RP1014u1: Energy efficient swimming pools – Engagement and utilization

Final report

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- originality
- methodology
- rigour
- compliance with ethical guidelines
- conclusions against results
- conformity with the principles of the Australian Code for the Responsible Conduct of Research (NHMRC 2007),

and provided constructive feedback which was considered and addressed by the author(s).

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Executive Summary

This report covers the activities of utilisation project "Energy efficient swimming pools – engagement and utilization". This involved project partners: School of PV and RE Engineering, UNSW, Simply Better Pool Savings, and Randwick Council.

This partnership enabled Simply Better Pool Savings to utilise the research outputs from the CRC LCL Project RP1014 which investigated the use of low flow operation of solar pool heating and low flow operation for pool filtering.

Residential pools account for up to 30% of a household's total energy consumption, making them one of the largest energy consumers in the home.

A typical residential pool filtering system uses a 1 kW pump and consumes over 2,000 kWh/year of electricity [1, 2]. A typical solar pool heating system normally operates over the swimming season (October to March). It utilises a pump that consumes ~0.75 kW or more and 6 kWh/day of electricity [3].

The Pool Efficiency Program has provided a total of 70 pool energy assessments and retrofitted 39 pump speed controllers to existing single-speed pool pumps. The free pool energy assessments that were offered to the participants included a tailored summary of how their pool currently consumes energy, simple suggestions to reduce energy consumption, and either the subsidised pool pump retrofit or a subsidised pump replacement.

On average, the Pool Efficiency Program has reduced the pool pump energy consumption by 71% (~1,740 kWh/year per household) and saved $486 on annual electricity bills. The associated GHG emission reductions are 1.67 tonnes CO_2-e per household per year, which is approximately the same amount of emissions produced by a typical car travelling 6,400 kilometres.

Over 94% of the participants who adopted a pool pump retrofit have reported that they are either 'satisfied' or better with their experience in Pool Efficiency Program. Over 44% said they were 'extremely satisfied'.

The pool pump noise has been reduced by approximately 86% on average, which was highly regarded by all participants.

As compared to the conventional pool industry in Australia, the pump retrofit option and setup optimisation provided by the Pool Efficiency Program is estimated to achieve ~44% higher solution adoption rates and obtain ~70% additional energy savings in every household that adopts the recommended improvements (~720 kWh/year). The energy savings were delivered by a) reducing the main filtering pump speed, and some combination of; b) reducing the solar pool heating pump speed and/or; c) optimizing the run times of the main filtering pumps and/or; and d) optimizing the run times of the pressure pool cleaner pumps. Where necessary and possible optimizations could also involve recommended changes to other existing pool equipment e.g. chlorinators.

Assuming all eligible residential swimming pools in the Randwick area were retrofitted with the pump speed controller, approximately 3.7 GWh of electricity could be saved every year, which corresponds to approximately 3.5 kt CO_2-e of GHG emission reductions.

1 Introduction

Residential swimming pool pumps use significant amounts of energy. Australia has the highest per capita ownership of residential swimming pools in the world [4]. At present, about 12% of Australian homes have a swimming pool (1.1 million residential pools) [1] and the pool filtering pump can account for up to 30% of the energy bill in those households [5]. As per the data from EES [6], residential swimming pools contribute approximately 2 Mt CO_2-e of GHG emissions in 2016. This corresponds to nearly 2% of the residential sector GHG emissions (both direct and indirect) and around 0.38% of the total annual GHG emissions in Australia in 2016 [7]. Pool pumps are also significant with respect to their impact on peak demand. Assuming a total load of 1.1 kW per pool, as reported by Ergon Energy [8], then the 1.1 million residential pools in Australia [1] would contribute to 1.2 GW of electricity demand.

Conventional pool pumping systems utilise fixed speed AC electric motors. Variable speed motors capable of running at slower speeds than conventional motors are a simple energy efficiency retrofit that can deliver energy and carbon reductions of about 75% [9-11]. This key energy saving approach is the result of operating the pool pumps at a low speed and a low flow rate, meaning that the system works at a much lower pressure (as pressure is proportional to the square of the flow rate) [12].

Recent CRCLCL project (RP1014) has investigated an energy efficient residential swimming pool system using a low flow approach. As pressure is directly proportional to the energy required by the pump, operating the pool filtering system at low flows can deliver significant pressure reductions and thus, energy savings without compromising the ability of the system to keep the pool clean [13]. If this high-efficiency pool filtering system were implemented across Australia, approximately 1 Mt of CO_2-e of GHG emission could be reduced and 1 GW of peak electricity demand could be avoided per year. Experimental results obtained in RP1014 also showed that operating a typical residential solar pool heating system under low flows was feasible and improved the energy efficiency significantly. Approximately 60% of the solar heating pumping energy was saved whilst the coefficient of performance increased by more than three times when compared to the Business as Usual (BAU) scenario (i.e. high speed and high flow). In order to keep the vacuum relief valve (i.e. at the highest point of the solar pool heating system) closed under low flow conditions and at all time, the throttle valve was adjusted to ensure the pump developed sufficient pressure. If all residential solar heated pools in Australia were retrofitted with the low-flow operating scenario proposed in RP1014, the annual electricity demand of residential pools would be reduced by around 10% (200 GWh/year). This is equivalent to 188 tonnes of CO_2-e of GHG emissions reduction per year.

Based on the research outcomes from the CRCLCL project RP1014, this Pool Efficiency Program (a utilization project) aimed to engage with the pool equipment industry to assess the real impacts of the research outcomes from the CRCLCL project RP1014 and encourage greater uptake of energy efficient pool systems. The UNSW research team has collaborated with Randwick City Council and Simply Better Pool Savings (the chosen industry partner of UNSW) to implement the energy-efficient retrofits on several residential pool systems. The main objectives of this project were:

- To assess the energy savings and owner perceptions of the implementation of high-efficiency solar pool heating system and pool filtering system.
- To develop and strengthen relationships with pool equipment suppliers in order to encourage them to adopt more efficient pool pumps or pump controls for pool filtering and solar pool heating.
- To assess commercial equipment that can be delivered to pool owners and prepare material for residents and local government to accelerate the uptake of energy-efficient residential pool systems.

Chapter 2 presents an introduction to the energy use of residential pool systems, which provides useful background information for the discussions of the results.

Chapter 3 presents the Pool Efficiency Program strategies. It also includes details of the optimisations and quality assurance safeguards that were conducted as part of the upgrades to ensure quality outcomes.

Chapter 4 presents the main details of the residential pool systems which participated in the Pool Efficiency Program. Key results of the program are also discussed, which include the impacts of the pool energy efficiency retrofits on pump energy use, noise level, pool thermal comfort (where applicable) and the overall water conditions. The participant perceptions of this program and the energy efficiency retrofits are also assessed.

Chapter 5 compares the outcomes from this Pool Efficiency Program to those that might be expected from the conventional Australian pool industry in Business as Usual scenarios. Outcomes are detailed in terms of the absolute energy and cost savings, and the cost-effectiveness of the Pool Efficiency Program retrofits by comparison to conventional pool industry options.

Chapter 6 summarizes the main results and provides insights for the future roll-outs and up-scaling of the outcomes of the Pool Efficiency Program.

2 Residential swimming pool systems and energy use

To ensure the quality of pool water, a pool system relies on a combination of filtration – to remove dirt, leaves, and other debris – and chemical treatments to kill bacteria and control algal growth. Figure 1 shows the physical layout of a typical swimming pool system, where

- A pool pump draws water and circulates it through other system components and back to the pool;
- A filter removes particles and debris in the circulated pool water;
- The skimmer(s) draws water from the pool and prevents big debris from entering the main pipework;
- The return(s) passes the filtered water back into the pool. They are typically installed on the walls;
- The pipework connects the pool pump, filter, and other system components with the swimming pool;
- A pool heating unit (optional) warms up the water and extends the swimming period.

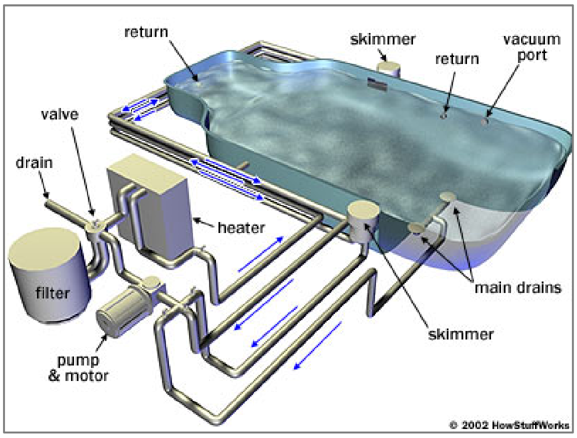

Figure 1. Swimming pool system layout. Source: Harris [14].

In addition to the features illustrated in Figure 1, a pool cleaner is normally used to enhance the cleanliness of the pool walls and floor and this supplements the work of the filtration function. Most pools now also have automatic chlorinators or other sanitising devices, which disinfect the water chemically. Smart controls and timers are also installed to schedule the operation of swimming pool equipment based on the owners' needs.

Figure 2 presents the energy use breakdown of all residential swimming pools in Australia as published by Wilkenfeld [15]. As seen, most of the pool energy use is due to the operation of the main filtering pump. For heated swimming pools (discussed further in Section 2.2), the pool heating appears to be the second energy-intensive aspect. This includes both electricity and gas supply for solar heater pumps and gas heaters. The remaining pool energy goes to chlorinators, controllers, and spas.

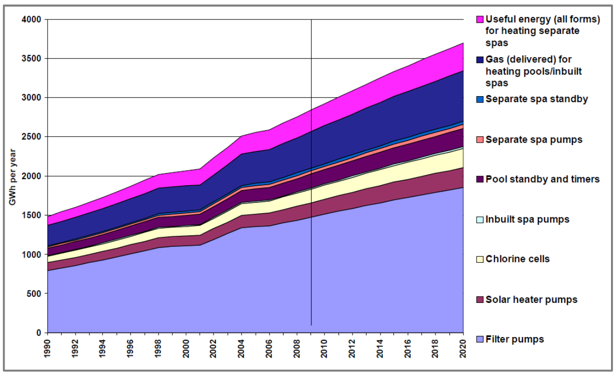

Figure 2. Energy consumption breakdown of all residential swimming pools in Australia. Source: Wilkenfeld [15].

Overall, the total energy consumption of Australian residential pools was estimated to be 10.5 PJ in 2016 [6], which corresponds to around 2.3% of the total residential energy in Australia for 2016 [16].

The following sections discuss in more detail the energy saving opportunities of the residential pools for the filtering and heating processes.

2.1 Pool filtering systems

2.1.1 Water pumps

As discussed previously, swimming pools require a filtering system that typically runs for several hours per day. A pump is needed to circulate the water through the filtration system and any ancillary elements of the system which may include auto-cleaners, chlorinator cells, heaters etc. Hence, as its core element, the pool filtering pumps need to be sized to perform all system tasks in an efficient way. Some tasks, such as priming, backwashing, driving the cleaning and chlorination equipment, operating spas and other water features occur only occasionally but require a much higher flow rate and pressure than the normal filtering of pool water.

As a conventional pump type used in pool systems, standard single-speed pool pumps are equipped with a single speed motor, which cannot change their speed or flow rate. Therefore, they are normally sized to produce very high pressure and flow rate to ensure proper operations under all circumstances. This, on the other hand, means that during the normal filtering process that lasts longer and requires much less pressure, the single-speed pumps are actually overworking, producing excessive pressure and drawing more energy than is necessary.

There are also other types of pool pumps available [1, 17]. These include:

- Dual-speed pumps that operate at two speeds with a 2-pole and 4-pole motor configurations;
- Multi-speed pumps that operate at several speeds;

- Variable-speed pumps that operate at a range of speeds using a permanent magnet (PM) motor paired with a variable-speed drive (VSD). The PM motors are more efficient than standard single-phase electric motors and are also more reliable and durable due to less pump wear [18], however, cost more.

2.1.2 Pool filters

Other system components like pool filters and pump-operated pool cleaners do not consume energy directly. However, their working conditions can influence the energy use of the pumps that power them. There are four common types of filters for residential swimming pools – sand, diatomaceous earth (DE), glass beads, and cartridge filters [3, 19]; and all need to be cleaned in order to ensure the dirt inside will not increase the workload of the filtering pumps [20]. No matter which type of filter is used, the benefits of having an oversized filter are also well documented [21, 22]. Firstly, it reduces the pressure that filters place on the system, therefore minimizing energy use. In addition, a larger filter contains more filtering media to collect debris and increases the cleaning intervals, which would save energy used for cleaning the filter. Also, the lifetime of both the filters and the pumps could potentially be improved. In contrast, for smaller filters, high flows from the pump may easily overwork the filter and cause premature failure, whilst the pumps are also working against the growing pressure drops across the filters.

2.1.3 Pool cleaners

In terms of pool cleaners, the most popular ones are the automatic pool cleaners powered by the main filtering pump. They can be attached to the return pipe of the main filtering pump (pressure auto-cleaners) (Figure 3a) or the suction side (suction auto-cleaners) (Figure 3b) [23]. In either configuration, the main filtering pump has to create enough pressure for the cleaner to work and run possibly longer to ensure the cleaning quality. Pressure automatic pool cleaners in some cases are operated by dedicated pumps and thus they can run independently of the main filtering pump, and therefore there is greater freedom for them to be run for shorter periods. This can reduce the workload and the energy use of the main filtering pump [17, 24].

