GUIDELINE ON THE PERFORMANCE OF SOLAR WATER HEATING COLLECTORS TO HEAT SWIMMING POOLS

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EXECUTIVE SUMMARY

Solar water collectors for heating swimming pools are increasingly being used in New Zealand. Typically these collectors are unglazed rubber or plastic mats / panels that work best at low temperature differentials between the ambient air temperature and the pool water temperature. Computer simulation of pools in Auckland and Dunedin has shown that these solar collectors are effective at raising the temperature of pool water, particularly where a pool cover is also used. However, in windy locations, or towards the lower South Island greater consideration should be given to using glazed collectors for heating pools that are maintained at a constant temperature during the pool heating season. Whilst these systems may cost significantly more, this cost can be offset by integrating the domestic water heating with the pool heating system.

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1. INTRODUCTION

The use of solar collectors to heat swimming pools is an established industry in both New Zealand and other countries. In general, large unglazed collectors are installed on the roofs of adjacent buildings, with a pump used to circulate the water. This pump can either be the pool circulation pump installed as part of the pool filtration systems, or a dedicated pump which is controlled by a differential temperature controller designed for pool solar heating systems. Unglazed pool collectors work by transferring large volumes of water through the collector at a small temperature differential.

This guideline has been produced to assist with the understanding, sizing, and energy performance of solar pool heating systems. The performance information is based on computer simulation and is therefore a guide only.

1.1. Energy requirements for heating pools

The energy required to heat swimming pools is considerable. For a typical indoor pool, heating can cost in the range of $5000 – $30,000 or more per year, depending on the size of the pool and the location. Often pools are closed during the winter months, as this is when the heating cost is the greatest, and presumably, the user demand is the lowest. In the case of school pools, it is assumed the pools are used during the first and last terms of the year. This covers the period of October to March, inclusive. Other community pools are assumed to have similar operating seasons. It is also assumed that the pool is open in the late afternoon for public use, and during the weekends.

In addition to solar heating, there are other methods commonly used to heat pools. These are:

1) electric, gas or oil thermal heaters. Of these, gas is the most common.
2) using transparent pool covers which allow the pool itself to collect solar energy,
3) pumping the water through a plastic manifold on a suitable roof (eg tiles), and allowing the water to re-enter the pool through the roof gutter system,
4) using heat pumps designed for pool use, and
5) utilising waste heat from some nearby process that generates low grade heat. This is often the case with schools that have a coal fired central heating system that pumps hot water through the classrooms.

1.2. Modes of heat-loss from pools

There are 5 ways pools can lose energy. They are:

a) *Evaporative loss*

Evaporative loss is the most significant of all the energy losses with a pool, particularly so when the pool is uncovered and exposed to the wind. Evaporation also increases the use of the pool chemicals required to keep the pool balanced.

b) *Radiative loss*

Radiative loss from the pool occurs when the temperature of the pool is warmer than the outside air. Radiative loss particularly occurs on clear nights.

c) *Convective loss*

Convective loss occurs through the warmer water in the pool rising to the top of the pool surface and then cooling due to contact with the cooler air.

d) *Conductive loss*

Conductive heat loss occurs through the walls and floor of the pool, with any groundwater movement around the pool increasing the conductive heat-loss occurring.

e) *Make up loss*

In most instances, the replacement water added to a pool is colder than the pool temperature.

1.3. Collector types and their performance

There are three major categories of solar collector types. The most common for pool heating is the unglazed collector. These typically consist of either a rubberised or plastic mat of thin tubes connecting an upper and lower manifold through which the water flows, or a flooded solid plastic panel. In the latter case, the water flow is restricted to narrow channels through the panel, between manifolds at the top and bottom.

Solar collector efficiency relates to the proportion of incoming solar radiation that is converted to heating the water in the collector. As the collector increases in temperature, some of the absorbed energy is re-emitted back to the environment in the form of infrared radiation and conductive transfer. The use of glazing on the collector reduces the absorption of the incoming radiation, but also reduces the heat-loss through conductive transfer.

