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Energy perceptions in South Africa: An analysis of behaviour and understanding of electric water heaters

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ABSTRACT

Using data from an online national survey conducted in South Africa, this paper aims to investigate: the awareness of energy savings measures for electric water heaters (EWHs); whether or not consumers are implementing suggested measures; and if consumers understand and effectively control their EWHs' energy usage. Additionally, the data is used to determine the success of educational and rebate programmes aimed at reducing residential energy usage and to determine possible motivations for encouraging users to reduce or alter their EWH energy and warm water consumption. The results of this questionnaire indicate that: convenience is a key factor in consumers' willingness to implement curtailment actions; users don't understand the energy consumption of their EWHs; and they don't know how to control their EWHs efficiently.

Introduction

South Africa is currently in the midst of an energy crisis as the national utility, Eskom, is unable to meet the nation's energy demands. However, this is not the first time the country has faced an electricity shortage. The start of 2008 saw the implementation of rolling blackouts (i.e. load shedding) across the country, which have subsequently returned. These blackouts typically last 2 to 4 h and are implemented at different times according to the pressure on the grid and the area in which they occur. Additionally, these blackouts can be implemented during business hours, which has a devastating effect on the country's economy, with a predicted cost of R89 billion (US$ 7.2 billion) per month to the private sector due to lost production, revenue and wastage (Mannak, 2015).

Since the beginning of the energy crisis in 2008, the government and Eskom have implemented various programmes to reduce the pressure on the national grid by promoting energy efficiency. The first of these initiatives is the Power Alert system which displays public messages on national television that are used to inform homeowners of the status of the national electrical grid (Eskom, 2015a). Additionally, users may also view forecasts of the national electrical demand for the current day in half hour intervals. These messages are divided into four colour-coded alert states (green, orange, red and black) which indicate the increasing severity of the load on the national grid. Each message also presents suggestions on which appliances to switch off during the present state. For example in the red state (second most severe) users are instructed to switch off lights in all unoccupied rooms as well as their electric water heaters (EWH), pool pump, air conditioner, dishwasher, tumble dryer and stove.

Additionally, the solar water heater (SWH) rebate programme is a joint effort from the South African Department of Energy (DoE), Eskom and the National Energy Regulator of South Africa (NERSA) and is aimed at promoting the use of alternative energy. Initially, Eskom subsidised the purchase of SWHs to incentivise households to heat water using solar power. The programme aimed to install one million SWHs by 2013 but only between 400,000 and 420,000 installations have been subsidised to date (Moodley, 2015; Pressly, 2015). Although the programme fell short of its ambitious target, it has still been successful in reducing national demand and providing warm water to communities who are not on the grid. However, Eskom has since withdrawn from the programme and it is presently being managed by the DoE, which suspended the programme due to numerous inefficiencies (e.g. poor quality of installations, lack of verification of number of installations). Additionally, the overall penetration of the SWH technology is still severely limited. A recent national household survey consisting of 2518 participants conducted by the DoE indicated that only 1% of surveyed households had a SWH installed (Department of Energy South Africa, 2013), indicating that the number of installations may be significantly lower than the reported estimates.

Interest in smart grids has been demonstrated by the establishment of the South African Smart Grid Initiative (SASGI) under the South African Energy Development Institute (SANEDI). SASGI was created with the purpose of assisting in the development of the South African smart grid and providing inputs and direction for related policies. South African municipalities are already in the process of conducting smart grid related pilot projects (Slabbert, 2015). The City of Johannesburg and its power utility, City Power, are presently implementing a

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smart metering pilot project in certain suburbs which is aimed at reducing the effect of load shedding on its customers (residential, businesses and industry). Requests are sent to consumers, prompting them to reduce their usage to a specified limit, using messages sent via short messaging service (SMS) as well as the smart meter's in house display (IHD) unit. Since the IHD displays their present consumption, customers are able to disconnect appliances (e.g. stove, EWH) until their consumption is below the specified limit. If consumers fail to comply they will experience a 30 s power cut, followed by 30 s of power provision in which to reduce their usage. This process is repeated five times or until the user complies with the request. If consumption is still above the given limit after the fifth iteration, a 30 min power outage is implemented. After this 30 min period has expired the process is repeated until the user complies or load shedding is suspended. A total of 65,000 households were equipped with the smart meters necessary to implement this scheme in April of 2015 and this number is expected to reach 150,000 by October 2015 (Slabbert, 2015).

Eskom has also released educational material, including several brochures, savings tips and videos, relating to energy conservation practices for commercial and residential customers (Eskom, 2015b). Since EWHs are one of most energy-intensive appliances in households, this material includes several means of reducing the energy consumption of EWHs. For example, the EWH fact sheet published by Eskom suggests lowering the set temperature of the EWH, resulting in a reduction in the standing losses. Eskom also produced educational videos that encourage users to switch their EWH off during peak hours (5 pm to 9 pm). Although this may have no net effect on the overall usage of the EWH, it reduces the peak demand on the national grid. Other proposed methods of reducing warm water energy consumption include: insulating the EWH tank and pipes to increase its thermal resistance; and the use of SWHs, which may not reduce users' energy consumption, but can reduce the pressure on the electrical grid as energy is obtained from an alternative source.

Contribution

Using data from an online national survey conducted in South Africa, this paper aims to investigate: the awareness of energy savings measures for EWHs; whether or not consumers are implementing suggested measures; and if consumers understand and effectively control their EWHs' energy usage. Additionally, the data is used to determine the success of the aforementioned programmes in reducing residential EWH energy usage and to determine possible motivations for encouraging users to reduce or alter their EWH energy and warm water consumption.

The rest of this paper is organised as follows: Related work section describes related work in examining household perception on energy usage; Survey description section describes electricity supply in South Africa and the demographics of the survey participants; Results section discusses the results of the survey conducted; and Conclusion section concludes the paper.

