Performance of Building Integrated Solar Hot Water Systems

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Abstract

The integration of solar energy systems into buildings has been the subject of considerable commercial and academic research, particularly building integrated photovoltaics. However, the integration of solar hot water systems into roofing systems has had far less attention. This paper presents the theoretical and experimental results of a novel building integrated solar hot water system developed using existing long run roofing materials.

This work shows that it is possible to achieve effective integration that maintains the aesthetics of the building and also provides useful thermal energy. The results of an unglazed $108m^2$ swimming pool heater and $8m^2$ glazed domestic hot water systems are presented.

The experimental results show that the glazed system performs close to the theoretical model and is an effective provider of hot water in certain climates. However it was also found that for larger scale building integrated solar water heating systems, special attention must be paid to the configuration and arrangement of the collectors in order to minimise problems with respect to flow distribution and its effect on collector and system efficiency.

Introduction

The integration of solar hot water systems into roofs has three potential advantages over conventional 'bolt on' systems; installation of both the roof and solar panel occur at the same time, reduced material cost and superior aesthetics.

Integration is however not straightforward making it difficult to turn the potential into a reality. One of the major barriers to the uptake of integrated systems is the mismatch between the technology and installation methods of the roofing industry and the solar industry. In New Zealand and Australia, in general the roof product manufacturers are conservative with long lead times for product development. In comparison the solar industry is experiencing a period of rapid growth and innovation.

This paper seeks to redress this disparity between the industries through the introduction of a novel method for integrating solar hot water systems directly into a roofing material.

Long Run Roofing

In New Zealand and Australia long run metal roofing is widely used for domestic, commercial and industrial applications. A typical example of such a roof is shown in Fig. 1.

Fig. 1 Long Run Metal Roof

Long run roofing comprises a substrate of steel strip, commonly 0.40 mm or 0.55 mm thick and coated with a 45% zinc, 55% aluminium alloy. A corrosion inhibitive primer and top coat (paint) are applied to the outer surface and is available in a wide variety of colours. The finished sheet is then roll formed or folded into the desired profile.

An investigation was undertaken to determine if commercially available painted steel was suitable for use directly as a building integrated solar thermal (BIT) panel. Two metre lengths of black painted steel were manufactured using a CNC folding machine. During the folding process a fluid channel, 35 mm wide was incorporated. Manifolds and end plugs were added. Finally a black painted steel collector plate was glued over the fluid trough as shown in Fig. 2.

The collector plate absorbs solar energy. As water or heat transfer fluid flows up the channel, heat is transferred from the underside of the collector plate to the fluid. Previous research [1] showed that steel is an effective material for a building integrated solar collector plate if the channel width is high, typically more than 20mm.

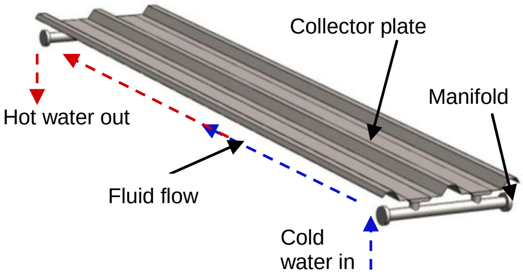

Fig. 2 Schematic of BIT Panel

A previous theoretical study and small scale testing of Building Integrated Photovoltaic Thermal (BIPVT) panels [2] had been undertaken by the Solar Engineering Research Group at the University of Waikato. BIPVT is a combined system that generates both electricity and hot water. The panels are identical to the BIT panels but have photovoltaic cells laminated onto the collector plate. The thermal performance of optimised BIPVT compared to commercially available flat plate solar thermal collectors is shown in Fig. 3.

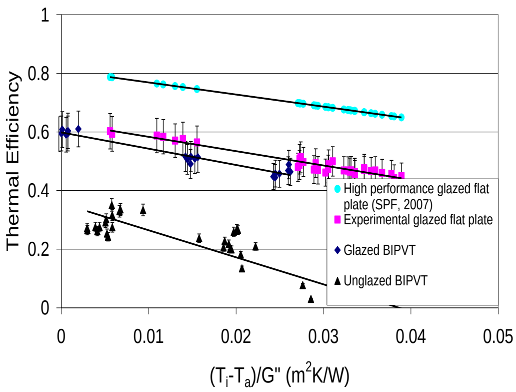

Fig. 3 Theoretical and Experimental Performance of Optimised BIPVT Collectors

It can be seen that the efficiency of the optimised glazed BIPVT is lower but still good enough to provide useful thermal energy in sunny regions such as Australia and relatively sunny regions such as NZ. However, in the two test rigs discussed in this paper no photovoltaic cells were included so that both experimental rigs operated as BIT only. One of the aims of the experiments was determine how purely BIT performance compared to BIPVT.