The unglazed collectors have a maximum efficiency of 80-95% (based on the gross area) when the water in the collector is the same temperature as the ambient air temperature. However, as the water temperature heats up, these collectors rapidly decline in performance. These collectors also have the lowest cost per unit area. The performance of these collectors is also influenced by the roof they are installed on, especially when there is little wind. A roofing material which absorbs and radiates heat (e.g. darker coloured tiles) will significantly increase the performance of some types of unglazed collectors.

Solar collectors used in domestic water heating can also be used for the heating of pools. These collectors come in two common forms – the glazed flat panel collector and the evacuated tube collector. In both cases, glass is used to reduce the conductive and convective heat loss from the absorber surface, leading to higher temperatures being achieved by the water. In the case of the vacuum tube, these heat-losses are almost entirely eliminated due to the vacuum between the absorber and the outside environment. A Compound Parabolic Concentrator (CPC) is when a focused curved reflector is placed behind the evacuated tubes in order to improve performance.

In terms of collector efficiency, the glazed flat panel collectors typically have a performance (based on gross area) of 65-80%, and the evacuated tube collectors (including the CPC types) between 40-60% when the water in the collectors is the same temperature as the ambient air temperature. In both cases, however, the rate of decrease in performance as the collector increases in temperature is significantly less than that of an unglazed collector.

For evacuated tube systems, the rate of efficiency decrease is about a third of that of a glazed panel, resulting in these collectors maintaining a higher efficiency at higher temperatures.

1.3.1. Cost of collectors

The different collector types have different costs per m^2 of coverage area. In general, cheapest of the collectors are the unglazed rubber mat types, and the most expensive are the evacuated tube types. However, due to the differences in collector efficiencies, a lower coverage area of the more expensive collectors is required for the same energy delivered. This particularly applies as the required water temperature from the collector increases.

For this study, the following collector costs have been used (based on the gross area, excluding installation, pumps etc):

- Unglazed collector $166/$m^2$
- Flat panel collector $250/$m^2$
- Evacuated tube collector: $280/$m^2$
- Compound parabolic concentrator (CPC) evacuated tube collector: $333/$m^2$

Due to the variation between different equipment suppliers, these prices should be taken as a guide only.

1.4. Covers

Pool covers have two main functions. They reduce the heat-loss from the pool, by virtually eliminating evaporation from the pool surface, as well as greatly reducing the conductive and radiative heat-loss. They also help to keep the pool clean by reducing the amount of debris entering the pool, and this reduces the filtration requirements of the pool.

There are two main types of pool covers. The thermal cover is a polyethylene closed cell foam cover with a protective layer of woven polyethylene. The insulation properties are good, but because the cover is not transparent, solar radiation is prevented from heating the water during the day. This is of less consideration if the pool is used most days.

The other cover type is the bubble cover. This is a transparent cover made from polyethylene. The cover has a ‘bubble wrap’ appearance and primarily prevents evaporative heat losses, with some reduction in conductive and convective losses. However, the cover allows the solar radiation to heat the water. The cover is more suited to pools that are predominantly covered.

The durability of the covers differs due to the construction type. In general, the bubble covers are much less durable than the thermal blanket types and are expected to last about 2 years. Thermal blanket covers will last longer, and are more suited for school pools, and indoor pools where they will be removed most days. Where transparency is not an issue, then the thermal blanket type of cover should be used.

1.5. Controllers

In most instances, a differential controller is the best way to control the flow of water through the collector. The controller determines the temperature of the water in the collector, and compares it with the temperature of the water in the pool. If the water in the collector is hotter, then the pump starts and the water is circulated. Because the collector efficiency decreases with increasing temperature, a small differential in temperature is used. The pumps used are typically 400 – 750 W, due to the high volume of water that is required. However, once the water returns to the pool from the collector, the load on the pump decreases due to the siphon effect. A vacuum break valve on the top of the collector allows the water to drain from the collector once the pump stops running. This mechanism also functions to prevent the collectors being damaged by frosts.

Some pool systems are installed using the existing pool filtration pump, to pump the water to the collectors. With these systems, the control is typically either manual, or are controlled using a day-timer. Some systems also use variable speed pumps, or an additional booster pump to get the water circulating through the collectors. Once the siphon effect is established, the booster pump switches off to save energy. The variable speed pumps reduce power consumption to achieve the same effect.

