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Research paper

A review of water heating technologies: An application to the South African context

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HIGHLIGHTS

- Domestic water heating technologies are reviewed.
- These technologies include tank and tankless storage.
- Artwork illustration are used to explain the operation principle.
- Technologies are discussed based on advantages, drawbacks, average life expectancy and payback period.
- Results of this review discuss and compare the feasibility of each water heating technology.

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ABSTRACT

The process of water heating consumes enormous amounts of energy. South African households may see up to 40% of their total energy be allotted to the heating of water. The implementation of energy efficient or renewable energy source technologies, for the main purpose of heating water, may assist in reducing the magnitude of the energy crisis that South Africans are facing daily. This will, in turn, reduce energy consumption and costs, so that the energy price hikes do not affect the consumers as severely as it would otherwise.

The purpose of this paper is to provide a survey of the most frequently used domestic water heating technologies. The paper aims to critically analyse and summarize recent advancements made in renewable and non-renewable water heating technologies, particularly in the South African case. These technologies include the electric storage tank water heater, solar water heaters (passive and active circulation), heat pump water heater, geothermal water heating, photovoltaic-thermal water heater, gas-fired tankless water heater, biomass water heater and oil-fired water heater.

Substantial research works and other academic studies focusing on efficiency improvement, optimal design and control, were consulted and categorized in terms of contributions, focus and respective technologies. The key findings of the review conducted on the various water heating technologies are discussed and organized, based on the advantages, drawbacks, approximate initial investment, average life expectancy and payback period.

The results of this survey identify gaps in existing research. The aim is to propose a new perspective on the importance of energy efficient hybrid water heating systems and the cost savings they might offer.

1. Introduction

Hot water is essential to maintain one's personal and household hygiene. Hygiene is of utmost importance when it comes to healthy living. Unfortunately, this comes at a great cost to most of South Africa's poverty-stricken citizens. Water heating may account for as much as 40% of the total energy consumed by a regular residential building (Duse et al., 2003).

The temperature of water is increased from an initial temperature, which is usually close to the ambient temperature of air to the user's specific comfort level, resulting in the usage of large amounts of energy. Obtaining ways of reducing energy usage of water heating activities, a substantial amount of money may be saved for other much needed necessities. Eskom, the national electricity supplier of South Africa, has experienced an increased demand over recent decades, as this demand grows to a point where it exceeds the suppliers generating capacity, the country is faced with rolling blackouts. A much-needed reduction in energy usage is required if these nationwide interruptions are to be avoided. Furthermore, price hikes in electricity according to NERSA

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Abbreviations

BWH	Biomass water heater
COP	Coefficient of performance
ESTWH	Electric storage tank water heater
ETC	Evacuated tube collector
ETWH	Electric tankless water heater
FPC	Flat plate solar collector
GFTWH	Gas fired tankless water heater
GHSWE	Geothermal hot spring water extraction
HIV	Human immunodeficiency virus
HPWH	Heat pump water heater
HSWH	Hybrid solar water heater
ICS	Integrated collector storage
LPG	Liquefied petroleum gas
NERSA	National Energy Regulator of South Africa
OFWH	Oil fired water heater
PDC	Parabolic dish collector
PV	Photovoltaic
PV/T	Photovoltaic-thermal
PV/TWH	Photovoltaic-thermal water heater
SWH	Solar water heater
USD	United States Dollar
WHO	World Health Organization
ZAR	South African Rand

(National Energy Regulator of South Africa) is increasing annually, making it increasingly challenging to afford electricity (Hohne et al., 2018a).

Energy management activities, such as energy efficiency improvements and the use of renewable energy systems, have recently been introduced by Eskom, in order to mitigate a total grid shutdown. Energy efficiency improvements aim to decrease the overall energy usage of a system, while energy management schemes attempt to shift peak demand energy usage to off-peak periods. Using Renewable energy as a source, rather than electrical energy from the grid for heating water, lowers the strain on the electricity supplier (Gets and Mhlanga, 2013).

Higher rates are charged during peak energy consumption periods, while a standard rate applies for intermediate energy usage periods and an off-peak rate for off-peak periods. Some renewable energy water heating systems have their control optimized, in order to shift usage to off-peak and standard periods and this may cut the energy costs in half (Kohler, 2014).

2. Water heating demand profiles and associated costs

2.1. Energy demand profile

Approximately 18% of the generated electricity in South Africa is supplied to the country's residential sector. In larger cities, 31% of electricity sold may be allocated to the residential sector. Most of the electricity demand occurs during the peak demand period, where electricity is charged at significantly higher rates, compared to standard and low demand periods (SEA, 2017). This is mainly due to the methods of electricity generation employed to meet the peak demand, as the electricity supply is constrained. The most costly electricity generation method entails the use of open cycle gas turbines. These turbines consume natural gas or liquid fuel (kerosene or diesel), which carries a high price tag. The electricity supplier of South Africa, currently under immense financial pressure, cannot afford the use of these turbines. Furthermore, the air pollution incurred by these systems may spell disaster for future generations (Mail and Guardian, 2018).

Fig. 1 shows the national demand profile of a typical week during the winter and summer seasons in Southern Africa. From the graph, a significantly large variation between the high and low electricity demand periods may be observed. Water is generally heated during these high demand periods. This increases the magnitude of these peaks, resulting in a need to utilize the costly open cycle generators (Magoro, 2018a).

The preferred method of heating water in South Africa usually entails the use of an electric storage tank water heater. A typical middle-class residential building using this preferred water heater may consume on average approximately 11 797 kWh/year. In this instance 36.1% may be allocated to the heating of water translating into an energy usage of 4259 kWh/year (Catherine et al., 2012).

2.2. Energy cost per kWh by source

In order to evaluate the impact of heating water during peak periods in terms of cost, the variations in energy prices for each period need to be analysed. Electrically supplied water heaters, particularly electric resistive water heaters, may have been the most popular technology in the past, due to the high efficiencies these systems offered, accompanied by the low implementation and electricity costs. However, in recent years, electricity prices have increased significantly and alternative energy source water heating technologies have been consulted to lower the overall operational costs involved (Hohne et al., 2018e).

Table 1 indicates the approximate costs per kWh for each respective alternative energy source for the year 2018, within South Africa. While it has been established that water is generally heated during peak energy usage periods, the electrical energy prices in the table indicates the approximate prices of using electricity during these high demand periods. When comparing the seasonal prices of electricity during peak cost regions the energy price per kWh for winter is near triple the amount charged for the summer season. Fortunately, the prices are solely in effect for three months (in winter), a total of 92 days of the year. This however does not justify the usage of electrically supplied water heaters, due to the higher demands of hot water and, as a result, higher electricity demands occur during winter, as seen in Fig. 1. This effectively negates the savings that may otherwise have been obtained during the remaining 273 days of the year (Hohne et al., 2018c).

From the table, the price of illuminating paraffin (Department of Energy, 2018a) and biomass pellets (EE Publishers, 2018), are proven to be the least costly, when compared to the other alternative energy sources. However, these prices differ depending on location and availability. LP gas prices are relatively similar to diesel/oil prices (Department of Energy, 2018b,c), while the water heating appliance may have different energy conversion factors that need to be taken into consideration. This further depends on the complexity and initial implementation cost of the heater system as a whole. Furthermore, the efficiency of the water heating technologies plays a significant role in determining the actual cost of water heating, for a specific household demand (Ellabban et al., 2014).

2.3. Residential water heating technologies: a review of usage statistics

While it is challenging in determining the exact amount of each water heating technology utilized in south Africa, a few assumptions can be made to obtain an approximate value. Nearly 84.4% of South African citizens have access to electricity, surveyed at

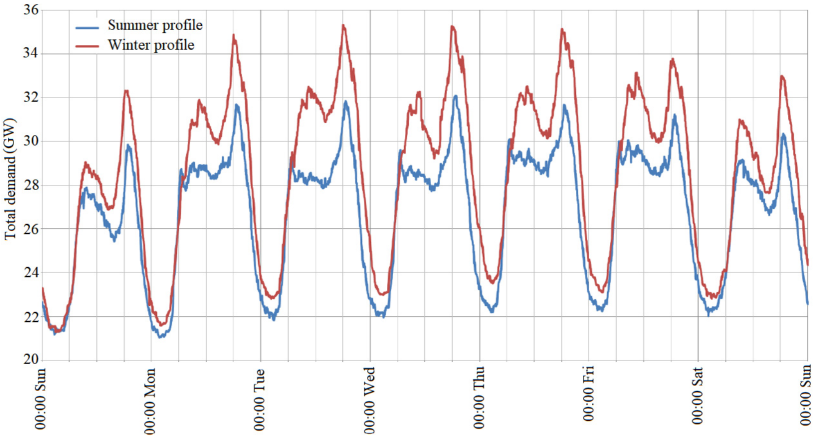

Fig. 1. Seasonal and weekly electrical demand profiles of South Africa (Magoro, 2018b).

Table 1
Cost of energy by source per kWh in South Africa.

