

Performance of a building integrated solar combisystem

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ABSTRACT: Solar combisystems providing both water and space heating to buildings are becoming commonplace in European and North American locations. However, the use of these systems in Australia and New Zealand is still in its infancy. While significant work has been undertaken to characterise the performance of these systems in northern hemisphere locations, this does not necessarily reflect their performance in Australia or New Zealand. This work examines the performance of solar combisystems utilising TRNSYS and F-chart simulations of an integrated solar thermal combisystem installed in a single storey detached dwelling under typical Australian and New Zealand climatic conditions. In doing this, it shows that there is significant scope for increased use of solar combisystems in the cooler climate regions of Australia and New Zealand.

Keywords: solar combisystem, space heating, Australia, New Zealand

INTRODUCTION

In recent times there has been a growing concern over the use and availability of energy sources. These concerns have been driven by a number of factors including ensuring security of supply, increasing costs and environmental issues. There has also been a widespread realisation that the rate at which existing fuel sources, in particular fossil fuels, are being consumed is unsustainable. The result has been an increasing amount of research directed towards renewable energy. In particular, the use of solar energy has been widely suggested as a means of reducing dependence on energy derived from fossil fuel sources.

The realisation of the need to make greater use of solar energy is particularly pronounced in Europe, where there has been growing interest in solar combisystems. Solar combisystems, though closely aligned to solar water heating, are significantly more complex systems. In essence a typical solar combisystem will use an array of solar collectors to deliver heat to a storage tank; from there heat is delivered to building occupants to provide domestic water heating and also space heating (Weiss, 2003). This can be achieved by a number of different systems, such as through a hydronic floor or by radiators, as are often used in central heating systems. The overarching aim of all these systems however, is to actively use solar energy in meeting not only the water heating but also the space heating demand.

Although these systems are becoming common in the northern hemisphere, their use in southern hemisphere locations is very much in its infancy. The only existing study into the performance of such systems in Australian or New Zealand climates was performed by Halawa et al (2007) for a single dwelling in Adelaide. In this they showed significant scope for meeting the heating requirements of their building using a solar combisystem.

Besides a lack of knowledge of how such systems will perform in Australian or New Zealand climates another significant impediment that such systems face is their initial cost. This issue is particularly pertinent with solar combisystems as the need to meet both water heating and space heating loads means the need to use larger array sizes, in some European locations in is not uncommon for systems with over 20m² of collectors to be used.

As such, this work examines the development of a low cost building integrated solar collector suitable for use in solar combisystems and explores the performance of a solar combisystem based on this collector for a typical house in a range of Australian and New Zealand locations.

1. BUILDING INTEGRATED SOLAR COLLECTORS FOR A SOLAR COMBISYSTEM

Unlike many commercially available collectors, the collectors in this study were not constructed from finned copper tubes. For this study the collectors were fabricated using commercially available colour coated (Colorcote®) mild steel sheets. The reason for doing this was to demonstrate that solar collectors can be made to integrate with buildings using standard building materials and need not be black. The sheets were folded using a brake press to form a trapezoidal roof profile and an integrated rectangular cross section tube as shown in Figure 1. Subsequently holes were drilled and nipples were soldered to the rear surface around these holes to allow a manifold to be attached, the ends were sealed and the top absorber sheet was bonded into place. A low-iron-glass cover was placed over the collector to reduce convective heat losses and in addition mineral fibre insulation was placed behind the roof sheet to reduce losses from the rear surface.