In both cases, it is important that the water to the collectors is sourced from the pool filter. Preferably there is also an additional filter. This is because the passages in the collectors are typically narrow, and can readily clog with debris.

1.6. Corrosion of copper

The chlorine used in pools means that traditional copper based glazed collectors cannot be directly used for pool heating. Should these panels be used, then a heat-exchanger is required between the collector circuit and the pool water. The heat exchanger separates the chorine containing pool water from the fluid in the solar circuit. Due to the low differential temperatures between the solar heated water and the pool water temperature, then the rated heat exchanger capacity needs to be at least several times larger than the energy input into the pool. Stainless steel heat-exchangers are susceptible to corrosion due to the chlorine in the pool water. Cupric-nickel and titanium based heat-exchangers are generally more suitable for pool heating applications.

1.7. Energy costs

School pools are usually heated with either a gas or coal boiler, or electricity. Often the pool is heated using the same coal or gas fired boiler that supplies the classroom heating of the school. Depending on the individual school, the price for purchased energy can vary considerably depending on location, energy retailer and school size.

Community pools are typically heated with gas or electricity.

For this study, it is assumed that the cost of gas is 1.56cents/MJ (5.6c/kWh), and the cost of electricity is 4 cents/MJ (14.4 cents/kWh). The gas boiler is assumed to be 85% efficient.

This report focuses on the use of solar energy to heat typical indoor and outdoor school sized swimming pools. If pools are currently unheated, then a solar system will increase the energy consumption by the pool (due to the pump), but the swimming season will be extended as a result.

2. METHODOLOGY

The simulation program PoolHeat™, developed by Emeritus Professor Graham Morrison at the University of New South Wales, Australia has been used to simulate the heating requirements of a typical school pool in Auckland and Dunedin. The pools have been simulated under a range of conditions with pool heating achieved using solar collectors, and supplementary gas / electric heating. The effect on the heating requirements from the use of covers has also been investigated.

2.1. Angle and slope of roof space

It has been assumed that there is sufficient North facing roof space available for the collectors, at an optimum roof pitch. Any deviation from this will decrease the performance of the pool heater from the results shown. The roof pitch chosen for the simulations was 25º in Auckland and 30º in Dunedin, reflecting the predominantly summer time use of the pool. Note: In New Zealand due North is approximately 20º to the West of magnetic North.

2.2. Size of collector area

Pool heating solar collectors are typically sized in reference to the pool surface area. This is because evaporation of water from the pool surface is the most significant mode of energy loss from the pool. The amount of water evaporated is proportional to the surface area of the pool. This report uses three area sizes (coverage) for unglazed collectors: 66% of pool surface, 100% of pool surface and 133% of pool surface area. Glazed collectors are modelled at a coverage of 25% and 50%.

2.3. Pool thermostat set temperature

Many school and community pools are outside, and are both uncovered and unheated causing the temperature to vary according to how sunny and sheltered from the wind the pool is. This leads to the pool swimming season being restricted by the temperature of the water. Solar water heating is likely to be considered by these pool operators to extend the swimming season, rather than to save energy consumption. These users are interested in the likely increase in average pool temperature achieved by the solar collectors.

Indoor pools are usually heated, and are typically set at 28-30ºC depending on the use of the pool. For pools used primarily for training purposes (e.g. traditional ‘lap’ pools), the set temperature is usually about 28ºC. Recreational pools are usually set a couple of degrees warmer. These pools are likely to consider solar water heating to save on energy usage to heat the pool. Some operators will use the money saved on summer heating to extend the opening season of the pool. Others will maintain their existing operating hours, and reduce the operating expenses on the pool.

2.4. Indoor and outdoor pools

It has been assumed for this report that pools modelled for Auckland are both outdoor and indoor types whereas in Dunedin the modelled pool is an indoor type. The Auckland indoor pools have been assumed not to have space heating in addition to pool heating, whereas in Dunedin the room is also heated. Humidity is controlled in the indoor pools in both cases to 80% during the day and up to 90% at night.