Energy source	Tariff region	Season	Cost per kWh in South African Rand (ZAR)	Cost per kWh in US Dollar (USD)
Electricity	Off-peak	Winter (June–August)	1.0051	0.071
	Standard		1.6141	0.114
	Peak		5.6634	0.401
	Off-peak	Summer (September–May)	0.8495	0.060
	Standard		1.4159	0.100
	Peak		1.9821	0.141
LP Gas	None	Year-round	1.7012	0.121
Biomass (wood)	None	Year-round	1.4001	0.099
Oil/Diesel	None	Year-round	1.6092	0.114
Illuminating paraffin	None	Year-round	1.146	0.081
Solar	None	Year-round	0[a]	0[a]

[a] Solar irradiance as energy source cannot be charged or regulated.

the end of 2017 (Stats SA, 2018). In some cases, particularly the low-income households, water is boiled using pots or kettles for bathing, cooking and cleaning purposes.

As discussed in Section 2.1, the residential sector consumes approximately 18% of the country's electricity. 30 to 40% of the total electricity used in a household may be allocated to the heating of water. Therefore, the approximate maximum electrical energy consumed, for the purpose of water heating, may account for up to 7.2% of the national energy consumption. 29% of water heaters in South Africa are electric storage tank water heaters. An unknown percentage of households use kettles or stoves to boil water. Additionally, a large number of South Africans use paraffin stoves to heat water. The remainder may be subdivided into alternative fuel sourced/renewable energy source or hybrid solar water heating technologies.

The department of energy implemented a national solar water heater roll-out programme to increase access to hot water for low-income households. The plan envisages the installation of 1.25 million solar water heating systems, by the year 2019, if realized the total amount of solar water heaters installed would reach 1.75 million (Engineering News, 2018).

3. Description and operation of various residential water heating technologies

In this section, the most common water heating systems in South Africa are discussed. In addition, a few existing alternative methods of water heating are mentioned, that may have relevance in the near future. The water heating systems will include standalone renewable energy systems, electrical input devices and hybrid systems, that may exist in various configurations. These configurations may consist of either hybrid renewable systems or a hybrid renewable system, coupled with an electrical input device.

3.1. Electric storage tank water heater (ESTWH)

The electric storage tank water heater has two functions: to heat water using electrical energy and storing the hot water the time it is required. Electrical energy is supplied to electrical resistive elements within the storage tank. Current flows through the elements in order to create heat and this thermal energy is exchanged to the surrounding water. The process gradually increases the thermal level of the entire water mass within the storage tank water heater. A thermostat maintains a certain thermal level set by the user. The electric element is switched on when the temperature of the water falls below a certain value, increasing hot water availability. Other type electric storage tanks have two electric elements, each controlled by an independent thermostat. One element located at the bottom of the storage tank, as illustrated by Fig. 1, assists in replacing lost energy, due to the temperature gradient between the ambient air and the water (Lutz et al., 2002). The upper element provides thermal energy to water when the demand is high, assuring that the dual element storage tank is more efficient than conventional single element systems (Delport, 2005; Sowmy and Prado, 2008).

3.2. Electric tankless water heater (ETWH)

This water heater works on the same principle as the ESTWH. Multiple elements heat water to ensure instantaneous hot water access. This system is a demand type water heater, meaning that water is heated solely when it is required. No hot water is stored, prevention standby losses. However, due to the large amounts of hot water needed at a specific time, the instantaneous heating of the water consumes a substantial amount of electricity. Referring to Fig. 3 as hot water is needed, cold water flows into the heater, where it is heated by 3 separate electrical resistive elements. The

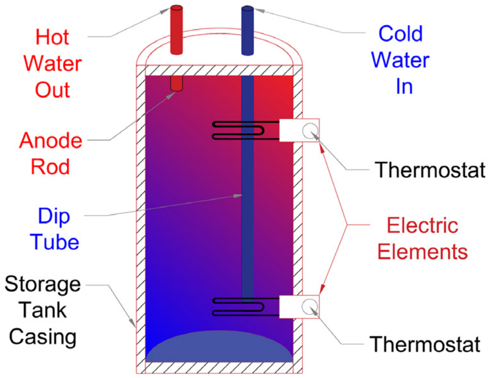

Fig. 2. Electric storage tank water heater (ESTWH).

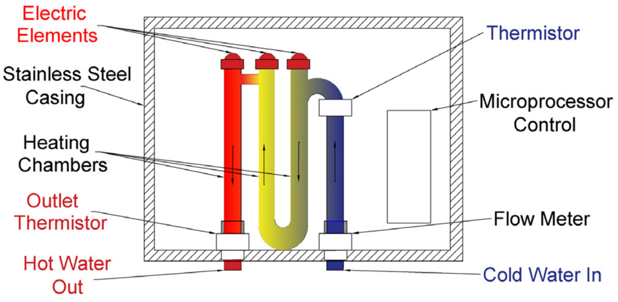

Fig. 3. Electric tankless water heater (ETWH).

water temperature increases as it passes through each heating segment, so that the final desired temperature is reached at the third and final element. The microprocessor control board regulates the amount of energy needed to heat the water to the temperature set by the user. Inlet cold water temperature, outlet hot water temperature and the flow of the water is monitored and the power is adjusted accordingly. Due to the absence of a storage tank, the heater requires less space, meaning that it may be placed near the hot water demand location. This, in turn, reduces heat losses (Milward and Prijyanonda, 2005).

3.3. *Solar water heater (SWH)*

South Africa, together with only a few other countries in the world, receives a particularly high concentration of solar irradiation, Fig. 4 presents the annual average direct normal irradiance from 1994–2013 in South Africa, indicated as kWh/m^2. From Fig. 4, the average daily irradiance may be calculated. It is evident that the Northern Cape Province receives the most radiation in comparison, which may be described as more than 8 kWh/m^2 per day. Other provinces, such as, KwaZulu-Natal and Mpumalanga, receive less than the overall daily average of 5.5 kWh/m^2 per day) (cres.sun.ac.za, 2017). All provinces in South Africa receive an adequate amount of solar energy for water heating purposes. It is evident that a solar technology, such as solar water heaters, may thrive in the South African climate, thus growing in popularity throughout the country.

Solar water heaters absorb thermal energy from the sun and exchange it to water. This method of water heating is beneficial, due to the fact that the energy used is free, abundant and indefinitely renewable. The solar collector placement plays a significant role in the amount of energy it may absorb. Optimal collector tilt angles depend on specific coordinates of the location where the collector is installed. Furthermore, these angles change significantly in passing seasons. It is preferred, by most collector users, to obtain the optimal tilt angle for the winter season and permanently secure the collector at this position, to ensure maximum hot water availability during the colder months of the year (Roux and Gabriel, 2016). It should further be mentioned that the collector should not, at any time of day, be obscured from the sun. This means that most solar collectors are mounted on the rooftops of buildings.

Most solar water heaters have thermal storage tanks secured in a position higher than that of the collector itself. This is done so that circulation may take place naturally through thermosiphon. Thermosiphon is a natural phenomenon, whereby higher density cold water displaces less dense hot water, through natural convection. The water circulates through the collector system and the tank, in order to continuously maintain the desired temperature (Joubert et al., 2016).

Solar water heating systems may be subdivided into active and passive solar water heating systems. The active system uses forced circulation to induce a flow of the fluid in the system. This means that the fluid is pumped to achieve the required circulation. Furthermore, active systems may have an open loop (direct heating of residential water supply) or closed loop (indirect heating of the water, by means of a heat transfer fluid) (Jamar et al., 2016). The passive system uses a natural method for inducing circulation through the thermosiphon phenomena. An integrated collector storage (ICS) system is an example of the passive system, where natural circulation takes place.

Four variations of collectors are currently available in solar water heating technologies. The Flat plate collector, as seen in Fig. 5, evacuated tube collector, as seen in Fig. 6 and concentrated solar collectors (parabolic collectors) as seen in Figs. 7 and 8. The integrated storage collector system is a solar collector (flat plate type), coupled with a thermal storage tank. The ICS system is not discussed, due to the low frequency of usage by consumers.

3.3.1. *Flat plate solar collector (FPC)*

Referring to Fig. 5, solar radiation penetrates the collector through the glazed cover. The heat absorbers receive thermal energy and transfer the heat radiation to the liquid substance flowing through it. This increases the temperature of the substance, reaching temperatures up to 80 °C. The heated liquid is transported to fluid tubes (usually fitted with heat fins to increase the surface area for maximum absorption), where it flows to storage. This collector type may heat water up to 80 °C. Fig. 5 demonstrates how the cold water flows from the storage tank to the collector where it is heated and through thermosiphon action, flows back to the tank. This process repeats itself to maintain a high temperature of the water in the storage tank (Hohne et al., 2018b).

3.3.2. *Evacuated tube collector (ETC)*

The top layer of the evacuated tube collector, the first transfer layer, consists of a glass tube casing, designed to protect the heat absorbing components within the collector. Heat radiation passes through the top layer of the evacuated tube and is absorbed by a cylindrical collector pipe (fluid tube). The cylindrical collector is covered in a black coating, for maximum heat absorption. A transfer fluid within the tube, absorbs the thermal radiation, which rises to the heat exchanger head. The heat exchanger heads terminate within an insulated manifold. Water flows past the heat exchanger heads in the manifold of the collector and gains thermal energy. The temperature of the water may easily reach 100 °C, in favourable weather conditions (Roberts, 2013). Through this action, the transfer fluid is cooled down and returns back to the bottom part, to be heated once more, as illustrated in Fig. 6. The water travels from the manifold to the storage tank through pipes, due to natural convection. The transfer fluid within the evacuated tubes have anti-freezing properties, making it an excellent solar water heater for countries that frequently experience freezing temperatures (Kamel, 2002).