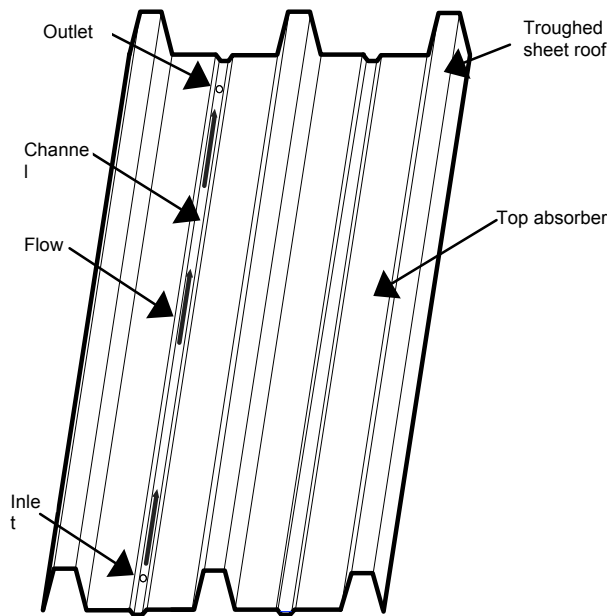


Figure 1: Building integrated solar collector

For this study two glazed prototype collectors were constructed for testing: one green and one grey. The thermal efficiency of the collectors was determined using a steady state outdoor thermal test setup similar to that recommended in AS/NZS 2535.1 (2007), (Figure 2). The global solar radiation on the collector surface was measured using a calibrated WMO First Class pyranometer mounted inline with the collector, at an angle equal to the local latitude (37 degrees). T-type thermocouples ($\pm 0.3K$) measured the temperatures at the inlet and outlet to the collector, as well as the ambient air temperature. A cup anemometer was mounted adjacent to the test stand to monitor the wind speed. The flow rate of water through the collector was set at a constant rate and monitored throughout the testing periods by measuring the time taken for a known mass of water to pass through the collector.

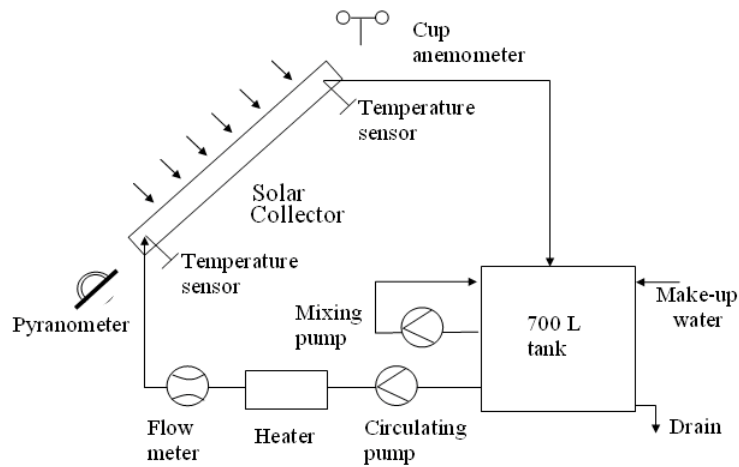


Figure 2: Solar collector test system

To accurately determine the experimental performance of the collector a number of outdoor tests were performed under a range of ambient conditions and for each condition was allowed to reach steady state. When analysing the collectors, the instantaneous collector efficiency was reached by taking the ratio of heat transfer in the collector to the product of the collector area and the global solar irradiance.

From the experimental data, the efficiency equation of the both coloured collectors was determined using a linear least squares regression analysis. As such two equations are determined that describe the grey and green collector efficiencies are shown in Equations 1 and 2 respectively.

$$\eta = 0.65 - 10.4 \frac{T_i - T_a}{G''} \tag{1}$$

$$\eta = 0.63 - 14.6 \frac{T_i - T_a}{G''} \tag{2}$$

2. MODELLING THE BUILDING INTEGRATED SOLAR COMBISYSTEM

In order to assess the performance of the solar combisystem, a simulation was performed using TRNSYS (SEL, 2007) for a "typical" house in Melbourne, Hobart, Auckland and Christchurch. TRNSYS is a widely used software tool for conducting transient simulations of solar thermal energy systems using quasi-steady models. The mathematical representations of the components of the solar energy system are presented as algebraic or ordinary differential equation models, which the software interconnects depending on energy and mass flows. Its flexible nature allows the user to configure any number of systems and to determine their performance at a large number of sites worldwide.

To demonstrate the performance of the solar combisystem, two simulations were undertaken. The first consisted of modelling the space heating demand of a typical house using the TRNSYS Type 56 building model with a single thermal zone. The second simulation involved taking the heating loads from the TRNSYS simulations and determining the performance of a large scale solar water heater using the F-chart method of analysis as detailed in Duffie and Beckman (2006).

2.1. Building space heating demand

One of the most significant issues in determining the space heating load for a "typical" house is in defining what "typical" means. For this study it was assumed that a typical house model was a moderately sized modern home with a floor area 160m² and an 8 foot ceiling height and that the entire building could be represented as one thermal zone. It was assumed that the north and east walls had a glazing ratio of 25%, while the west and south walls had a glazing ratio of 15% (French et al, 2006a) and that all windows were single glazed. Additionally it was assumed that the walls were insulated to R1.5, the floor to R1.3 and the ceiling to R3.9, suggesting a relatively well insulated house for both Australia (Gregory et al, 2008) and New Zealand (French et al, 2007). Furthermore, air tightness is a recognised factor in determining the thermal performance of buildings and traditionally both Australia (Biggs et al, 1986) and New Zealand (French et al, 2006b) exhibit poor air tightness, however for this study it was assumed that the building was relatively air tight with a leakage rate of 0.5ACH.