2.4.1. Indoor pools

An indoor pool is typically maintained at a constant temperature during its operating season. In Auckland, this tends to be about 27-28ºC, and in Dunedin this is 28-29ºC. In both cases, 28ºC has been used for this report. Indoor pools have a greatly reduced potential for solar radiation directly heating the water, and for this report this is assumed to be the case. Therefore the use of covers is limited to the thermal blanket type. The absence of UV and exposure to the weather results in the cover lasting significantly longer. We have therefore explored the benefits of using a thicker foam cover with an R value of 1, as well as the usual thermal blanket with an R value of 0.088.

3. Case 1. Outdoor school pool, Auckland

An outdoor pool of dimensions 20m x 14m x 1.3m (average depth) has been simulated using the POOLHEAT™ simulation program. The pool has the following parameters:

- Total surface area of 280 m^2 and total volume of 350 m^2.
- Pool is sheltered from the wind, and has minor shading.
- Pool is used from 09:00 to 18:00 7 days a week.
- Filter back flush uses 0.1% of the pool volume per day.
- Swimmer usage of 400 people / day.
- Solar collectors used are of the flooded plastic panel type, glazed flat panel and evacuated tube types. The collectors have been simulated at different coverage areas.

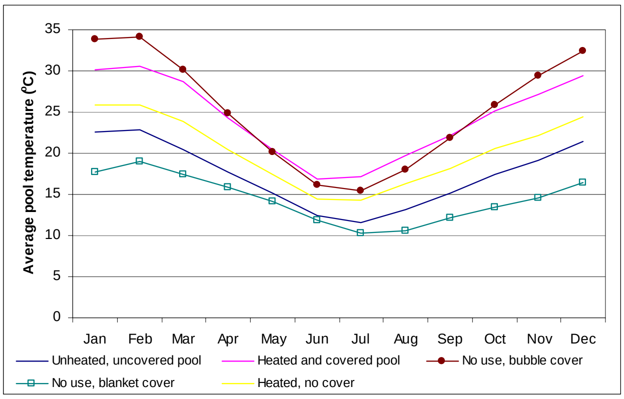

Figure 1: Effect of covers on pool heating.

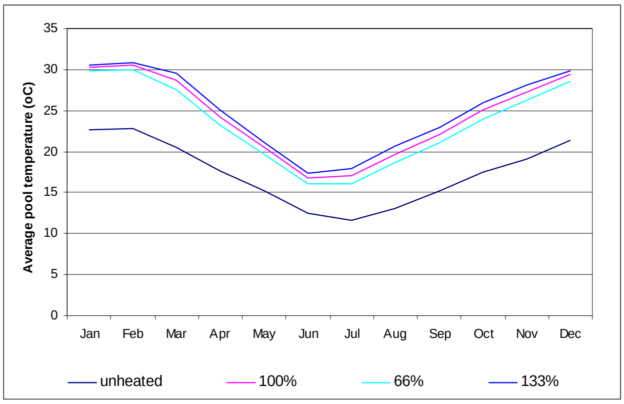

Figure 2: Effect of collector area on pool temperature.

An outdoor pool has the potential to absorb significant quantities of solar radiation. This is illustrated by Figure 1, which shows the effect of the two cover types on a pool that is always covered (and therefore, never used). The thermal blanket cover type has the better insulation qualities, but this is negated by the lack of solar transmission. The bubble cover type maintains the pool temperature at a very high temperature for 6 months a year solely through the transmission of the solar radiation through the cover. In contrast, the thermal blanket covered pool never warms up to a useable temperature during the year, and has an average temperature up to 5ºC below the temperature of an uncovered pool.

The use of an unglazed solar collector at a coverage of 100% significantly increases the temperature of the pool for the 6 months from October to March (inclusive). The pool temperature is maintained above 28ºC for most of this time, whereas, without the solar collector the pool would never reach this temperature with frequent use. Also, if the pool is heated, but does not have a cover, then much of the benefit of the solar heating is lost.

Figure 2 shows the effect of increasing the collector area on the average pool temperatures. There is little increase in the pool temperature from the increase in the collector area.

