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Effect of solar water heating system in reducing household energy consumption

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Abstract: Electricity demand has increased in recent years in South Africa beyond the capability of the South African grid. This has resulted in the increase of electricity price hike of more than 24% over the last 5 years. In addition, the economy of the country has been greatly affected with the frequent rolling blackouts. It is estimated that in South Africa, about 40% of household's electricity consumption is used for heating water using geyser. There is an urgent need to reduce household's energy consumption and to improve the quality and the security of supply. This could be accomplished by using renewable energy such as solar energy. This paper investigates the effectiveness of using solar water heaters to reduce the energy consumption in South African households. The effectiveness of the solar water heaters is studied together with heat pumps by comparing these two technologies based on energy consumption, cost and payback period.

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Keywords: Heat pumps, cost solar heaters, payback time, energy consumption

1. INTRODUCTION

Quality of Supply in South Africa has declined in recent years due to the lack of adequate power generation and ageing transmission and distribution infrastructure. This has led the power utility to initiate a compulsory load shedding in 2008 and more recently in 2014. Since 2008, there has been an increase in electricity price. The electricity price hike has reached more than 24% over the last 5 years. Studies have shown that the South African security of supply is most likely to be tight over the next five years or so (Eberhard and Newbery, 2008). It is estimated that about 40% of an average South African household's electricity consumption is used for water heating using geyser. At present, this electricity is mainly coming from the South African national grid which power stations are mainly coal-fired plants. This is putting a lot of pressure on the system. However, this pressure could be relieved if renewable energy such as solar power and wind power were used for heating. (Veldman, *et al*, 2011).

The South African government and the power utility have been providing subsidies to encourage more people to install solar water heaters. With new, bigger subsidies, a household will recover its initial investment within approximately five years, and then go on to use free hot water. Given the fact that South Africa is the biggest contributor to greenhouse gas emissions on the African continent (90% of its electricity is generated from coal-fired power stations), using renewable energy sources to generate electricity can contribute positively not only in reducing the greenhouse gas emissions but also in maintaining the reliability of the electricity supply (Colombo, *et al*, 2010); (Fahmy, *et al*, 2010); (Banerjee, and Pillai, 2007); (Swedish Institute HP., 2012); (Zhou, and Liu,2010). Since solar is the most abundant and easy to harvest renewable energy in South Africa, it is not surprising that the South African government is advocating the use of solar energy to heat water instead of other forms of energy such as biomass, gas, etc. This paper investigates the effectiveness of using solar water heaters and heat pumps to reduce the energy consumption in South African households. The solar water heaters are studied together with heat pumps by comparing these two technologies based on energy consumption, cost and payback period. For illustration purposes, only simplified steady-state models are used (as opposed to detailed dynamic models). Simulation results show that overall, solar water heaters are more cost effective than heat pumps. However, heat pumps are more efficient in terms of the energy consumption from the grid than solar water heaters. However, the initial investment in heat pump is quite high. This could be one of the main reasons why fewer people in South Africa are using heat pumps.

2. OVERVIEW OF SOLAR HEATER AND HEAT PUMP

2.1 Solar water heating system cycle

Fig. 1 shows the diagram of a solar water heater operation. It can be seen from this Figure that a solar water heater comprises of an array of solar collectors which are connected to the storage tank. These solar collectors are used to collect heat by absorbing sunlight. The collected heat is then carried to the storage tank by circulating liquid through collector tubes. At this point, the heat is used by the heat exchanger for hot water production. After the hot water is removed from the storage tank, cold water is immediately supplied to make sure that the storage tank is always filled with water (Ijumba, 2009). The tanks are normally located above the solar

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collectors to allow thermosiphon flow. Thermosiphon flow allows the heated water in the storage tank to rise up while the cooler one runs down to be heated. However, they can be positioned anywhere with an additional pump added to move the water.