Glazed BIT – Test Rig

To investigate the performance of glazed BIT, a solar water heating system was built using a similar construction method to a conventional long run metal roof (see Fig. 4). The BIT was installed using standard building paper, rafters, battens and insulation. Folded polycarbonate sheets were used for the glazing on the black BIT panels. The test rig enabled the performance of glazed BIT to be evaluated almost as if it had been installed on an actual building.

The rig comprised three parallel rows of eight coloured BIT panels in series, black, green and grey. Each row was plumbed so they could operate independently of the others, allowing for comparative testing of collectors of different colours [3].

Figure 4 Glazed BIT Test Rig

Initial tests showed a flow distribution problem with eight panels in series. The central panels had little or no flow so the panels were split into groups of four in series. This resolved the problem but highlighted a potential problem with the manifolds.

Performance testing of the glazed black BIT panels was undertaken to determine their efficiency when in a 'real' installation and to investigate the maximum water temperatures possible.

To achieve this, a small insulated tank was filled with 35 litres of water at ambient temperature. On a clear sunny day, with average solar insolation of 828W/m^2, the pump was switched on and the water circulated through the glazed BIT. The inlet and outlet temperatures were measured along with the flow rate and solar insolation. The system operated all day and night. Night time running allowed the water to be cooled by radiation ready for the next day's testing.

The water temperature for good summer day is shown in Figure 5. It can be seen that the maximum temperature reached was approximately 95°C. This is well above the required 50-60°C of domestic hot water and demonstrates that glazed BIT can reach the required temperature.

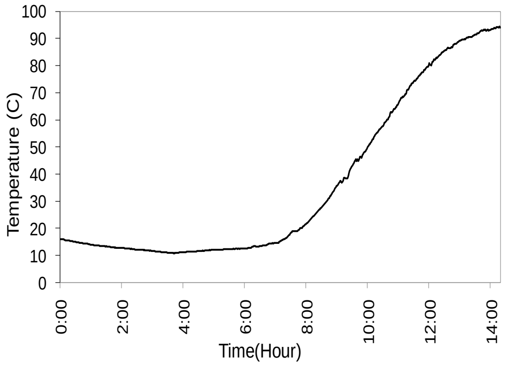

Fig. 5 Water Temperature from Collector

Using the mass flow rate, insolation, water and ambient temperatures, the instantaneous efficiency of the test rig's black glazed panels was found as shown in Figure 6.

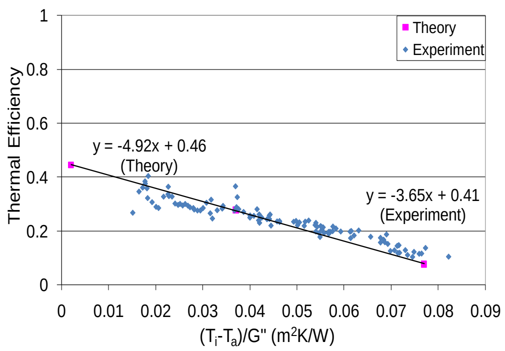

Fig. 6 Theoretical and Experimental Performance of BIT

The glazed BIT was not optimised as was the glazed BIPVT. When trying to realise a practical BIT system compromises had to be made to achieve a 'real world' BIT system. Consequently the collector surface, optical properties of the glazing and the fin efficiency were not as good as the optimal glazed BIPVT resulting in a lower thermal efficiency. None the less the glazed BIT still performed well enough to be an effective solar hot water heater system in 'sunny' regions.

Further investigations are being undertaken to determine if the glazed BIT can be improved and have a performance similar to that of the optimised glazed BIPVT.

Unglazed BIT – Dive Pool

The second application was $108m^2$ of unglazed BIT installed at the University of Waikato's $400m^3$ dive pool shown in Figure 7.

A special frame was made so that the BIT panels for heating the dive pool also acted as a sun shade. It can be seen that the BIT system looks like a conventional long run painted steel roof. The outer parts of the roof were made from standard roofing and integrated seamlessly with the BIT. This shows that it is possible to use long run roofing material not only for BIT but in conjunction with it. It should also be noted that the entire roof (without the plumbing) was installed by roofers with some training of how to handle the BIT panels.

A range of sensors measuring; flow rate, temperatures, wind speed and solar insolation were installed on the BIT system and a data logger used to collect and store the sensor readings.

Fig. 7 Unglazed BIT Dive Pool System

A schematic of the unglazed BIT system is shown in Figure 8. A heat exchanger is used to transfer thermal energy between the BIT system and dive pool water.

