

An investigation into the energy savings and economic viability of heat pump water heaters applied in the residential sector

A comparison with solar water heating systems

Updated: current market economics (original article released in sept 2008)

When this article was originally released in 2008, South Africa had been amidst a power supply crisis. Rolling black outs started in November 2007 and was experienced for several months, with the problem eventually addressed in March 2008 by the forced reduction of electrical consumption at all heavy industries to 90 percent of typical energy consumption.

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Two years has since passed with almost no load shedding activity, indicating a currently stabilized power supply vs. demand scenario in South Africa. Credit needs to be given to ESKOM for improving its security of power supply. However, South Africa is still experiencing a looming national electricity shortfall. With a fledging economy and subsequent electricity demand growth predictions, ESKOM's electricity supply is still predicted to be extremely tight in the next three to five years. This results in steeply increasing electricity prices and therefore a strong impetus for improving energy efficiency exists.

The main challenge confronting us is how to reduce energy consumption with a sustainable demand side management effort. The temporary shut-down of all mining operations during January 2008, as well as the on-going rationing of power to these industries, is a clear example of un-sustainable demand side management. Currently the power rationing causes a drop in production levels and mining companies have stated concerns over the viability of mining in certain areas and that subsequent job losses could occur. The same principle is applicable for all other industrial and commercial business and even the residential sector. Reducing energy consumption by for example reducing manufacturing outputs, service levels in the hospitality industry, or quality of life at home, to name but a few, is not the most effective way to achieve a sustainable reduction in energy consumption as it has a negative effect on our economy and living standards.

Sustainable Energy Consumption

The only way to achieve a sustainable energy consumption reduction will involve the implementation of energy efficient programs in all sectors. These programs typically aim at installing energy efficient devices that consume less energy whilst, most importantly, still provide the same service levels. An example of this is the installation of Compact Fluorescent

Lights where the electrical energy consumption are significantly reduced compared to conventional incandescent light bulbs, while still maintaining acceptable illumination levels. The Department of Minerals and Energy and ESKOM recognises this challenge. A solution that has therefore been discussed since 2008, and is indeed gaining momentum, is the use of a so-called Energy Conservation Scheme (ECS). The ECS will be a combination of power rationing schemes and energy saving incentive schemes. Power rationing schemes will result in all the different market sectors required to reduce energy consumption by a predetermined percentage, for instance 10 percent for the residential sector. Energy saving incentive schemes will involve either energy efficient equipment rebates or Standard Offer Programs (SOP) that pays customers for verified or deemed savings delivered by energy efficient equipment. In the field of sanitary water heating Solar Water Heaters (SWH) has received significant attention as an energy efficient technology for residential applications. ESKOM also supports SWH's in the form of a subsidy scheme that discussed since 2008, and is indeed gaining momentum, is the use of a so-called Energy Conservation Scheme (ECS). The ECS will be a combination of power rationing schemes and energy saving incentive schemes. Power rationing schemes will result in all the different market sectors required to reduce energy consumption by a predetermined percentage, for instance 10 percent for the residential sector. Energy saving incentive schemes will involve either energy efficient equipment rebates or Standard Offer Programs (SOP) that pays customers for verified or deemed savings delivered by energy efficient equipment. In the field of sanitary water heating Solar Water Heaters (SWH) has received significant attention as an energy efficient technology for residential applications. ESKOM also supports SWH's in the form of a subsidy scheme that attempts to promote the economic feasibility of such installations. However, the ESKOM rollout program failed to make a significant impact in early years due to the

excessive cost involved in SWH installations and the poor economic returns obtained from such installations. In response to the failure by the SWH program to make any significant impact, ESKOM has increased equipment rebates on SWH's. The program now also differentiates between different sizes and quality of SWH systems. This is a definite step towards improving the economic viability of solar water heater installations for residential customers. ESKOM has however also embarked on rebate programs for the roll-out of heat pump units in the residential sector, as a direct competitive alternative to the SWH program. ESKOM and the National Energy Regulator of South Africa (NERSA) believe that both technologies can play an important role towards achieving energy saving targets in the residential sector. This updated article will repeat the economic comparison study between SWH's and Heat Pumps as presented in the original article, but will use updated equipment cost figures, rebate contributions and electricity tariffs.