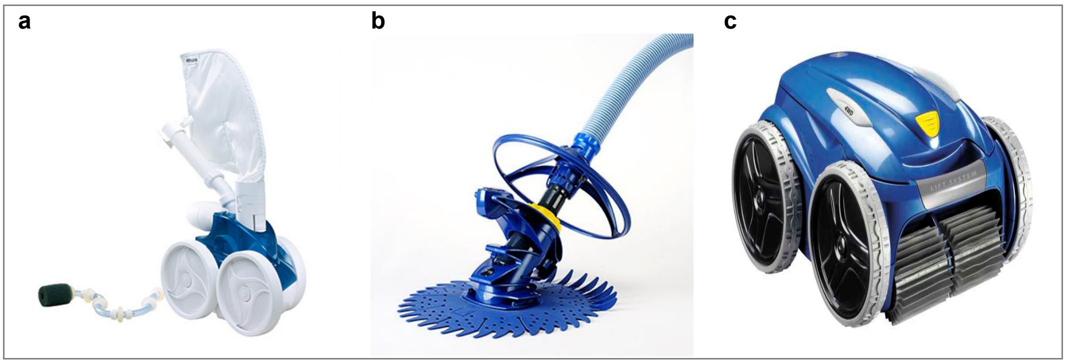

Figure 3. a) Pressure auto-cleaner; b) Suction auto-cleaner; c) Robotic pool cleaner. Source: Zodiac [25].

Robotic pool cleaners shown in Figure 3c are relatively new on the market and they share the same cleaning methodology as the suction cleaners, but do not need a pump to supply the water flow. Instead, they are operated directly by independent low voltage power sources. In this case, the pumps may no longer need to run at high speeds during cleaning cycles, which allows the maximum energy savings to be realized by filtering at low flow rates.

Other forms of pool cleaning do exist, such as manual cleaning (more time-consuming) and in-floor cleaning systems.

2.1.4 Energy saving options

Given that the single-speed pumps take up 70% of the market share in Australia [1], they contribute significantly to the total energy use in the residential section and there is great potential for energy savings. For residential pools with no water heating, DEE [1] estimated that the filtering system accounts for around 70% to 90% of the total pool electricity consumption. With an estimated energy consumption of 5.6 kWh a day or more than 2,000 kWh a year[1] [1, 2], the pool filtering pump can account for up to 30% of the energy bill for households with pools [5]. DEE [1] stated that pool pumps in Australia are deemed to cost the consumers around $224 million a year in avoidable electricity costs.

[1] Estimated based on an average power consumption of 1 kW for most pool pumps in Australia and an average daily filtering time of 5.6 hours/day. The pool filtering system operates for 365 days a year.

The theoretical background on the energy use of the water pumps has been addressed by Barnier and Bourret [26] and [27] and numerous studies have investigated the energy savings by reducing the pump speed and water flow rate [9, 10, 28-30]. Based on the well-known Pump Affinity Laws, Sproul [29] reported that pump power is proportional to the cube of the water flow rate and therefore, by reducing the flow rate significant hydraulic power could be saved. It is important to note that the pump had to run for longer (i.e., in proportion to the amount of flow rate reduction) in order to accomplish the same quantity of water turnover. As such, a reduction of flow rate to a half of the original resulted in electrical energy savings of around 75% if the pump/motor efficiency was maintained at the reduced flow rates. It is also worth noticing that depending on the real pool operating scenarios, in some cases it can be necessary to increase filtering hours after a flow rate reduction, in other cases they may be held stable, and in yet other they can be reduced whilst maintaining satisfactory and compliant water turnover rates and filtering outcomes. Further discussions are given in Section 4.2.2.

Considering the whole swimming pool filtering system, Zhao and Bilbao [13] reported that main system components (pool chlorinator and discharge-side pressure cleaners) have minimum required flow rates of 1 L/s and 1.3 L/s respectively. More importantly, operating the pool filtering system with a discharge-side pressure cleaner at 1.3 L/s achieved 60% energy savings in comparison to the Business as Usual scenario (flow rate of ~3.7 L/s). When using a robotic pool cleaner, energy savings of more than 70% are obtained by operating the filtering system at a lower flow of 1 L/s. In both energy efficiency scenarios, the low flow operations did not compromise the overall system performance and significantly improved the water quality.

2.2 Pool heating systems

The heating energy use is another major driver of the pool energy demand. Approximately one-third of residential swimming pools in Australia are heated and a majority of them (~90%) are heated with solar collectors [2, 31]. The rest are heated with gas heaters and heat pumps. Gas heaters have a very large heating capacity of 200 – 400 MJ/hr [32], which can heat a pool quickly and on demand. Pool heat pumps are a good option when gas is not available as they are powered by electricity. Pool heat pumps' efficiency is measured by the coefficient of performance (COP). With a typical COP between 3.0 and 7.0 [33], a pool heat pump can generate 3 to 7 units of heat output for every unit of electricity consumed. Both gas heaters and heat pumps are ideal for achieving year-around swimming. Gas heaters, in particular, can maintain the pool temperature regardless of the climate. However, the energy use of gas pool heater and pool heat pumps, as shown in Table 1 were estimated to be around 36 times and 7 times larger than that of the solar pool heating systems [3].

Table 1. Energy usage and GHG emissions of different residential pool heating options. Source: Ausgrid [3].

	Solar pool heating	Heat pump pool heating	Gas pool heating
Estimated energy use	6 kWh/day	43 kWh/day	786 MJ/day
GHG emissions (CO_2-e)	45 kg/week	290 kg/week	354 kg/week

Solar pool heating systems are more appealing to householders in comparison to the conventional heating options not only for its less energy use, but also for the reason that the residential pools are normally used during summer and the main aim for heating is to expend the swimming period [34]. Australia and the USA have big solar pool heating markets [35], which account for nearly all the nationwide energy yield solar water collectors and Australia has the highest per capita utilization of solar pool heating in the world [35].

As seen from the layout of a typical residential solar pool heating system (Figure 4), the pool water is circulated by a water pump through the solar thermal collector, where it is heated before returning to the pool directly. Typical residential solar pool heating systems also have temperature sensors, flow control valves, vacuum relief valves (noted as vacuum breaker in Figure 4) to ensure proper and efficient operation.

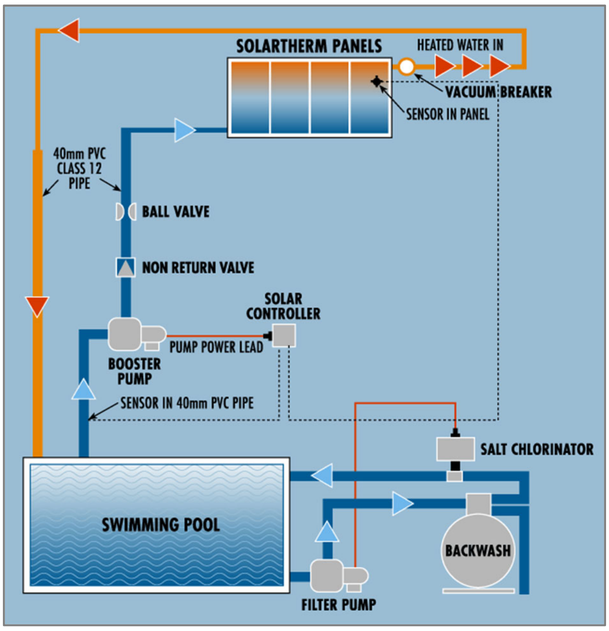

Figure 4. The layout of a typical residential solar pool heating system. Source: Solartherm [36].

The vacuum relief valve is an essential component in the system, which is normally located near the top-end of the solar collector (the highest point of the system). It is designed to allow water to drain out when the solar pump is switched off. For collectors located well above the pools (e.g. on multi-storey houses), in which a pressure drop of several meters normally exists, the system might operate at pressures lower than the atmospheric pressure (i.e., negative pressures) near the highest point. In this case, the vacuum relief valve would open and let air enter the system, causing noisy operations and excessive consumption of the chemicals due to bubbling [37, 38]. To avoid this situation, a throttle valve (restriction valve) is recommended by the standards to be installed and used. Though not presented in Figure 4, a throttle valve is normally fitted on the downstream pipework where the heated water flows back into the pool. It can be adjusted to increase the pressure at the location of the vacuum relief valve and keep it closed [38]

2.2.1 Energy saving options

Same as the pool filtering systems, operating the water pumps in solar pool heating systems under the low speed and low flow conditions could also save energy. During the CRCLCL project RP1014, Zhao et al. [39] reported that operating a three-speed pump (Viron P280) at the low-speed setting required only 40% of the pump energy of a typical system. The water flow rate per unit collector area was around 0.02 kg/s/m^2, which was only 20% of the Business as Usual (BAU) flow of 0.08 kg/s/m^2. Reducing the flow rate, however, has reduced the thermal efficiency the solar collector by 15% and to achieve the similar swimming pool thermal performance, the modelling results suggested to increase the system run time by 1.3 hours per day on average or to increase the collector area by 15%. It is also important to note that the throttle valve (discussed in the previous section) was partially closed under the low flow conditions to maintain the vacuum relief valve closed.

3 The Pool Efficiency Program strategy

3.1 Pool energy-saving retrofits

The program focusses on four key areas of savings opportunities:

1) Reducing the flow rates of the main filtering pump;
2) Optimising the run times of the main filtering pump;
3) Optimising the run times of the booster pump for pressure auto-cleaner, where one exists.
4) Reducing the flow rates of the solar pool water heating pump where one exists.

Reducing the flow rates of the main filtering pump can be achieved by either adding a pump speed controller (a variable frequency drive) to the existing single-speed main filtering pump or by discarding the existing single-speed pump and replacing it with a variable-speed pump (with built-in speed controls). Either way, the savings benefits flow when the pump motor speeds and system flow rates are dialled on to a lower, more optimised level. All participants were offered both options.

Optimising main filtering pump run times can be achieved using an optimisation model provided by UNSW's chosen industry partner Simply Better Pool Savings. The model was verified by the UNSW research team throughout the project. The model is informed by leading research into pools in Australia and overseas, it incorporates and reflects the complexities bought about by interdependencies between the different pieces of pool equipment in a typical pool system. The model also allows for key variables relating to the pool itself, the pool's equipment and setup, the settings on that equipment, the satisfaction of the pool owner with water chemical balance to be captured and processed by optimisation algorithms. Variables relating to the participant's electricity supply and billing arrangements are also captured and processed by the model and the model's outputs reflect the requirements of the relevant standards (e.g. Australian Standards AS 3633 [38]).

Optimising the run times of booster pumps for pressure auto-cleaners can be achieved in a similar fashion to optimisations on run times of the main filtering pump. That is, by using an optimisation model provided by UNSW's chosen industry partner Simply Better Pool Savings. The remarks about this optimisation model in respect of the main filtering pump apply equally here.

Reducing the flow rates of the solar pool water heating pump can be achieved by adding a pump speed controller (a variable frequency drive) to the existing solar pool water heating pump, or by discarding the existing single-speed pump replacing it with a multi-speed pump. Using a multi-speed pump and running it at low-speed setting has been investigated by Zhao and Bilbao [39] in the CRCLCL project RP1014. However, this was not included as a practical retrofitting option in this program because no such dedicated, multi or variable-speed solar pool water heating pumps are available on the market. Applying other pumps, such as the main filtering pump or pumps from other areas (e.g. drainage), was deemed as involving unnecessary complexity for the purposes of this program.

It is important to note that energy saving options associated with other system components, e.g. oversizing the pool filters or retrofitting the pressure cleaners with robotic pool cleaners (as reported by Zhao and Bilbao [13]), were not implemented in this program. However, they have been clearly demonstrated to all participants during the site visits.

3.2 Measurements and calculations

The power use of the pump (both the main filtering pump and the solar pool heating pump) before and after the retrofit was measured by a digital power meter, based on which the pump energy consumption was calculated. Since lowering the pump speed reduces the pump noise, which is an additional benefit of the pump retrofit [1], sound measurements were also taken. The sound level of the pool filtering pump was measured by a digital sound meter before and after the retrofit. In terms of the solar pool heating system, since the water flow rate in the solar thermal collector directly affects the thermal performance of the solar thermal collector and thus the pool water temperature, the research team used an ultrasonic flow sensor to measure the water flow rate before and after the solar pump retrofit. The potential impacts of the flow rate reduction were evaluated using a validated Transient System Simulation Tool (TRNSYS) model developed by Zhao and Bilbao [39] in the CRCLCL project RP1014.

The experimental equipment used in the Pool Efficiency Program is shown in Appendix 9.1.

The energy savings and GHG emission reductions were calculated based on the estimated annual energy consumption before and after the retrofits. The project team is confident in the stability and veracity of the measurements and estimates for a variety of reasons including that Simply Better Pool Savings has conducted trials over long periods that demonstrate that pump power, pressure and flow rates are very stable in reasonably well-maintained pools. Furthermore, the physical measurement of actual pool pump power consumption, rather than simply referencing the pump rating was a significant advance on many of the prior recognized studies in this area, e.g. Wilkenfeld [24]. For the main pool filtering pump retrofits, the annual energy use before the retrofits was calculated using the measured pump power and the owner specified pump run times; and after the retrofits, it was based on the optimized pump run time (discussed in Section 3.1). For a significant portion of pools in the study site visits were undertaken in addition to remote, online pool assessments. These visits provided an opportunity to check the hours of pool pump running reported by the pool owner online and the actual run times as indicated by the pool's timers and controllers. For the solar pool heating system, which operates largely depend on the weather, the pump run time was modelled using a validated system model in TRNSYS [39].

