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SOLAR ROOFING SYSTEM THERMAL PERFORMANCE ANALYSIS

Beyond Today's Infrastructure

Research and development work on Building Integrated Solar Energy Systems (BISES) has become an area of growing interest, not only in New Zealand (NZ) but worldwide. This interest has led to a significant growth in the use of solar energy to provide heating and electricity generation. This paper presents the theoretical and experimental results of a novel building integrated solar hot water system developed using commercial 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 a 6.73m^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. Further work is needed to identify and design a control strategy for the Building Integrated Thermal (BIT) system and determine how the performance can be optimized.

Keywords: BIT, thermal performance, roofing system

1. INTRODUCTION

There has been significant growth of research and development in renewable energy technologies such as solar, wind, tidal, and geothermal linked to concerns about climate change caused mainly by greenhouse gas emissions from fossil fuels. Solar energy has emerged as one of the most rapidly growing of these renewable energy sources.

Solar energy is an abundant, free, non-polluting, and renewable resource. The solar energy reaching the earth's surface is close to 7000 times current global energy consumption (Nielsen, 2005). Therefore, it is possible that solar energy systems could, in the future, become a significant supplier of the world's energy.

The most common use of solar thermal technology is for domestic water heating. NZ residences use about one-third of total energy consumption, with the majority of residential demand being for water heating, space heating and lighting as shown in Figure 1.

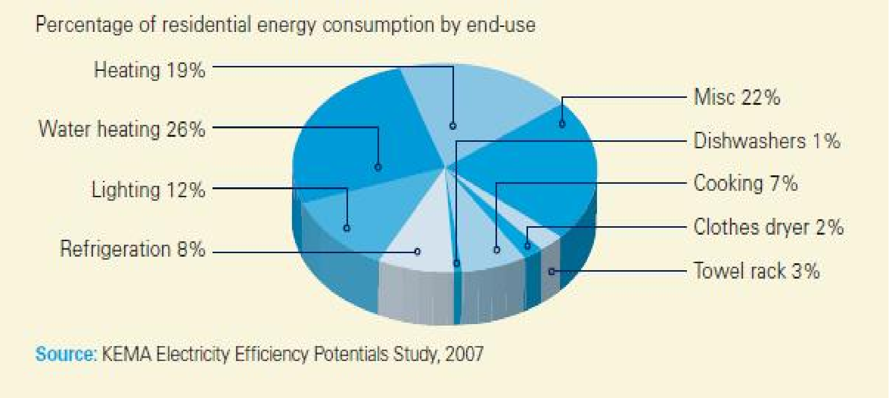

Figure 1: Percentage of resident energy consumption by end use (ElectricityCommission 2010)

There is a competitive market in NZ for solar hot water heating systems. Around 35,000 home owners in NZ have now installed solar water heating systems, and currently there are around 3,500 new solar water heating systems installed each year (EECA 2008).

Traditionally, research in the field of solar water heating has been conducted in relative isolation from the building industry. Although this has led to the development of high performance systems, there appears to have been little consideration into the integration of these systems with the buildings they are typically used in. In a study by Probst and Roecker (2007) it was shown that there are a number of factors that need to be addressed in order to achieve better integration of solar devices and the built environment. In particular they note that future building integrated solar collectors "should be conceived as part of a construction system". This view was also expressed by "PV Catapult" project (2005) when reflecting on the integration of photovoltaic systems into buildings.

The use of water heating solar collectors as building elements has, until recently, been largely ignored. Ji et al. (2006) and Chow et al. (2007) both examined a photovoltaic/thermal system for integration into building walls in Hong Kong. They showed that these systems could make useful heat gains while also acting to reduce thermal load on the building. However these systems were essentially integrated *onto* a building rather than *into* the building (i.e. individual collectors were used as the material for the wall, rather than using the wall as the material for a collector). Similarly, Kang et al. (2006) discussed the performance of a roof integrated solar collector which again consisted of a series of "standalone" collectors used as a roof. According to Probst and Roecker (2007) this method of integrating solar collectors is considered to be "acceptable" to architects, but is still only demonstrating the integration of collectors *onto* a building rather than *into* the building.