Related work

Attari et al. (Attari et al., 2010) conducted an online national survey which included 505 participants in the United States of America (USA). The survey was aimed at investigating the public's perception of energy consumption and savings for several household, recycling and transportation activities. Participants were first asked about the most effective strategy they could implement to conserve energy. The majority of participants responded with curtailment actions (e.g. use appliances less) as opposed to efficiency actions (e.g. using energy efficient light bulbs). This might be attributable to the cost associated with efficiency improvements in comparison to curtailment actions which have no cost (e.g. reducing speed in comparison to purchasing low-rolling resistance tires). Gardner and Stern (Gardner and Stern, 2010) found that efficiency-improving actions tend to save more energy than curtailing the usage of inefficient appliances for realistic alternative scenarios for households in the USA. However, it should be noted that there may be unforeseen consequences as a result of these efficiency improvements. A rebound effect may occur when consumers use efficient appliances more regularly as a result of their efficiency, which can result in a net increase of energy consumption (Hertwich, 2005). Participants were then asked to estimate the energy used by nine appliances (e.g. a laptop) and the energy saved by six household activities (e.g. replacing incandescent bulbs with compact fluorescent lamps). The results of this data indicate that individuals underestimate energy use and savings by a factor of 2.8 on average, suggesting that information on the energy use and potential energy savings may have positive influences on household energy conservation.

Iwata et al. (Iwata et al., 2015) conducted a household residential survey with similar aims to that of Attari et al. but for a Japanese sample group. The survey was conducted in Soka City, a suburb of Tokyo, and included 250 respondents. In contrast to Attari et al., their results show that individuals overestimate the benefits of energy savings actions by US$ 100 per year on average. The difference in the results from these studies suggests that the provision of information about the benefits of energy saving actions may be an effective policy to address global warming issues in one country but not necessarily in all countries. For example, consumers may cease an energy-saving action if they are informed that they are overestimating the financial benefits of the action. However, the results also show that there are disparities amongst individuals and indicate that energy saving initiatives should be targeted at specific individuals as well as specific activities. For example, they found that a 70 year old married woman who lives with several family members underestimated the impact of energy saving actions with a large associated benefit (i.e. more than US$ 45 per year). In comparison, a 20-year-old unmarried man who lives alone overestimates the monetary benefits of all energy saving actions, indicating that individual perceptions may differ significantly from the average.

The DoE of South Africa (Department of Energy South Africa, 2013) conducted an annual national household survey with the purpose of obtaining information about the energy related behaviour in South Africa (2518 participants), including non-electrified households and all end uses of energy (cooking, space heating, etc.). Their survey reports on the public awareness of energy savings measures, such as closing windows and doors when an electric heater is in use. The results indicate an increased average awareness of 10% over the previous year, with a maximum increase in awareness of 19% for boiling only as much water as needed. Additionally, the survey also investigates the number of respondents who are aware of these measures and practice them as part of their lifestyle. Table 1 shows a summary of the energy saving measure awareness and practices relating to EWHs. From these results, it is clear that individuals are more aware of curtailment actions than efficiency actions for their domestic warm water energy usage. Additionally, individuals are also much more likely to practice curtailment actions, such as switching their EWH off intermittently, than efficiency actions, such as insulating their EWH and pipes.

The survey also investigated which policies individuals believed should be prioritised by government (e.g. free energy for low income

Table 1
Awareness and practice of various energy savings measures in South Africa. (Department of Energy South Africa, 2013).

Energy saving measures	Aware (%)	Practice (%)	Aware vs practice (%)
Take short shower or bath with minimal water	47	26	55
Switch off EWH at certain times	56	28	51
Insulate your EWH and pipes	28	6	22
Install SWH instead of EWH	37	4	12

households) by selecting three policies that government should prioritise. The results are as follows: 75% of participants prioritised keeping the price of electricity low; 46% prioritised avoiding of load shedding or power outages; 40% of participants prioritised the provision of information on energy saving measures; and 25% indicated that government should prioritise subsidies relating to renewable energy. Additionally, consumers' preferred sources of electricity were also investigated by the survey. The results show that: 31% of participants don't care about the source as long as electricity is cheap; 24% support the use of wind, solar or water power; 14% preferring any source as long as it is not damaging to environment; 8% support coal and oil; 6% prefer natural gas; only 2% support energy made from crops. These results indicate that the majority of users are very concerned with economic considerations, such as the price of electricity. This is most likely due to the average electricity price increase of 25.5% from 2008 to 2011, to an average of around R0.65/kWh (roughly US$0.05/kWh) in 2011, with variation between municipalities. With this increase, 34 and 38% of households indicated that the price of electricity is “far too high” and “too high”, respectively. However, these results also indicate that significant importance is also placed on environmental concerns, such as the use of renewable energy and the impact of electricity generation on the environment. Further support of renewable energy is indicated by 41 and 37% of participants being “strongly in favour” and “in favour” of government spending money to replace EWHs with SWHs, respectively.

Table 2 provides a summary of several statistics of USA, Japan and South Africa. From these statistics, both USA and Japan are classified as high income countries, while South Africa is a upper middle income country. The gross national income per capita values of USA and Japan are approximately 8 and 7 times that of South Africa, respectively. Additionally, both Japan and USA consume larger amounts of electricity than South Africa. The electric power consumption per capita of USA and Japan are approximately three and two times that of South Africa, respectively. Even though Japan consumes twice as much electricity per capita, the national grid emissions factor for Japan was 552 kg CO_2/MWh in 2012, while that of South Africa was 913 kg CO_2/MWh. This is most likely as a result of South Africa's heavy reliance on coal for satisfying its energy demands.