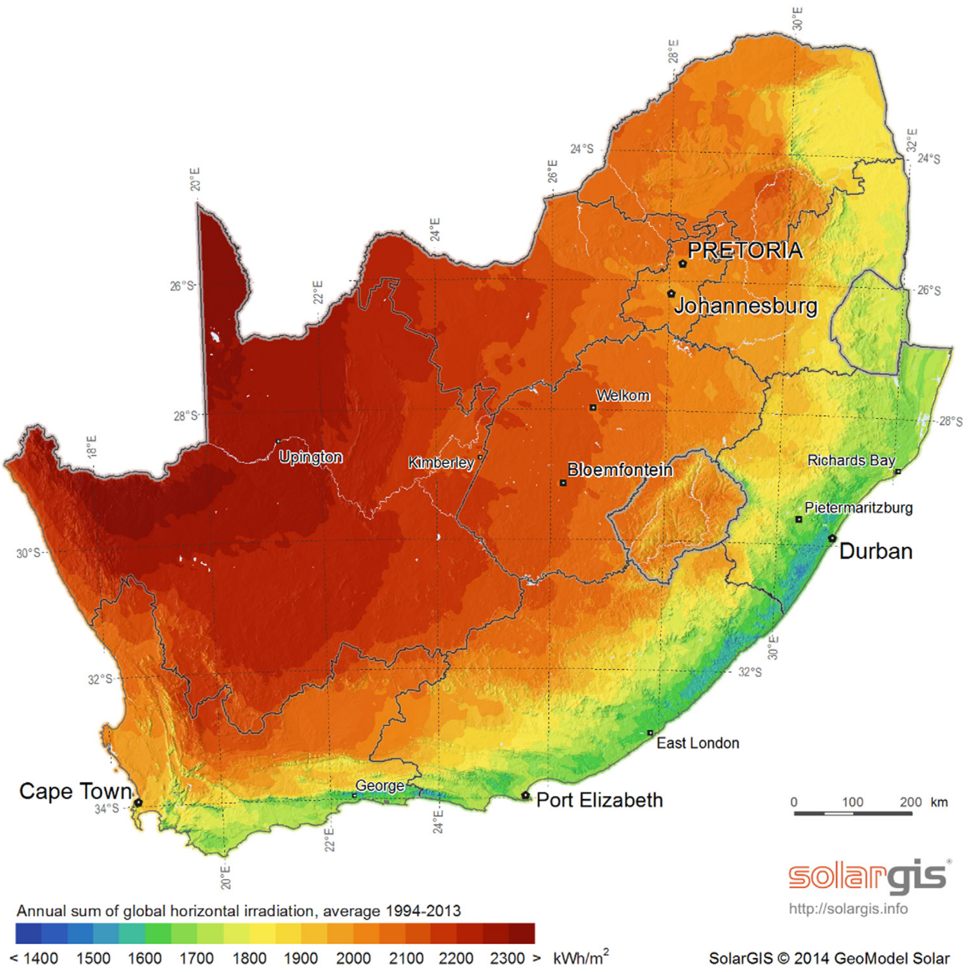

Fig. 4. Annual solar irradiation in South Africa (cres.sun.ac.za, 2017).

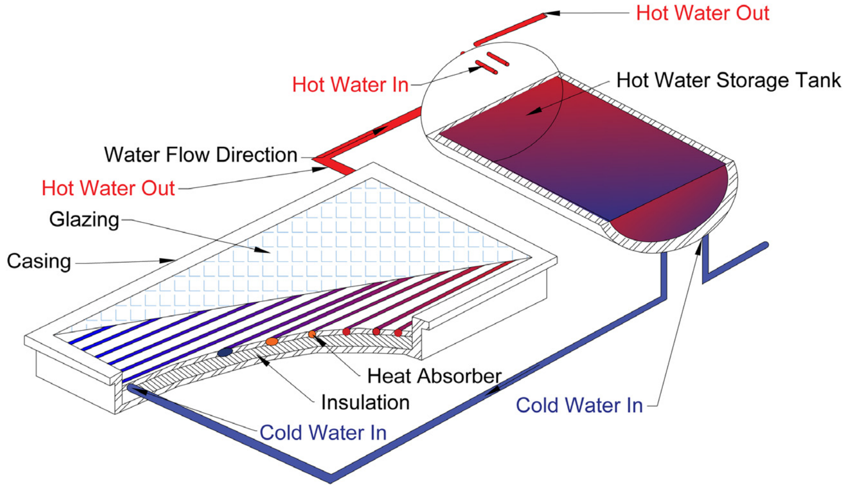

Fig. 5. Flat plate collector (FPC).

3.3.3. *Parabolic dish collector (PDC)*

The parabolic dish collector (PDC) in Fig. 7, uses concentrated solar energy to heat a water heating receiver at the focal point of the dish. The collector dish tracks the movement of the sun on both axes, in order to maximize the absorption of solar energy throughout the day. The tracking system requires electrical energy to operate the solar tracking mechanism. The receiver absorbs the focused solar energy and transfers it to the circulating fluid within. The circulating fluid may be a refrigerant or water. The water flows to the storage tank for recirculation. Several experimental studies report that this collector may heat water to temperatures of up to 60 °C, in a domestic setting (Ayompe and Duffy, 2013; Sagade and Shinde, 2012).

This type of collector may either generate electricity through thermal generator action, or directly heat a circulating fluid (Aweda et al., 2016). The parabolic dish collector is less common in the

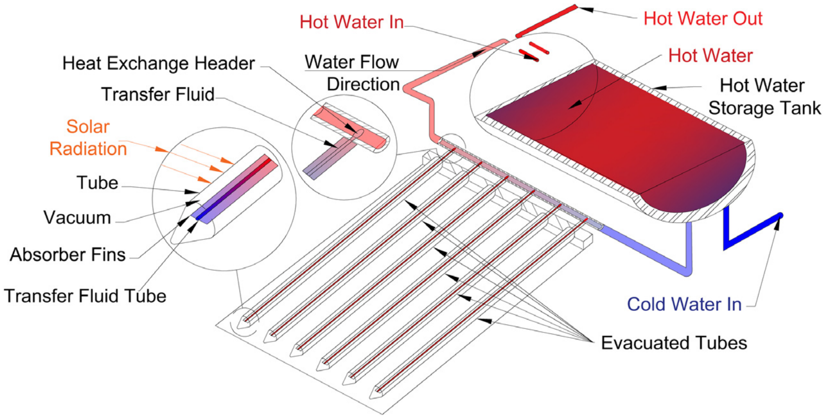

Fig. 6. Evacuated tube collector (ETC).

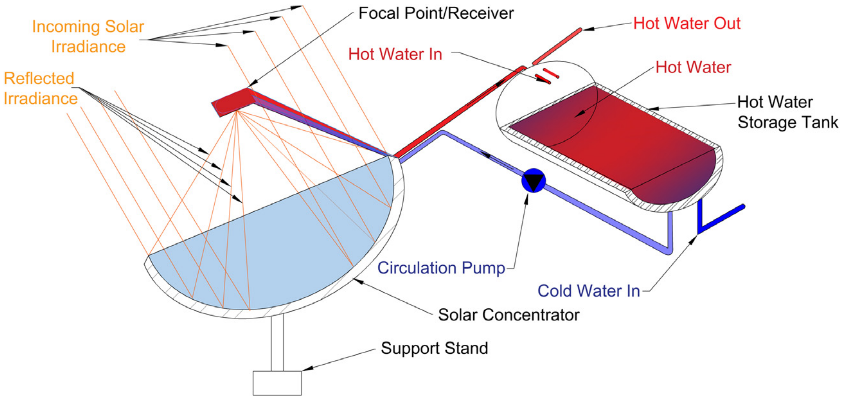

Fig. 7. Parabolic dish collector (PDC).

South African case, due to the complexity of the solar tracking system. However, the efficiency of the system has increased in recent years and looks to be a competitive alternative for some regions.

3.3.4. Parabolic trough collector (PTC)

The parabolic trough collector (PTC) works on the same principle as the PDC. This system however has single axis solar tracking, where the solar tracking solely takes place on the horizontal axis. This system has a focal line, rather than a receiving point. The concentrator consists of a semicircular reflective metal, which focuses solar energy onto the focal line. A tube is fitted inside the focal line with the water or transfer fluid, the fluid is heated with the absorbance of the reflected solar irradiance. The tube is encased in glass with a black coating (Mohammed, 2012).

Circulation takes place with the assistance of a circulating pump. Temperatures of up to 60 °C may be reached for the domestic type collector. However, significantly higher temperatures have been reported that with larger commercial systems (Eickhoff).

It is usually recommended to place the collector facing north so that maximum absorption can take place in winter. Fig. 8. presents the system setup and operation of the parabolic trough collector (Khare et al., 2014).

3.4. Hybrid solar/electric storage tank water heater (HSWH)

Standalone solar water heaters may at times prove insufficient in heating water. Solar radiation is solely available during the day and poses a significant challenge in meeting the hot water demand. When hot water is required throughout the day and night, the SWH discussed in Section 2.3 may be fitted to an existing ESTWH (described in Section 2.1), so that water can be heated when the solar radiation is inadequate.