The GHG emissions were calculated using an electricity emission factor of 0.96 kg CO_2-e/kWh for New South Wales, Australia [40].

3.3 Key program processes

The Pool Efficiency Program was delivered by the following key processes:

1) Invitation to this program was sent by Randwick City Council to the local residents via its weekly email newsletter. The targeted households were those with a swimming pool and use a single-speed pump for pool filtering purpose. The households with a solar pool heating system were also preferred. The selection criteria for participants in this program are attached in Appendix 9.2. An online expression of interest (EOI) form was used to collect the details of the local households, from which a list of households which met the program criteria was prepared.
2) Site visits were scheduled with a selection of households, during which the project team assessed the swimming pool system, demonstrated potential energy savings to the participants (pool owners). For some pool owners, this assessment was conducted remotely and online through an Online Pool Assessment Tool provided by Simply Better Pool Savings and verified by UNSW. Either at this initial assessment when it was conducted on-site or at an install appointment, participants were also asked to complete a paper questionnaire. The paper questionnaire was to find out how the pool owners normally run their pools and their perceptions regarding the operation of their existing pool systems.
3) After the assessment, the project team delivered all participants the assessment reports, which summarized the following aspects:
    - Current energy use and costs of the pool;
    - A shortlist of the most potent retrofits;
    - Simple economical evaluations of the retrofits and their potential carbon reductions;
    - Guidance and how to most easily assess the solutions in the market;
    - A rebate of $250 if the participants want to implement the retrofits[2].
4) The project team contacted all participants one week after the delivery of the site assessment reports to ascertain if they wanted to proceed with the proposed retrofits. Participants had the opportunity to pursue retrofits of either an add-on controller and/or a new replacement variable-speed pump with the supplier of their choice. In practice, because every participant chose the add-on controller option, and because this is not an option offered widely by the conventional pool industry, all retrofits were conducted with the program's chosen industry partner, Simply Better Pool Savings.
5) Between two weeks and two months after the retrofits, the project team contacted the participants to check if any operational problems were encountered and to circulate the online surveys. Together with the paper questionnaire completed by the participants during the first site assessment, the online surveys were used to evaluate the participants' perceptions of the overall performance of the pool systems before and after the retrofits, and to understand the actual impacts of the retrofits.

3.4 Quality assurance of outcomes

Energy efficiency outcomes will only be acceptable to pool owners if pool water cleanliness and aesthetics are maintained or improved as part of the process. Any outcome that reduces water cleanliness or clarity will not be welcomed by pool owners and will result in poor feedback, significant unwinding of the improvements, and poor persistence of energy savings over time. Changes that lead to an increase in pool care workload carry the same risks.

Every backyard pool setup involves a collection of equipment that combines to deliver clean and clear water when it is set up and maintained correctly. When the settings on one piece of equipment are changed it often has ramifications for the settings on another piece of gear within the system, and for the cleanliness and clarity of the pool water.

When householders change the main filtering pump speed and do nothing else, the cleanliness of every litre of water that passes through the filter will be improved. This is because the filter's sand bed or filter screen catch more dirt, and finer particles of dirt when the water passes through more slowly. But if daily running hours of the main filtering pump were the same, fewer litres of water are running through the filter each day. So, are householders getting a better or sufficient filtration outcome, or a worse and insufficient one? Pre-emptive decisions about if and by how much to adjust pump running times are essential to ensuring that sufficient or better filtration outcomes are a feature of the retrofit.

Once changes are made somewhere in a pool system the same questions of better or worse, sufficient or insufficient arise across an array of important dimensions, not just in regards to filtration outcomes. For example, is the pool still getting a sufficient chlorine dose each day? Is the suction or pressure auto-cleaner still operating adequately? Is the pool heating system delivering the same heat output after the upgrade as it was before? and so on.

The only way to answer these questions is to also recalibrate these elements of the system for the new, lower flow rates. Given that energy efficiency outcomes are now also an important outcome, alongside clean and

[2] The rebates were provided jointly by Cooperative Research Centre for Low Carbon Living (CRCLCL) and Randwick City Council.

beautiful pool water, it makes sense to undertake this recalibration with an optimisation mindset.

Examples of optimisations and quality assurance safeguards that were undertaken in this program are listed below. These safeguards were achieved by virtue of the optimisation model that was bought to the program by Simply Better Pool Savings, verified by the UNSW and utilised throughout the program.

1) That total daily pump running times are recalibrated for the new, slower flow rates. The change in pump speed and water flow dictates that a decision be made about daily pump running times. Can they be reduced? Do they need to increase? Or, should they stay the same?

2) That the combination of new, slower flow rates and potentially different total daily pump running hours after the upgrade deliver enough water circulation to satisfy the one-turnover per day guideline detailed in the relevant Australian Standards AS 3633 [38]. That this be a requirement even if the flow rates and hours were failing to deliver against this standard prior to the retrofit.

3) That any automated chlorination system, like a salt or mineral-cell chlorinator, ionizer, auto-doser etc. continues to deliver sufficient daily doses of chlorine after the retrofit as it did before.

4) In pools with suction or pressure auto-cleaners, that the changes to flow rates and potentially to running hours of the main/filter pump continue to support the satisfactory operation of the pool cleaner.

5) In pools with heating systems, that the changes to flow rates and potentially the reductions in main filtering pump run times were achieved subject to the constraint that the running time of the heater, and therefore the amount of heat it produces could not be compromised.

6) That the guidelines for when within each day a pool pump was run took account of, balanced and optimised; the cheaper electricity tariffs at certain times of the day, time-slots when pool pump noise restrictions are in effect, optimum times of the day for chlorine production where relevant, optimum times of the day for pool skimming effectiveness, any impacts in terms of solar pool heating performance where relevant, optimising any opportunity to take advantage of electricity generated by a householder's rooftop solar PV panels if they have them etc.

7) That these optimised guidelines for when within each day to run pool pumps changed across the year as seasonal changes impact factors like; electricity tariff time-of-use windows, the seasonal performance of any rooftop solar PV panels, the changing appetite for heat output from any pool water heating system over the year.

4 The Pool Efficiency Program results

Overall, 133 householders (all own a backyard swimming pool) in the Randwick City Council area have expressed their interests in the program. 70 households who were eligible also completed the required eligibility survey, the necessary program formalities such as a Participant Information Sheet and Consent Form, and a pool assessment (either on-site or remotely online).

4.1 Details of the assessed pool systems

70 residential swimming pool systems have been assessed in this program. The major findings are summarized as follows:

a) The average pool size is 41.6 m^3, which is in agreement with the volume estimated (i.e., ~40 m^3). The smallest pool is 18 m^3 and the biggest one is 87 m^3.

b) The most common type of pool water is salt water, which accounts for 81%.

c) The average power rating of the single-speed pumps is 1.1 kW, which supports the test results published by DEE [1].

d) The typical swimming season in Australia was assumed to be between October and March, during which a residential pool is used more often. Over this period, the pool filtering pump runs longer (an average of 7.1 hours/day), as compared to non-swimming season (an average of 5.2 hours/day). The overall average throughout the year is 6 hours/day.

e) The average energy use of the pool filtering pump is 2,312 kWh/year (6.3 kWh/day).

f) The average energy use of the solar pool heating pump is 927 kWh/year (5.1 kWh/day) (a residential solar pool heating system normally operates during typical swimming season from October to March).

g) As shown in Figure 5, the hydraulic pool cleaner (pressure or suction) is the most common type of pool cleaner amongst all households (63%) and 44% are suction auto-cleaners operated by the main filtering pump. Most pressure auto-cleaners are operated using a separate booster pump. The robotic cleaner shares the same proportion as manual cleaning (~17%). There are also three swimming pools using an In-Floor cleaning system (4%).

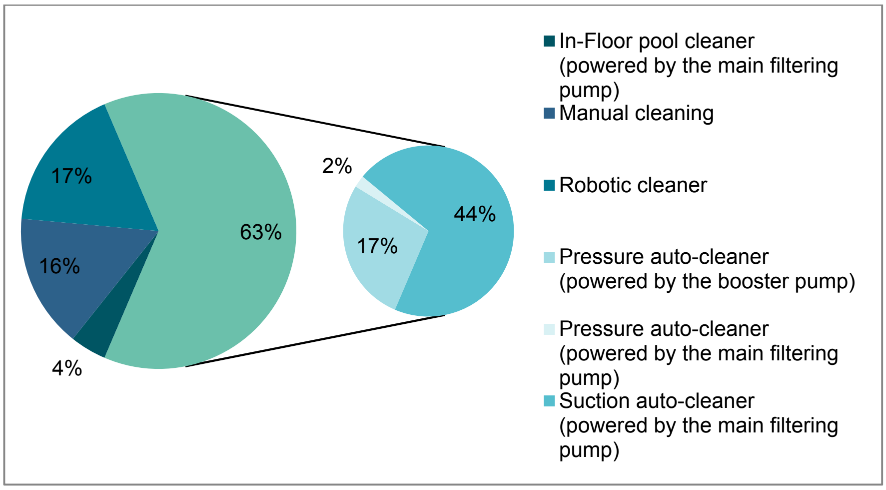

Figure 5. Proportions of the cleaners used in 70 assessed residential swimming pools.

h) 26 of the assessed swimming pools (38%) have auxiliary heating and 20 of them have a solar pool heating system, i.e., a typical plastic-tube solar thermal collector on the roof for heating pool water. This represents a penetration rate of approximately 30% for the residential solar pool heating systems (Figure 6), which matches the findings reported by Wilkenfeld [31] and Woolcott Research and Engagement [2]. Similar proportions as Wilkenfeld [31] are also obtained for gas and heat pump pool heating systems, i.e., 6% and 3% respectively.

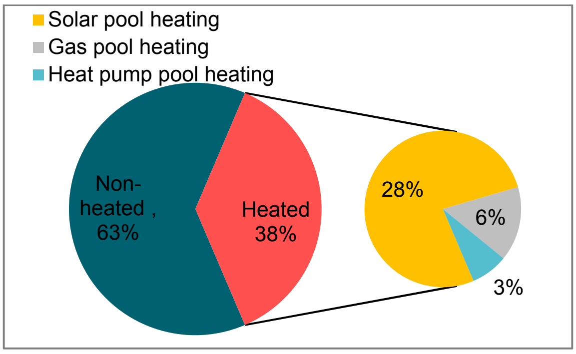

Figure 6. Proportions of the heating options used in 70 assessed residential swimming pools.

i) Although it is recommended by Australian Standards AS 3634 [38], that a throttle valve should be fitted in a solar pool heating system on the downstream pipework where the heated water flows back into the pool (as explained in Section 2.2), only four of the 20 solar pool heating systems have a throttle valve (20%). It is also interesting to note that about half of the solar pool heating systems are integrated as part of the pool filtering circuit (i.e., an in-line system). This penetration rate is lower than that reported by Wilkenfeld [31] (>75%); and this could possibly be because these solar pool heating systems were installed after the pools were built and adding an independent solar pool heating system (i.e., digging the ground for the pipework and creating extra suction intake valves in the pool wall) was costly.

j) Also note that all the solar pool heating systems assessed in this program are operated by a separate single-speed pool pump.

k) A majority of the swimming pools (56) have a sand filter and 13 pools have a cartridge filter (one remotely assessed pool did not provide the filter type). According to the boxplot shown below, the volumes of the pools with a cartridge filter distribute between the range of 20 m^3 to 50 m^3, whilst those with a sand filter distribute over a wider range with an outlier of more than 80 m^3.

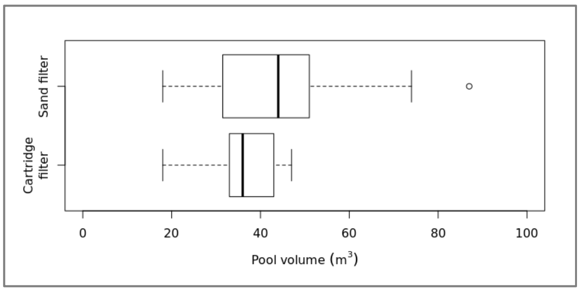

Figure 7. Boxplot of the swimming pool sizes (volume) with two types of pool filter in use.

The following sections focus on the results obtained from the retrofitted residential pool systems, which include energy and GHG emission savings obtained by the retrofits, the cost-effectiveness of the retrofits, and the householder perceptions of the program outcomes.

4.2 Energy savings and GHG emission reductions of the pool pump retrofits

It is encouraging to see over half (36) of the assessed households (70) proceed with a pool pump retrofit. All households chose to install an add-on pump speed controller to their existing pump rather than throw out their existing pump and replace it with a new pump with built-in speed controls. Presumably this is because the add-on controller delivered the same benefits at approximately half the outlay of a new pump and was simpler to install. The related cost analysis of the two retrofitting options will be presented in Section 4.3.

Three of the 36 pools added the same pump speed controller on their solar pool heating pumps.

In this program, all add-on controllers were provided by Simply Better Pool Savings as they were the chosen industry partner of this study and as the add-on controller is not an option commonly offered by the conventional pool industry. Examples of pump speed controllers installed on the main filtering pump and a solar pool heating system are demonstrated in Figure 8.