Survey description

To examine the understanding of EWHs and behaviour of EWH users in South Africa, an online national survey was conducted through a Facebook campaign. South Africa has a population of 54 million people and an electrification rate in the vicinity of 83 to 90% (Department of Energy South Africa, 2013) (varies between national surveys and census). The national power utility, Eskom, is responsible for 95% of electricity supply in South Africa, of which 90% is generated in coal-fired power stations (Department of Energy South Africa, n.d.). It is estimated that there are over 5.4 million EWHs in South Africa and it is the main source of warm water for bathing purposes in 44% of formal urban households (Department of Energy South Africa, 2013). Additionally, the most common appliances used to heat water for bathing purposes in electrified households are: EWHs (31%); electric kettles (23%); and a combination of an electric kettle and stove (7%) (Department of Energy South Africa, 2013). Participation was incentivised through the chance to win an electronic tablet (worth approximately R 2000 or US$ 160) in a lucky draw. The survey had a minimum age restriction of 23 and includes 457 respondents in total. Of these respondents, 83 and 17% are male and female, respectively. Additionally, the age distribution of participants is summarised in Table 3. The complete questionnaire is available http://goo.gl/D2AfJuonline.

Table 2
Annual statistics of USA, Japan and South Africa. (The World Bank, 2014).

Country	CO_2 emissions $\left(\frac{\text{Metric tons}}{\text{capita}}\right)$	Electric power Consumption $\left(\frac{MWh}{capita}\right)$	GNI per capita (US$×1000)
USA	17	12.95	55.2
Japan	9.3	7.75	42.0
South Africa	9.3	4.40	6.8

Results

Motivation and convenience

Several questions in the survey were aimed at determining the motivation that consumers have for reducing their EWHs' energy usage. Additionally, these questions also asked users if they were still willing to switch their EWH off if it would be inconvenient for them (i.e. need to shower or bath at different times). The results of this section are summarised in Table 4. From these results, it is clear that convenience plays a crucial role in the willingness of respondents to participate in demand side management (DSM) programs. For example, 89% of people are willing (i.e. agree or strongly agree) to turn their EWH off during times of non-use for environmental benefits. However, only 47.4% of respondents are willing to switch their EWH off if it is inconvenient for them (i.e. change in usage times is required). This result is expected as consumers are less likely to practice an energy saving action if it has a high behavioural cost with regard to money, effort or convenience (Steg, 2008). Slightly more participants (57.8%) are willing to implement switching if it would mitigate the need for load shedding. Financial incentives seem to have the strongest influence, with approximately 81.9% of participants willing to shift usage to inconvenient times (different times) if they are compensated financially. These results agree with the priority of the concerns investigated by the DoE of South Africa's national household survey. However, the effects of financial incentives typically cease once the incentive is removed (Steg, 2008) and, therefore, may not lead to sustainable behaviour change. Additionally, the incentives must be high as consumers may find the financial benefit of an energy saving action too insignificant to warrant behavioural change (Spence et al., 2014).

It was found that 25.5% of participants think that switching their EWH on and off manually is not easy, which indicates additional participants may be willing to perform this action if it were more convenient. For example, waking up an hour earlier to manually switch an EWH on requires significant effort from consumers. Furthermore, 65.9% of participants switch their EWH on and off on a daily basis and, of these respondents, 55.3% do so manually. Additionally, 71.5% of respondents indicated that they would install a device that allows them to control their EWH remotely if it were affordable. These results indicate that there is significant potential to increase the percentage of consumers that implement this energy saving action by making it more convenient.

Understanding

The temperature of the water inside the EWH tank is a complex function which depends on both the temperature of the air surrounding the tank (which determines the rate of heat dissipation) as well as the

Table 3
Age distribution of participants as percentage of total.

Age (years)	% of Total
18 – 24	5
25 – 34	8
35 – 44	18
45 – 54	24
55 – 64	28
65 – 74	15
75 and over	2

Table 4
Percentage of respondents willing to switch off their EWH and/or defer their hot water usage for various incentive options.

Incentive	Convenience	Strongly agree	Agree	Don't know	Disagree	Strongly disagree
Environmental	Convenient	47.8	41.3	6.1	2.8	2.0
	Inconvenient	16.6	30.8	17.2	29.7	5.7
Load shedding	Convenient	44.8	42.6	4.6	5.7	2.4
	Inconvenient	20.5	37.3	12.9	24.0	5.2
Recognition	Convenient	41.7	35.2	11.6	8.1	3.5
Financial	Inconvenient	45.2	36.7	7.4	7.9	2.8

amount of warm water that is extracted for usage events. The questionnaire therefore contained several questions that were used to ascertain if participants are able to understand how their EWH consumes energy and how the temperature of the water in the tank varies as a result of usage and heat losses. The amount of energy required to heat the water in the EWH tank can be calculated using the following equation:

$$E_{heat} = m_{tank} c \Delta T [\text{kWh}] \quad (1)$$

where: E_{heat} is the energy required to heat the entire contents of the EWH tank; m_{tank} is the mass of warm water contained in the EWH; c is the specific heat capacity of water ($4180 \frac{\text{J}}{\text{kg}\cdot\text{K}}$) (Booysen et al., 2013); and ΔT is the difference in temperature between the cold and warm temperatures. The heating time required to heat the entire contents of the EWH can be calculated using a set temperature of 65 °C and calculating the energy taken for the entire tank to be heated from cold (i.e. 20 °C):

$$E_{heat} = (150)\left(\frac{4180}{3.6 \times 10^{6}}\right)(65-20) = 7.84\text{kWh} \quad (2)$$

where the value of c is modified to obtain the result in kiloWatt hours (kWh). The time taken for a 150 l EWH with a 3 kiloWatt (kW) power rating to heat all the water in the tank is, therefore, approximately 2 h and 37 min. Similar results are obtained if the analysis is repeated for a 200 l EWH with a 4 kW power rating. Additionally, the temperature decay of the water inside the EWH in the absence of usage events can be modelled using the following equation (Booysen et al., 2013):