Medved et al. (2003) however examined an unglazed solar thermal system that could be truly integrated into a building. In their system they utilised a standard metal roofing system as a solar collector for water heating. They found that in a swimming pool heating system, that they were able to achieve payback periods of less than 2 years. This translated to a reduction of 75% in the time taken to pay for a glazed solar collector system. Similar systems to that of Medved et al.

have been developed and discussed by Bartelsen et al. (1999), Colon and Merrigan (2001) and Anderson (2009).

However, despite the recent research and the recognition of the market for building integration of solar collectors, the work undertaken in the field is relatively small in comparison to work on stand-alone collectors. Although standalone collectors can successfully be integrated *onto* buildings it has been suggested that this does not necessarily result in an attractive finish. As a result, this study aims to examine the performance of a building integrated solar thermal collector based on sheet metal roofing that displays a greater level of integration, and satisfies more of the requirements identified in the literature than many of the previous systems.

2. BUILDING INTEGRATED THERMAL (BIT) SYSTEM

In NZ 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 Figure 2.

Figure 2: 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 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 Figure 3.

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 (Anderson 2009) showed that steel is an effective material for a building integrated solar collector plate if the channel width is high, typically more than 20mm.

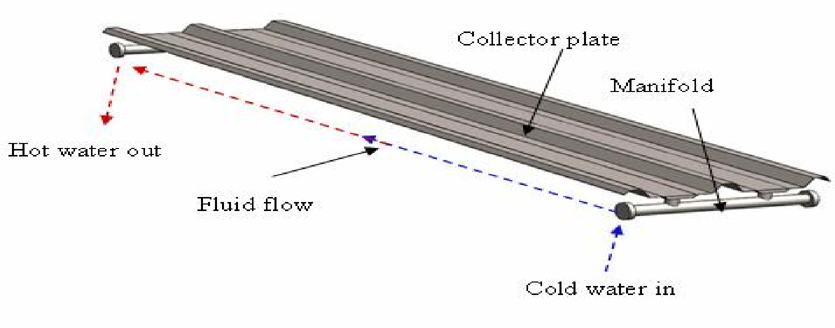

Figure 3: Schematic of BIT Panel

A previous theoretical study and small scale testing of Building Integrated Photovoltaic Thermal (BIPVT) panels (Anderson 2009) 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 Figure 4.

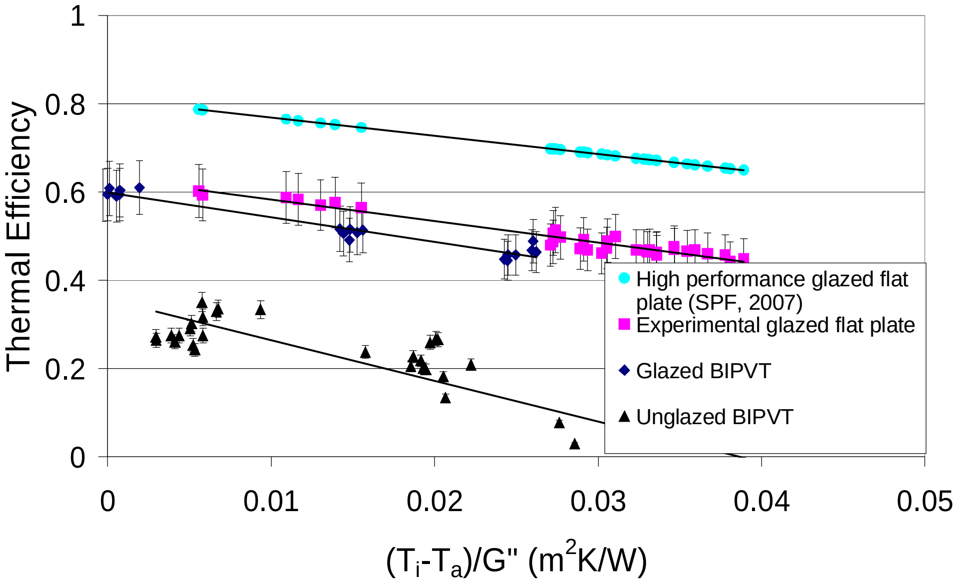

Figure 4: Theoretical and Experimental Performances of Optimised BIPVT Collectors

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 this paper no photovoltaic cells were included so that the experimental rig operated as BIT only. One of the aims of the experiments was to determine how purely BIT performance compared to BIPVT. A basic schematic diagram of the BIT system is shown in Figure 5. 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 Figure 6).