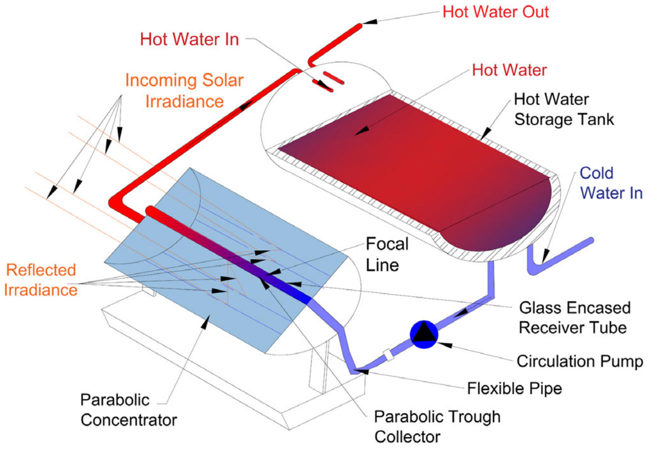

Fig. 8. Parabolic trough collector (PTC).

Referring to Fig. 9, the electric element within the storage tank increases the temperature of the water when the thermal level of the water falls below the desired value (Bari, 2001). This hybrid system incorporates a circulation pump, due to most existing electric storage tanks being fitted beneath the roof of a residential building. The solar collector is fitted at an optimal absorption angle on the rooftop of the building. When the storage tank is lower than

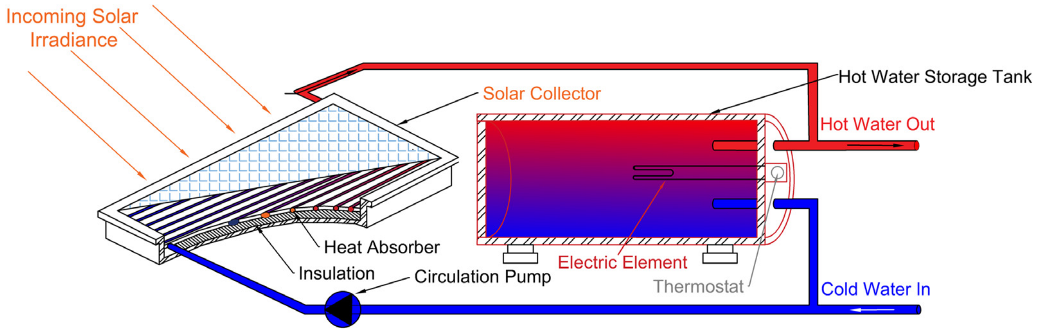

Fig. 9. Hybrid solar/electric water heating system (HSWH).

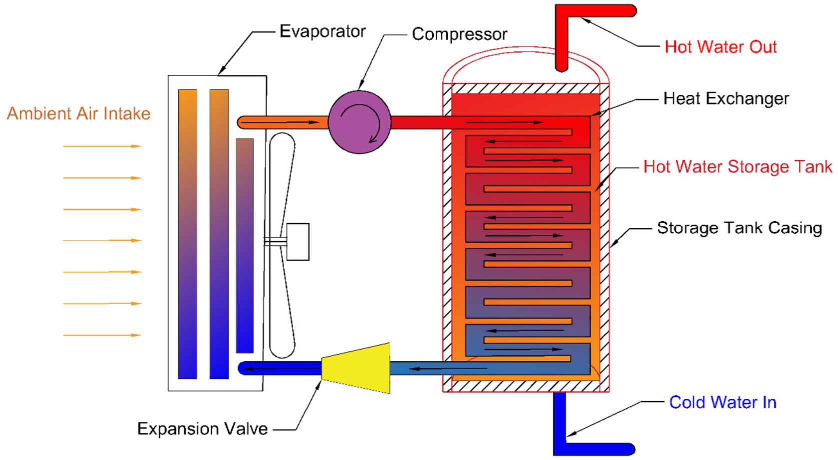

Fig. 10. Heat pump water heater (HPWH).

the collector, natural convection (thermosiphon) cannot take place to circulate the fluid, hence the circulation pump is required to assist in circulation.

3.5. Heat pump water heater (HPWH)

The heat pump water heater extracts ambient energy from the surrounding air in order to heat water. This method of water heating is more efficient than any other electrical source water heater. Other electricity based water heaters convert electrical energy into thermal energy, where the heat pump water heater solely transfers the thermal energy from one place to another.

A heat pump has low energy consumption. Approximately two thirds less than resistive element water heaters, due to the coefficient of performance (COP). The COP describes the ratio of useful heating (or cooling) provided to the work required. If work was to be converted to heat, the COP would be equal to one, assuming 100% efficiency. Rather, the heat pump water heater transfers additional heat from external sources, to increase operating efficiency. Typical COP values are in the range of 2 to 4, for domestic applications (Kakaza and Folly, 2015).

The temperatures in which these heat pump water heaters may achieve in water heating, depends on the ambient air temperature. Hence, the maximum temperatures these systems may reach usually range from 45 to 50 °C, with favourable ambient air temperatures (Liu et al., 2017b).

The major parts of the heat pump water heater are the compressor, evaporator, expansion valve and the condenser. The refrigerant is contained within a closed loop, where it absorbs thermal energy from ambient air. The same refrigerant is compressed in order to exchange heat with water, as illustrated in Fig. 10, condensed while the heat is exchanged and then expanded, in order to return back to the evaporator for reabsorption of ambient energy. The component that consumes the most energy is the compressor, while this is a small amount when compared to the electrical energy used by conventional electric water heaters (Hepbasli and Kalinci, 2009).

3.6. Gas-fired tankless water heater (GFTWH)

This water heater instantaneously heats water when a demand for hot water presents itself. The water heater is switched on by igniting liquefied petroleum gas (LP) supplied to the heater. After ignition, a constant flame is maintained by the regulator control valve. The constant flame produces thermal energy captured by heating fins. These heating fins exchange the energy to the water flowing through conductive pipes, as shown in Fig. 11. Sensors located at the cold water inlet valve and hot water outlet valve send data to the microprocessor, where decisions are made to decrease or increase the gas flowing to the burner (Bourke et al., 2014). The gas supplied will be increased within operating limits, if the temperature at the hot water outlet side is below the desired temperature set by the user. Similarly, the gas will be decreased if the water temperature exceeds the desired temperature. The water flow rate may be adjusted to suit the users needs, but an increase in flow rate will require an increase in gas supplied to the burner. This heater offers the same advantages as the electric tankless water heater, the sole difference being the source of energy supplied (Boros et al., 2015).

3.7. Oil-fired water heater (OFWH)

Similar to the gas fired water heater, the oil-fired water heater ignites oil/diesel in order to initiate combustion. Oil is forced under

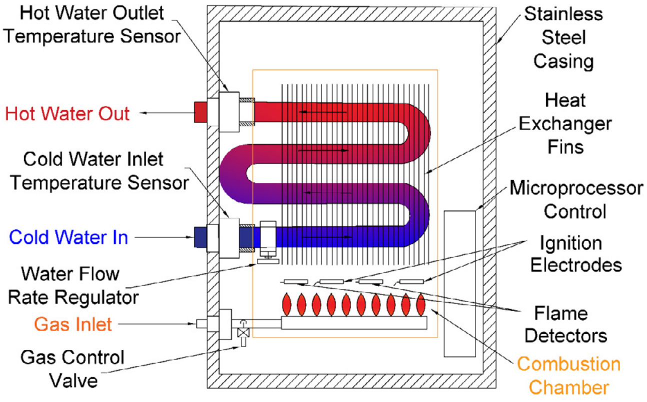

Fig. 11. Gas-fired tankless water heater (GFTWH).

pressure through a nozzle to the combustion chamber, so that a fine spray, or atomization, may take place.

The major component of this system consists of a converter and a motorized fan. The motorized fan is attached to the converter system which contains an ignition transformer. The transformer creates a spark to ignite the atomized oil, while air is supplied by the fan system at the end of a blast tube or combustion chamber. The air and oil mixture are carefully regulated in order to heat the water to a specified level.

Fig. 12 shows the layout of this system, with emphases on the varying temperature of the water circulating in the system. Heat from the combustion chamber travels to the heat capturing fins. Cold water is supplied to the oil-fired water heating system and the heating fins transfer thermal energy to the water. The heated water is subsequently fed to the storage tank and ready for use by the hot water consumer (Batey, 2003).

3.8. Biomass water heater (BWH)

Biomass consists of any material of organic origin. Burning organic material may release energy used in water heating applications. The organic material is usually processed from wood sources and formed into equally sized pellets. These pellets are carbon neutral as a renewable energy source, meaning that the amount of CO_2 released while burning the pellets are equal to the amount that was absorbed during the growth or development of the tree/plant, from which the organic material was extracted.

In Fig. 13, the biomass is supplied to a furnace through a pellet feeder system, the pellets are thereafter burned in the furnace, which is surrounded by the water that should be heated. Therefore, the area adjacent to the furnace acts as a heat exchanger, which heats water directly. The heated water travels to the storage tank to be consumed by the hot water user. Large amounts of pellets may be stored and fed into the furnace to ensure that heat is continuously transferred to the water that should be heated.