$$T_{inside}(t) = T_{\infty} - [T_{\infty} - T_{inside}(0)]e^{\frac{-t}{cm_{tank}R}}[^{\circ}\text{C}] \quad (3)$$

where: $T_{inside}(t)$ and $T_{inside}(0)$ are the average temperature of the water inside the tank at time t and at time 0 respectively; R is the lumped thermal resistance of the EWH; and T_{∞} is the ambient temperature of the EWH surroundings. For the purposes of this analysis, we assume a low set temperature of 55 °C and an low ambient temperature of 10 °C in order to calculate the decay for the worst case. The standing losses of an EWH in South Africa must meet a minimum specification as outlined in the South African National Standard (SANS) 151, which stipulates that the maximum tolerable standing losses for a 150 and 200 l EWH at 65 °C over a 24 h period is 2.59 and 3.02 kWh respectively (Anon., 2010). This results in a thermal resistance value of 17.4 $\frac{^{\circ}\text{C}\cdot\text{day}}{\text{kWh}}$. Substituting these values into Eq. (3) and calculating the temperature decay after one day has expired:

$$T_{water}(1) = 10.0 - [10.0 - 55.0]e^{\frac{-1}{3.03}} = 42.4\ ^{\circ}\text{C}. \quad (4)$$

This calculation shows that, even in the worst case, the temperature of the water in the EWH would take more than 24 h to decay to 20 °C in the absence of usage events. A typical shower in South Africa consumes 59.1 l of water in total (Jacobs and Haarhoff, 2004) and the desired temperature (i.e. mixed temperature) of the water at the shower outlet is typically 40.2 °C (Jacobs and Haarhoff, 2004). This analysis indicates that, even after no heating has occurred for 24 h, a 150 l EWH would still be able to provide enough warm water for 2 typical shower events if water for these events was drawn only from the EWH (i.e. no cold water is mixed with warm water from EWH). Similar results are obtained if the analysis is repeated for a 200 l EWH.

The survey examined if participants are able to estimate the length of time taken for an EWH to heat from cold (i.e. 20 °C) to warm (i.e. 65 °C). Misconceptions of the heating and cooling times can cause participants to be less likely to switch their EWH off intermittently. For example, participants will be unlikely to implement a control schedule if they believe that the warm water inside the EWH will be cold within an hour or two and would take several hours to heat the water again for them to use. From Eq. (1), the time taken to heat the entire contents of the entire EWH tank from 20 to 65 °C is approximately 2 h and 35 min for both a 150 and 200 l EWH. However, the time taken to heat enough water for a typical shower depends on the power rating of the EWH element. To heat enough water for a typical shower event, therefore, takes approximately 30 and 20 min for a 150 and 200 l EWH respectively. Therefore, respondents indicating a heating time of between 20 min and 3 h were assumed to be correct. It was found that 82% of respondents were able to correctly estimate the duration taken to heat the water in the EWH tank from cold. Of the respondents who responded correctly, 70% switch their EWH off on a regular basis to reduce electricity costs. Of the respondents who answered incorrectly, 89% switch their EWH off to reduce electricity costs. This indicates that even participants who have experience with switching their EWH may have misconceptions about the heating time. Additionally, 61% of the respondents who answered incorrectly overestimated the time taken by the EWH to heat the water in the tank. This implies that users may be switching their EWH on for too long to heat water and have the potential to further reduce their energy consumption by implementing a more suitable control schedule.

The survey also investigated whether participants are able to estimate the time taken for the water inside the EWH to cool down (i.e. to 20 °C) after heating had occurred (i.e. water at 65 °C) and in the absence of usage events (i.e. heat is only lost through dissipation to environment). From the results of Eq. (4), answers indicating that the cooling would take more than 24 h were accepted as correct. Only 9% of respondents answered this question correctly. Furthermore, 53 and 67% of the respondents who answered correctly and incorrectly, respectively, switch their EWH off on a regular basis. Once again these results indicate that even experienced users can have false perceptions of their EWHs' performance and overestimate the amount of heat lost when their EWH is switched off. These results also indicate that the majority of participants are under the erroneous impression that their EWH cools down mostly as a result of the standing losses when, in fact, energy is consumed much more rapidly by warm water usage events. This can be illustrated by calculating the energy consumed by a typical shower event. For the purposes of the analysis, we can assume that the warm water in the EWH tank is at the nominal warm water temperature setting for EWHs in South Africa (i.e. 65 °C) (Meyer, 2000) and that the inlet temperature is 20 °C. Additionally, we assume a typical shower volume (i.e. 59.1 l) and assume that the temperature of the water at the shower outlet is also typical (i.e. 40.2 °C). This implies that the volume of warm water at 65 °C required to create a typical shower event is 26.53 l. Based on the assumption that the amount of energy used by an event will remain constant for different warm water temperatures (Hirst and Hoskins, 1978) and that water at the inlet temperature is at baseline energy (Booysen et al., 2013):

$$E_{usage} = m_{usage} c \Delta T [\text{kWh}] \quad (5)$$

where: E_{usage} is the total energy used by the event; m_{usage} is the mass of warm water consumed by the event; and ΔT is the difference in temperature between the inlet and set temperatures. Solving Eq. (5):

$$E_{usage} = (26.53)\left(1.1611 \times 10^{-3}\right)(65-20) = 1.39\text{kWh}. \quad (6)$$

Therefore, a typical shower event can be assumed to consume approximately 1.39 kWh of energy. This implies that a typical shower event, which is only several minutes in length, consumes approximately half as much energy as the maximum allowable total standing losses of an EWH with a set temperature of 65 °C for an entire day (i.e. 2.59 and 3.02 kWh for a 150 and 200 l EWH respectively).