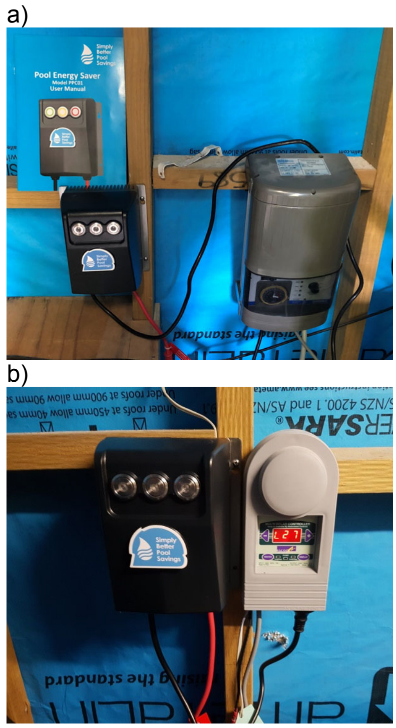

Figure 8. SBPS pump speed controllers attached to a) Main pool filtering pump and b) Solar pool heating pump.

The following sections present the energy savings and GHG emission reductions obtained separately by the three main retrofitting options (shown in Section 3.1) delivered in the Pool Efficiency Program. The associated cost savings will be presented in Section 4.3 together with a comparison to other energy efficiency retrofits the residential sector.

4.2.1 Reducing the flow rates of the main filtering pump

For all 36 households with the pump speed controller retrofitted to the main pool filtering pumps (single-speed), the pump speed controllers were set at the Green setting. As per SBPS, the Green setting lowers the speed of the pump motor and the water flow rate by 33%. Since the pump power is proportional to the cube of the water flow rate (discussed in Section 2.1.4), the reductions in power consumption on the Green setting approach about 70%, and for the same pump run time, energy savings of about 70% would be realized.

In this program, reducing the flow rates of the main filtering pumps (with no changes in pump run times) achieved total energy savings of 56.2 MWh (~1.6 MWh per household) per year. This corresponded to a total of 54 kt CO_2-e (1.5 kt CO_2-e per household) of GHG emission reductions per year. Given that the annual energy use of all pool filtering pumps investigated in this program was around 83.2 MWh/year, the measured energy savings attributable to reducing their flow rates were 68%, which are comparable to the theoretical value of 70% as discussed above.

An additional benefit of reducing the pump speed and water flow rate is the reduced pump noise. According to the noise level measurements during the site assessments, around 86% of the original pump noise could be reduced and the pumps after retrofitting are producing an average noise level of approximately 55 dB. For comparison, hotel lobbies and school restaurant usually have noise levels of 50 – 55 dB [41]. Note that the pump noise measurements were recorded in the daytime, so background noise did exist. Considering most filtering pumps are sheltered, the householders especially those with no rooftop PV systems, could potentially shift the pool filtering load to a cheaper electricity tariff at night, without a negative impact to the neighbours' lifestyle.

The householder perceptions on the pump noise level before and after retrofitting are presented in Section 4.4.3.

4.2.2 Optimising the run times of the main filtering pump

As discussed in Section 3.1, the research team verified the model developed Simply Better Pool Savings and used it to optimize the run times of the main pool filtering pumps.

Putting aside all other improvements, the optimization of main filtering pump run times in the study, has in isolation and on average reduced the pump's run times from 6.3 hours/day to 5.8 hours/day – about an 8% reduction on average. The contribution of optimising main filtering pump run times to the overall energy consumption reduction of the project as a whole was 2.6 MWh/year (or 0.07 MWh/year per household). The associated GHG emission reductions were 2.5 kt CO2-e for all households undertaking an upgrade (or 0.07 kt CO2-e per household).

Whilst an average reduction of pump running hours of 8% might seem modest at first glance, it's noteworthy that this reduction has been achieved at the same time as pump speeds and water flow rates are being reduced, and whilst pool water cleanliness and aesthetics have also been maintained or improved. Further analysis of results reveals important benefits from the optimisation that might otherwise be overlooked. The following are a few examples:

- In more than 20% of households, the energy savings obtained by the main filtering pump run times optimisation were between 10% and 25% higher than they would have been if no optimisation was undertaken. The corresponding energy savings of the main filtering pumps were over 75% on average for this cohort of households, and are all larger than 62%.

- In a significant majority of households (75%), the pump run times after optimization were lowered. This lowering of pump run times took place whilst all quality assurance safeguards outlined in the "Quality Assurance of Outcomes" section were being observed e.g. water circulation after the retrofit satisfied the one-turnover per day guideline detailed in the relevant Australian Standards AS 3633 [38], and any automated sanitisation equipment such as salt-cell chlorinators that were present continued to deliver the same amount of chlorine after the retrofit as they did before the retrofit.

- This evidenced conclusion is the opposite of the common and erroneous notion often repeated by practitioners in the pool industry and sometimes also by pool owners – that pump run times will need to be increased as part of a change to lower pump speeds. The corresponding energy savings of the main filtering pumps were over 71% on average for this cohort of households, and are all larger than 59%.

Overcoming erroneous advice and mindsets of this kind can play an important part in encouraging the adoption of these types of improvements more broadly. So, the inclusion of optimisation of this kind in future roll-outs will stimulate and support the required change in attitudes.

- In 25% of households, the main filtering pump run times were increased. This might at first seem alarming to a pool owner, as they fear these increased running hours might reduce their savings. But the evidence demonstrates clearly that even in the minority of cases where an increase in pump run times was required, that increase does not undermine the strong overall savings results that can be achieved on these main filtering pumps when their speed was reduced. The corresponding energy savings of the main filtering pumps were over 66% on average for this cohort of households, and are all larger than 57%.

Once again, this evidenced outcome runs counter to some of the prevalent but flawed narratives common to both pool owners and pool industry insiders. Using the optimisation approaches utilised in this study in further roll-outs will encourage narratives that are more evidence-based and supportive of positive changes.

It is the view of the partners of this study that as well as adding significant benefits to pool owners, pump run time and associated gear optimisation is essential to pool owning participants in future roll-outs, as well as to the entities involved in conducting the roll-out. Failure to include optimisation raises a number of risks, not least of which being that outcomes are not maximised. Equally important risks of not conducting an optimisation at the time of switching from single-speed pumping to variable-speed pumping include for example; that pools that were compliant with Australian Standards AS 3633 [38] before the intervention are no longer compliant afterwards; or that chlorine dosing levels before the upgrade are not maintained after the upgrade, and that pool water becomes unsafe and pool users get sick.

4.2.3 Optimising the run times of booster pump for pressure auto-cleaner

The project team helped two householders achieve significant additional energy savings by reducing the run times of their pressure auto-cleaners, which are driven by a booster pump in both households. According to the PG&E study in the USA and the lab testing of residential pool cleaners [42], the average required daily run time for pressure pool cleaners is 2 – 3 hours. However, both pool cleaners were set to run for 4.5 – 5 hours per day, consuming extra energy. By optimizing the run times of these pressure auto-cleaner pumps, annual energy savings of 1,040 kWh/year and 1,300 kWh/year could be realized for each household.

4.2.4 Reducing the flow rates of the solar pool heating pump

Nineteen out of 20 solar pool heating systems have been assessed in the Pool Efficiency Program (one was exempted due to a collapsed solar collector) and 9 were feasible to operate under low pump speed, low flow conditions. For the other 10 systems, either large amounts of bubbles were observed in the pool from the solar collector or the water circulation was interrupted when the speed of the solar pool heating pumps was reduced. This indicates that the pumps couldn't generate enough pressure to keep the vacuum relief valves closed, letting air in the system and this caused noisy operations and could increase the pool chemicals consumption due to bubbling [37, 38]. Installing a throttle valve on the downstream pipework from the solar collector may resolve such issues. However, as this would involve cutting into the existing pipework to install the throttle valve, many of the pool owners saw this as "too invasive" – that is they didn't like the idea of changes being made to the solar heating pipework. Hence this meant that only systems with an existing throttle valve could be studied. Interestingly, Australian Standards require solar pool heating systems to have a throttle valve to be installed but from this project we found that the majority do not (Section 4.1).

In terms of the four solar pool heating systems that did have a throttle valve, only one system was not operable under low speed, low flow conditions. This, as outlined by the pool owners to the project team, was related to the damage of the vacuum relief valve. Further testing of this system would be required after a new vacuum relief valve was installed.

Therefore during the program, three households elected to retrofit the solar pool heating systems, i.e., adding a pump speed controller to the existing solar pool heating pump to reduce the pump speed. Table 2 presents the key results of the retrofitted solar pool heating systems. For SP4 and SP23, which had solar collectors on the roof of the second story of the home, the add-on pump speed controllers were set at the 'Orange' (medium) speed for the solar pool heating pumps and the existing throttle valves were minimally adjusted in order to maintain a closed vacuum relief valve at the rooftop during operation of the solar heating (i.e., stable water flow from the solar thermal collector with no bubbles). In addition, the 25% drop in the water flow rate had no material impact on the thermal performance of these swimming pools (SP4 and SP23) with the modelled swimming period remained unchanged after retrofitting. The energy savings achieved were approximately 50% in comparison to the BAU case.

Table 2. Results of the solar pool heating systems retrofits.

Pool	**Throttle valve?**	**Before retrofitting**			**After retrofitting**				**Energy Saving**
		Measured flow rate[3] (kg/s/m²)	Modelled solar pump energy (kWh/year)	Modelled swimming period[4] (days)	Solar pump speed controller setting	Measured flow rate (kg/s/m²)	Modelled solar pump energy (kWh/year)	Modelled swimming period[4] (days)	
SP1	No	0.07	751	133	Green	0.034	270	130	64%
SP4	Yes	0.08	1081	84	Orange	0.06	537	84	50%
SP23	Yes	0.11	791	88	Orange	0.08	415	88	48%

[3] Mass flow rate per unit solar collector area.

[4] The number of days with average pool water temperature beyond 26°C over the typical swimming season in Australia (October to March).

For SP1, it was interesting to see the system could work with the ‘Green’ (low speed) setting on the pump speed controller without a throttle valve. This is possibly due to the low elevation of the solar collector in reference to the solar pool heating pump for a single storey house and thus the pump can operate at a lower speed and lower flow rate while still generating sufficient pressure to keep the vacuum relief valve closed. Since the flow rate was halved after retrofitting (0.034 versus 0.07 kg/s/m^2), the associated impacts on the swimming pool thermal performance are more evident than the other two cases (SP4 and SP23). The energy saving achieved in this case was a 64% reduction compared to the BAU case. Although the modelling results showed that the swimming period for SP1 was only decreased by 2% (i.e., three days over the whole swimming season), which was deemed to be negligible and perfectly acceptable by the householders based on their feedback. Further details regarding householders’ perceptions on the retrofits will be presented in Section 4.4. For these three households, reducing the flow rate of the solar pool heating pumps would save about 1.4 MWh of electricity per year in total (0.47 MWh/year per household on average), which represents an energy saving proportion of 53%. The corresponding GHG emission reductions are 1.3 tonnes CO_2-e per year.

4.2.5 Overall results

Table 3 summarizes the pump energy and GHG emission reductions achieved by the implementation of the energy efficiency retrofits during the Pool Efficiency Program. The retrofits of the pool filtering pumps saved approximately 59 MWh of energy per year for all 36 households, which accounted for nearly 71% of the original energy of the main filtering pumps. For individual households, the lowest savings from the filtering pump retrofit were 58% and the highest were 85%. Also note that a majority of the total savings (~96%) was from reducing the pump speed and water flow rate with the remaining from optimizing the pump run times.

Table 3. Summary of energy savings and GHG emission reductions obtained by Pool Efficiency Program.

Retrofits	Reducing flow rate of filtering pump	Optimizing run times of filtering pump	Reducing the run times of pool cleaner booster pump	Reducing flow rate of solar pool heating pump	Total
Number of households	36	36	2	3	36
Total energy savings (MWh/year)	56.2	2.56	2.34	1.40	62.5
Total GHG emission reductions (tonne/year)	54.0	2.46	2.25	1.34	60.0
Average energy savings per household (MWh/year)	1.56	0.07	1.17	0.47	1.74
Average GHG emission reductions per household (tonne/year)	1.50	0.07	1.12	0.45	1.67

Considering additional energy savings obtained by the retrofits of solar pool heating pumps (1.4 MWh/year for all three households), the overall energy savings of the Pool Efficiency Program were around 63 MWh (73% reduction), i.e., 1.74 MWh/year energy savings for each household. The total annual GHG emissions reductions were 60 tonnes CO_2-e per year or 1.67 tonnes CO_2-e per household per year.

The next section will present the economic assessments of the swimming pool pump retrofits along with a comparison to other typical residential energy efficiency retrofits.

4.3 Cost savings and financial assessments of the pool pump retrofits

To evaluate the financial feasibility of the pool pump retrofits, the payback period was taken into account. It was calculated based on the upfront cost of the pool pump retrofits (i.e., cost of the SBPS pump speed controller) and the cost savings obtained by the reduced pump energy. Note that since the actual electricity price varies between the households, the project team used a conservative tariff of AU$0.28/kWh for the purpose of this study. This was estimated by Randwick City Council based on the advised electricity prices of all providers available in the Randwick area, taking the available discounts into considerations (e.g. pay-on-time, direct debit). For comparison, the Australian Energy Market Commission [43] reported a weighted average electricity price in New South Wales of AU$0.3059/kWh (excluding GST).

The add-on pump speed controller supplied by Simply Better Pool Savings normally costs AU$690 installed. Considering a further AU$250 rebate per retrofit provided by the CRC for Low Carbon Living and Randwick City Council during the program, the upfront cost of one pump speed controller was reduced to AU$440 installed.

It was found that adding a pump speed controller to the pool main filtering pump save a household AU$457 a year on average in this sample and based on the electricity price of 0.28 AU$/kWh. The associated payback time (averaged over 36 households) is only 12 months with a rebate of AU$250. Even if no rebate was provided, the pool filtering pump retrofit still had a compelling payback period of 1.5 years.