3.1. Economic analysis

The purpose of a solar collector on an unheated outdoor pool is to extend the swimming season of the pool. Therefore, there is no energy displaced by the solar collector. However, the energy delivered to the pool by the collector can be quantified as the energy that would have been required to heat the pool to the temperature achieved by the solar collectors. Table 1 shows the energy savings for the 6 months from October – March inclusive, had the energy delivered from the solar collectors been purchased. Also shown is the energy saved when the monthly average temperature is greater than 22ºC (the usable temperature). The (marginal) carbon emission savings when compared with gas or electric heating are shown.

Collector type	6 Months Eqv.energy (MWh)	6 Month (Gas) 5.6 c/kWh (85% eff)	6 Months (Elect). 14.4 c/kWh	Usable Temp Eqv.energy (MWh)	Usable Pool (Gas)	Usable Pool (Elect).	Usable Period for Pool (months)
Unglazed, 100%, thermal blanket	136	\$8965 28 t/CO_2	\$19595 95 t/CO_2	171	\$11253 35 t/CO_2	\$24597 28 t/CO_2	8
Unglazed, 100% Bubble cover	128	\$8457 26 t/CO_2	\$18484 90 t/CO_2	163	\$10745 33 t/CO_2	\$23487 26 t/CO_2	8
Unglazed, 100%, No cover	200	\$13183 41 t/CO_2	\$28814 140 t/CO_2	170	\$11163 35 t/CO_2	\$24400 41 t/CO_2	5

Table 1: Energy from the solar collectors converted to savings compared to heating with electricity or gas. Carbon emission factors: 0.194 $kTCO_2/PJ$ (electricity)[1], and 0.057 $kTCO_2/PJ$ (Gas)[2].

These figures need to be interpreted with caution. Solar collectors work more efficiently when the water is colder. As a result, the solar collectors on the uncovered pools collect more solar radiation however, this energy is lost to the environment more readily due to the absence of a pool cover. The number of months the pool is usable is correspondingly less.

3.2. Conclusions

If the pool is infrequently used and with minor shading, then a bubble cover is likely to be the most cost effective way to heat the pool. If the pool is frequently used, then a solar collector will result in a significant increase in the temperature of the pool water. In Auckland, a collector coverage rate of 60-70% of the pool surface area should be sufficient unless the pool is in a shady location. It is essential to use a pool cover in conjunction with solar heating if the benefits of pool heating are to be realised. If the pool is to be used most days, then either cover type can be used. However, the less frequently the pool is used, the more the bubble cover type could be considered but the durability of these covers needs to be taken into consideration. The carbon emission potentially avoided by the solar contribution to the pools ranges from 26 $t/CO_2/yr$ with the bubble cover and gas heating, to 140 $t/CO_2/yr$ without a cover and electric heating. If the pool was previously unheated, then no energy or CO^2 could be claimed to be avoided, although energy or CO^2 avoided may be justified if the pool was planned to be heated by fossil fuel derived energy sources.

[1] Marginal electrical carbon emissions offset from Huntly thermal generation of electricity
[2] Carbon emissions from generating heat energy from natural gas

4. CASE STUDY 2: AUCKLAND INDOOR POOL

An indoor pool in Auckland was simulated to determine how effective different types of solar collector are to heat a pool in Auckland that is used during the warmer period of the year. The pool is heated to maintain a constant temperature of 28ºC for the 6 months from October to March (inclusive). The building is unheated. The following parameters were used in the simulation.

- Pool dimensions of 20 x 14 x 1.3 m. Total surface area of 280 m^2 and total volume of 350 m^2.
- The pool is housed within a building with a surface area of 2100 m^2 and a volume of 2800 m^3.
- Pool is used from 09:00 to 18:00 7 days a week.
- Heating is begun at 06:00 and ends at 16:00.
- Supplementary heating capacity is 1000 MJ/hr
- Filter back flush uses 0.1% of the pool volume per day.
- Swimmer usage of 400 people / day.
- The collectors simulated are of 4 different types.
    - Unglazed collector is of the plastic tube with manifolds type
    - Flat panel collector is of the black chrome selective surface type.
    - Evacuated tubes are of the heat-pipe type.
    - The CPC collector is an evacuated "U" tube with curved reflector.
- Supplementary heating is by both gas and electric boilers.