Potential savings

When switching the EWH off intermittently, it is possible to reduce the standing losses of the EWH, not the amount of energy consumed by usage events. The energy required by usage events can only be reduced if consumers reduce their consumption through behavioural changes. For example, consumers could take shorter showers or use a lower blended temperature at outlets. An EWH model was used to simulate the energy consumption of an EWH for several typical usage profiles and the results summarised in Table 5. Heating was assumed to occur 2 h before major usage events to determine the maximum amount of savings that can be achieved for each profile. For profiles 3 to 5, the events are assumed to occur within 12 h of one another. For example, profile 3 in Table 5 consists of one shower and one bath occurring once at 06:00 and 18:00, respectively. For profiles 6 and 7, the 2 usage events are assumed to occur simultaneously, while the third usage event is assumed to occur within 12 h of the initial two events. For example, profile 6 consists of two baths and one shower occurring once at 06:00 and 18:00, respectively. From Table 5, a possible reduction of 31% in the standing losses is possible for profile 2, which reduces the total energy consumption (and therefore electricity cost) by approximately 17%. This profile illustrates the consumers with the highest potential for reducing the energy consumption of their EWH. It should be noted that, although profile 8 has the highest percentage reduction in standing losses, it has a lower total energy reduction than profiles 1 and 2. This is because the energy consumed through usage events in profile 8 constitutes a larger portion of the total energy usage than that of profiles 1 and 2 as there are four major usage events as opposed to just one.

An open ended response question was used to examine if participants are able to estimate the potential cost savings (as a percentage of the total electricity cost of the EWH) from switching their EWH off intermittently on a typical day. The results indicate that 41% of respondents believed that savings of greater than 20% can be achieved, indicating that the majority of participants are overestimating the impact of this energy saving action. Additionally, of the respondents who estimated a savings reduction of more than 10% and less than or equal to 20% (13% of total), 44% indicated that they have 4 or more major usage events during a typical day and are, therefore, also overestimating the possible savings. Of the respondents who don't believe that switching their EWH off can reduce its energy usage (7.4% of total), 37% estimated that the electricity savings achievable from switching their EWH off are zero. However, of these respondents, 22% indicated having 3 or fewer major usage events during a typical day, indicating that they are underestimating the potential savings that can be achieved. Additionally, 36% of all participants were unsure of the cost savings that can be achieved. These results indicate that there is still significant potential to educate consumers on how energy is consumed by their EWH and the potential savings that can be achieved.

Table 5
Potential reduction in EWH energy consumption.

	Usage events		Potential savings	
Profile #	# Baths	# Showers	Standing losses [%]	Total energy [%]
1	0	1	26.12	16.11
2	1	0	31.02	16.84
3	1	1	21.71	8.83
4	2	0	24.05	8.98
5	0	2	19.16	8.56
6	2	1	30.96	9.33
7	1	2	28.32	9.15
8	2	2	38.20	9.61

Efficient control

The optimal switching time of an individual EWH is a complex problem which depends on: the frequency and volume of warm usage events; the thermal resistance and size of the EWH tank; the power rating of the EWH element; as well as electricity tariffs (if cost is being considered). The thermostat of an EWH maintains the temperature of the water within a certain temperature range, typically within a few degrees of the chosen set temperature. When the temperature drops below the lower limit, the EWH switches on and heats the water until it reaches the upper limit. However, when an EWH is switched off for a prolonged period of time (i.e. several hours) the temperature of the water in the tank continues to decrease below the lower limit. When the EWH is switched on again, it must reheat the water that has cooled to the set temperature, which is referred to as the cold load pickup (Saker et al., 2011). If the switching times of the EWH are inefficient, energy is consumed to heat the water unnecessarily (i.e. when it is not needed) and the standing losses of the EWH are, therefore, increased. However, if the switching times are coordinated efficiently with warm water usage, the energy usage of the EWH can be reduced significantly (Booysen et al., 2013).

The survey also examined participants' ability to effectively control their EWHs by presenting a usage profile of one shower in the morning at 6:00. Participants were then asked to create a heating schedule for the given profile by specifying the times that the EWH should be switched on and off to ensure that the warm water demands of this profile are met. To ensure that the entire EWH tank's contents are at the set temperature would require approximately 2 and a half hours of heating for both a 150 and 200 l tank. Additionally, the time taken to heat enough water from cold to warm for a single typical shower event is approximately 30 and 20 min for a 150 and 200 l EWH respectively. Therefore, responses that indicate that heating should occur between 20 min and 3 h before the usage event in the given profile were accepted as correct.

It was found that 61% of participants identified a suitable starting time for the heating to occur (i.e. 20 min to 3 h before usage event). The total heating duration for each recommended schedule was also evaluated and the results summarised in Table 6 and Fig. 1. These results show the proposed heating duration (t) in hours for: all the participants (shown as "Total"); the respondents able to identify the starting heating time correctly (shown as "Correct"); and the respondents who incorrectly identified the starting heating time (shown as "Incorrect"). It was found that 62.1% of all participants were able to correctly estimate the heating duration required for the given profile. Of the participants who correctly identified when the EWH should be switched on (i.e. starting heating time), 85.0% were also able to correctly identify the heating duration. Additionally, of participants who incorrectly identified the starting heating time, 34.6% overestimated the total heating duration required, with 26.6% estimating a heating duration of over 6 h. This is approximately 2 to 3 times longer than is actually required to heat the entire EWH tank's contents, indicating that these respondents are incorrectly controlling the time and duration of heating for their

Table 6
Total heating duration (t) of proposed schedules in hours.

