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An International Survey of Electric Storage Tank Water Heater Efficiency and Standards

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ABSTRACT

Water heating is a main consumer of energy in households, especially in temperate and cold climates. In South Africa, where hot water is typically provided by electric resistance storage tank water heaters (geysers), water heating energy consumption exceeds cooking, refrigeration, and lighting to be the most consumptive single electric appliance in the home. A recent analysis for the Department of Trade and Industry (DTI) performed by the authors estimated that standing losses from electric geysers contributed over 1,000 kWh to the annual electricity bill for South African households that used them. In order to reduce this burden, the South African government is currently pursuing a programme of Energy Efficiency Standards and Labelling (EES&L) for electric appliances, including geysers. In addition, Eskom has a history of promoting heat pump water heaters (HPWH) through incentive programs, which can further reduce energy consumption. This paper provides a survey of international electric storage water heater test procedures and efficiency metrics which can serve as a reference for comparison with proposed geyser standards and ratings in South Africa. Additionally it provides a sample of efficiency technologies employed to improve the efficiency of electric storage water heaters, and outlines programs to promote adoption of improved efficiency. Finally, it surveys current programs used to promote HPWH and considers the potential for this technology to address peak demand more effectively than reduction of standby losses alone.

1. INTRODUCTION

Water heating is one of the main consumers of energy in South African households, often exceeding cooking, refrigeration, and lighting to be the most consumptive single electric appliance in the home. Electric resistance storage tank water heaters, known as geysers, typically provide hot water. Geysers are far from universal, however. In the lowest income households, hot water is provided with biofuel, coal, or other sources over a stove, while in the highest income households, the relative share of water heating is smaller due to the number of other appliances and equipment. Therefore, water heating electricity share is potentially highest for middle income homes. A recent survey performed by Eskom estimated that the average household consumes 1,100 kWh per month, and that geysers accounted for 39% of this, or over 5,000 kWh per year [1]. Further, a recent analysis for the Department of Trade and Industry (DTI) performed by the authors estimated that standing losses alone from electric geysers contributed over 1,000 kWh to the annual electricity bill for South African households that used them, which is roughly consistent with the overall electricity consumption from water heating [2]. Fortunately, practical options exist for improving the efficiency of electric water heaters. These include increasing insulation to reduce standby losses and employing heat pump technology to improve water heating efficiency over electric resistance heating.

Globally, there is a large variation in the product class and use of hot water heaters. Climate and culture play important roles in the need for hot water and dictate the practices of its use. This wide variation in climate and culture is correlated to the variation in type and size of water heaters used in households and available locally. Colder and wealthier countries tend to use large storage tank water heaters, and also are highly reliant on natural gas to heat water. In warm-climate countries, if households have a dedicated water heater at all, these units tend to be smaller and are not turned on continuously. Instantaneous water heaters have been popular in many countries (e.g. Brazil and China) historically, and by now have gained popularity in others (like Australia and the United States). While electric resistance storage tank water heaters (geysers) are most common in South African households with water heaters, solar water heaters are gaining in popularity with strong government support. Household ownership of geysers is about 40%, with 45% penetration for middle-income homes[3]. Water heaters fired by natural gas, instantaneous water heaters, and heat pump water heaters are not typical.

A second feature of storage tank water heaters compared to other household appliances is that there is not a large import market for them in most countries, rather they are generally produced domestically. They are relatively simple devices to manufacturer, but are bulky due to the storage tank, making shipping them overseas not cost effective. South Africa is no exception to this rule, with domestically produced electric water heaters capturing close to 100% of market share[4].

Finally, because of the variation in product types and use patterns, each major country government tends to develop its own procedures for testing and rating water heaters. These reflect the different draw patterns typically used in local households, and typical installation practices.

These factors can make applying international best practices to water heater efficiency regulations complicated. However, there is some commonality between international testing and use practices that provides the basis for comparison of regulations as all include some evaluation of standby losses from storage tank water heaters.