Besides the physical construction of the house, it was assumed the heating of the house was provided by a heater with a maximum output of 6.4kW. This heating system was assumed operated with a maximum temperature set-point of 18°C; the average winter evening temperature of a New Zealand living room (French et al, 2007). Furthermore, French et al (2007) noted that occupants of New Zealand houses tend to operate heating systems only when they are in the house, as such it was assumed that the heating system was not continuously operated, but was turned on between 6:00 and 8:30 am and 5:00 to 11:00 pm for months between April and October.

2.2. Solar heating system output

In order to determine the fraction of the building heating load that could be supplied by a solar heating system, it was decided to use the F-Chart method of analysis. Before the analysis of the heating system could be undertaken however, it was necessary to determine some meteorological characteristics. NIWA (2010) provided basic data for the mean monthly air temperature and mean daily global radiation in Auckland and Christchurch, while BOM (2010) provided data for Melbourne and Hobart, as shown in Table 1. In addition the mean day for each month and declination on this day are also shown, as given by Duffie and Beckman (2006).

This data however cannot be directly applied in the F-chart analysis. Firstly it is necessary to calculate the sunset hour angle (ω_s) for each day at the locations latitude (ϕ) and the mean day declination (δ) using Equation 3.

$$\cos \omega_s = -\tan \phi \tan \delta \quad (3)$$

By knowing the sunset hour angle, it is possible to determine the integrated daily extraterrestrial radiation on a horizontal surface (\overline{H}_0) using Equation 4. The extraterrestrial radiation is the amount of radiation that would theoretically be received if there was no atmosphere for a given day (n) and based on the solar constant (G_{sc}).

$$\overline{H}_0 = \frac{24 \times 3600 G_{sc}}{\pi} \left(1 + 0.033 \cos \frac{360n}{365} \right) \times \left(\cos \phi \cos \delta \sin \omega_s + \frac{\pi \omega_s}{180} \sin \phi \sin \delta \right) \quad (4)$$

Subsequently, by taking the ratio of the mean daily extraterrestrial radiation to the measured daily mean global radiation (\overline{H}) we are able to determine the mean daily clearness index (\overline{K}_T), as shown in Equation 5.

$$\overline{K}_T = \frac{\overline{H}}{\overline{H}_0} \quad (5)$$

Having the clearness index allows us to determine the fraction of diffuse radiation (\overline{H}_d) based on Collares-Perreira and Rabl's correlation, as given by Duffie and Beckman (2006), shown in Equation 6.

$$\frac{\overline{H}_d}{\overline{H}} = 0.775 + 0.00606(\omega_s - 90) - [0.505 + 0.00455(\omega_s - 90)] \cos(115 \overline{K}_T - 103) \quad (6)$$

Table 1: Monthly average climatic data

Month	Mean Day	Declination (degrees)	Melbourne		Hobart		Auckland		Christchurch	
			Global Radiation (MJ/m ²)	Air Temp (°C)	Global Radiation (MJ/m ²)	Air Temp (°C)	Global Radiation (MJ/m ²)	Air Temp (°C)	Global Radiation (MJ/m ²)	Air Temp (°C)
JAN	17	-20.9	24.2	20.0	22.6	17.3	23.1	19.3	21.9	17.4
FEB	47	-13.0	21.6	20.3	19.6	17.2	20.1	19.8	18.6	17.1
MAR	75	-2.4	16.0	18.4	14.3	15.8	16.0	18.5	13.9	15.5
APR	105	9.4	11.0	15.3	10.1	13.4	11.7	16.2	9.5	12.8
MAY	135	18.8	7.4	12.5	6.4	10.9	8.3	13.7	6.1	9.6
JUN	162	23.1	5.9	9.9	5.1	8.8	6.6	11.6	4.6	6.9
JUL	198	21.2	6.7	9.2	6.0	8.3	7.9	10.8	5.1	6.6
AUG	228	13.5	9.1	10.2	8.6	9.1	10.0	11.3	7.7	7.7
SEP	258	2.2	12.6	11.8	12.6	10.7	13.8	12.6	12.1	10.0
OCT	288	-9.6	17.4	13.8	17.1	12.4	17.5	14.1	16.8	12.3
NOV	318	-18.9	21.0	16.1	20.1	14.1	20.9	15.8	20.6	14.0
DEC	344	-23.0	23.7	18.2	21.8	15.7	23.1	17.8	22.2	16.0