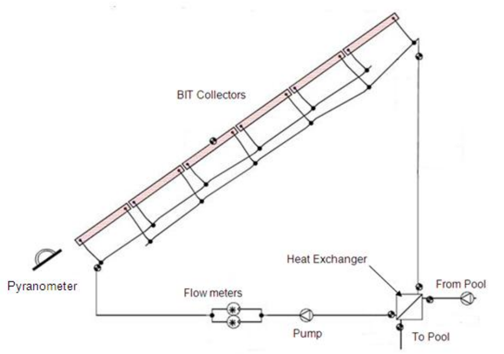

Fig. 8 Schematic of Dive Pool System

During initial testing, there were major problems with flow variation in the BIT panels. Large areas had little or no flow leading to hot spots and low overall system efficiency. To help rectify this, the pipe layout was altered and the number of BIT panels in series was reduced from eight to four. This resolved the problem somewhat but not completely. Irrespective it was found that the instantaneous efficiency of the system was approximately 25% on a typical sunny day (Fig. 9).

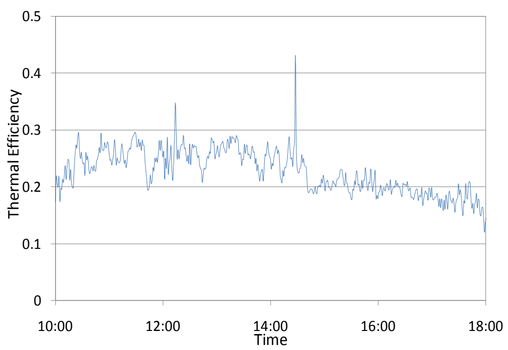

Fig. 9 Efficiency of unglazed BIT at the dive pool during a typical day

In addition, temperatures of both the dive pool and the adjacent main pool were monitored by staff over the 08/09 and 09/10 seasons as part of routine maintenance procedures. These were manually collected normally three times a day using a digital thermometer, typically between 12 pm – 6 pm. Although temperatures were not recorded every day, the data collected still gives a very good indication of the performance of the BIT system.

Fig. 10 shows the average temperature of the dive and main pools during the 08/09 and 09/10 summer seasons. It should be noted that the temperature scale has been selected to highlight the small difference between the main and dive pool temperatures. It can be seen that in 08/09 with no BIT, the temperatures of the two pools are very close over the entire season. The dive pool was on average 0.2 °C warmer than the main pool.

During the recent summer season, 09/10 with the aid of the BIT system, the average difference between the dive pool and main pool temperatures increased by more than a degree, to 1.3°C. Although this does not sound a great difference it was noticeable when swimming in both pools. Even though a scientific study was not undertaken, both staff and swimmers were questioned about the temperature of both the main and dive pools. All stated that the dive pool was noticeably warmer. It should also be noted that there were no covers on either pool so heat was lost every night.

In addition it should be noted that compared to the 08/09 season the 09/10 main pool temperature is 0.8°C lower. It is therefore assumed that the 08/09 summer was sunnier and warmer than the 09/10 summer.

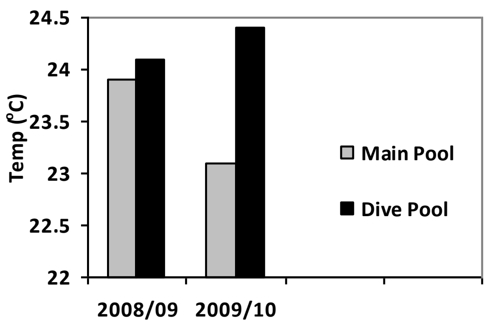

Fig. 10 Temperature of dive and main pools over the 08/09 and 09/10 seasons

Based on the data the average efficiency of the BIT system over the season was found to be 22.4%. The monthly performance of the unglazed BIT dive pool system is summarised in Table 1.

Table 1: Dive Pool BIT Output Summary

2009/ 2010	Average Pool Temp. (°C) (5-6 pm)	Max. Daily Output (kWh)	Average Power Output (kW)	Average Daily Output (kWh)
Nov	21.2	178.2	17.4	73.3
Dec	24.5	156.5	16.3	94.5
Jan	25.1	160.4	15.4	90.4
Feb	26.5	139.1	14.9	115.8

It can be seen (Fig. 3) that when compared to the efficiency of the optimised unglazed BIPVT panel of 35% maximum efficiency, the unglazed BIT is over 10% lower. The reasons for this are probably a combination of differing collector surface, poor insulation, uneven flow distribution and a lower than optimal fin efficiency. Further investigations are being undertaken to understand and optimise the system.

Conclusions

The glazed and unglazed BIT systems show that it is possible to integrate solar thermal systems directly into conventional roofing material.

Moreover, they show that this integration can make significant contributions to heating systems both at the low temperatures found in swimming pools or the high temperatures found in domestic water heating systems.

The BIT systems are not optimised and further work is needed improve their performance.

References

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