As mentioned previously, electric storage water heating is a relatively simple device, generally consisting of an electric resistance heating element submerged in a tank which is then connected to the plumbing system. The efficiency of the heating element itself is close to 100% since all heat produced in the element is eventually transferred to the water. The main source of loss, therefore, is thermal transfer from the water to the environment, which is reduced with insulation around the tank. Losses can also occur through heat transfer from the tank into the connected plumbing system. For this reason, many test procedures contain a component of testing a connected system. Because standing loss, measured in kWh per unit time, is a simple function of the temperature difference between the water and the environment and the thermal performance of the insulation between them, differing metrics and test procedures for standing loss can be converted and compared.

In addition to reduction of standing losses in electric resistance water heaters, heat pump water heater (HPWH) technology offers a dramatic improvement in overall water heating efficiency. HPWHs extract heat from the environment and transfer it to water using a compression cycle rather than resistance heating, and can therefore provide heat transfer at greater than 100% efficiency. In addition, because the heating occurs at a slower rate than with electric resistance heating, this technology provides greater opportunity for peak load reduction than standing loss reduction alone.

The following section provides a survey of international electric storage water heater efficiency metrics and regulations, with a focus on standing loss, which is then compared to the scheme currently proposed in South Africa. In order to facilitate the comparison, the standing loss component of regulations in each country is extracted from procedures that include more general measurements of efficiency. Following this, we consider the potential for heat pump water heaters as a peak load reduction strategy and survey international programs designed to promote them.

2. COMPARISON OF INTERNATIONAL STANDARDS

Following the variations in use patterns, climates, and technology choice, countries have chosen (or not chosen) a variety of policy tools to regulate or encourage efficiency of electric storage water heaters. The three main policy tools in use are a) minimum energy performance standards (MEPS), where the government prohibits manufacturers from selling products that are less efficient than some minimum level; b) comparative labels (CL), where governments implement energy efficiency information labels for appliances that give consumers information about energy use of the appliance relative to others on the market; and c) endorsement labels (EL), where the government authorizes a label only to products that meet specified criteria of energy use, to indicate that the product is among the most energy efficient models available.

These MEPS and labelling programs are commonly referred to as energy efficiency and standards and labelling, or EES&L. Some countries implement all three tools or some combination. Table 1 lists data from The Collaborative Labeling & Appliance Standards Program (CLASP) database that summarizes current MEPSs, CLs, and ELs in place for electric storage water heaters.

Table 1 – Summary of international EES&L Programs for Electric Water Heaters (Source: CLASP online database www.claspIonline.org)

Country	MEPS	CL	EL	Date of Last Activity
Argentina		X		unknown
Australia	X	X		2011
Canada	X			1995
China	X	X	X	2013
Egypt	X			2007
European Union	X	X		N/A
Hong Kong	X	X		2013
India		X		2010
Iran	X	X		unknown
Israel	X	X		1986
New Zealand	X	X		2005
Peru	X	X		2009
Russia	X	X		2012
South Africa	X			2011
Thailand		X		2011
United States	X	X	X	2013
Vietnam	X			2009

2.1 STATUS OF WATER HEATER REGULATIONS IN SOUTH AFRICA

The 1998 White Paper on Energy Policy (Department of Minerals and Energy) recognised that EES&L for household appliances should be one of the first measures to be put in place to implement energy efficiency[5]. This was followed up with the National Energy Efficiency Strategy in 2005 which called for the introduction of mandatory EES&L and then in 2008 by the Energy Act of 2008, which made provision for the Minister to pass regulations for MEPS and labelling[6][7].

Then, in August of 2011, a joint action plan, issued by the Department of Trade and Industry and the Department of Energy, to introduce an appliance energy efficiency standards and labelling (EES&L) programme coincided with the development of the of the application for United Nations Development Programme / Global Environment Fund (UNDP/GEF) funding to support the programme. GEF funding is a function of projected emissions avoided over a ten year period as a result of the implementation of the programme.

The household appliances selected for the EES&L programme were based on South African National Standard 941(SANS 941), as a result of a study conducted by the Government to identify the appliances which would yield the greatest energy savings and which were deemed to be the easiest to implement. The SANS 941 initially did not include electric water heaters, but when added, the carbon dioxide emissions reduction potential would more than double, increasing from 124 to over 400 thousand metric tons of CO_2 annually.