Now assuming that the collectors are mounted at an angle (β) to the horizontal it is necessary for us to calculate the average daily beam radiation ($\overline{R_b}$) on the tilted surface using Equation 7, for a site in the southern hemisphere.

$$\overline{R_b} = \frac{\cos(\phi + \beta) \cos \delta \sin \omega'_s + \left(\frac{\pi}{180}\right) \omega'_s \sin(\phi + \beta) \sin \delta}{\cos \phi \cos \delta \sin \omega_s + \left(\frac{\pi}{180}\right) \omega_s \sin \phi \sin \delta} \quad (7)$$

Where:

$$\omega'_s = \min \left[\begin{array}{l} \cos^{-1}(-\tan \phi \tan \delta) \\ \cos^{-1}(-\tan(\phi + \beta) \tan \delta) \end{array} \right]$$

Finally, it is possible to determine the monthly mean daily radiation on the tilted surface ($\overline{H_T}$) using the Isotropic Sky model developed by Liu and Jordan and as given by Equation 8. Where $\overline{H_b}$ and $\overline{H_d}$ are the monthly average daily beam radiation and monthly average daily diffuse radiation and ρ_g is the ground reflectance, which is taken to be zero in this study.

$$\overline{H_T} = \overline{H_b} \overline{R_b} + \overline{H_d} \left(\frac{1 + \cos \beta}{2} \right) + \overline{H} \rho_g \left(\frac{1 - \cos \beta}{2} \right) \quad (8)$$

Now, having determined the radiation to which a tilted solar collector is exposed it is possible to determine the solar fraction that can be obtained from a solar energy system using the F-Chart method. The F-Chart method is commonly used for the design of active solar heating systems and has been developed from a large number of simulations of solar heating systems (Duffie and Beckman, 2006).

For a typical liquid heating system, the solar fraction (f) contributed by a system is given by Equation 9.

$$f = 1.029Y - 0.065X - 0.245Y^2 + 0.0018X^2 + 0.0215Y^3 \quad (9)$$

Where:

$$X = \frac{A_c F_R U_L (T_{ref} - \overline{T_a}) \Delta t}{L} \quad Y = \frac{A_c F_R (\overline{\tau \alpha}) \overline{H_T} N}{L}$$

And A_c is the collector area, F_R the collector heat removal factor, U_L the collector heat loss coefficient, $\overline{T_a}$ the monthly average temperature, Δt the seconds per month, $\overline{\tau \alpha}$ the monthly average transmittance-absorptance

product, L the heating load, N the number of days in month, T_{ref} is a reference temperature (100°C) and T_a is the ambient temperature.

3. PERFORMANCE OF THE BUILDING INTEGRATED SOLAR COMBISYSTEM

To validate the space heating loads produced by the TRNSYS simulation, the annual heating loads produced by the simulation were compared to the data of French et al (2007). From the simulations it was found that the building in Auckland had a heating energy consumption of approximately 2400kWh per annum compared to the published average of 2637 kWh. Similarly for Christchurch the simulated result was approximately 5700kWh, whereas the published average was 2859kWh. However, for both instances, the simulated results were well within the range of data that had been published. As no similar data was available for Australian locations it was assumed that the conditions modelled offered a valid approximation of a typical house and heating system for not only the New Zealand locations but also the Australian.

Based on this method, it was possible to determine the heating contribution provided by a solar combisystem for the combined space heating load determined by TRNSYS and the water heating load suggested in AS4234 (1994). For these conditions the monthly heating loads for each location are shown in Figure 3.