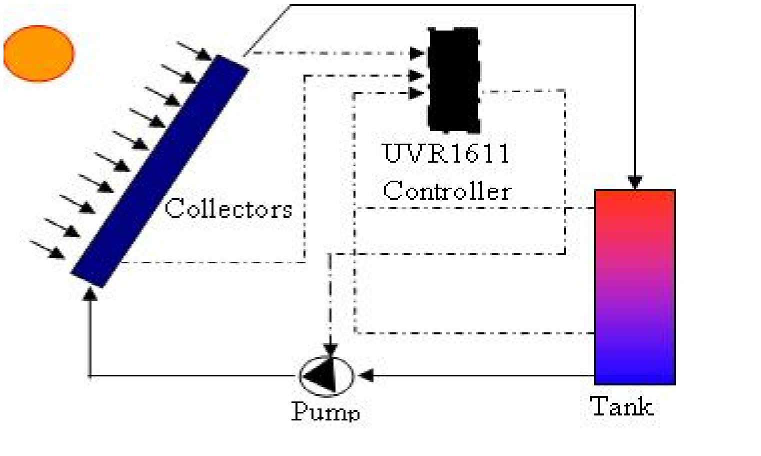

Figure 5: Schematic diagram of the BIT system

Figure 6: Glazed BIT Test Rig

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 (Anderson 2010). 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.

3. TESTING AND RESULTS

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 929 W/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.

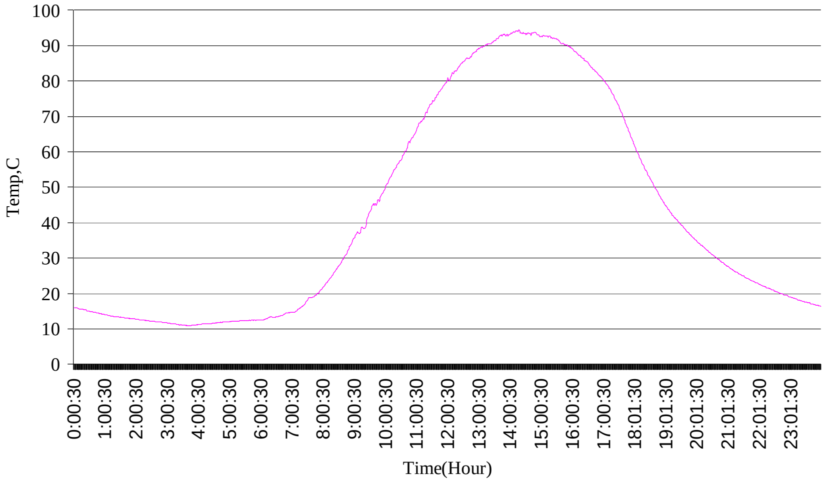

Figure 7: Water Temperature from Collector

The water temperature for a good summer's day is shown in Figure 7. It can be seen that the maximum temperature reached was approximately 90°C. This is well above the required 50-60°C of domestic hot water and demonstrates that glazed BIT can reach the required temperature.