Since that time, the UNDP / GEF programme has commenced and a project manager was appointed in April 2013. The project is following the outcomes defined in the UNDP / GEF project document. Final appliances which are included in the EES&L program include refrigerators, freezers, room A/C up to 5kW, washing machines, dishwashers, tumble dryers, ovens, and electric water heaters. Regulations are currently being drafted, laboratory technicians are being trained and equipment needed for new testing laboratories are being assessed.

2.2 DISCUSSION OF TEST PROCEDURES AND METRICS

In this section, we present a sample of electric water heater test procedures and metrics used in some major economies. These include the European Union, the United States and India, which serve as a reference for comparison to the testing regime established by the South African programme.

- The South Africa water heater standard has a standing loss test to measure the heat loss from the tank, a hot water output test, and reheating time test[8]. The proposed MEPS for water heaters are given as a maximum standing loss that varies for different volumes. The standing loss test measures the energy consumed by a full water heater connected to the electrical supply (after steady state conditions have been reached) during any 24 h period when no water is withdrawn. The water in the tank is maintained at 65 °C, while the ambient temperature is maintained at 20 °C. The energy consumption of the water heater is measured for 48 hours, and corrected to 24 hours.

- The Indian test procedure for water heater efficiency, IS 2082:1993, is also a standing loss test. The standing loss is also reported as kWh/24h/45°C.

- The EU draft standards are awaiting adoption. Energy efficiency is calculated using primary energy. The output is measured as useful energy content (above certain temperature and flow rate). The water heater standard is defined for eight separate load profiles, according to likely use patterns for specific product types (capacities). A water heater is rated on the largest load profile it can meet. The energy efficiency standards for hot water storage tanks are based on standing loss.

- The US test procedure is a simulated use test of six draws totaling 243.4 liters at 1 hour intervals. The rating metric is energy factor, an efficiency descriptor. Standing heat losses are determined after the draws are completed. The air-hot water temperature difference is 37.5ºC. The cold water temperature is colder than the air temperature. Efficiency is measured with site energy. The test procedure is currently under revision. Test parameters for each economy are summarized in Table 2.

Table 2 – Test parameters for electric storage tank water heaters

Economy	Test Parameters
South Africa	48 hour standing loss test, ΔT 45°C
India	Standing loss, ΔT 45°C
European Union	Proposed, simulated use test. Eight draw patterns. Separate standing loss test for hot water storage tanks
United States	Simulated use test, six draws at one hour intervals, ΔT 37.5°C

2.3 COMPARISON OF STRINGENCY LEVELS

The labels and MEPS from different countries can be compared when they are based on standing losses. Figure 1 shows standing loss requirements for various labels and MEPS for South Africa and India. The comparable metric from the EU is the MEPS for hot water storage tanks, not water heaters as the proposed standard for EU water heaters is an efficiency rating based on specific draw patterns. The US energy factor can be transformed to a standing loss. The efficiency of immersed electric heating elements is nearly 100%, so simple algebraic transformations can yield an equivalent standing loss. This conversion is possible for electric resistance storage water heaters only.

In South Africa, the majority of geysers models have a capacity between 150 liters and 200 liters. Accordingly, Figure 1 compares ratings across countries for 200 liter geysers using the volume dependence as defined by each economy. The comparison includes the South African label definitions (defined to be equivalent to those used in the EU), the Indian 5-star rating system, and the adopted US MEPS level which takes effect in 2015. In India, the one-star level designates an effective MEPS, since sales of geysers below the 1-star label efficiency level are banned. Similarly, the South African MEPS corresponds roughly to the Chinese 'level 5' designation, which also represents an effective MEPS.