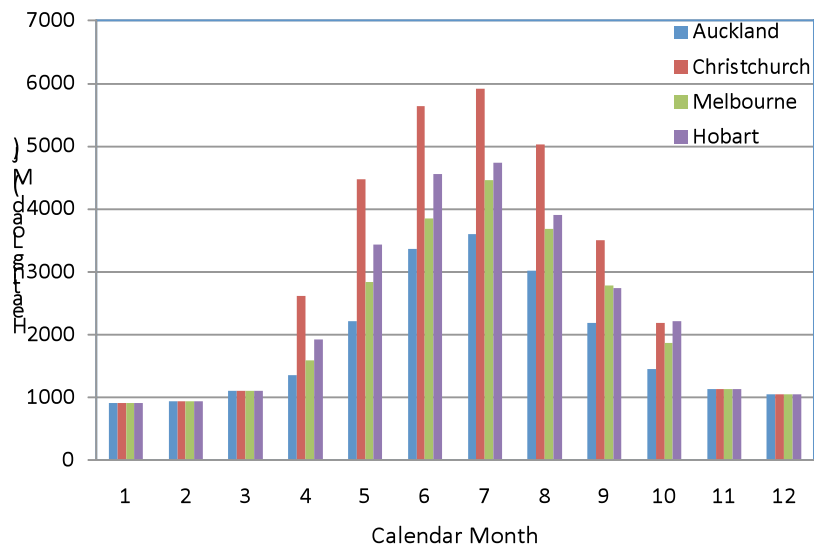


Figure 3: Combined space and water heating loads

Now for each location it was assumed that the collectors were oriented to face true north and were tilted at angle of 60 degrees in order to capture as much of the winter solar radiation as possible. Similarly, it was assumed that the grey collector with the efficiency given in Equation 1 would be used, and that the collector area would be between 5 and 30 m². On this basis it can be seen (Figure 4) that the fraction of the combined load that can be met by the solar combisystem increases with increased collector area.

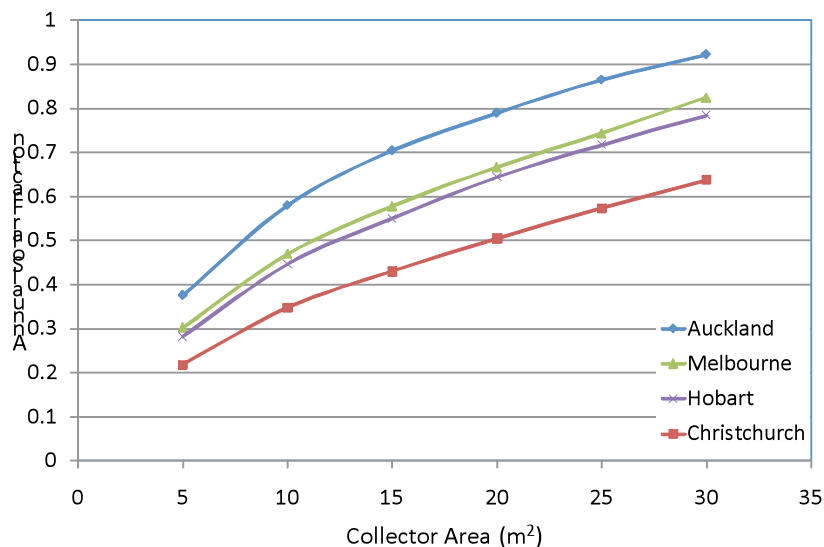


Figure 4: Space heating fraction met by solar arrays of various areas

However, when we consider that the collector described earlier in this study is meant to integrate with typical Australian and New Zealand buildings one could argue that having them act as the roof with a pitch of 60 degrees is not an accurate representation of building construction commonly seen in either country. As such it was assumed that the pitch of the roof was reduced to 30 degrees. In Figure 5 it can be seen that despite a significant reduction in the pitch of the roof and hence the collectors, there is only a minor decrease in the fraction of the heat load that can be met by the combisystem. The reason this occurs is because of the bias of the heating load towards winter, during this time there is an increase in space and water heating but also a reduction in solar radiation. Furthermore, as the system is not designed for long-term seasonal storage although significant amounts of energy are available during summer, this cannot be harnessed to meet the winter load. In essence this means the performance is somewhat limited by the energy that can be harvested during winter.