For a solar pool heating system that only runs during the swimming season (half a year), the pump retrofit could save a household AU$131 a year on average, which is about AU$300 less than the yearly savings of the pool filtering pump retrofit. Nevertheless, the discounted payback periods (assuming a discount rate of 5% and an inflation rate of 3%) are 3.5 years and 5.6 years respectively for the cases with and without the rebate, and both are less than the average pool pump lifetime of 7.3 years [1].

It is interesting to see how the residential pool pump retrofits (i.e., adding a pump speed controller to a pool filtering pump or a solar pool heating pump) compare to other typical energy efficiency retrofits in the residential sector, e.g. LED lighting retrofit. Lighting accounts for 10% of the average household electricity demand in Australia [44] and the LED retrofit has significant impacts on reducing the lighting costs. The project team could not identify an impartial and reliable source that had calculated payback periods for residential LED lighting upgrades and that provided transparency of the underlying calculation method and assumptions. So, the project team has carried out its own conservative calculation. The resulting calculated payback period of LED lighting in the residential sector is approximately 4.1 years (the assumptions for this calculation are presented in Appendix 9.3). The residential PV system was also included in the comparison considering over 20% of Australian households have rooftop PV systems [45]. Currently, a standard PV system in Sydney Australia has an average payback period of approximately 5 years [46]. Figure 9 presents the payback periods of various household energy efficiency retrofits. Note that no rebates were applied to any of the retrofits.

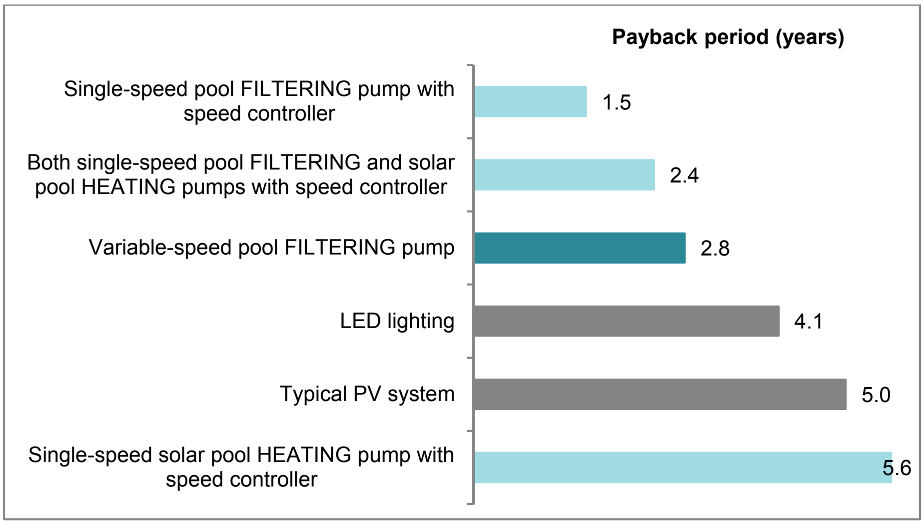

Figure 9. Payback periods of residential pool pump retrofits (adding a pump speed controller) compared to other household retrofits.

As seen from Figure 9, the pool filtering pump with added speed controller has the shortest payback period, i.e., 2.6 years and 3.5 years shorter than typical LED lighting retrofit and rooftop PV systems respectively. More importantly, in comparison to a variable-speed pool filtering pump[5], the add-on pump speed controller is significantly more cost-effective, paying itself back 1.3 years faster. This is the likely explanation for all 36 householders choosing the add-on pump speed controller retrofit rather than replacing the existing pump with a new variable-speed pump.

The lower annual savings of the solar pool heating retrofit (discussed above) contribute to the relatively longer payback periods compared to main filtering pump retrofit. Nevertheless, the retrofit of the existing solar pump with an add-on controller has a payback not significantly longer than that for Solar PV. Taking into account the $250 rebate the payback also drops to 3.5 years, generally considered to be a compelling short payback period. Given that all three households who upgraded their solar pump also upgraded their main filtering pump, it's reasonable to consider the payback of these two retrofits as a combined bundle. As seen from Figure 9, adding a speed controller to both the main pool filtering and solar pool heating pumps achieves an attractive payback of 2.4 years, which is only 11 months longer than the main filtering pump with an added speed control.

[5] The cost of a variable-speed pump in Australia was assumed as AU$1250 (installed). The associated energy savings were assumed the same as the single-speed pump with an added speed controller.

4.4 Householder perceptions

This section discusses the survey results of the participants' perceptions regarding the outcomes of the Pool Efficiency Program, particularly the major characteristics of their retrofitted pool systems. These include the pump noise level, pool thermal comfort (water temperature), pool water conditions, and general maintenance.

4.4.1 General satisfaction with the program

35 of 36 householders have completed the post-install survey and they have rated the satisfaction with this Pool Efficiency Program. It is very encouraging to see that a majority of the householders were very satisfied with the Pool Efficiency Program. According to Figure 10, 33 householders (94%) rated their level of satisfaction as either "satisfied" or better (i.e., a rating of 3, 4 or 5 on a 5 point scale where 3 is "satisfied" and 5 is "extremely satisfied"). 16 of those householders (45%) rated their level of satisfaction as "extremely satisfied". An average rating of 4.2 on the provided 5 point scale was obtained.

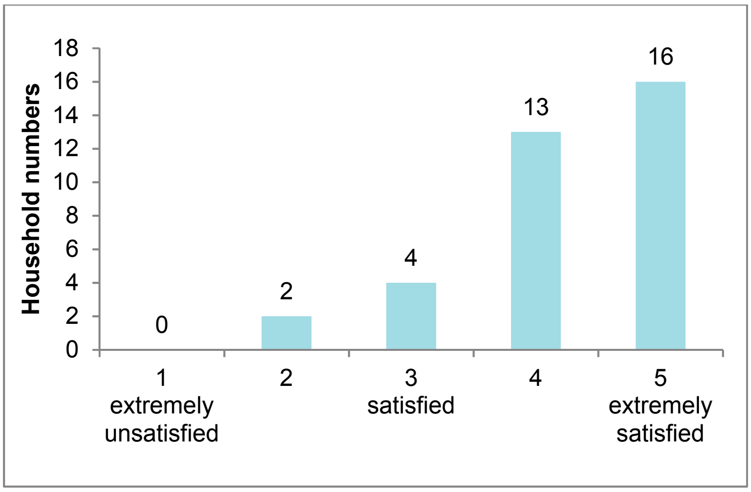

Figure 10. Householders' level of satisfaction with the Pool Efficiency Program.

Some householders who rated 4 or 5 have also given detailed comments on this program and a selection of these is shown in Table 4. In addition to the savings in electricity and carbon footprint, they were satisfied with the easy-to-install and easy-to-use mechanism of the add-on pump speed controller as well as the optimization, consultation and service provided by the project team. Many householders were also very pleased with the pump noise reduction, which turns out to be a significant contributing factor towards householder's positive perceptions. More detailed householder perceptions on the pump noise reduction are presented in Section 4.4.3.

Table 4. A sample of householders' general comments on the Pool Efficiency Program (satisfaction level of 4 or 5).

Swimming pool number	Level of satisfaction	Comments on Pool Efficiency Program
SP1	5	*I'm very happy with the improvement in energy consumption and noise reduction.*
SP2	5	*Brings a sensible improvement to my electricity bill. I have a 5 KW solar PV installation and have already changed all my lightings to LED. The pool pump was next in line. I am extremely satisfied with the result.*
SP6	4	*The team in the program was great, friendly, efficient, and informative. A credit to all. Thank you (and for motivating me to overcome my inertia to apply this simple solution to reduce my energy/carbon footprint).*
SP11	5	*The device seems to work. Saves us money and the pool is still ok. Chemical balance still good.*

SP12	5	*Dramatic drop in pump speed expected to save electricity costs. System was easily installed.*
SP15	4	*Thank you - very efficient and helpful! We are all enjoying a peaceful sleep.*
SP16	5	*System works well and reduces the noise level around the pool area. Communication has been excellent, the system works well and has been a positive improvement on our pool area for entertainment.*
SP18	5	*Excellent experience, fast, knowledgeable and friendly.*
SP20	5	*Pool looks a lot cleaner and runs a lot quieter and smoother. All good and I am happy. The new device is very easy to use and runs very quietly.*
SP26	5	*The sound level from the pump has drastically reduced, which is a great outcome.*
SP33	4	*Very happy with the team, added value over and above efficiency program. I was unable to get the best outcome on the saver but was still able to reduce the speed by half. Very satisfied with the whole experience.*
SP35	4	*Opened my eyes to some significant savings. Using half the chemicals compared to pre-change.*

It is worth understanding the reasons given by the six households who provided a slightly lower rating (rating 2 or 3 out of five). These comments were particularly valued by the project team because of the learning opportunity they presented. The team endeavoured to stay in close contact with all pool owners so as to understand the full breadth of experiences. Only three of the six householders who provided lower ratings also provided clarifying remarks (SP17, SP19 and SP30). The remarks of these three householders were in respect to perceptions of water quality and maintenance workload, so they are dealt with in the next section that addresses these areas specifically.

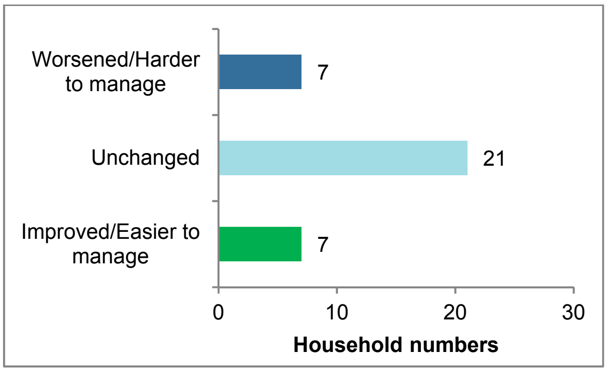

Figure 11. Householders' satisfaction with the pool water condition and pool maintenance after the retrofits.

4.4.2 Satisfaction with pool water condition and maintenance

All householders were asked to evaluate the impacts of the pool pump retrofits on the pool water condition and pool maintenance. Figure 11 presents the number of households who reported the impacts on pool water condition and maintenance as a) Improved/Easier to manage; b) Unchanged; c) Worsened/Harder to manage. A selection of detailed responses from these householders is presented in Table 5.

According to Figure 11, 21 householders (~60%) reported the pool condition remained unchanged while seven householders (~20%) reported an improvement in the pool water quality and/or the pools were easier to manage. E.g. SP6, SP9, SP35, and SP36 reported the workload to manage the pool was reduced, while SP20 and SP36 noted the pools became much cleaner after the retrofits.

Table 5. Householders' comments on pool water condition and pool maintenance.

Swimming pool number	Impacts on water condition and pool maintenance	Comments
SP4	*Worsened*	*Pool water is greener.*

SP6	*Improved and easier to manage*	*The workload to manage the pool reduced fractionally.*
SP9	*Improved and easier to manage*	*Pool Efficiency Program coincided with replacement of old pool vacuum and workload to manage pool has been markedly reduced.*
SP10	*Worsened and hard to manage*	*Pump is running well but finding the pool is not getting enough chlorine on the running time set*
SP17	*Worsened and hard to manage*	*There is sediment on the floor of the pool.*
SP19	*Worsened and hard to manage*	*I am happy with the project savings on electricity bill, but less happy with the water quality (more noticeable small particles) after running the filter on lower speed, something that wasn't mentioned as a risk.*
SP20	*Improved and easier to manage*	*Pool looks a lot cleaner*
SP30	*Worsened and hard to manage*	*Pool is running an extra 2 hours per day compared to when installed.*
SP35	*Improved and easier to manage*	*Pool maintenance workload reduced a little.*
SP36	*Improved and easier to manage*	*Reduced workload to manage the pool and it is much cleaner.*

As detailed above, the project team endeavoured to stay in close contact with all pool owners including the five who did report inconveniences (SP4, SP10, SP17, SP19, and SP30 as shown in Table 5) together with explanatory remarks. Details of the cases where negative perceptions where raised and the troubleshooting that took place are contained in Appendix 9.5.

It's worth noting that in six out of the seven cases where there was a reported perception that could be interpreted as negative the pool owner elected to maintain the upgrade and continue with the recommended optimisations suggested by the project team. Apparently, they valued the overall benefits of the solution such as the energy and cost savings, noise reductions etc. over and above any perceived negative consequences.

4.4.3 Satisfaction with pump noise

33 householders have rated their level of satisfaction regarding the pump noise level before and after the retrofits. As discussed in Section 4.2.1, the drop in pump speed using the pump speed controller has led to significant reduction in the pump noise (~86%) and thus, it is encouraging to see from Figure 12 that all householders were satisfied with the pump noise level after the retrofits (a rating of 3 or higher), and 22 (~67%) of them being extremely satisfied (a rating of 5). More importantly, the three householders who were concerned about the pump noise before the retrofits have all given a satisfaction rating of 3 or above (i.e., 'satisfied' or better).