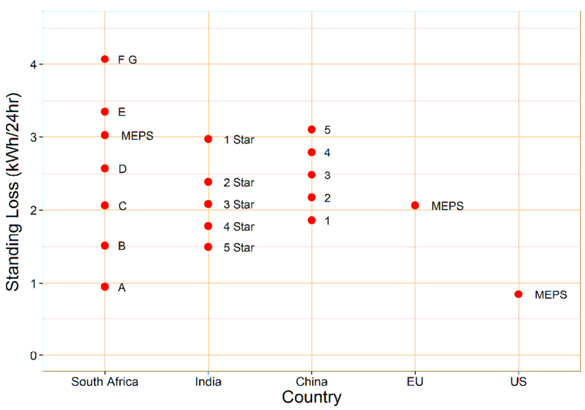

Figure 1 – Comparison of standby loss requirements for MEPS and labelling categories for 200 liter geysers.

Some conclusions can be drawn from Figure 1. First, the proposed EU MEPS is equivalent to a ban on levels D through G based on standing loss alone. Some models in the A, B and C range could also be eliminated based on overall efficiency performance. Second, the proposed South African MEPS is roughly equivalent to the India 1-star level. The South African system, however, rewards products with an A rating that significantly exceeds the requirements of the Indian 5-star level. The South African MEPS permits an annual standing loss on the order of 1,000 kWh per year, which represents a rough approximation of losses that could be experienced in household use. Finally, the upcoming U.S. MEPS requires standing losses below even the South Africa / EU A rating. It should be noted that this standard requires heat pump technology for storage tank sizes over 208 litres (55 gallons).

A simple calculation assuming standing losses are present at all times allows for a rough estimate of savings that could be expected from reduction of standing losses. The proposed South African MEPS allows for a standing loss of about 3 kWh per day. Improvement to the 'C' level saves about 1 kWh per day, or 365 kWh per year, while improvement to the 'A' level saves about 2 kWh per day, or 730 kWh per year. While these estimates are very approximate, they give an idea of the large potential savings from standing loss reductions.

3 ELECTRIC STORAGE TANK WATER HEATER EFFICIENCY TECHNOLOGIES AND PROGRAMS

Fortunately, practical options exist for improving the efficiency of electric water heaters, including through increased insulation that reduce standby losses, and other technologies that can also reduce the peak contribution of electric storage water heaters.

3.1 REDUCING STANDBY LOSSES

There are a number of techniques used in South Africa and around the world to increase the efficiency of electric storage water heaters. One popular method in South Africa that has been supported by Eskom, is geyser blankets. Geyser blankets are extra insulation wrapped around the entire geyser, aiding heat retention. Two South African studies estimated that geyser blankets can improve efficiency from 18% to 27% [9][10]. Extending added insulation to the plumbing system can also provide significant benefit. Additional insulation added during manufacturing can also have the same or better effect of reducing standing losses. Additional insulation is the primary method that manufacturers use to meet various MEPS standards around the world.

Table 3 shows the standing loss, expected annual savings, and estimated consumer price for 50 gallon (189 liter) electric storage water heaters with additional insulation. These numbers were derived from the values used in the US rulemaking to set the MEPS[11][12]. It also gives values for the cost of conserved energy (CCE) for additional insulation over the baseline of 38mm. Using a 15 year lifetime and a discount rate of 10%, the CCE for additional insulation is very cost effective, assuming an electricity tariff of 0.89 Rand[13], for all but the highest efficiency level. Since the volume evaluated is close to 200 liters, the values in Table 3 can be compared roughly to Figure 1. It should be noted, however, that the baseline level of 38mm of insulation in Table 3 results in a lower standing loss than the proposed South African MEPS. In fact, roughly speaking this baseline, which is the result of successive regulations in the U.S., corresponds to the European 'B' level. Therefore, cost of conserved energy cannot be directly compared. However, since the main efficiency option of added insulation is the same at both baseline levels, CCE are expected to be similar, and even lower at lower baseline efficiencies.

Table 3 –Estimated savings and price impact of thicker insulation.