The thermal efficiency (h) can be determined directly from the experimental results based on the Hottel-Whillier equation (Duffie and Beckman, 2006). It is defined simply as the ratio of heat transfer in the collector Eq.1 to the product of the collector area and the global solar irradiance, as shown in Eq. 2.

$$\dot{Q} = \dot{m} C_p \Delta T \qquad \text{(Eq.1)}$$

$$h = \frac{\dot{Q}}{A_{collector} G''} \qquad \text{(Eq.2)}$$

From the experimental data, the efficiency of a solar collector for all conditions can be represented by a linear equation of the form shown in Eq. 3.

$$h = h_{0A} - a_1 \left(\frac{T_i - T_a}{G''} \right) \qquad \text{(Eq.3)}$$

It was possible to derive the efficiency equation for BIT collector analysis using a linear least square regression analysis (Anderson 2009). The result from the experimental data measured during testing is shown Eq.4.

$$h = 0.4532 - 4.0864\frac{T_i - T_a}{G''} \qquad \text{(Eq.4)}$$

Where:
G'' = solar irradiance (W/m^2)
$\dot{m}$ = mass flow rate (kg/s)
C_p = specific heat of the collector cooling medium (J/kg/^{o}C)
ΔT = differences between fluid out temperature,(T$_o$) and inlet temperature (T$_i$)
$A_{collector}$ = collector area (m^2)
T$_i$ = inlet temperature (^{o}C)
T$_a$ = ambient temperature (^{o}C)
h_{OA} = collector optical efficiency

The significance of the efficiency equations can be better understood from an inspection of Figure 8.

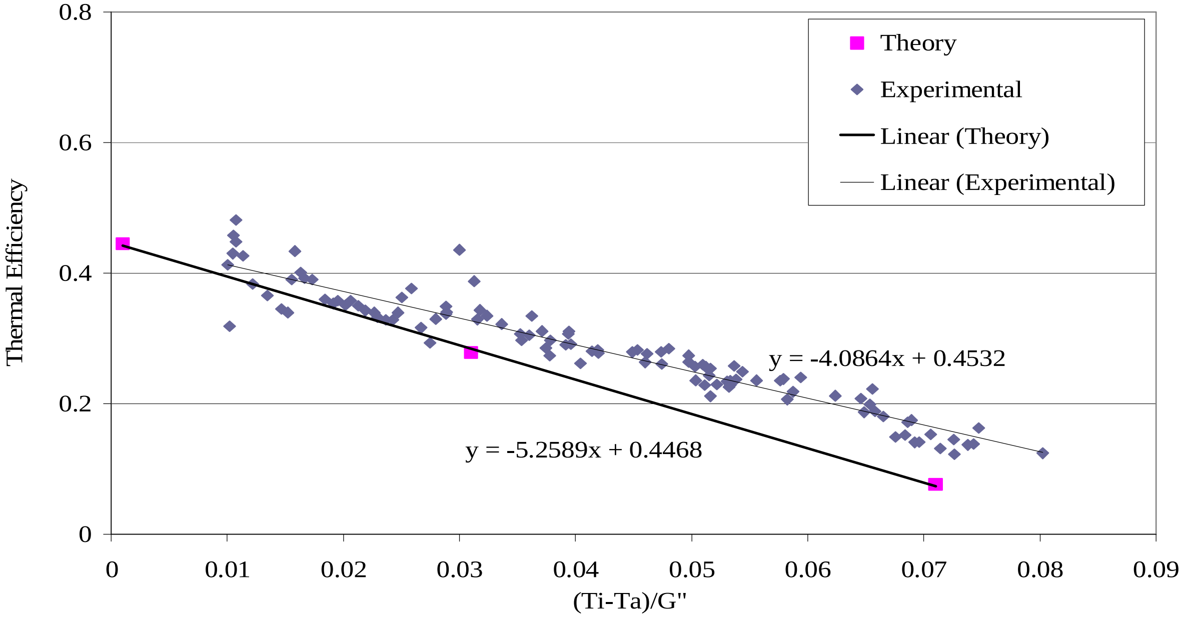

Figure 8: Theoretical and Experimental Performance of BIT

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.

4. CONCLUSION

The BIT solar collectors performed well and reached the required temperature for domestic hot water systems. The thermal performance of a solar roofing system was evaluated numerically and experimentally. The experimental efficiency is in good agreement with the theoretical result. This work shows that it is possible to integrate an effective solar hot water system directly into standard roofing material, thus maintaining the aesthetics of the building.

Further work is needed to identify and design a control strategy for the BIT system and determine how the performance can be optimized. 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.

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