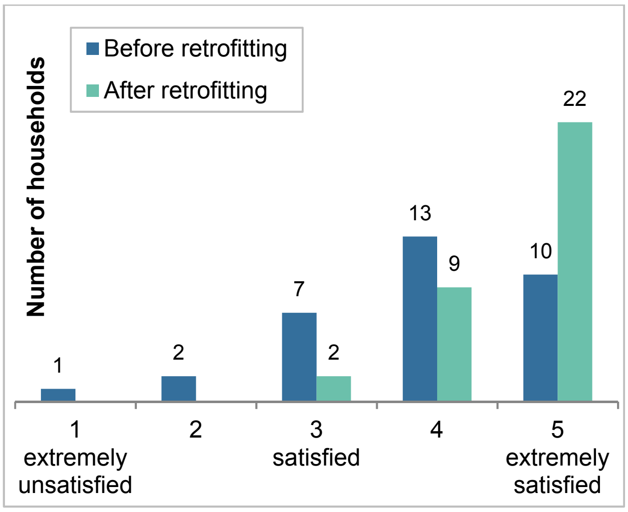

Figure 12. Householders' level of satisfaction with the pump noise before and after the pool pump retrofits.

Table 6 presents a selection of the comments from the householders in regards to the pump noise before and after the retrofits. In terms of the householders who did report the noisy operations of the pool pumps (e.g. SP8, SP9, SP15, and SP35), their levels of satisfaction have all increased after the pump speed controllers were retrofitted.

Table 6. Householders' comments on the pump noise level before and after the retrofits.

Swimming pool number	Before retrofitting	After retrofitting
SP8	*3 – Noisy with no pump housing.*	*5 – Cannot hear the pump running at all. Fabulous!*
SP9	*4 – Bit noisy. Neighbours complained at night. Installed vacuum lid and noise reduced in skimmer box.*	*5 – Pump noise has substantially reduced. Neighbours have expressed pleasure at reduction of pool pump noise.*
SP15	*1 – Prefer to have the pump run much quieter because the bedroom is very close to the pump housing.*	*4 – The pump noise is significantly reduced.*
SP16	*4 – No discernible effects on neighbours but it is near the pool so there has been "background" noise all the time when it is on.*	*5 - Large reduction in the noise level of the pump system. Hard to hear and has had a positive impact on neighbours and ourselves as the entertainment area is next to the pump.*
SP28	*4 – No impacts.*	*5 – Much quieter, almost silent so can now run at night for even more savings.*
SP35	*3 – The main pump is a bit noisy nice to reduce the noise.*	*4 – Absolutely, much quieter.*

It is also worth noting from Table 6 that even though some householders did not consider the pump noise as an issue (e.g. SP16 and SP28), they were extremely satisfied with the reduction of the pump noise and as SP28 reported, with the pump running much quieter, it would be possible for the householders to shift the pool filtering load to a cheaper electricity tariff at night, without a negative impact to the neighbours' lifestyle.

4.4.4 Satisfaction with pool water temperature

The project team surveyed the three householders who have retrofitted the solar pool heating pumps on whether they have noticed any changes to the pool water temperature after the retrofits.

Table 7 shows the householders' perceptions regarding the pool water temperature before and after the solar pool heating pump retrofits. It is clear that negligible changes were identified by the householders and all are very satisfied with the pool water temperature after the retrofits. This also supports the modelled swimming period before and after the retrofits as discussed in Section 4.2.4. It is also good to know that the householder of SP1 understands that lowering the flow rate of the solar pool heating speed reduces heat output from the solar collector, and the householder reported an immaterial impact on the pool water temperature.

Table 7. Householders' comments on the pool water temperature before and after the retrofits.

Swimming pool number	**Before retrofitting** *(Are you satisfied with the pool water temperature?)*	**After retrofitting** *(Any change in water temperature?)*
SP1	*Solar heating is good.*	*Marginally slower heating effect, but the difference is negligible and perfectly acceptable.*
SP4	*Ok in peak summer but not warm enough in spring and autumn.*	*No noticeable changes.*

SP23	*Solar panels get hot often goes 3~4 degrees above set temperature.*	*No change.*

5 Improving conventional pool industry practice

Variable speed pumping technology has been available for swimming pools since the mid-2000s [1]. The swimming pool industry hasn't had strong success promoting this opportunity to save energy. Even today, more than 70% of the residential pools in Australia have not successfully been migrated onto variable-speed pumping arrangements and pool pumps in Australia are costing consumers $224 million per year in avoidable electricity costs. The fundamental reasons behind were outlined by DEE [1] as follows:

- *'Energy efficient pumps comprise around 25-27 per cent of current pool pump sales market;*
- *This proportion is not growing as a share of national pool pump sales;*
- *Early growth in sales of energy efficient pumps has tapered off.'*

Thus, as well as isolating the components of savings delivered to pool owners as part of this study (Section 4.2.5), the project team also distinguished the approaches that were delivering savings in the study but would not be replicated by the conventional pool industry. That is, where savings might be missed in the current everyday practices of the conventional pool industry in Australia.

Table 8 shows the energy savings, returns on investment, and the payback period delivered by the Pool Efficiency Program compared to those likely to be delivered by the conventional Australia pool industry on a household by household basis. The calculations for the savings delivered by the conventional pool industry can be found in Appendix 9.4.

Table 8. Energy savings return on investment, and payback delivered by the Pool Efficiency Program and those likely to be delivered by conventional pool industry in Australia.

Pool Efficiency Program (UNSW, Randwick City Council and Simply Better Pool Savings)	The Conventional Australian Pool Industry
Energy Savings per year, per household **1.74 MWh**	**Energy Savings** per year, per household **1 MWh**
Return on Investment 23.7% per household, per year main filtering pump only no rebates	**Return on Investment** 13.7% per household, per year main filtering pump only no rebates
Payback Period 18 months per household, per year main filtering pump only no rebates	**Payback Period** 52 months per household, per year main filtering pump only no rebates

It can be seen from Table 8 that the Pool Efficiency Program on average delivered 1.74 MWh/year of energy savings (from both the pool filtering and solar pool heating pumps retrofits) for each household, which is around 70% higher than what the conventional pool industry is likely to deliver. In addition, considering the lower upfront costs (~50% lower) in compared to a typical variable-speed pump, the pool pump retrofit adopted by the Pool Efficiency Program presents a strong return of investment of 23.7% and a payback of 18 months, more than twice as fast as a variable-speed pump retrofit.

The key components explaining the difference between what the program delivers across these 36 houses and what the conventional pool industry delivers are as follows:

1) The Pool Efficiency Program utilised a pool-by-pool assessment approach to optimise each pool owner's main filtering pump run times – the conventional pool industry typically tells pool owners to simply "run your pump 8 hours in summer, 6 in winter" regardless of pool size, flow rates and other relevant variables;
2) The Pool Efficiency Program in some cases retrofitted the solar pool heating pump. Opportunities to make savings from slowing flows on residential solar pool heating systems have been investigated by Cunio and Sproul [47] and Zhao and Bilbao [39]. These opportunities are not typically understood or accepted by the conventional pool industry;
3) The Pool Efficiency Program utilised a pool-by-pool assessment approach that isolated excessive hours pressure automatic pool cleaners runs and corrected it – the conventional pool industry generally does not isolate this excessive use in a systematic approach so is not well positioned to correct it;

As well as generating higher savings and improved return and payback metrics at the household level, the approaches adopted by this Pool Efficiency Program can also be expected to generate higher solution uptake or adoption rates than those being achieved by the solutions and approaches currently offered by the conventional pool industry. So, more is saved per household, *and* more households make savings.

Comprehensively quantifying the complete impact of increased adoption rates is beyond the scope of this study and would require further research, most probably some conjoint marketing analysis and/or larger market trials. To answer such questions as, "How many more pool owners would adopt a variable-speed pumping solution if it has an 18-month payback compared to one that has a 54-month payback?"

However, a *portion* of the total uplift in adoption rates can be more easily quantified as it is of a binary nature. Specifically, the conventional pool industry has adopted narratives that exclude many pool setups and label them unsuitable for variable-speed pumping arrangements. These narratives often exclude:

1) Pools with in-line plumbed, suction-side pressure cleaners;
2) Pools with in-line plumbed, discharge-side pressure cleaners;
3) Pools with in-line plumbed, solar pool heating systems;
4) Etc.

These and other limiting narratives in the conventional pool industry have been identified by both Messenger et al. [48] and Woolcott Research and Engagement [2]. They also reflect the experiences of Simply Better Pool Savings in the market more broadly. The project team has however proven throughout this Pool Efficiency Program that these limiting narratives are not supported by evidence and that variable-speed pumping can be successfully implemented in these scenarios.

Assuming that the conventional pool industry misses the opportunity to install variable speed pumping in 50% of the three scenarios identified above, the conventional pool industry would have achieved a 44% lower adoption rate in the sample than this Pool Efficiency Program. That is, in the sample of 70 pools PEP approaches achieved 36 retrofits (an adoption rate of ~51%) and the conventional pool industry would have achieved 20 retrofits (an adoption rate of ~29%).

Combining the impacts of higher savings for each pool that adopts a variable-speed solution with the Pool Efficiency Program approaches, and the conservatively estimated higher adoption rates from Pool Efficiency Program approaches, the difference in savings across the population of residential pools in Australia that currently have single-speed pumps (~770,000) are presented in Table 9. Note that the GHG emission savings were calculated using an electricity emission factor of 0.9 kg CO_2-e/kWh for Australia [40]. To calculate the equivalent number of cars that would produce the same amount of GHG emissions, annual GHG emissions of 4.74 metric tonnes were used for a typical passenger vehicle [49].

Table 9. Projected energy and carbon savings across the population of Australian residential pools using the Pool Efficiency Program approaches by comparison to the current approaches of the conventional Australian pool industry.

Pool Efficiency Program (UNSW, Randwick City Council and Simply Better Pool Savings)	The Conventional Australian Pool Industry
Energy Savings per year, Australia wide	**Energy Savings** per year, per household
689 GWh	**220 GWh**
GHG Emission Savings ≈ equivalent cars off the road	**GHG Emission Savings** ≈ equivalent cars off the road
131,000 Cars	**42,000 Cars**

6 Future roll-outs and up-scaling

Pool pump use in Australia involves a significant waste of electricity and is a significant unnecessary contributor to carbon emissions. 'Modelling by the Department of Environment and Energy [1] indicates that pool pumps in Australia are costing consumers $224 million per year in avoidable electricity costs.

DEE [1] also explained that poor uptake of energy efficient pool pumping is the fundamental problem contributing to this waste. Compounding the problem is poor uptake. Despite being available in the market since about 2005;

- *Energy efficient pumps comprise around 25-27 per cent of current pool pump sales market;*
- *This proportion is not growing as a share of national pool pump sales;*
- *Early growth in sales of energy efficient pumps has tapered off.*

Future roll-outs and upscaling of the solutions trialled in this research program represent a significant new pathway forward and through which the above problems and failures can be addressed.

The following is a list of some of the critical success factors of this program that fostered the strong uptake results and provided lessons for future roll-outs and scaling-up of programs of these kinds and for the acceleration of uptake of variable-speed pumping efficiencies generally.

1. Changing now makes sense – dollars and cents

The approach of this program is a proactive one. It actively reaches out to pool owners encouraging them to change now. Day-by-day electricity use savings from making the change now are strong enough that a decision to wait invariably comes with negative financial outcomes for the pool owner.

The program offers pool owners the chance to migrate to variable-speed pumping either by;

a) Attaching an add-on controller to the existing single-speed pump. Effectively turning their existing single-speed pump into a variable-speed pump. Or by;

b) Throwing out their existing single-speed pump and changing to a variable-speed pump with built-in speed controls

The conventional pool industry does not proactively approach pool owners with a change now mindset or offer. Instead, it overwhelmingly waits for pool owners to experience a pump failure and then it may, or may not, suggest a change to a variable-speed pumping arrangement. Whether the existing pump still works or has failed, the conventional pool industry will invariably offer only the second option above: b) a new variable speed pump with built-in speed controls.

This program utilised the add-on controller provided by Simply Better Pool Savings and also their digital infrastructure and processes to streamline the proactive outreach and engagement with potential participants. UNSW verified the suitability of the controller, the digital assets and the processes and they were tailored to fit a research trial. When combined with the reach of Randwick City Council's e-newsletter there was significant interest shown by pool owners to more than meet the targeted scope of the program.

2. Changing now is easier, cheaper - there's now a better way

Of the 70 pool owners who participated in the study, 36 chose to migrate to variable speed pumping now. All 36 chose to make this change using option a) the add-on controller. The add-on controller enables the change to be achieved at about half the price of the alternative (i.e. throwing out the existing pump and buying a new pump with built-in speed controls). It also delivers all the same benefits and is significantly easier to enact. A comparison on the ease or complexity of the two options is detailed in the following table.

Table 10. Comparison of two retrofits proposed in the Pool Efficiency Program.

Option a) Plug-and-play style add-on controller with existing single-speed pump	Option b) Throw out existing single speed pump and replace with a pump with built-in speed controls
-	De-couple existing pump
Buy the controller	Shop for, correctly size and buy a new pump
Take delivery	Ship and/or collect pump
-	Source a pump installer
Mount controller and plug it in	Install new pump including; pipework, plumbing, unions, etc. plug in
-	Dispose of old pump

3. Changing now circumvents changing never

There are two moments of opportunity the conventional pool industry recognise for a pool to be set-up with variable speed pumping;

1) When the pool is built

2) When an existing pump expires

Sometimes these moments involve their own challenges. For example, when the pool is built, pool builders describe that '*pool owners generally compared quotes that detailed the whole pool – but none of the builders really thought that the customer was making comparisons at the level of the pump that was included or recommended'* [2].

When a pump breaks and needs replacing, getting involved in the complicated up-sell of variable speed pumping also has challenges. For example, energy efficiency was only mentioned first by 14 per cent of respondents as a feature that was important to them when they purchased a new pump [2]. Other comments in this study reported as being representative was a pool maintenance operator who explained, '*Many customers are initially simply seeking like-for-like*' and for many of the field operators this allows for a simple an uncomplicated install with a minimum of changes to pipework, less new plumbing, fewer adjustments to the size or elevation of the pump footbed, etc.