	$t \leq 1$	$1<t \leq 2$	$2<t \leq 3$	$3<t \leq 4$	$4<t \leq 5$	$5<t \leq 6$	$t>6$	Don't know
Total	17.7%	31.5%	13.4%	7.5%	2.9%	2.0%	12.2%	12.7%
Correct	24.6%	45.1%	15.3%	9.0%	2.2%	0.7%	3.0%	0.0%
Incorrect	6.9%	10.4%	10.4%	5.2%	4.0%	4.0%	26.6%	32.4%

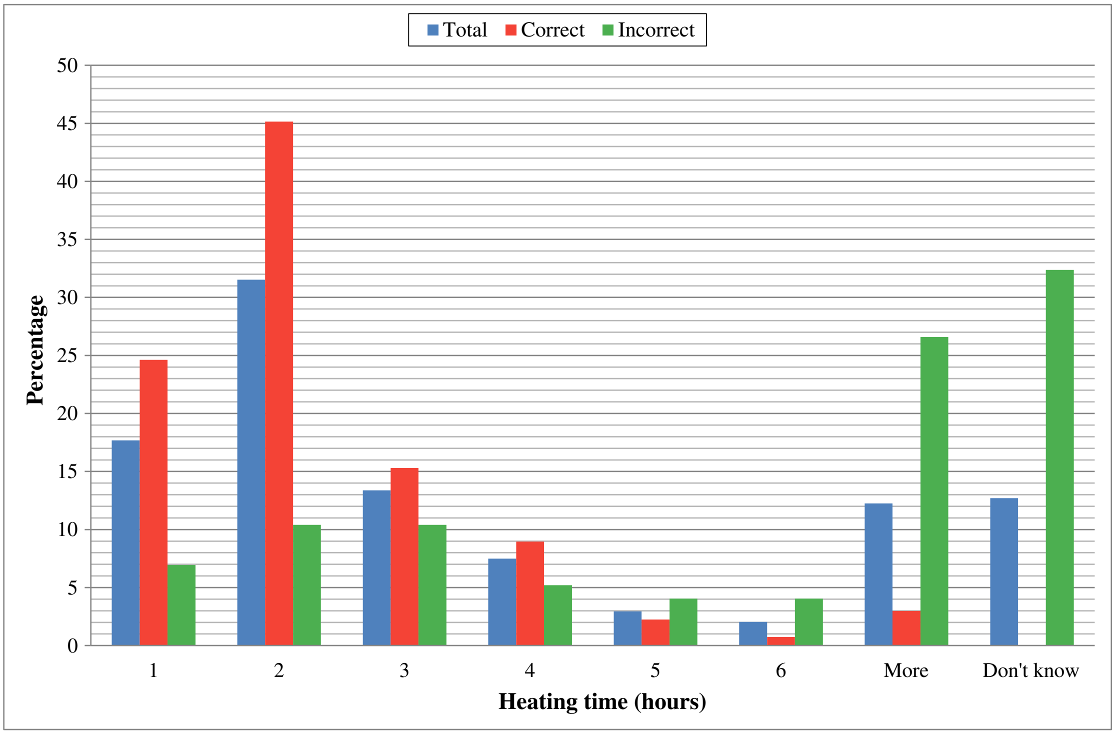

Fig. 1. Histogram showing proposed heating durations and disaggregation of participants who correctly and incorrectly identified the starting heating time for the given usage profile. These results indicate that 85.0% of the respondents that correctly identified the starting heating time (show as "Correct") were also able correctly identify the heating duration required (i.e. between 20 min and 3 h). Of the participants that were unable to identify the correct starting heating time (show as "Incorrect"), 34.6% overestimated the heating duration required and 32.4% indicated that they "Don't know" the correct heating duration.

EWHs and have the potential to greatly reduce their EWH energy consumption. Also, 32.4% of these participants indicated that they "Don't know" the correct starting heating time or heating duration for the given profile.

Awareness and implementation

Respondents were asked a number of questions aimed at determining which energy savings measures they were aware of (i.e. switching and set temperature reduction) as well as which measures were actually being practiced. These questions focused on the methods highlighted by the informational brochures distributed by Eskom, including switching the EWH off intermittently and lowering its set temperature. Several questions in the questionnaire were used to examine participants' habits (e.g. how regularly) pertaining to intermittently switching the EWH off and the results thereof on the energy consumption of the appliance. A summary of the results of these questions are summarised in Fig. 2. The results indicate that 98% of the survey respondents indicated that they are aware of how to switch their EWH on or off manually (i.e. at the switch) and 77% of participants believe that switching their EWH off for certain times during the day can reduce its electricity usage. Although 91% of participants implement switching, only 66% of respondents actually switch their EWH off to reduce electricity on a regular basis while 25% only switch their EWH when away from home for several days. Of the respondents who switch their EWH off intermittently on a regular basis, 93% believe that it will reduce their electricity costs. This indicates that there is a strong correlation between participants' beliefs and behaviours. In other words, those respondents who believe that they can reduce their electricity costs through switching are more likely to practice switching their EWHs off. Only a minority of respondents don't switch their EWHs off at all (9%) and, of this group, only 43% believe that switching their EWHs off will reduce their electricity costs. Additionally, of these respondents, 14% are unsure if switching their EWHs off will reduce their electricity costs and 9% believe that it can reduce their EWH energy consumption but don't know how to switch off their EWH. The results also indicate that participants aged 45 years or older are more likely to switch their EWH off on a regular basis than respondents aged younger than 45 years.

Several questions were used to investigate respondents' awareness and implementations with regard to lowering the set temperature of their EWHs to reduce its energy consumption. Fig. 3 shows an overview of the results obtained. The results indicate that 92% of respondents are able to adjust the temperature setting of their EWHs and 82% of respondents agree or strongly agree that lowering the set temperature of their EWH can reduce its energy consumption. Of these respondents, 81% and 65% have a set temperature less than 70 and 65 °C respectively. Participants were also asked what they believed to be the optimal set temperature for their EWH. The optimal range of temperatures was chosen to be between 50 and 75 °C. These limits were chosen because temperatures lower than 50 °C can cause the growth of harmful bacterium (Lacroix, 1999). Temperatures higher than 75 °C result in unnecessarily high standing losses and can be dangerous. For example, at 52 °C it takes two minutes to cause full thickness burns of adult skin (Feldman et al., 1998). Additionally, between 7 and 17% of childhood scald burns that require hospitalisation in the USA are caused by tap water (Feldman et al., 1998). 85% of respondents correctly identified the optimal set temperature within this range. Of the respondents who did not correctly identify the optimal set temperature, 34% underestimated and only 4% overestimated the optimal temperature, while 62% did not know the ideal temperature (i.e. responded with "Don't know"). Furthermore, only 63% of respondents who identified an optimal set temperature (correct or incorrect) implement what they believe to be the ideal set temperature. Of these respondents, 93% agree or strongly agree that reducing the set temperature of their EWH can reduce its energy usage, further indicating that participants are more likely to implement these measures if they believe that they will have a positive effect.