Solar Water Heaters

During the past few years solar water heating has been improved significantly through research to provide a low maintenance solution mainly aimed at the residential market. This concept has several benefits, but also disadvantages:

The main benefit of SWH is a reduction in electricity cost that is normally incurred by electrical resistance heating of sanitary water as found in conventional geysers. The cost of water heating typically contributes between 30 percent and 50 percent of a household's electricity cost. Solar water heaters have been shown to save 55 percent- 70 percent of water heating costs [2]. It can therefore save a significant fraction of the typical household's electrical bill of between 17 percent and 35 percent. Unfortunately the disadvantage of the concept is the high capital cost of acquiring and installing such a unit. Even with recently increased electricity costs, payback periods for typical solar water heater installations still range between three to four and a half years. The SWH industries response to the general negativity regarding pricing has been to offer smaller and therefore less costly systems to clients. Even though these systems still save an appreciable amount of energy, the fraction of savings is impacted negatively for large homes where hot water consumption far exceeds the heating capacity of the smaller SWH. This implies that the rest of the hot water requirements will still be heated by the geyser electrical resistance element.

Heat Pump Water Heaters

There is another energy-efficient water heating concept that has proven to be highly successful; known as a heat pump. Until now this success was mainly achieved in the commercial building market (hotels, hospitals, university residences, etc.) [4]. This success is recognised by ESKOM DSM through the creation of a heat pump technology stream program, one of only six technology stream programs at ESKOM DSM. Large scale projects using heat pump technology is currently being executed in the commercial and industrial sector using ESKOM DSM part-funding.

A heat pump is essentially a vapour compression cycle, similar to an air conditioning unit. However, instead of the cycle being used for air cooling purposes with the associated heat as a by-product, a heat pump utilizes the heat generated in the cycle to heat water. In brief; energy is extracted from the ambient air using a finned coil heat exchanger, also known as an evaporator, using a refrigerant at low pressure and temperature as the working fluid inside the tubes. This refrigerant is then compressed to a high pressure and temperature by an electrically driven compressor. The high pressure refrigerant is then circulated through a refrigerant-to-water heat exchanger, also known as a condenser. Here energy is

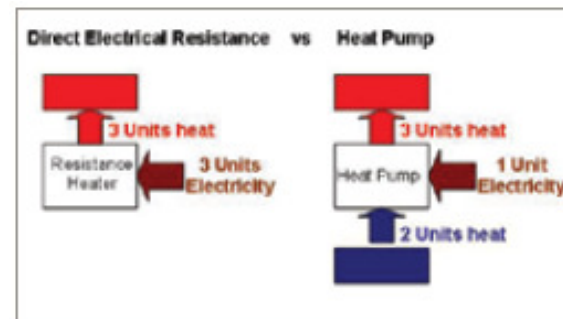
exchanged with water, at a lower temperature, thus heating the water to temperatures in the region of 60 °C. The refrigerant leaving the condenser is then expanded back to a low pressure by using an expansion valve before it enters the evaporator to start the cycle once more. This is a continuous process, and the only electrical energy used is to drive i) the compressor, ii) a pump to circulate water through the refrigerant-to-water condenser, and iii) fan power to cycle air through the finned air-to-refrigerant evaporator.

This cycle typically consumes one unit of electrical energy for every 2.5 – 3.5 units of heating produced; i.e. only 30 – 40 kWh_{electrical} is used to produce 100kWh_{thermal}. 60 - 70 percent of the electrical energy consumption can therefore be saved compared to conventional electrical resistance heating.

Heat pumps have several advantages: With water heating by conventional geysers contributing 30- 50 percent of a typical household electricity cost, it means that a heat pump can save 18-33 percent of the cost. This is more than what would typically be required from proposed residential power rationing schemes. As stated earlier to date a figure of ten percent power consumption reduction for the residential sector has been proposed. Heat pumps are relatively easy to install. All that a heat pump requires is a free air arrangement resulting in it usually being an outside installation. Heat pumps are built to be weather proof and comply with the SANS IP ratings for outdoor electrical installations. Heat pump installations, while more expensive than a conventional electrical resistance heater, are much less expensive than solar water heating installations. This will be shown in this article. Payback periods in the residential sector vary between 1.3 - 3 years for most installations. The variance in payback periods is a function of several factors including levels of usage and the ease of installation. In the next section a comparative study will be done to evaluate the two energy efficient solutions mentioned in this paper.

Economic and Savings Comparison: Heat Pumps vs. Solar Water Heaters

This section provides simulated case studies for residential hot water facilities. Comparisons are



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made between conventional electrical resistance heaters found in geysers, heat pumps and solar water heaters. Data for solar water heating was obtained from previous studies [2], [3]. Data for heat pump systems and conventional electrical heating systems is also obtained from previous studies ([1], [4], [5], [7], [8], [9], and [11]). Detailed comparisons will be made for the Johannesburg region in Gauteng.

Assumptions

For purposes of comparison, the following assumptions are made allowing the three concepts to be evaluated on equal terms.