This program and players in the market like Simply Better Pool Savings who have an equipment upgrade and optimisation model create a third opportunity window, a retrofit opportunity that can be triggered at any time during the life of an existing single-speed pump.

The value of this third window of opportunity is immediately apparent when considering the slow adoption of variable speed pumping since its inception in about 2010 and its more recent plateauing – see statistics at the beginning of this section. Further insights into the value of the third window and the lessons from this program about how offers can be structured to maximise that value and increase uptake in the population of Australian residential pools include:

- *Involvement of entities who are intrinsically and primarily motivated to reduce energy use*

Start-ups like Simply Better Pool Savings with a single offer oriented primarily around energy reduction can broadcast the problem of high pool energy costs without fear of undermining their profitability - in fact their survival depends on raising awareness of this issue and presenting clear and credible solutions. The conventional pool industry, by comparison, is generally better off if more and more new pools are built. If the high energy cost of maintaining a pool is often obscured or not understood [1] then it is naive to expect the conventional pool industry who is motivated by a future with more pools to be the champion that raises awareness of this cost. In being constrained in highlighting the problem, the conventional pool industry is impaired in its capacity to solve it.

Randwick City Council and UNSW have overlapping and different motivations for acting to reduce energy consumption; to help constituent householders reduce the cost of living, to achieve sustainability goals, to stretch current innovations and advance thought leadership etc. What is common, however, is an unrestrained foundation and an inherent motivation to raise awareness of and resolve the core challenge of this program –lowering residential pool energy use.

- *Can-do mindset to variable speed pumping solutions and their benefits*

In interviewing a cross section of conventional pool industry players on behalf of the Department of Environment and Energy (DEE), Woolcott Research and Engagement [2] noted that there were '*mixed reactions to the claims that variable speed pumps were more efficient… that there does not appear to be a consistent message emerging from the industry in relation to pool pumps…some were adamant energy efficient pumps were not actually energy efficient.*'

The two main reasons given by pool industry participants for the claim that energy efficient pumps were not actually energy efficient were:

1. The unfortunate claim that "a variable-speed pump running at low speed would have to run for longer in order to generate the required flow rate/water turnover."

   Whilst true in 25% of pools that underwent an upgrade in this study, this unfortunate claim entirely overlooks the inherent and fundamental impact of the Pump Affinity Laws on pump efficiencies and savings. That is, it fails to reflect that relatively small reductions in pump speed and flow rates generate much greater relative reductions in power. For example; a 33% reduction in pump speed and water flow reduces power consumption by 70%.

   To illustrate this impact by way of a simplistic example, imagine a 1 kW pumping 10,000 litres of water per hour at top speed. It would take 5 hours to circulate 50,000 litres of water which is the typical size of an Australian backyard pool. It would consume 5 kWh of electricity. Reducing flow speed by 33% means 6,667 litres of water per hour are now pumped. Requiring 7 ½ hours to turn over the same 50,000 litres of water. But the overall electricity consumption to produce the same 50,000 litre outcome is reduced according to the following formula:

   7 ½ hours X 0.3 kW (70% reduction from 1kW) = 2.25 kWh

   It's evident that a fall in consumption from 5 kWh to 2.25 kWh yields a 55% energy saving - even when daily pump running hours are increased.

   The claim also overlooks the ability to utilise the excess capacity inherent in much of the other equipment in the system, and correct through optimisation the frequent over-running and over-circulation that occurs in Australian pools. When this is properly taken into account, as it is quickly and easily through the optimisation model initially developed by Simply Better Pool Savings and utilised by UNSW as part of this study, then in three pools out of four the running hours were able to be reduced rather than increased, and overall energy saving of more than 71% on average were achieved.

   Even when daily pump running hours were increased, in 25% of upgrading pools in this study, the impact of the Pump Affinity principles meant that strong savings were still achieved, i.e., an average energy saving of 66% for these pools.

   The widespread belief in the conventional pool industry that main filtering pool pumps need to be run eight hours a day in summer and six in winter has been refuted in other studies. For example Messenger and Hays [48] reported that: *'Most pools can be maintained in sparkling condition with pool pump run times of four hours or less'* and this claim was supported by the following: *'More than 100 pools with daily run times of four hours or less were monitored over a 2-year period. A comparison was made of water quality between the experimental pools and a random sample of non-participating pools which were run on average of more than eight hours per day. There was no significant difference in owner satisfaction with pool water quality'.*

Other examples of commonly repeated myths in the conventional industry that were similarly proven to be the contrary of evidence in this trial of over 100 pools for more than two years include [48]:

- A belief that "cutting back on pump hours increases the need for chemicals". In fact, the data showed that there was no significant increase in chemical use when pumps were run 5 hours per day less in one summer season after an optimisation exercise than they were run in the summer prior.
- The flawed belief that "cutting back on pool pump hours increases the need for brushing and vacuuming". This belief was tested and there was no evidence found to support it.
- A belief not supported by the evidence that "Circulating water will keep algae from forming on steps and pool walls." Rather, the evidence showed that failure to maintain the chemical balance and undertake proper physical maintenance was amongst the key causes of algae, and no amount of pump running would compensate when these factors were neglected.
- Misunderstandings that "the pump must be running to keep the chemicals mixed and working" which leads to advice to run pumps longer each day rather than less. Field observations of these 100+ pools over two years supported theoretical analysis of this dilemma. Both provide evidence that "chemical mixing and action does not depend on pump operation"

2. A belief that "manufacturer (efficiency) claims were overstated." Regardless of the degree of any over-claiming, an adoption of this rationale for explaining that "energy efficient pumps are not actually energy efficient" is an extreme and unhelpful case of 'throwing the baby out with the bathwater'.

   Regardless of what pump manufacturers claim, application of variable-speed pumping has been shown to clearly benefit pool owners. 71% savings was the average of all pools undergoing a retrofit in this program and claims by manufacturers make no difference to this result or it's applicability to the population of residential pools in Australia.

Resistance was also often reflected in apparently commonly held views amongst the industry insiders that variable-speed pumping was not suitable in settings where this program clearly demonstrates it is suitable. For example:

1. "*They're not suitable for salt water pools.*" Pool Professional [2].

   Contrary evidence: In the region of 90% of Australian pools are salt water pools. Of the 36 pools where an upgrade was successfully achieved in this program, 89% of them were saltwater pools.

2. "*Variable speed pumping was perceived to be unsuitable or less suitable in pools with pressure cleaners*" [2].

   Contrary evidence: Almost 20% of the pools in this study sample had pressure cleaners. Of the 70 pools where an assessment of variable-speed pumping was undertaken as part of this program, the pressure cleaner did not mean that variable-speed pumping could be accomplished and that strong energy savings (always in excess of 58%) were achieved.

3. Situations "*where the timing device on the variable speed pump was not compatible with the timing device on other features or pool equipment.*" [2]

   Contrary evidence: Over 90% of Australian pools involve timers. Usually on most or all of the pool equipment in the system. Of the 70 pools where an assessment of variable-speed pumping was undertaken as part of this project, there was not a single incidence where incompatibility with existing timers rendered a pool unsuitable for a variable-speed pumping arrangement. Of the 36 pools where variable-speed pumping was implemented all had timers and achieved strong efficiencies (always in excess of 58%).

- *Investment in solutions that enhance variable speed pumping solutions and make them compelling*

  Simply Better Pool Savings, and other innovators are developing solutions that amplify the benefits of a straightforward change to variable-speed pumping as it is likely to be implemented by the conventional pool industry. In some cases this involves reductions in pool maintenance workload through automation, in others it includes ancillary measures to boost the savings, and importantly it can be about reducing the costs of changing to a variable-speed setup. In this program, it was the latter two levers that were employed.

  In this program, lower upfront costs were made possible by offering pool owners the add-on controller that they could use with their existing single-speed pump as one of two ways to migrate to a variable-speed pumping setup. As well as the simplifying effect this option has and that are detailed elsewhere in this document, the add-on controller option comes to the pool owner at approximately half the cost of the alternative (throwing out the existing pump and buying a new pump with built-in speed controls).

In this program, ancillary measures to boost savings beyond what would be delivered by an upgrade undertaken by the conventional pool industry were driven by leveraging two items. First, the UNSW's innovative thought leadership on efficiencies for solar pool water heating systems. Second, various optimisations delivered through Simply Better Pool Savings tools and innovations.

The Simply Better Pool Savings' innovations included; streamlined and automated participant registration in the program, an Online Pool Assessment tool, the automatically generated YourPoolInsights report, automated processes for participant relationship and experience management, etc.

The optimisations include such things as; optimising main/filter pump total daily running times across they seasons, similarly optimising run times of pressure auto-cleaner pumps, enhancing the efficiency of pool chemical water balance so that run times of equipment such as chlorinators and main/filter pumps can be further reduced, optimising when during the day pumps are run to balance, optimise and take advantage of the best intra-day timeslots depending on intra-day electricity time-of-use pricing windows, generation of electricity by a rooftop solar PV system if the household has one, regulations and restrictions on pump running times in regard to neighbourhood noise.

On average these optimisations delivered quantifiable uplift in the savings of over 11% on average. Whilst this might seem modest on average, an analysis of some pools shows the additional savings are significant and can reasonably be considered to have been a swing factor in a considerable portion of pool owner's decision to adopt or decline the upgrade. For example:

- In more than 20% of households the total main filtering pump savings with just one optimisation, that of optimising total daily run times of the main filtering pump across the seasons, were between 10% and 25% higher than they would have been if this lone optimisation was undertaken. This significant uplift in savings for these households has material positive impacts on metrics like their payback period as it involves no capital outlay and no new equipment.
- Main filtering pump savings of over 75% on average, and are all larger than 62% were achieved by this cohort of households.
- In houses where auto-pressure cleaner run times were optimised savings were more than 83% higher than they would have been if the conventional pool industry had undertaken this upgrade and were this additional optimisation was not undertaken.

In houses where solar pool heating pumps also had their run speeds reduced the savings were 53% on average. In the 70 pools assessed in this program almost 30% of pools have solar pool water heating. This is approximately the same portion that are understood to have solar pool heating in the population of residential pools in Australia.

- *Development and utilisation of assets that simplify the complicated upsell of variable speed pumping.*

Convincing pool owners of the benefits of variable-speed pumping is not easy or cost free. The figures at the beginning of this section, which detail slow and plateauing uptake rates, attest to how difficult and challenging it is. The investment of intellectual and financial resources to simplify and streamline this act of education and persuasion is significant.

Delivering this educative activity at low cost, and maximising its persuasive effect is a critical success factor to any future initiative to increase uptake of variable-speed opportunities. In this program, this was achieved due to two key factors.

First, the credibility that is bestowed on the program by virtue of the involvement of parties like UNSW and Randwick City Council. Whilst the impact of this was not quantified as part of this study it is the judgment of all parties that it was fundamental to the high uptake rates achieved by the program.

Second, the assets, processes and infrastructure provided to the program by Simply Better pool Savings. We have throughout this report identified overall metrics and specific examples of the considerable uplift that was achieved in customer outcomes such as yearly electricity bill savings, return rates, and payback periods as a result of utilising these tools in this program. However, the complete impact of these improved outcomes on increased uptake rates would require further research and was not quantified as part of this study. It is, however, the judgement of all parties that it was fundamental to the high uptake rates achieved by the program.

In summary, creating this third, additional, proactive window of opportunity to present the benefits of variable-speed pumping to pool owners, taking that new opportunity to amplify the benefits and minimise the costs of the change through innovative solutions, of presenting an engaging, educative and persuasive narrative in an inexpensive way, and mitigating or circumventing the elements of resistance or blockage in the conventional pool industry are critical success factors that are fundamentally important to future successful efforts to improve residential pool energy efficiency.

7 Conclusions

During October 2017 and March 2019, the University of New South Wales, Randwick City Council, and Simply Better Pool Savings collaborated in the Pool Efficiency Program, which aims to enhance the uptake of energy efficiency improvements for swimming pools in the residential sector. From the 70 pool site assessments undertaken during the Pool Efficiency Program, it was found that the average pool in the Randwick LGA has a size of 41.6 m^3; the main pool filtering pump (single-speed) has an average power rating of 1.1 kW and it operates 6 hours per day (7 hours/day in summer and 5 hours/day in winter). The average energy use of the main pool filtering pump was estimated to be 2,312 kWh/year or 6.3 kWh/day. The program also found that 26 (38%) of the 70 assessed swimming pools are heated and a majority of them are heated by solar pool heating.

In comparison to the conventional Australian pool industry, the project team adopted the following approaches in the Pool Efficiency Program to deliver the best energy saving outcomes to the participants:

- Increase the up-take of energy efficient pool systems by retrofitting the pools with in-line plumbed, pressure cleaners or pools with in-line plumbed solar pool heating systems;
- Optimizing the run times of the main pool filtering pumps and pressure pool cleaners;
- Reducing the pump speed and flow rate of the solar pool heating systems without materially affecting the pool water temperature;

The program achieved a higher adoption rate with more than 50% (36) of the 70 assessed pools installed an energy efficient pump speed controller (supplied by Simply Better Pool Savings) on the main pool filtering pumps. Three of them also installed the speed controller on the solar pool heating pumps. The major achievements of the Pool Efficiency Program are:

- ➢ The total annual energy savings of ~63 MWh/year in 36 households (~1.74 MWh/year/household);
- ➢ The average reduction in pump energy consumption of ~71% (~72% for pool filtering system and ~53% for solar pool heating system);
- ➢ The annual electricity bills savings of ~AU$486/year/household;
- ➢ The total GHG emission reductions of ~60 tonnes CO_2-e/year in 36 households (~1.67 tonnes CO_2-e/year);
- ➢ The average reduction in pump noise of ~ 86% (ranging from 60% to 97%).