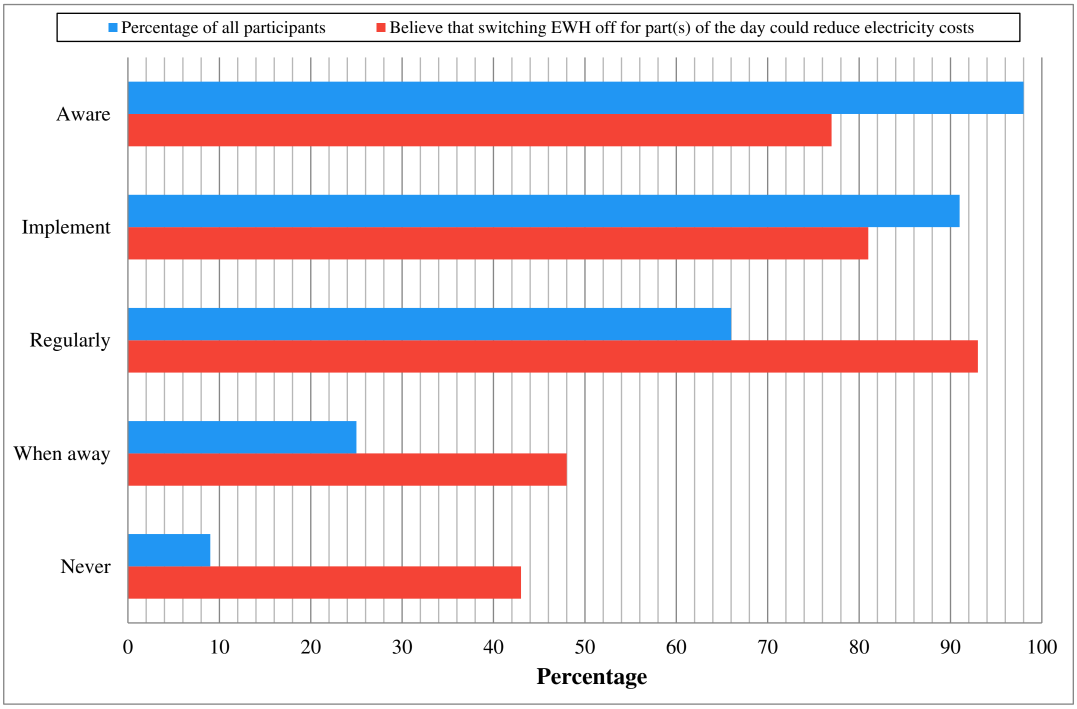

Fig. 2. Bar graph illustrating the percentage of respondents that: know how to switch their EWHs off ("Aware"); either implement switching regularly or when they are away ("Implement"); switch their EWHs off on a regular basis to reduce their electricity costs ("Regularly"); only switch their EWHs off when away from home for several days ("When away"); and never switch their EWHs off ("Never"). The percentage of participants that believe switching their EWH off intermittently can reduce their electricity costs is shown for each of these groups. The results show that 93% of users that regularly switching their EWH off to reduce their electricity costs also believe indicate that doing so will reduce their electricity costs. Only 43% of respondents that never switch their EWHs off believe that it will reduce their electricity costs. These results indicate that participants are more likely to implement an energy saving action if they believe that there is a benefit associated with its implementation (e.g. cost savings).

It was found that 5% of participants believe that a set temperature lower than 50 °C is the ideal set temperature for their EWH. Most likely these respondents assumed that a lower set temperature would result in less standing losses, which implies that the lowest temperature possible is the ideal temperature setting. However, warm water between 20 and 45 °C allows the growth of a harmful bacterium, namely Legionella pneumophila (Lacroix, 1999). Eskom released an informational brochure in 2012 which highlights the dangers associated with this bacterium and provides recommendations on the set temperature of EWHs to prevent its growth (i.e. recommended to be set above 55 °C).

Only 18.8% of respondents reported having a SWH installed (either independently or in conjunction with an EWH). These results, similar to that of Attari et al., indicate that participants are more likely to implement curtailment measures (i.e. switching) than efficiency actions. Additionally, it was found that participants aged 45 years or older are more likely to have a SWH installed than respondents aged younger than 45 years.

Suitability

A major factor in DSM is the suitability of consumers for participation. Users may not consume electricity or water during peak periods and are therefore not suitable for participation in DSM programs aimed at peak shaving (Atikol, 2013). Similarly, certain users may not be able to apply a schedule to reduce the energy usage of their EWHs. As the amount and frequency of usage increases, efficient management has less of an impact on the energy usage of the EWH. This is because, if warm water is required by the household throughout the day, then there is no way to reduce the standing losses through switching the appliance off periodically. However, other households may only require warm water for one or two major usage events that may occur within several hours of one another. These households are able to greatly reduce the energy requirements of their EWH through efficient management.