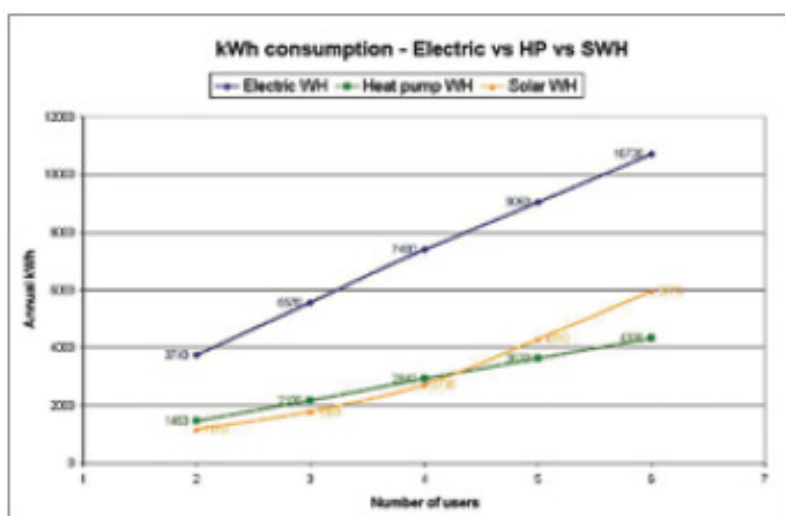
- Average inlet water temperature for Johannesburg is 14°C.
- Average solar radiation value is: 1750kWh/m² annually for Johannesburg.
- 55°C is chosen as the hot water storage temperature. 55°C has been proven as an ideal storage and supply temperature, reducing scaling, heat losses and the risk of scalding, whilst eliminating the growth of harmful bacteria which can occur at lower temperatures [12].
- Hot water is stored in an insulated vessel with heat loss characteristics: $Q_{loss,daily} = 0.11 \times Q_{max,vessel}$, where $Q_{max,vessel}$ represents hot water stored at 55°C.
- For heat pump installations the existing geyser will be utilized as storage vessel for hot water generated by the heat pump unit.
- Solar water heaters will however have their own storage vessels installed.

Energy Savings Results

The results for this comparative study will be shown as a function of number of occupants in a household, from households with two persons through to households with six persons. Typical hot water consumption patterns and figures have been obtained from a study by Meyer [6]. Consumption varies between 80 litres at 55°C per person in summer and 120 litres at 55°C per person in winter. Several other studies have used similar figures in hot water system design and evaluation ([5], [9], and [10]).

The conventional geyser found in most homes is usually either a

- 3kW, 150 litre unit (typically two-three people) or a
- 4kW, 200 litre unit (typically four-six people).
- The proposed heat pump unit for both vessel sizes is 3.6 kW thermal, using 1.3 kW electrical.
- The solar heating system varies as follows:
 - 200 litre, 2.45m² collector span (two-three people)
 - 250 litre, 3.80m² collector span (three-four people)
 - 300 litre, 4.52m² collector span (four-six people)
- 300 litre represents the maximum system size available in the South African Market.



The systems as specified are provided as inputs to a simulation program [8]. The simulation program performs a first law conservation of energy analysis, and takes into account the annual distribution of hot water consumption and daily consumption profiles as proposed by Meyer [6].

The figure below shows the annual electricity consumption per heating method.

The following is observed:

1. Both the heat pump and solar water heater consume significantly less energy compared to the conventional electrical resistance geyser heater.
2. Heat pumps and solar water heaters consume more or less the same amount of electrical energy up to four persons per

household. Heat pumps consume less energy at larger households with five-six persons since it is able to cope with the increased hot water demand, whereas the maximum solar water heater size of 300 litres means that the excess hot water consumed above 300 litres has to be heated by the electrical geyser elements.

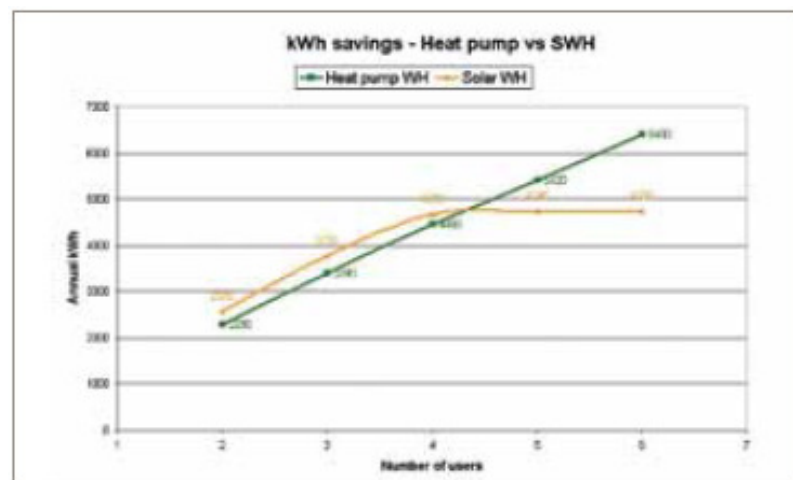
3. Heat pumps use about 38 percent of the electrical energy (compared to the geyser element) to provide power to the compressor and water pump.