In a few instances, particularly in Southern Africa, these systems lack a biomass feeder system, whereby wooden logs are fed manually into the furnace. In some areas of South Africa, specifically where extreme poverty is experienced, just a large pot of water is placed over a cheap makeshift wood fire stove to heat water for hygienic purposes (Verma et al., 2009).

3.9. Hybrid gas-fired heat pump water heater (GFHPWH)

This setup uses a conventional heat pump water heater, described in Section 3.5 and gas fired water heater (Section 3.6), that acts as a gas booster system. This hybrid system offers increased reliability, due to the ability of the two systems to operate independently if one system should fail.

Refrigerant is heated by the heat pump through the process, described in section 2.4. The heat from the refrigerant cycle is exchanged with a secondary closed loop heat exchanger system (Waddicor et al., 2016), as shown in Fig. 14. The transfer fluid inside the secondary closed loop system has its thermal level increased further, by means of the gas fired water heater (Park et al., 2014). The secondary exchanger loop has a higher thermal level due to this process and heat is once more exchanged with water that will be used by the consumer. In the case of colder climates, when thermal energy in the ambient air is insufficient to heat water to desired temperature levels, the gas-fired water heater may then increase the temperature independently.

Standby losses and inadequate ambient energy will increase gas consumption, which in turn will increase the operating costs in colder climates (Li, 2018).

3.10. Geothermal water heating systems

Geothermal water heating systems may be divided into two types of systems: geothermal hot spring water extraction and geothermal (ground-source) energy extraction.

3.10.1. Geothermal hot spring water extraction

Geothermal energy heats groundwater, which then emerges from the crust of the Earth. The heated water at Earth's surface level forms a hot spring. The geothermally heated water occurs naturally and hot spring locations can be found in many locations across the world. Some locations have hot springs where the water temperature is adequate for bathing. Only hot springs with water temperatures not exceeding safe bathing limits may be used as a hot water source. Similarly, most hot springs have unacceptably low thermal levels also not suitable for bathing purposes. When a hot spring with a suitable thermal level is found, the hot water from the spring can be pumped to households, as long as these areas are in the vicinity of the hot spring. The close proximity will minimize heat losses. The water should be treated or filtered to avoid bacterial infection. The hot spring water may be used for hygienic purposes. Referring to Fig. 15, eight thermal springs in South Africa have thermal levels deemed appropriate for household use (exceeding 50 °C) (Tshibalo et al., 2015).

3.10.2. Geothermal heat pump water heater (GHPWH)

Geothermal heat pumps extract thermal energy beneath ground level. High thermal levels beneath the ground may be attributed to solar radiation absorbed by the surface of the earth, while at night, temperatures drop and thermal inertia increases with depth. Hence, the rapid change in temperature experienced on earth's surface level is reduced, compared to lower levels beneath ground level, where temperatures approach constant values.

A conventional heat pump system is used, but in this arrangement, heat is extracted from the ground. This type of heat pump, otherwise known as a ground-source heat pump water heater, has increased complexity and initial implementation costs, compared to the conventional heat pump water heaters. The system consists of a primary and secondary heat exchanger system. The primary heat exchanger has a transfer fluid flowing within and the second has a refrigerant. Part of the primary heat exchanger is buried underground (Han and Yu, 2016). The depth at which it may be buried is at approx. 10 m below the earth's surface. Fig. 16 shows that at approximately 10 m below ground level, the temperature ranges between 10 °C and 12 °C. Depending on the heat requirement or space restrictions, the depth level may be increased to suit the user's requirements. The costs incurred are directly proportional to the depth at which heat exchanger systems are buried (Hepbasli

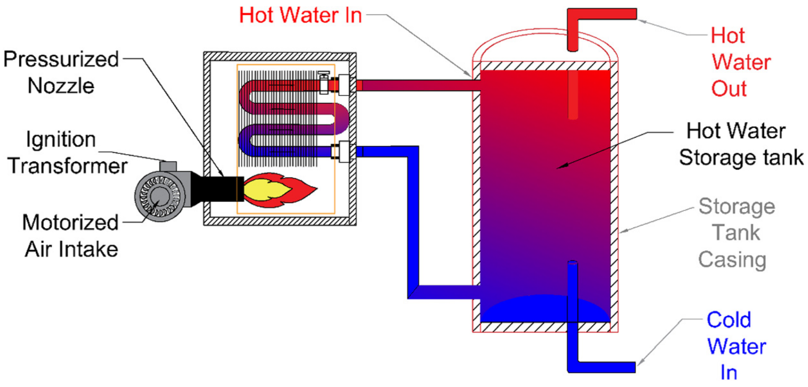

Fig. 12. Oil-fired water heater (OFWH).

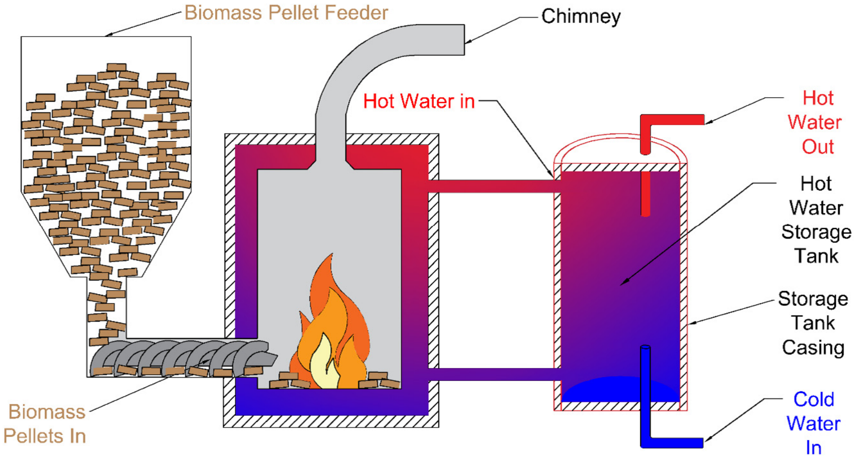

Fig. 13. Biomass water heater (BWH).

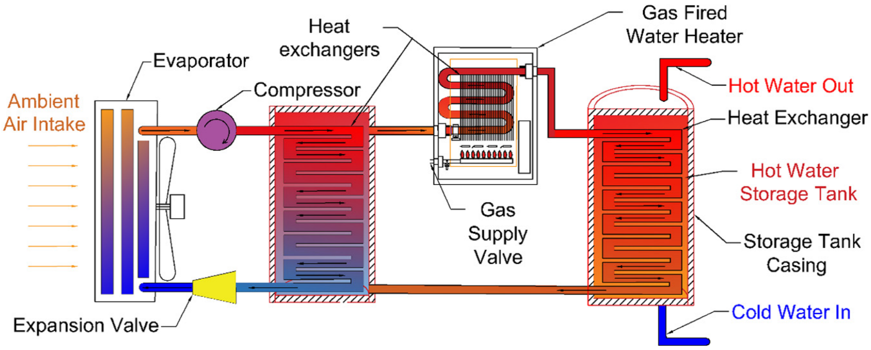

Fig. 14. Schematic diagram of the hybrid gas-fired heat pump water heater (GFHPWH).

et al., 2003). The temperature remains constant throughout the year, even during winter months where the air temperature is known to fluctuate significantly.

After the energy extraction from the earth, heat is exchanged with the secondary heat exchanger, where it is compressed, condensed (process of secondary heat exchange with water) and expanded, in order to begin the cycle again. The result being hot water for consumption by the user as shown in Fig. 17. This system is recommended for winter months. During summer months, the heat pump may be retrofitted for standard operation with the air-source evaporator. The energy in the ambient air is significantly higher in warmer months, as compared to the energy in the ground (Naili and Hazami, 2016).

3.11. Photovoltaic-thermal water heater

The photovoltaic-thermal (PV/T) collector is the combination of a SWH and a PV cell. A PV cell's efficiency is highly dependent on temperature. If the temperature of the cell is too high, the efficiency drops significantly. This efficiency drop may be mitigated by introducing a solar collector (Su et al., 2016). The solar collector acts as a heat sink while it uses the thermal energy gained to heat water.

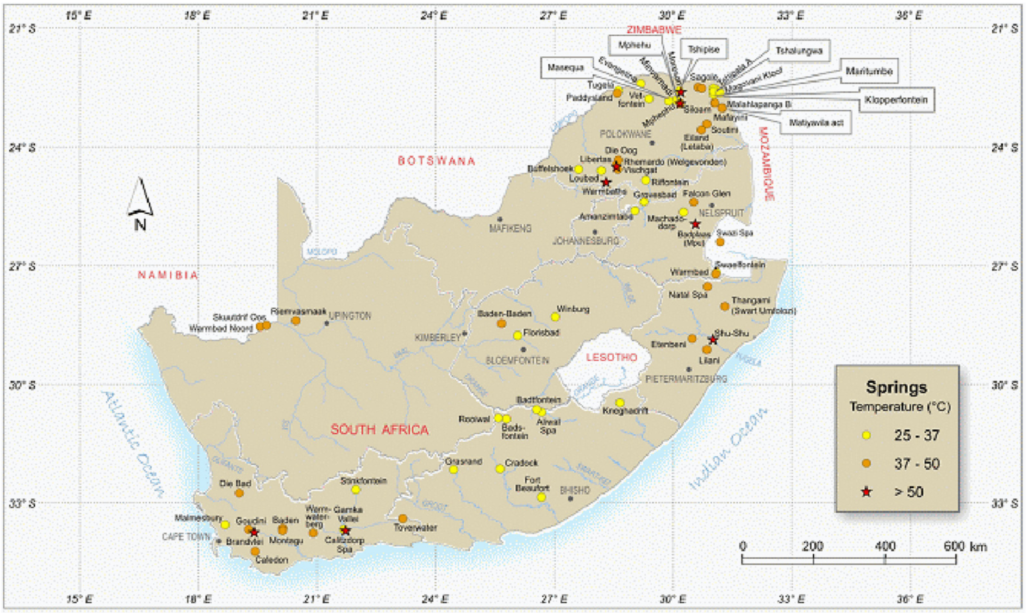

Fig. 15. Distribution of thermal springs in South Africa (Tshibalo et al., 2015).