For example, a household that requires warm water for two shower events in the morning and one bath event in the evening can implement a schedule which heats the water in the EWH tank for only a few hours before each event. This allows the EWH to meet the household's warm water demand while significantly reducing the standing losses, and therefore energy usage, of the EWH (Booysen et al., 2013). The survey included questions used to ascertain the number of bath and/or shower events (i.e. major usage events) that participants' households have during a typical day. It was found that 54% of the respondents in our survey stated that their household have 3 or less major usage events (bath and shower combined) during a typical day and are therefore ideal candidates for efficient EWH management. Additionally, 14% of respondents only have one major usage event during a day in their households. These households have the highest potential for reducing their standing losses as they only require large amounts of warm water for a short duration each day. The EWH can be switched off for the remainder of the day and its set temperature can be reduced to 55 °C for the on cycle to greatly reduce its energy consumption, while easily fulfilling the household's warm water requirements. The analysis by Booysen et al. (Booysen et al., 2013) examines the effect of implementing timer control which only heats water prior to usage for a typical 150 l EWH. The usage profile is assumed to consist of one 75 l warm water usage event every 12 h. This would be the equivalent of almost 3 consecutive typical showers in South Africa. The results of this analysis indicate that, even for the high usage profile assumed, energy savings of approximately 15% are still possible if an efficient schedule is implemented. It should be noted that, although water heating should only occur before major usage events, enough water could be heated during these times

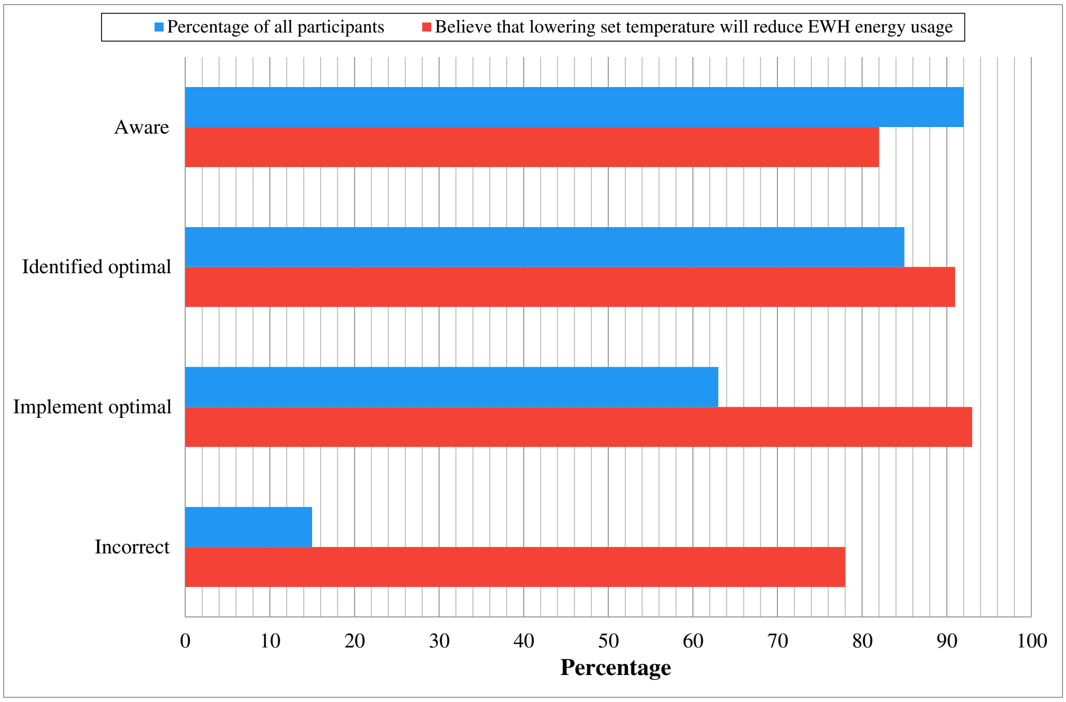

Fig. 3. Bar graph illustrating the percentage of participants that: are able to adjust the set temperature of their EWHs ("Aware"); correctly identified the optimal set temperature for their EWHs ("Identified optimal"); implement the optimal temperature that they identified ("Implement optimal"); and were unable to correctly identify the optimal set temperature for their EWHs ("Incorrect"). The percentage of participants that believe lowering the set temperature of their EWH will reduce its energy usage is shown for each of these groups. The results show that 93% of users that regularly identified and implement an optimal set temperature value also believe that reducing the set temperature of their EWH can reduce its energy usage.

to allow the EWH to still supply warm water for smaller usage events (e.g. washing dishes) that may occur in the interval between the major usage events.

Conclusion

The results of the survey indicate that convenience is a crucial factor in consumers' willingness to switch their EWH off to reduce their energy usage. Consumers were less willing to switch off their EWH if it would require them to defer their usage (i.e. a behavioural change) due to a lack of warm water availability. The exception being if consumers were offered a financial reward for deferring their usage, as is typical for DR programs. Additionally, the majority of participants would be willing to install a device that allows them to remotely control their EWH if it were affordable. It was also found that the majority of participants overestimated the impact of standing losses on the temperature decay of the water in their EWHs. Of these respondents, approximately two thirds switch their EWH off on a regular basis, illustrating that even experienced users have difficulty understanding their EWHs' energy consumption. Furthermore, around a third of the respondents were unable to identify a suitable starting time for the given usage profile. Additionally, approximately half of these participants overestimated the time required to heat the water for this profile, with around a quarter of them estimating a heating time of over 6 h a day (i.e. 2 to 3 times longer than necessary), indicating that users who don't understand EWHs are consuming excess electricity to meet their warm water demands. These results demonstrate that users would benefit from a tool that is able to assist them in implementing effective heating schedules based on their usage. Furthermore, around a third of the participants were unsure of the cost savings that can be achieved through switching their EWH on and off intermittently. It is crucial for consumers to understand the energy and cost savings if they are expected to participate in DR programs. These results illustrate that users would benefit from a tool that can aid them in understanding the impact of switching their EWH off intermittently and/or modifying the set temperature. Finally, approximately a half of the respondents indicated having 3 or less major warm water usage events during a typical day and are therefore ideal candidates for efficient EWH management.

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