4. Solar water heaters theoretically consume very little electrical energy during operation (a small fraction to drive a water circulation pump in some designs), but an appreciable fraction of electrical energy is still consumed during certain periods by the backup electrical element:

- During the night time when solar energy is not available and hot water demand exceeds stored hot water capacity.
- During winter and cloudy days when daily hot water demand exceeds the daily delivery capacity of the solar panel.
- Where daily hot water demand is higher than the installed solar collector can provide.

The following figure shows the annual savings that can be obtained by heat pumps and solar water heaters.

The figure is obtained by simply comparing annual energy consumption of both technologies with the annual energy consumption of a standard electrical geyser.



The following can be observed:

Heat pump and solar water heater savings are comparable up to four persons per household. Heat pump savings is higher in bigger households of five-six people where hot water demand exceeds solar water heater capacity, whereas heat pumps can still supply the amount of hot water required in these households.

Economic Comparison

This section provides an economic comparison between heat pumps and solar water heaters using the energy savings as obtained in the previous section and the current installation cost of these systems.

Please note that for comparative purposes the ESKOM DSM rebate is included for both technologies. The official rebate value as per ESKOM SWH program is utilised, including the differentiation for system capacity.

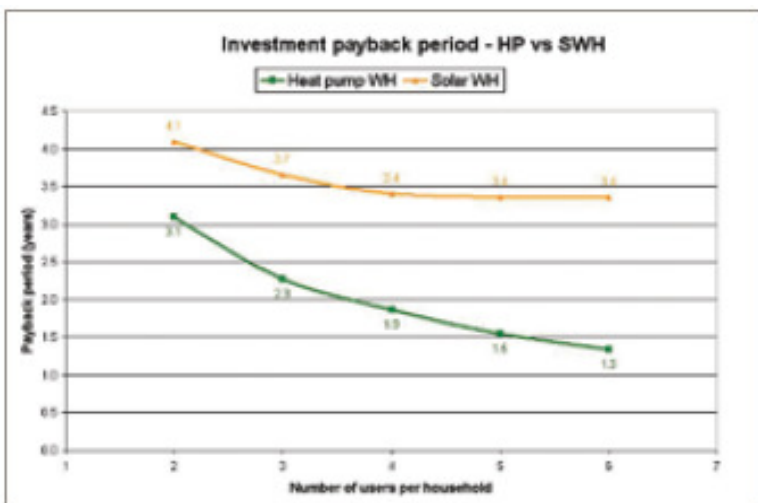
On the heat pump side a rebate value of R4500 is used, although it should be noted that this figure has not been officially released by ESKOM DSM as the heat pump rebate value.



The figure on the following column indicates the investment payback period calculated using the above installation cost estimates and the calculated energy savings (kWh), with an average energy cost of 0.82c/kWh. (The energy cost is based on the typical 2010 financial year municipal tariff for residential customers).

From the graph it is clear that better economic returns are obtained for both heat pumps and solar water heaters with an increase in users. From 4-6 users per household however the investment payback period for Solar Water Heaters remains relatively constant. However, it is also clear that heat pumps provide a significantly better investment payback period when compared to solar water heating.

The main reason for this is the much lower installation cost of heat pumps, while still achieving basically the same savings that solar water heating can provide for small and medium size households, and increased savings at bigger households.



The investment payback period for heat pumps in households with four-six persons is less than two years, with a six person household paying back the investment in only 1.3 years. The investment for such households would therefore be basically the same as investing money in the bank at an interest rate return of 44 percent - 70 percent per annum, an excellent investment indeed.

This article reports on a scientific investigation conducted under the auspices of the North West University, to compare the different technologies for water heating that are available in the residential sector. This article showed that heat pumps can provide a very feasible alternative to solar water heating in the residential market. Heat pumps achieve similar energy savings that is possible with a comparable solar water heating system, but at a much lower installation cost, thus leading to a significantly improved payback period. Typical payback periods for heat pumps vary between 1.3 years (6 person household) to

3.1 years (two person household). This compares favourably to solar water heater installations where payback periods vary between 3.4 years (six person household) to 4.1 years (two person household).

In conclusion, this investigation shows that an alternative to solar heating exists for energy efficiency applications in the residential sector.

This is a market that has huge savings potential that will benefit both ESKOM and the residential customer. *PA*

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