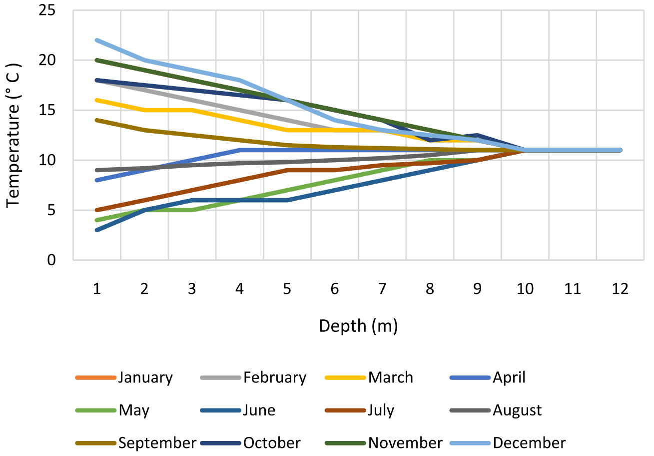

Fig. 16. Ground temperature at each depth level (adjusted approximation for the Southern hemisphere).

Any PV module may easily and affordably be retrofitted to become a water heater.

Referring to Fig. 18, the PV cell is surrounded by water flow ducts protected by a metal casing. The top and bottom layer of the upper collector is made up of glass, so that solar radiation can be transferred to the PV panel (Huang et al., 2001). The lower collector is enclosed and forms part of the collector casing. Small circular channel cut-outs form part of the circulation path and regulates heat distribution.

Cold water is supplied to the collector system and heated, while thermosiphon assists in the circulation of the water through the entire system. This ensures continuous heating of the water, so that the water may be used by the consumer (Chow, 2010).

4. Review of different relevant works on water heating systems

Recent studies suggest several methods for increasing the efficiency of water heating technologies. Furthermore, various hybrid system configurations are compared, in terms of initial costs, payback periods, efficacy, etc. Several authors conducted works based on design, modelling, simulation, experimental analysis, review for standalone heating systems, as well as hybrid configurations, to further decrease parameters such as operation costs, input energy required, size, etc.

Table 2 depicts several papers linked to water heating technologies with their respective source authors, focus, methodology used and key findings. It should be noted that these systems are the most widely used in the Southern region of Africa.

5. Discussion

5.1. Key results/findings

After reviewing the research studies linked to domestic water heating technologies, it is evident that a wide spectrum of hybrid arrangements has emerged. These hybrid systems can consist of two or more water heating technologies. Consequently, higher

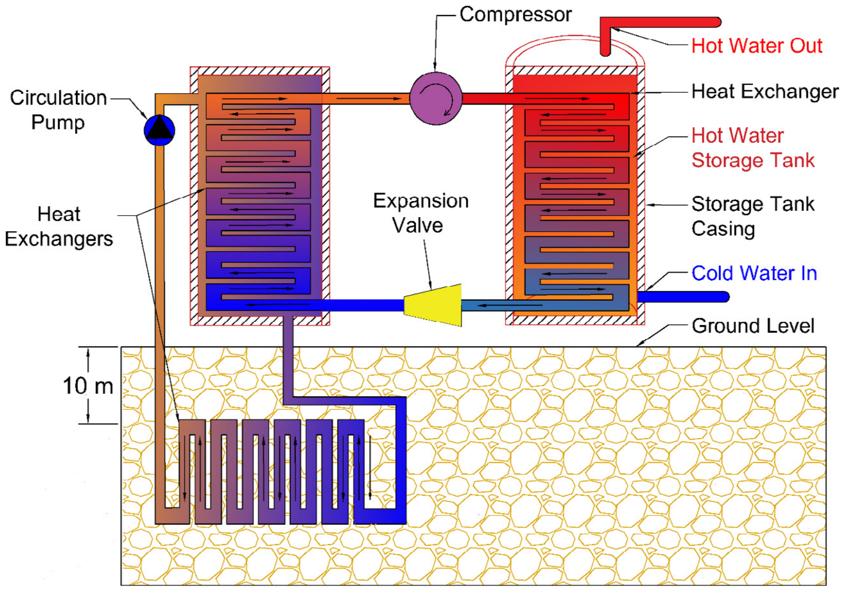

Fig. 17. Ground source heat pump water heater (GHPWH).

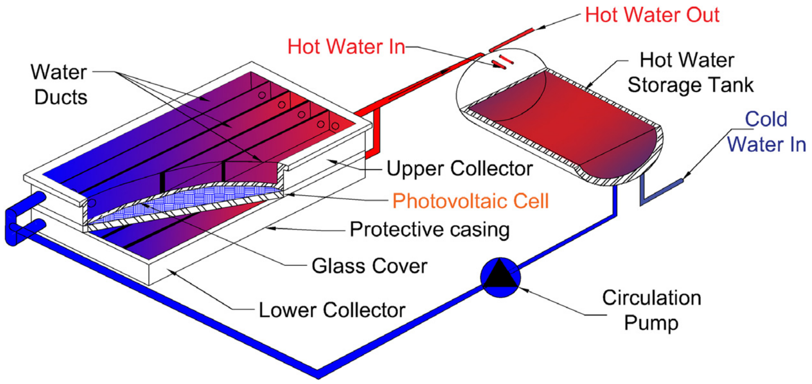

Fig. 18. Photovoltaic-thermal water heater (PV/TWH).

energy and cost savings are observed in domestic households. Table 3 presents some advantages, drawbacks, average installation cost, life expectancy and the discounted payback periods for each point based on the net present value, has been calculated and compared to other research works. To calculate the discounted payback period and the associated net present value, some factors need to be taken into consideration. These factors include the rate at which inflation and energy prices change, the annual savings in energy costs achieved and the total initial investment cost. The average inflation over a 20-year period was denoted as 5.46% for South Africa, obtained from World inflation data (2018). This means that the discount rate can be taken as 5.46%. Similarly, the change in energy prices needs to represented in accordance with future increments. This is achieved by accounting for an annual increase of 10% of each source (Hohne and Kusakana, 2018d). Finally, the discounted payback period can be calculated by using all previously defined variables.

The electric storage tank water heater is used as reference in order to calculate the base energy usage and cost. This information gives an indication on which technologies are most suited for the specific case of South Africa.

In the case of South Africa, the majority of hot water consumers prefer not only a high hot water availability, but a low water heating energy cost. Furthermore, it may be assumed that in most cases, these two preferences share equal priority. A lower water heating energy cost may result in a lower pay back period, increasing the economic feasibility of a system.

Comparisons between the water heating systems, with regards to consumer preferences in Table 3, depicts a clear distinction, with reference to the hybrid solar water heating system. The average payback period of this system is observed to be the shortest, compared to other systems in the study. Additionally, the high life expectancy of this system may offer further savings in cost by delaying and, in turn, reduce the frequency of costly replacements.

However, a major drawback of this hybrid water heater is an increased initial investment cost, due to the relatively high cost of the solar collector. Nevertheless, this cost may be refunded in terms of energy cost savings, further substantiated by the short payback period.

Moreover, for energy cost savings to be increased, several energy efficiency activities may be employed. These activities include: insulating the storage tank and hot water conduits to decrease standby losses, temporizing the electric storage tank water heater in order to avoid power consumption during peak energy usage periods and lowering the thermostat temperature. In retrospect, it may be determined that the hybrid solar water heating system aligns with hot water consumer predilection in South Africa.

Table 2
Highlights of selected studies on different water heating configurations in terms of technology/contribution.