The swimming pool was simulated with a range of collector coverage area, (depending on the type of collector). The unglazed collectors have a 66%, 100% and 133% coverage rate. The glazed collectors were simulated at 25%, 50 % and 75% (flat panels) coverage rate. A typical thermal blanket (R = 0.088) was used.

The monthly cost of heating the pool (Figure 3) increases towards winter, due to the decrease in the ambient air temperature. The cost of heating with gas is approximately half that of heating with electricity, at the energy tariffs used. As expected, the greater the solar collector area, the less supplementary heating is required. The use of a cover greatly reduces the cost of pool heating, with the pool that had 100% coverage rate of the unglazed collector, but no cover, using more supplementary energy than the pool with a cover, but no solar collector (Figure 4). The pool that was uncovered, and heated only with gas would require more than $18000 of gas a year to heat. The pool that was covered when not in use and had an unglazed solar collector would require approximately $4,000 of gas a year to heat.

The glazed collectors also were effective to heat the pool, even at coverage areas much lower than used for the unglazed collectors. This is due to the increased heat-loss of the unglazed collectors. The simulation was for a pool that was relatively sheltered from the wind. Should the collectors be installed in a more exposed location, then the use of glazed collectors is recommended.

The CO_2 emission factor for gas is approximately a third less than that of electricity (marginal emission factor used). As a result, supplementary heating with gas is preferable to electricity for the pools. The solar systems achieve reductions in CO_2 in proportion to the energy delivered by the solar collectors.

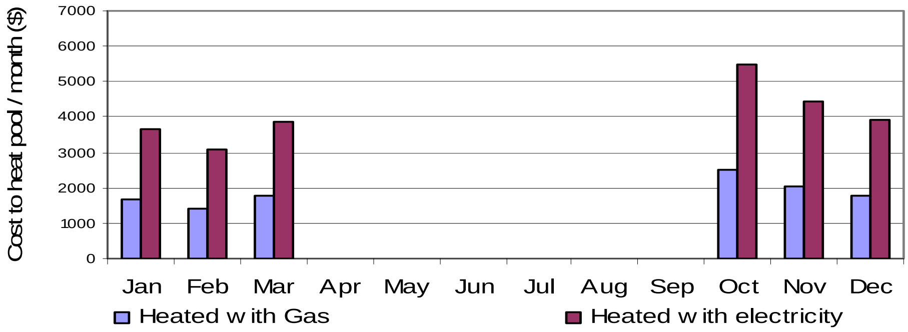

Figure 3. The monthly cost of heating the pool with electricity or gas.

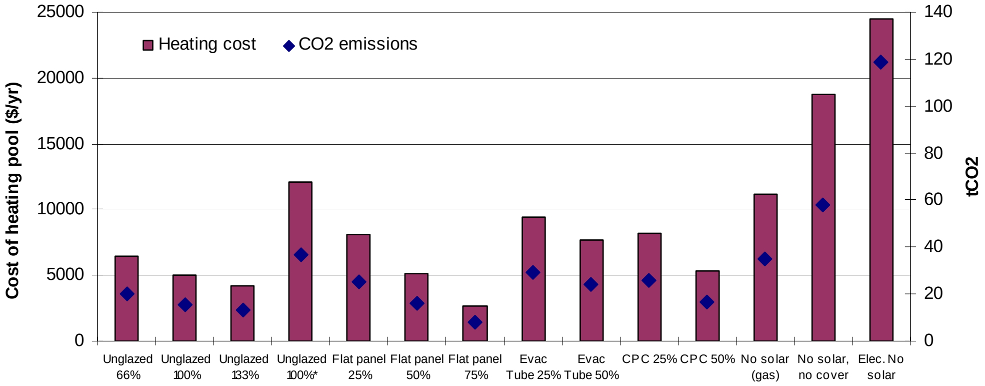

Figure 4. The annual cost of heating the pool with different types and areas of solar collectors. Heating is with gas. *Without a cover. The marginal emission factor for electricity is used.