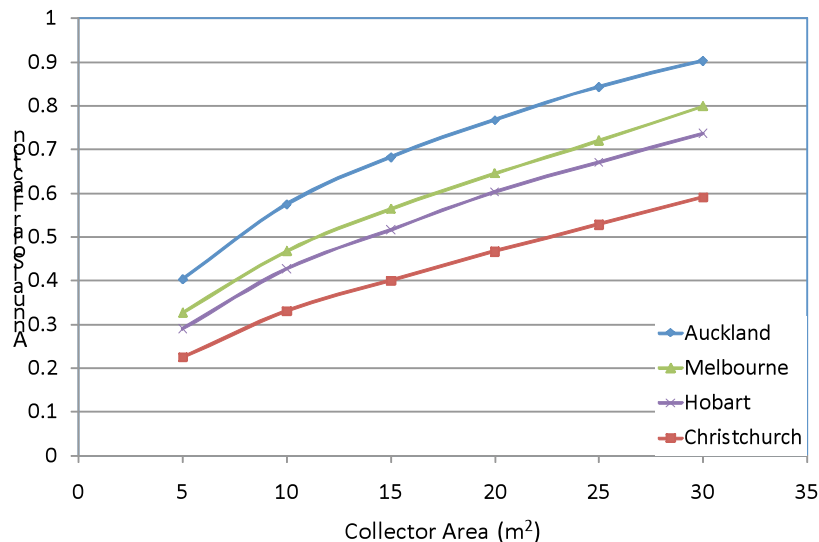


Figure 5: Space heating fraction met by solar arrays at a pitch of 30 degrees

CONCLUSION AND DISCUSSION

As solar combisystems become more common in Australia and New Zealand, there is a need for an increased understanding of the contribution these can make to reducing energy consumption in buildings. Although significant work has been done to characterise the performance of these systems, this work is not necessarily valid for the different building construction style or climates of Australia and New Zealand.

In this study, a new style of collector was developed and hypothetically implemented into a “typical” building for several Australian and New Zealand locations. Based on the annual heating loads encountered in this building, it was found that moderately sized building integrated solar collector arrays could make fairly significant contributions to meeting this demand. However, it was observed that in some respects the performance of the system was limited by the available winter solar radiation. In this regard, it could be argued that the system may have a future as a combisystem for solar cooling during the summer months, when there is an excess of thermal energy.

In more general terms, it can be said that there is significant benefit to using building integrated solar combisystems in the cooler areas of Australia and New Zealand. Moreover, with improved building construction and the use of solar combisystems, there is even further scope to reduce energy use in buildings.

REFERENCES

- Biggs, K.L., Bennie, I. and Michell, D., (1986), Air permeability of some Australian houses, *Building and Environment* 21, pp. 89–96
- BOM, (2010), *Climate statistics for Australian locations*, Retrieved from www.bom.gov.au [cited 26/07/2010]
- Duffie, J.A. and Beckman, W.A. (2006), *Solar engineering of thermal processes*, Wiley, New York
- French, L.J., Camilleri, M.T., Isaacs, N.P., Pollard, A.R., (2006a) Winter Temperatures in New Zealand Houses, Proceedings of 2006 Windsor Conference: Comfort and Energy Use in Buildings—Getting Them Right
- French, L.J., Camilleri, M.T., Isaacs, N.P., Pollard, A.R., (2006b) Exploration of Summer Temperatures in New Zealand Houses and the Temperature Drivers, Proceedings of 2006 Windsor Conference: Comfort and Energy Use in Buildings—Getting Them Right

- French, L.J., Camilleri, M.T., Isaacs, N.P., Pollard, A.R., (2007), Temperatures and heating energy in New Zealand houses from a nationally representative study—HEEP, *Energy and Buildings* 39 pp. 770–782
- Gregory, K., Moghtaderi, B., Sugo, H. and Page, A., (2008), Effects of thermal mass on the thermal performance of various Australian residential constructions systems, *Energy and Buildings* 40 (4) pp. 459–465.
- Halawa, E., Bruno, F. and Saman, W., (2007) Potential Application of Combisystem for an Australian Climatic Region, *Proceedings of ISES World Congress 2007*, (Vol. I – Vol. V), pp. 876-880
- NIWA, (2010), *Climate Summaries*, Retrieved from www.niwascience.co.nz [cited 26/07/2010]
- Solar Energy Laboratory (2007) *TRNSYS 16 User Manuals*, SEL, Madison
- Standards Australia (1994), *AS 4234-1994 Solar water heaters - Domestic and heat pump - Calculation of energy consumption*, Standards Australia, Sydney
- Standards Australia (2007), *AS/NZS 2535.1 Test methods for solar collectors Part 1: thermal performance of glazed liquid heating collectors including pressure drop*, Standards Australia, Sydney
- Weiss, W. (2003), *Solar heating systems for houses – a design handbook for solar combisystems*, James & James Science Publishers Ltd, London