Technology	Highlights/Contribution	Authors
Biomass water heater	• Small-scale biomass combined cooling and heating is gaining interest in science and industry. • Policies can promote combined cooling and heating in areas with high energy costs and low grid stability.	Wegener et al. (2018)
	• Implementation of biomass boilers for heating and domestic hot water was reviewed simulated. • CO_2emissions were reduced by as much as 94%. • The non-renewable primary energy consumption decreased by 93% • Biomass solution was economically viable.	Las-Heras-Casas et al. (2018)
Electric storage tank water heater	• Development and experimental analysis of exergy clearance and stand by time between discharging periods, tested for altering initial volume discharges. • More exergy efficient storage tank designs and strategies of operation can be of result when evaluating correlations.	Atikol and Aldabbagh (2015)
	• Optimized linear model developed under one-way communicated incentives. • Up to 12% savings were observed when compared to normal operation.	Kepplinger et al. (2015)
	• Experimental field testing of autonomous demand side management method of electric storage tank water heaters. • Results show that thermal mixing is improved in the triangular style 2 enclosure.	Kepplinger et al. (2016)
	• Triple reduction of the grid's peak demand when applying control algorithm. • Minimizes pick-up demand during the initial stages of the on cycle of a resistive element whilst ensuring the consumers hot water supply.	Moreau (2011)
	• Cost and energy comparison regarding 3 different domestic water heating technologies. • Gas-fired heat pump water heaters have a payback period of around 4 years when compared to electric storage tank water heater. • Electric heat pump water heaters have a payback period of about 3.6 years.	Keinath and Garimella (2017)
Gas fired heat pump water heater	• Experimental analysis of Coefficient of Performance of a gas-fired heat pump water heater under different water and ambient temperature test conditions. • Performance was successfully predicted whereby the system uses a 227-liter storage tank. • Standby losses response was investigated.	Keinath (2015)
Geothermal heat pump water heater	• Geothermal energy harvesting technologies caused reservations concerning environmental impacts and technical viability. • Decentralized geothermal energy sources are not "ready-made" and need to be modified in order to improve compatibility to the situation.	Bleicher and Gross (2016)
	• Investigation of ground source heat pump water heater field data. • Maximized seasonal Coefficient of Performance of the HPWH is predicted.	Del Col et al. (2015)
	• Experimental thermal response test done on geothermal source. Smart control implementation on hybrid ground/air source heat pump water heater. • Testing confirmed that increased efficiency was obtained with the hybrid heat pump system.	Tinti et al. (2017)
Gas fired tankless water heater	• Modelling and verification of a gas fired water heating system. • Model predictions of energy consumption correlates with field data.	Johnson and Beausoleil-Morrison (2016)
Heat pump water heater	• Model was simulated with summer and winter temperatures in order to evaluate the average efficiency of the setup throughout the year. • Small size HPWH connected in a parallel arrangement can increase energy savings by setting the cut-off temperature below the boiler temperature, whereas larger systems have no advantages applying this method.	Bagarella et al. (2016)
	• Grey system theory used to predict energy consumed by a domestic heat pump water heater. • Investigation shows positive results from using the evaluated theory with high accuracy heat detection.	Zou et al. (2017)
	• Dual source heat pump water heater designed and performance was simulated with different refrigerants. • R744 refrigerant satisfied both energy saving and environmental requirements.	Li et al. (2015b)
	• Development of an air source heat pump water heater in conjunction with a compressor casing thermal storage. • Hot water with a volume of 10 Liters at a temperature of 30 °C was gained at the standard heating time of 2$\frac{1}{2}$ h.	Liu et al. (2017a)
	• Development and validation of a Quasi-steady-state model of a HPWH with an electronic expansion valve, a shortened tube orifice and thin internal diameter tube as expansion devices. • Results indicate that shortened tube orifice was an appropriate fit to the heat pump water heater with the most benefits.	Peng et al. (2016)
	• Optimized control of a heat pump and instantaneous water heaters supplied by integrated energy systems. • Optimized model shows that 7.5 kWh can be sold to the grid, while energy costs can be reduced by 19% daily.	Wanjiru et al. (2017)

(*continued on next page*)

Table 2 (*continued*).

Technology	Highlights/Contribution	Authors
	• Survey of heat pump water heaters in terms of performance and system efficiency. • Increased Coefficient of Performance (COP) of 2.8 to 5.5 can be observed with new technological advances. • The survey identifies and recommends key focus areas for future work in order to boost COP numbers.	Willem et al. (2017)
	• Development and validation of a domestic heat pump water heater model with the performance of off-design components in mind. • Using experimental data from literature, it was deduced that the heat pump performance was competitive in cold weather.	Yang et al. (2016)
Hybrid gas/solar water heater	• Experimental analysis of the performance of in line gas boosters coupled to solar water heating systems. • Condensing gas booster has higher performance when used in conjunction with solar water heaters, however non-condensing gas boosters was found to lag behind.	Bourke and Bansal (2012)
Hybrid Photovoltaic-thermal/heat pump water heater	• Dual source HPWH was analysed with emphasis on one of the sources which was the solar PVT water heater. • Efficient operation was noted.	Qu et al. (2016)
	• Model developed of a heat pump water heater being supplied by thermal and electrical energy from a PVT collector. • Model results shows increased accuracy and adequate confidence.	Tsai (2015)
	• Modelling of HPWH and absorption chiller mainly for air conditioning purposes supplied by PVT collectors and grid input. • Thermo-economic evaluation of a poly-generation system. • With incentive, the system payback period calculated is approx. 8 years.	Calise et al. (2016)
Hybrid solar/electric water heater	• Experimental evaluation on a SWH in conjunction with phase-change energy storage. • Comparison of performance between phase-change energy storage collector and evacuated tube direct heating system. • Phase-change SWH performs less efficiently than the evacuated tube system under exposure for same collector area.	Xue (2016)
Hybrid solar/heat pump water heater	• Investigation of performance of a hybrid solar and air source heat pump water heater. • Results show that higher performance is obtained when the amount incoming solar irradiance is low.	Weishi and Yu (2016)
Oil fired water heater	• Experimental analysis of biomorphic silicon carbide filtering systems to reduce particulate emissions from oil boilers. • Some samples showed high initial filtration efficiency with high permeability.	Orihuela et al. (2017)
	• Evaluation of replacing of bioethanol with oil in oil-fired boilers. • Experimental analysis shows that fuel switching is possible and results in lower pollutants.	Barroso et al. (2010)
Parabolic trough collector	• Survey of mathematical methods, design parameters and simulated models of the parabolic trough collector in several countries. • Results indicates that optical efficiency values are close to 63% and possible maximum optical efficiency can be at 75%	Hafez et al. (2018)
	• Baffled parabolic trough solar collector water heater was designed to improve hot water output. • The percentage increase in outlet temperature is directly proportional to the amount of incoming solar irradiance.	Sathyamurthy and Harris Samuel (2016)
	• A proposed compact parabolic trough collector for heating water in colder areas was tested to verify if a viable solution to shortcomings of conventional solar collectors could be found. • The parabolic trough collector had good operation in cold testing conditions with exceptional anti-freezing properties.	Zou et al. (2016)
Photovoltaic-thermal water heater	• Performance of a photovoltaic thermal water heating system coupled with a phase-change material arrangement experimentally analysed. • Temperature increase was observed with the phase change material in place rather than without.	Browne et al. (2016)
	• An integrated solar collector system combined with a photovoltaic cell was modelled in order to observe the change in PVT power conversion efficiency. • An increased area of the collector has a decreased system efficiency as a result.	Ziapour et al. (2014)
	• Forecast model was developed to predict the uptake of PV's and solar water heaters. • Considerable differences in the efficacy of different policy scenarios to increase the uptake of PV systems and solar water heaters was observed.	Higgins et al. (2014)

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5.2. Impact of alternative energy source water heating systems on the South African energy efficiency program

The idea of using hybrid water heating systems in South Africa has become increasingly popular in recent years. This is mainly due to its ability to shave off significant energy costs and high reliability (Ibrahim et al., 2014).

Rebates and incentives from the government have played a key role in the rise of renewable energy systems implementation in the country. This is not only positive information to for the consumer, but further to the electricity supplier, Eskom.

Eskom mentions that saving 1000 kWh may reduce CO_2 production by 990 tons, which translates into a saving of 60 kilotons of CO_2 released into the air annually (Nel and Booysen, 2016).

Table 2 (*continued*).