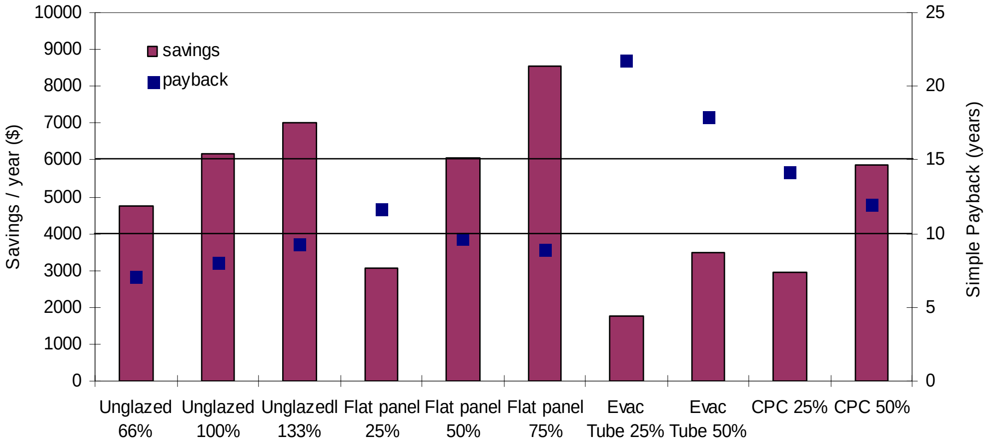

Figure 5. Comparative savings and payback times expected for the systems

In terms of payback, the best payback with the unglazed collectors occurred with the smaller collector area sizes (Figure 5). However, as expected, the savings that could be achieved increased as the collector area increased. The glazed collectors, however, had a decreasing payback as the area of the collector increased. This is due to the heat-exchanger. The cost of the heat-exchanger, and installation is a significant part of the cost of these systems, and a smaller heat-exchanger is not proportionately cheaper than a larger one.

4.1. Conclusions

The system achieving the shortest payback time for the collectors tested was the unglazed type collector. However, the glazed flat-panel collectors are also a good option for pool heating, with a similar payback time expected despite the initially higher cost. The flat panel system would be a good option if hot water was required for a higher temperature application such as showers as well as the pool heating.

5. CASE STUDY 3: INDOOR POOL DUNEDIN

A similar pool to that of Auckland was considered. The difference was that there was space heating in the pool building during the operating season of the pool. The pool building was simulated to maintain 20ºC during the opening hours of the pool, and drop to 16ºC at night-time. The room humidity was held at 70 – 90% (operating / non operating hours respectively). The energy cost to heat the room has been discounted in this analysis, as this is constant between solar collector types.

The monthly pool heating costs are expected to range from approximately $2,000 to $2,800 using gas and about double that using electricity during the operating season without a solar heating system (Figure 6). The annual cost is expected to be $14,000 (gas) and $30,000 (electricity) as shown in Figure 7. With a solar water heating system, this is reduced to $10,600 to $12,000 for most systems when heated by gas. However, with the use of flat panels at a 75 – 50% coverage level, the heating cost reduces to $7,000 - $9,000. These systems also show the best payback period of 10 – 12 years respectively (Figure 8). If the system is installed in a more exposed location, or has significant shading during the summer months, the savings will be less.

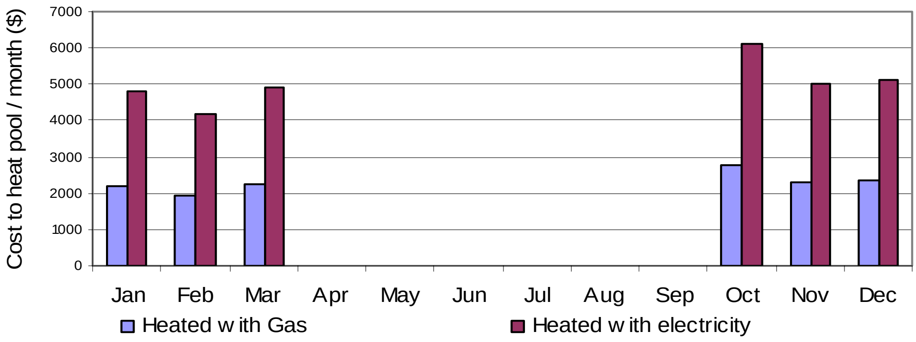

Figure 6. The monthly cost of heating the pool.