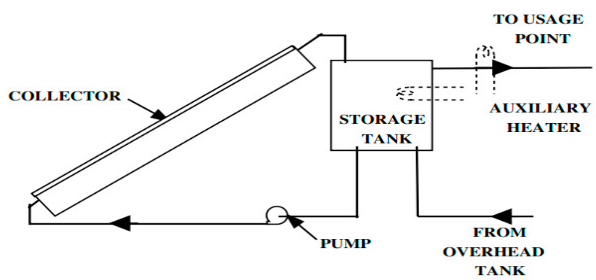

Fig. 1: Operation of solar water heating systems (Fahmy, *et al*, 2010)

Efficiency of solar water heaters is measured by Solar Energy Factor (SEF) and Solar Fraction (SF) (Ijumba, 2009).

$$SEF = \frac{E_d}{E_i} \quad (1)$$

$$SF = \frac{E_d}{E_r} \quad (2)$$

where

E_d- energy delivered

E_i-input energy

E_r- energy required

2.2 Heat pump

A heat pump is a machine that moves heat from a low temperature renewable source to a high useful temperature. It does this by means of mechanical work in the form of a compressor (Veldman, *et al*, 2011). A compressor is a device that is used to supply air or other gases at an increased pressure. The renewable source can either be air or ground (Perko, 2011). However, the most reliable source is ground because its temperature is approximated constant throughout the year. Ground temperature at depths greater than 10 meters is considered constant and is dependent on geographical location. On average, ground temperature is about 6 degrees Celsius (Colombo, and Badiali, 2010).

Heat pumps can also extract waste heat from ventilation air system, cooling equipment or industrial processes and make it suitable for reuse (Swedish Institute HP., 2012). Only a small amount of power is required to convert a low grade heat into a useful heat using heat pumps. The total energy required to drive a heat pump is only one third or even less than the useful heat produced during conversion (Zhou, *et al*., 2010).

Fig. 2 shows the operation of heat pump which is very similar to that of a refrigerator except that it can also work in the reverse configuration to provide heating. It can be seen from Fig. 2 that heat is extracted from heat source using evaporator. Within an evaporator, the heat is transferred to a working fluid, changing it from liquid to gas. The evaporator and hence the working fluid are at a low temperature at this point. However, this temperature is not sufficient to provide heating and therefore needs to be raised. This is achieved using compressor which increases the gas pressure, causing a temperature rise. A rise in temperature will produce a hot gas which is then transferred to a condenser. The heat from the condenser can now be used for hot water production or indoor area. After the working fluid has delivered the heat, it exits the condenser and enters the liquid container. The purpose of this container is to balance the pressure and the volume of the media in the entire line of heat pumps. The working fluid is still at a high temperature at the moment. It is then passed through an expansion valve so that the pressure can be reduced. In doing so, the fluid becomes cold and returns back to its liquid state before entering evaporator. At this point, evaporator is ready to re-take the heat from the heat source and the cycle continues. This process can be simply reversed for cooling (Colombo, and Badiali, 2010);

The efficiency of heat pumps is determined by the coefficient of performance (COP) which indicates the number of unit of useful energy that a heat pump provides on the basis of one unit of purchased energy (Zhou, *et al*., 2010). The coefficient of performance can be used to measure both heating efficiency and cooling efficiency as given in equation (3).

$$COP = \frac{Q_o}{P_i} \quad (3)$$

where
Q_o-output heat produced by the system
P_i-input power required by the system

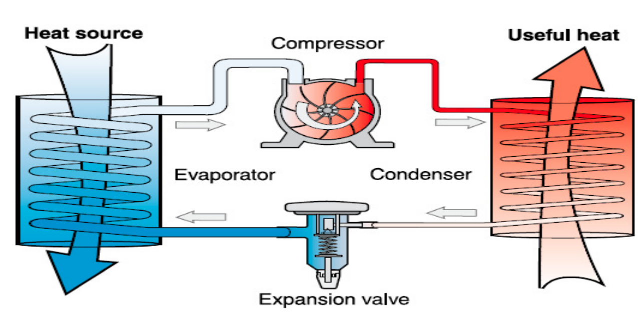

Fig. 2: Operation of a heat pump (Zhou, *et al*., 2010).

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