Technology	Highlights/Contribution	Authors
Solar water heater	• Refrigerant Parametric Quantification method was developed for optimal thermosiphon operation for SWHs. • CO_2 has a high quality factor when compared to other refrigerants while R-1234yf showed superior characteristics for commercial heating applications.	Abas et al. (2017)
	• Feasibility evaluation of solar water heater systems for low density residential areas with estimated water consumer profiles. • Results show that the payback time is onwards of 8 years and exceeds the life cycle warranty period by 3 years.	Ferrer and Friedrich (2017)
	• Parabolic dish concentrator coupled to an integrated collector storage system was designed in order to increase energy absorbed from solar irradiance. • Results showed higher temperatures obtained.	Benrejeb et al. (2015)
	• Truncated parabolic dish reflectors coupled to an integrated collector storage system was designed in order to increase energy absorbed from solar irradiance that could operate while insulation periods are low at acceptable thermal comfort levels. • Manufacturing costs will decrease with the proposed truncation. • Optimal thermal performance has been found.	Benrejeb et al. (2016a)
	• Effect on optical and thermal performance of full parabolic concentrators was investigated when adding truncation. • Optical and thermal performances remained acceptable for domestic use.	Benrejeb et al. (2016b)
	• Porous solar water heater numerically investigated with focus on heat transfer and fluid flow. • Results show an increased Nusselt number when increasing the radiation parameters.	Bovand et al. (2016)
	• Modelling and optimization in discrete solar water heaters in favour of increased heating efficiency. • Triangular-type 2 enclosure casing has increased internal thermal mixing.	Das and Basak (2016)
	• Experimental testing of a flat plate collector solar water heater with micro heat pipe arrangement packed closely for maximum solar irradiance absorption and surface area maximization. • Tested collector showed excellent thermal operation and heat absorption.	Deng et al. (2015)
	• Review of integrated solar collector storage water heater systems with the use of compound parabolic reflector developments. • Latest designs in the integrated solar collector storage water heaters shows good operating possibilities with the added benefit reliability for longer periods of time.	Devanarayanan and Kalidasa Murugavel (2014)
	• Evaluation and review of solar energy supplied water heaters and market their market potential. • Review indicates that solar water heaters have gained popularity across the world with a high market potential.	Gong and Sumathy (2016)
	• Heat and flow transfer performance of SWH with elliptical collector arrangement were numerically investigated. • Results show that velocity measurements were not equal, while temperature distributions of the tube segments remained similar.	Li et al. (2015a)
	• Thermal performance investigated experimentally of nanofluid (CuO/H_2O) prepared from $Cu(CH_3\ COO)_2$ on passive based indirect flat plate SWH. • Increased efficiency was noted with an increased laminar flow to turbulent flow, performance was increased when using nanofluid in thermosiphon circulation test condition.	Michael and Iniyan (2015)
	• Examination of the heat capture rate of a diffuse flat reflector fixed to the back of an evacuated tube collector system. • Overall increase of 85.53% of annual energy savings was noted.	Milani and Abbas (2016)
	• Evaluation of performance of a SWH with multiple inlet locations under discharge. • Results indicates that hot water availability has been maintained for longer periods of time.	Murali and Mayilsamy (2016)
	• Experimental analysis comparing Nusselt numbers of V-trough SWH with helix shaped tape, square cut helix tape, V-cut helix tape in identical operational conditions. • Comparisons show that V-cut helix has a Nusselt number of 9.13% higher than helix, and V-cut has a Nusselt number of 3.08% higher than square cut.	Saravanan et al. (2016)
	• Review of several solar collector systems with phase change materials and heat retaining properties. • Heat loss reduction strategies for colder periods, thermal performance and respective design characteristics were reviewed.	Singh et al. (2016)
	• Flat plate passive circulation solar collectors with and without solar selective absorbers were tested in order to obtain data about ability to withstand freezing temperatures. • Non-solar selective absorber type collectors may suffer from damage due to temperatures below 0 °C, while solar selective absorbers have a reduced chance of damage due to freezing temperatures.	Tang et al. (2010)

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However, with the increasing population, the demand will soon exceed the generating capacity. Eskom has had some challenges in the past with meeting electrical demand. Innovative ways of saving energy is needed more than ever to save the electrical grid from

Table 2 (*continued*).

Technology	Highlights/Contribution	Authors
	• Experimental investigation on evacuated tube solar collector with direct heating in order to measure reverse flow and heat loss during night time. • Increased reverse flow was observed at night time, reverse flow caused mainly by collector tilt angle rather than atmospheric disturbances. Low heat losses during the night was observed.	Tang and Yang (2014)
	• Experimental analysis on drained water heat recovery on FPC and ETSC setups. • Flat plate solar collector produces approx. half the energy that an evacuated tube solar collector with the same area produced annually.	Tanha et al. (2015)
	• Indirectly heated, natural flow solar water heating setup with a cylindrical tube ring arrangement as heat exchanger was designed and analysed. • The new design had improved performance when compared to helical coil as heat exchanger setups.	Tse and Chow (2015)
	• A larger application based evacuated tube solar air heater in conjunction with a compact compound parabolic reflector with a concentric heat exchanger was developed to provide high temperature air flow for water heating purposes. • Thermal efficiency was noted to be 52% with an air temperature of 70 °C and 35% at a temperature of 150 °C. Efficiencies decline with higher air temperatures.	Wang et al. (2015)
	• Exergy usage and loss management and minimization for cost saving purposes for solar water heater. • High amounts of exergy losses occur in the storage tank, careful consideration in the design of the tank should be taken in order to improve exergy efficiency.	Xiaowu and Ben (2005)
	• Development of an optimal design method regarding tank volume and collector area of a SWH system. • The storage tank size is highly dependent on the collector area, while the collector area optimization is not affected significantly by the tank size.	Yan et al. (2015)
Solar water heater and heat pump water heater	• Review of most commonly used water heating setups. • Solar water heating systems and heat pump water heaters was observed to be most economically feasible.	Ibrahim et al. (2014)

total shutdown. Furthermore, price hikes approved by NERSA have recently dampened the mood of many South Africans.

Statistics show that approximately 54% of South Africa's population lives under the poverty line, making it challenging to withstand the price hikes that the electricity supplier has recently announced (statssa.gov.za, 2017). In addition, a large number of South Africans live with HIV, making it easier for opportunistic diseases i.e. legionnaires disease to be contracted. Legionnaire's disease is caused by legionella pneumophila bacteria commonly located in water. In order to eliminate this bacterium, the water should be heated to at least 60 °C once per day, according to the World Health Organization (WHO) (Celia et al., 2015; Strickhouser, 2007). The South African population should be educated in the importance of hygiene and saving energy, not only to save money, but more importantly, to secure a future with a pollution free environment.

6. Conclusion

Conventional water heaters may consume as much as half of the total energy used by a regular household. This high consumption of energy is mainly due to inefficient outdated electric storage tank water heating technologies, combined with a lack of energy efficient activities. Research and development on new, more energy efficient water heating technologies has been done surrounding most aspects associated with energy management and design. Furthermore, heat loss reduction and optimization studies have further brought significant changes to energy consumption and load management of these water heating systems.

This paper presented a survey of improvements and research done on various water heating technologies. These technologies include electric water heaters, solar water heaters (passive and active systems), heat pump water heater, geothermal water heaters, photo-voltaic/thermal water heater, gas-fired tankless water heater, biomass water heater and the oil-fired water heater.

An increased reliability and the potential to lower energy costs was observed for hybrid systems, if these systems are combined in such a way that they could function independently. The feasibility, cost effectiveness, life expectancy and payback period of each technology was discussed. Drawbacks and benefits have been outlined, for clear comparison between the various technologies, with the solar collector water heater, coupled with an electric storage tank appearing to be the most viable. This viability is based on hot water availability and energy cost saving being of highest concern to consumers. Additionally, the system presents the lowest payback period, compared to water heating systems with high hot water availability. The low payback period originates from energy costs being avoided, or reduced, with the use of the hybrid renewable energy (solar irradiance) system. The amount of solar radiation the country receives makes it an ideal water heater system for all provinces. Provinces where temperatures are likely to reach freezing point, should use an evacuated tube collector system to avoid damage to the collector (anti-freezing properties). Low income households may benefit from Eskom rebates to implement these systems. The ESTWH part may assist in the prevention of infection by heating water to 60 °C daily.

Consumers should be able to implement a system that suits their geographical and hot water requirements, with the suitable financial support from the governing body, in order to reduce the use and dependency on fossil fuels. Energy efficient systems, with applicable knowledge of the advantages these systems, may offer a decrease in the severity of the energy crisis that South Africa is facing. This will, in turn, allow South Africans to improve their financial condition. The authors of this paper have strong confidence that the work presented would be of benefit for consumers, engineers and researchers in the related field.

Acknowledgment

The Authors would like to thank the Central University of Technology for financial support.

Table 3
Techno-economic comparison of water heating systems in South Africa.

Technology	Specific comments applicable to the South African case	Approximate initial investment per thermal kW (USD)	Average life expectancy (years)	Payback period (years)
Electric storage tank water heater	• Hot water always available • Large input energy required. • High standby losses due to tank	60–90	10	Reference
Electric tankless water heater.	• Hot water always available • Compact • No standby losses	184–199	5–8	5–7
Solar water heater	• Hot water available only during the day • Consumes renewable energy (at no cost) • Increased standby losses during night time	165–273	8–20	3–6
Heat-pump water heater	• Hot water availability limited to warmer seasons. • Consumes less electrical energy compared to ESTWH and ETWH • Standby losses due to tank	180–282	5–8	5–7
Gas fired tankless water heater	• Hot water always available • Consumes significant amount of non-renewable energy • Compact • No standby losses	63–88	6–8	5–6
Oil fired water heater	• Hot water always available • Consumes significant amount of non-renewable energy • Relatively compact • Standby losses due to tank	500–2000	10–15	6–14
Biomass water heater	• Hot water always available • Bulky • Requires frequent maintenance (cleaning)	1350–2300	10–12	9–15
Geothermal water heating (springs)	• Hot water always available • Limited hot spring locations • Uses small amount of electrical energy (pump) • Heat losses through lengthy pipes	N/A (Method of hot water transport cost may vary)	N/A (Depends on pumping system)	N/A
Hybrid Photovoltaic/Thermal (PVT) water heater	• Hot water only available during the day • Only small amounts of water can be heated per cell. • Low retro fitment cost • Increases efficiency of the cell • Standby losses during night	80–102 (180W panel and copper piping)	10–15	7–8
Hybrid heat pump gas fired water heater	• Hot water always available • Large combined input energy required. • Offers higher efficient compared to ESTWH • Standby losses due to tank	243–370	5–8	6–8
Hybrid solar electric water heater	• Hot water always available • Offers higher efficient compared to ESTWH • Uses renewable energy as its primary energy source • Standby losses due to tank	226–363	10	4–6
Hybrid geothermal heat pump water heater	• Hot water always available • Offers higher efficiency compared to standalone HPWH • Bulky • Standby losses due to tank	180–282 (with an additional $480 for underground heat exchanging conduits)	5–8	6–8

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