the performance of both types of technologies, particularly solar systems, can be markedly improved through the use of auxiliary controllers (e.g. timers) to prevent the non-environmental energy source coming on during the daytime. This result is in good agreement with Prud'homme and Gillet, 1998 who found that the solar fraction increased from 15% to 46% with the introduction of an optimal boost control strategy. Heat-pump systems are likely to benefit from the use of timer set for afternoon operation during the winter months to reduce the risk of icing of the evaporator coils. Further work needs to be done on optimising the boost control methodology as applying it to real households will have to take into account the complexities of highly variable draw off rates and times and possible interaction with utility load control strategies.

NZ is currently adopting a common set of standards with Australia in order to encourage the industry to maintain a higher level of product but this is difficult to enforce especially when systems are allowed to be retrofitted to existing storage tanks, as was the case for the pumped flat plate collector tested. In addition, unless the standard requires physical testing of all combinations of product available, a move that would be both expensive, time consuming and resisted by the industry, real savings from systems with a high degree of user variability are unlikely to match those promoted by the industry and, importantly, used to calculate greenhouse gas savings. In this regard the move by the NZ government to implement a subsidy program based on whole system performance, as determined by TRNSYS simulations, (with physical measurements for components) is clearly in the right direction.

5. REFERENCES

Anderson, E., 1998. *Thermal Performance of Small Solar Domestic Hot Water Systems In Theory, In The Laboratory And In Practice.* In: Proceedings of EuroSun 1998.

Aye, L., Charters, W. W. S., Chaichana, C., 2002. *Solar heat pump systems for domestic hot water.* Solar Energy, 73, 169-175.

BRANZ, 2004. *Energy Use in New Zealand Households*, Study Report No. SR 133 – Report on the Year 8 analysis for the Household Energy End-use Project (HEEP), Building Research Association of New Zealand.

Carrington, C.G., Sandle, W.J., Warrington, D.M., Bradford, R.A., 1984. *Demonstration of a hot water heat pump system. New Zealand Energy Research And Development Committee*, Report No. 102, ISSN 0110-1692.

Dennis, M.K., 2002. *Predictive energy balance for solar hot water systems*. In: Proceedings of Solar 2002 – Australia and New Zealand Solar Energy Society, ANZSES

Duffie, J.A., Beckman, W.A., 1991. *Solar engineering of thermal process.* Second ed. Wiley Interscience, New York, pp 450-451

EECA 2006, Energy Efficiency and Conservation Authority of NZ. *Increasing the solar uptake of solar water heating. A government discussion document*, September 2006.

EECA/CAE, 1996. *New and Emerging Renewable Energy Opportunities in New Zealand*, A joint publication by the Energy Efficiency and Conservation Authority and the Centre for Advanced Engineering (CAE), University of Canterbury, New Zealand

EECA, 2007. Solar water heating programme newsletter, Issue 4 – 2 April 2007.

Guthrie, K., Hines, R., Stockwell, S., Doddathimmaiah, A., 2005. *Victorian Solar Hot Water Rebate Program, Review of Outcomes 2000-2004*. In proceedings of Solar 2005 - Renewable Energy for a Sustainable Future, A challenge for a post carbon world - ANZSES 2005.

Jordan, U., Furbo, S., 2005. *Thermal stratification in small solar domestic storage tanks caused by draw-offs*. Solar Energy, 78, 291-300.

Kerr and Lloyd C.R. 2006 *Experimental and Simulated Performance of Commercially available Solar and Heat-pump Water Heaters in New Zealand*. Paper presented at the Australian and New Zealand Solar Energy Society annual conference, Melbourne , Australia , 2006

Knudsen, S., 2002. Consumers' influence on the thermal performance of small SDHW systems — Theoretical investigations. Solar Energy, 73, 33-42.

Lloyd, C.R., 2001. Renewable energy options for hot water systems in remote areas. Renewable Energy, 22, 335-343.

Lloyd, C.R., Callau, M., 2005. *Monitoring of energy efficiency upgrades in state houses in southern New Zealand*. In proceedings of Solar 2005 - Renewable Energy for a Sustainable Future, A challenge for a post carbon world - ANZSES 2005.

Merrigan, T., Parker, D., 1990. *Electrical Use, Efficiency, and Peak Demand of Electric Resistance, Heat Pump, Desuperheater, and Solar Hot Water Systems*. American council for an Energy Efficient Economy, Asilomar conference centre, Pacific grove, August 1990.

Monbiot G. *Green consumerism will not save the biosphere*. Guardian Newspaper, UK, 24th July 2007

Morrison, G.L., Anderson, T., Behnia, M., 2004. *Seasonal performance rating of heat pump water heaters*. Solar Energy, 76,147-152.

Morrison, G. L., Tran, N. H., 1984. *Long term performance of evacuated tubular solar water heaters in Sydney, Australia*. Solar Energy, 32, 785-791.

Prud'homme, T., Gillet, D., 2001. *Advanced control strategy of a solar domestic hot water system with a segmented auxiliary heater*. Energy and Buildings, 33, 463-475.

Prud'homme, T., Gillet, D., 1998, *Optimisation of solar domestic hot water systems*, Proceedings of Eurosun 98.

Ragoonanan, V., Davidson, J.H., Homan, K.O., Mantell, S.C., 2006. *The benefit of dividing an indirect thermal storage into two compartments: Discharge experiments*. Solar Energy, 80, 18-31.

Retscreen 2005: Retscreen International. Clean Energy Project Analysis Software. Version 3.1. Minister of Natural Resources Canada 1997-2005. CTEC-Varennes.

Shariah, A.M., Ecevit, A., 1995. *Effect of hot water load temperature on the performance of a thermosyphon solar water heater with auxiliary electric heater.* Energy conservation management, 36, 289-296.

Shariah, A.M. and Lof, G.O.G., 1997. *Effects of auxiliary heater on annual performance of thermosyphon solar water heater simulated under variable operating conditions*. Solar Energy, 60, 119-126.

Standards Australia 1994 AS 4234, *Solar water heaters - Domestic and heat pump - Calculation of energy consumption* Published by Standards Australia, Homebush, NSW Australia.

Thomas, S.E., Lloyd, C.R., 2005. *Experimental and simulated Performance of commercially available solar and Heat-pump Water Heaters in New Zealand*. In proceedings of Solar 2005 - Renewable Energy for a Sustainable Future, A challenge for a post carbon world - ANZSES 2005.

Thur, A., Furbo, S. and Shah .J., 2006. *Energy savings for solar heating systems*. Solar Energy, 80, 1463-1474.

Tully, N., 1995. *The influence of electrical backup element size on the performance of a solar thermosyphon DHW system.* Solar Energy, 20, 209-217.

Van Amerongen, G.A.H., Bergmeijer, P.W., 1991. *Investigations on solar DHW systems combined with auxiliary heaters.* In: NORTHSUN 90 Energy conservation in buildings, pp 260-271.

Weiss, W. et al., 2005. *Solar Heating Worldwide – Markets and contributions to the energy supply* 2003, IEA Solar Heating and Cooling Programme, May 2005, International Energy Agency.