Considering an average household electricity demand of 19.2 kWh/day in the greater Sydney region [50], the pump energy savings account for about 25%. In addition, the total reductions of GHG emissions are equivalent to those produced by a typical car travelling nearly 6,500 kilometres.

The Pool Efficiency Program's outcomes were very favourably received by the participants and an average satisfaction level of 4.2 was achieved (5 was the maximum). Over 94% of participants who adopted a retrofit have reported that they are either 'satisfied' or better with their experience in the program. About 46% rated it a 5 out of 5, saying they were 'extremely satisfied'.

In terms of the impacts of the pump retrofits, 60% of the householders who adopted a retrofit reported unchanged pool water conditions and pool maintenance; and 20% of them reported improved water conditions and the pool maintenance became easier. Although the remain 20% reported either the pool water conditions were worsened or the pool was harder to maintain, six out of the seven cases where there was a reported perception that could be interpreted as negative the pool owner elected to maintain the upgrade and continue with the recommended optimisations suggested by the project team.

It is encouraging to know that all the three participants who installed the pump speed controller on the solar pool heating pumps were satisfied with the pool water temperature after the retrofits. All reported there was no change in the water temperature which further supported the modelled pool thermal performance obtained by the project team.

Savings in energy consumption, emissions and electricity bills were a key focus and driver behind the program. However, the reduction in noise intensity – whilst expected – was interestingly found to be a significant contributing factor towards householder's positive perceptions. Of the 36 householders who adopted the energy efficient retrofit, all (100%) reported that the pumps after retrofitting – some even claiming that they can "no longer hear the pump running at all". For the householders who do not have rooftop PV systems, the pool pumps working much quieter means that operating the pool filtering systems over the night is feasible, which can take the advantage of the cheaper off-peak electricity with no negative impact on the neighbours' lifestyle. This would also contribute to reducing the peak electricity demand.

For the households with an existing PV system, the pool energy efficiency retrofit would increase the cost-effectiveness of the PV system. As reported by Zhao and Bilbao [13], reducing the pool filtering load increased the PV fraction significantly (i.e., the proportion of period when the pool filtering system load is completely covered by the PV system) which resulted in less amount of electricity being purchased from the grid, and therefore, a shorter PV system payback was achieved.

The project team is hopeful that the positive outcomes of this study can be replicated and up-scaled. Perhaps with the synergistic collaborative structuring of local government, academia, and open-minded and innovative industry partners similar to Simply Better Pool Savings. With the inclusion of a $250 rebate (jointly provided by the Cooperative Research Centre for Low Carbon Living (CRCLCL) and Randwick City Council), the average payback time is 12 months for adding the pump speed controller to the main filtering pump and 3.5 years for adding it to solar pool heating pump. However, even without the inclusion of the rebate, the payback time for the main filtering pump retrofit is 1.5. In addition, retrofitting both the main filtering pump and the solar pool heating pump with a pump speed controller has a payback of 2.4 years. For comparative purposes, the average payback times for rooftop solar in Sydney is ~5 years [46]. As such, local councils which are unable to include a rebate in their pool pump offering could still promote the program with confidence that its energy savings would outweigh many of the energy efficient retrofits in the residential sector.

Together, this Pool Efficiency Program has approved residential swimming pools can be cost-effectively retrofitted with pump speed controllers to achieve higher energy efficiency. Not only can it save the householders noticeable energy costs, there is also great potential to reduce the peak electricity demand and GHG emissions. When scaled to all Randwick City Council households with pools (assuming 70% of the total ~3000 residential pools have a single-speed pool filtering pump and could be retrofitted), at least 1.6 GW of peak electricity demand can be avoided and this could be expected to save investments on further grid upgrades. In addition, approximately 3.5 kt CO_2-e of GHG emissions would be saved per year, making a positive long-term impact on achieving Australia's 2030 climate change target [51]. These potential impacts could be even more significant if the Pool Efficiency Program can be rolled out in other local city councils across Australia.

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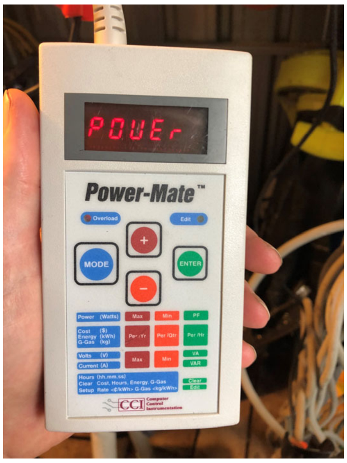
9 Appendix

9.1 Experimental equipment

Table A - 1. Experimental equipment used in the Pool Efficiency Program

Digital power meter (PM10AHDS Power-Mate 10A Heavy Duty Serial)	**Digital sound meter** (Digitech sound level meter QM-1589)	**Ultrasonic flow sensor** (Zedflo DMTFH ultrasonic flow meter)
		

9.2 Inclusion criteria of the program

To be eligible participants, the households may meet the following requirements:

- The householder has an outdoor swimming pool (essential);
- The householder is sole owner-occupier of the property/pool;
- The pool has a solar pool heating system (preferred);
- The pool systems and the pumps are operable (essential);
- The householder is generally comfortable with the cleanliness and the chemical levels in the pool (essential);
- The pool filtering system is run by a single speed pump (preferred); if it is run by a pump with more than one speed and it must run at high speed at all times.

9.3 Payback period of residential LED lighting retrofit

The assumptions used for calculating the payback of typical residential LED lighting retrofit are as follows:

- The average cost of a LED downlight is AU$25 and its power consumption is 11 W [52].
- The average cost of a halogen downlight is AU$5 and its power consumption is 30 W [53].
- The average daily lighting hours in the residential sector are 2.5 hours/day [54].
- Same as the pool pump retrofits, the electricity price is AU$0.28/kWh.

9.4 The energy savings likely to be delivered by the conventional pool industry

The following assumptions and calculations were for the energy savings likely to be delivered by the conventional pool industry in Australia. These were considered as conservative and were based on the perceptions of the pool industry regarding variable speed pool pumping documented in a recent market research report. The report was prepared by Woolcott Research and Engagement [2] for the Department of Environment and Energy.

Sample of pools (same as the retrofitted pools in the Pool Efficiency Program)	36
Number of pools with robotic pool cleaners or manual cleaning	17
Number of pools with in-line plumbed, pressure pool cleaners (both suction-side and discharge-side)	19
Number of pools with in-line plumbed, solar pool heating systems	4

- If the run times of the main pool filtering pump were HIGHER than 8 hours/day in summer and 6 hours/day in winter, we assumed the run times remain unchanged.
- If the run times of the main pool filtering pump were LOWER than 8 hours/day in summer and 6 hours/day in winter, we assumed the run times would be increased to 8 hours/day in summer and 6 hours/day in winter.
- ALL pools using either robotic cleaner or manual cleaning were retrofitted with variable speed pumping.
- 50% of pools with in-line plumbed, pressure cleaners (both suction-side and discharge-side and regardless of the presence of a booster pump for the pressure cleaner or sole reliance on the main filtering pump) were retrofitted with variable speed pumping.
- 50% of pools with in-line plumbed, solar pool heating systems were retrofitted with variable speed pumping.
- The pump power after the conventional pool industry's variable speed pumping retrofits was the same as that obtained in the Pool Efficiency Program.
- The average cost of a variable-speed pump in Australia was assumed as AU$1,250.

9.5 Householder perceptions – further notes

As detailed in the main body of this report, seven households provided remarks about their perception that water condition or pool maintenance had worsened and/or it was harder to manage after the retrofit.

In each of these cases the project team contacted the pool owner to better understand the perceptions and see if simple steps could be undertaken to improve outcomes. In most cases the challenges were easily resolved either with email and phone assistance from the project team or by the pool owner of their own accord.

It was a feature of the project that every pool owner would be able to unwind the upgrade and recover any costs they incurred in its implementation if they were unsatisfied. In every case, where pool owners reported a perception that there were unwelcome changes to their pool the offers to unwind the upgrade were repeated. With the exception of one case, the pool owners elected to keep the upgrades and optimized settings, apparently valuing the benefits of the change more highly than any perceived inconveniences.

The following table describes the cases where negative cases were explained:

Swimming pool number	Pool Owner Perceptions	Comment
SP4	*Pool water is greener.*	The project team contacted the pool owner. They explained that shortly after the install there was a period of heavy rain and some greener water. They rectified this issue using the normal practices they have always applied during these weather events. Thereafter they have been happy with pool water clarity. They emphasized that their remarks were not intended as a reflection on the upgrade but that they felt it important to report all details of their experience in the study feedback.
SP10	*Pump is running well but finding*	The project team contacted the pool owner. The project team explained how the optimization guidelines for pump run times and settings on the

	the pool is not getting enough chlorine on the running time set	chlorinator were structured so that the delivered amount of chlorine from the system was the same after the upgrade as it was before the upgrade. It was explained to the pool owner that lower levels of chlorine in the pool water are often a result of a variety of possible changes in the pool's system or the environment (e.g. longer daylight hours and more direct sunlight in peak summer which degrades the produced chlorine faster, a deficiency of stabilizer in the pool water to protect chlorine from the degrading impact of direct sunlight, periods of high winds and failure to empty leaf baskets, higher pH levels in the water limiting the available chlorine's effectiveness etc.) and not always caused by lower chlorine production levels. The pool owner understood that changes in chlorine production levels as a result of the upgrade were not a likely cause of his current chlorine sufficiency issues. Nevertheless, options to address chlorine insufficiency by either increase chlorine production and/or action to mitigate the variable external influences that can degrade the chlorine or limit its efficacy were discussed. The pool owner opted to move forward with the upgrade and optimized settings and expressed an eagerness to address chlorine sufficiency in his pool by better managing overall chemical water balance and thereby secure all the available efficiency gains.
SP17	*There is sediment on the floor of the pool.*	The project team worked closely with the pool owner to troubleshoot a variety of pre-existing issues with their pool setup that could be contributing to the sediment on their pool floor. For example, improving return flows with better use of return eyeball jets, using a weir swing-gate at the mouth of the skimmer box where it had been missing prior to the upgrade, fixing leaks in the feed hose of the pressure cleaner which was impacting its coverage of the pool floor. Some other possible causes, also not related to the upgrade, like hairline cracks in the lateral pipework at the base of the pool's filter were discussed but no corrective action was pursued as the problem wasn't considered significant enough to warrant the trouble or expense. Further possible causes like the significant nearby parkland remediation at Mistral Point were discussed but it wasn't possible to identify exactly what the cause of the issue was or what role the upgrade played in causing it, if any. The troubleshooting resolved the sediment issues on the pool floor but some sediment remained on the steps which the auto-cleaner does not climb either before the upgrade or after it. The pool owner has elected to keep the upgrade and follow the optimized guidelines and accept the perceived extra sediment on the pool steps.
SP19	*I am happy with the project savings on electricity bill, but less happy with the water quality (more noticeable small particles) after running the filter on lower speed, something that wasn't mentioned as a risk.*	The project team contacted the pool owner and aspects of the likely causes of this problem were shared along with steps to resolve them. The fact that the lower flow speeds from the upgrade would contribute to better filtration outcomes for every litre of water passing through the filter was an element of these communications. As was the fact that the optimized settings that formed part of the upgrade delivered pool water turnover rates equal to or in excess of those required by the relevant standard – Australian Standards AS 3633 [38]. Possible changes not related to the upgrade, either to the pool system (pool water chemical imbalances) or in the surrounding environment (windy periods, nearby neighbourhood construction projects and construction dust etc.) were also highlighted. Offers to unwind the upgrade where a feature of the program for all pool owners at all stages of the project. When perceived problems were raised these offers were repeated and this case was no exception. The pool owner however elected to continue with the improved setup and appeared to value the electricity bill savings more highly than any perceived issues with 'more noticeable small particles' in the pool water.

SP30	*Pool is running an extra 2 hours per day compared to when installed.*	The project team contacted the pool owner. It was explained that the recommendation was for a significant reduction in pool pump running hours for this pool and that this reduction had been implemented at the time the install was adopted. The householder explained that their partner was the primary custodian of pool maintenance and he would re-check the situation with pump running hours to make sure the guidelines were being followed. The pool owner was eager to continue with the upgrade.

In the one case where the pool owner elected to unwind the upgrade, it was agreed that the cause of the problem was more likely to be shortcomings in aspects of the pool's setup other than the upgrade. Some of these shortcomings were corrected as part of the troubleshooting (e.g. the suction auto-cleaner needed a new rubber skirt and diaphragm). Chief amongst the remaining shortfalls in the pool owner's mind was a significantly degraded salt chlorination cell. The pool owner was planning to delay the replacement of this cell several months until the start of the following summer. The pool owner was enthusiastic about trying the upgrade again after the install of the new salt cells. When that upgrade reoccurs the project team feels a more accurate understanding of the actual causes of the pool owners perceived problems could be achieved with improved measurement of overall pool water chemical balance. This would assist in the effective isolation and resolution of negative perceptions more likely to do with pool water chemical imbalances that are unrelated to the upgrade (e.g. the pool water being "sticky" and possibly caused by elevated pH).

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