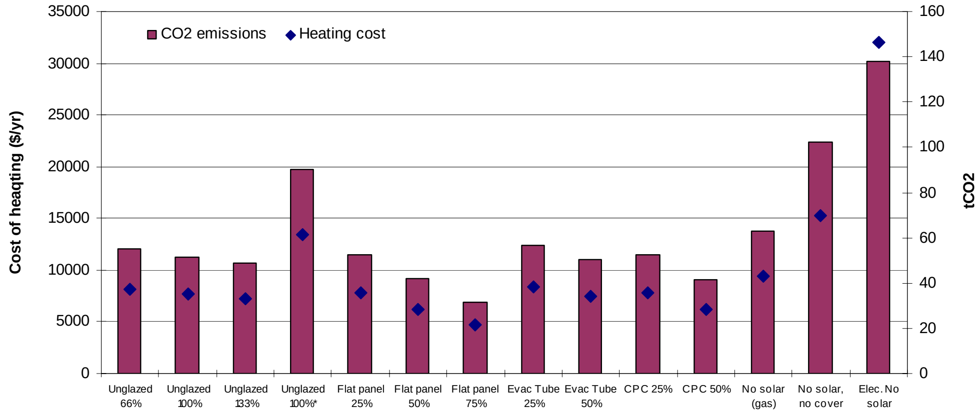

Figure 7. The annual cost of heating the pool with different types and areas of solar collectors. Heating is with gas. The marginal emission factor for electricity is used.

*Pool heated without cover

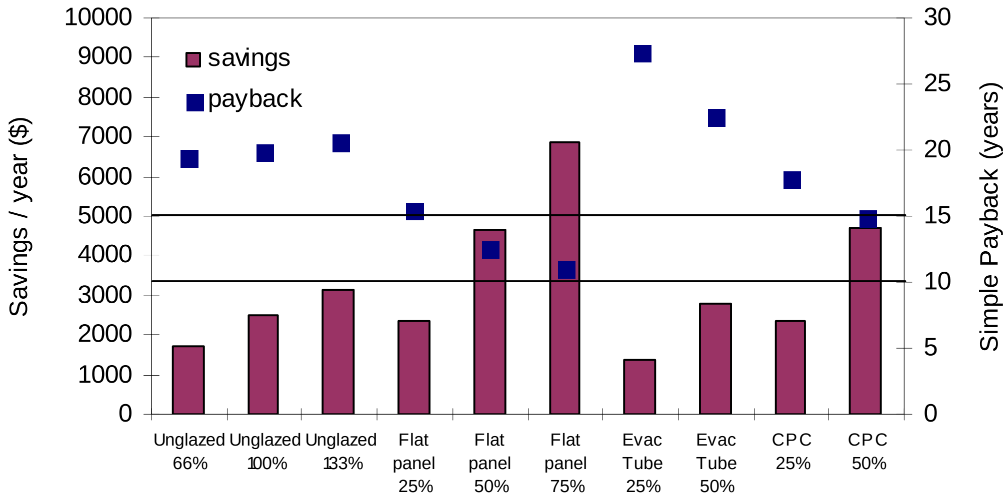

Figure 8. The comparative savings and payback times expected for the system

5.1. Conclusions

An indoor pool in Dunedin requires significantly more energy to heat it than the equivalent pool in Auckland due to the colder ambient air temperatures. The air temperature also results in the glazed solar collectors being, in general, a more appropriate choice for heating the pool than the unglazed collectors. The payback times for the solar collectors in this application is significantly longer than for Auckland, due to the larger solar collectors required, and the reduction in solar irradiation. The increased cost of installing a glazed collector system may be offset by using the system for domestic water heating in addition to pool heating. Where supplementary heating is used to maintain the pool temperature, then gas heating has a lower carbon emission cost than electricity.

6. Disclaimer

The pool simulations in this report are based on the POOLHEAT™ thermal simulation program. Whilst all reasonable care has been taken in producing this report, Project Solar Ltd will not be held responsible for the accuracy, or otherwise, of the results of the simulations. This report cannot be reproduced, except in its entirety, unless written permission has been obtained from Project Solar Ltd.