Insulation thickness (mm)	Standing loss (kWh/24h/ 45°C)	Annual Energy loss (kWh)	Retail price (Rand)	CCE (Rand, 15 yr, 10%) (Rand)
38	1.59	580	4,416	na
51	1.41	516	4,644	0.47
57	1.24	454	4,763	0.25
64	1.08	393	4,904	0.30
76	0.91	333	5,154	0.55
102	0.75	275	5,718	1.28

Geyser design options can also be optimized to save energy. One design option is a dual element system. A dual element system has a vertical tank and an upper and lower element and two thermostats. They can save energy by disabling the lower element for significant portions of the day, and allowing the bulk of the water to be colder than it would be normally, which reduces the temperature difference between the air and the tank and also the standing losses. Performance is not compromised if the lower element is turned on during periods with larger draw volumes. Geysers can also be outfitted with circulation pumps that pump hot water left in pipes back into the geyser to eliminate losses in the pipes. Geysers with programmable timers can also reduce standing losses by decreasing the average temperature difference between the environment and the water. Finally, heat traps can be installed on the cold water inlet and hot water outlet to reduce standby loses. Heat traps are designed to prevent the unwanted convection of heated water out of the tank due to thermosyphoning, or natural convection. It further prevents hot water from leaving the tank at the cold water inlet.

3.2 PEAK LOAD REDUCTION TECHNOLOGIES

As previously mentioned, in South Africa, water heating accounts for much of the residential energy consumption. Additionally, residential load contributes significantly to peak system demand, 30%-35%[10]. With water heating accounting for 25-40% of the residential load by many estimates, geysers are on the order of 10-14% of peak load.

Many of the options for reducing standby loss also reduce peak load. Programmable timers and dual elements can be particularly effective. Timers can be used to shift water heating load to off peak times. Dual elements geysers can be programmed to only use one element at peak times, effectively cutting peak use in half. Additional insulation, either geyser blankets or manufacture added insulation can also reduce peak, but to a lesser extent.

One of the most effective ways to reduce peak electricity use of electric storage water heaters is HPWH technology. Unlike traditional geysers that use electricity directly to heat water, HPWH use electricity to move heat from one place to another. HPWH function like a refrigerator in reverse and share many of the same components. They can be two to three times more efficient than traditional electric storage heaters. Due to the operation of the technology-HPWH operate at lower power for longer periods of time, heating water more gradually than a traditional geyser. Thus, the peak load reduction when switching to a HPWH is substantial. HPWH efficiency, or coefficient of performance (COP), is heavily influenced by a number of factors including:

- Ambient air conditions (temperature and humidity)
- Set point temperature (efficiency falls with high set points)
- Hot water draw profile (heat pump water heaters have slower recovery times than traditional electric storage water heaters, and efficiency falls if large amounts of water are drawn at once as back up elements are used

Further, while HPWH are less efficient in colder temperatures (less heat and humidity in ambient air source heat from), they are less dependent on weather conditions than solar water heaters, and therefore provide more consistent savings throughout the day and year.

Figure 2 presents estimates of water heating load profiles for current geysers[14], for efficient geysers (assuming a savings of 20%), and for HPWH (assuming an average COP of 2.0). From this figure, it is clear that there is a high peak coincident use of geysers, that HPWH can provide a substantial peak savings, estimated to be 70%, and efficient geysers are estimated to save 20% energy, both at peak and overall.

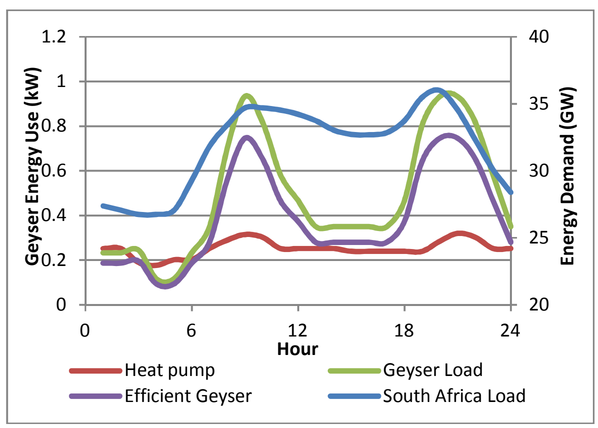

Figure 2 – Average South Africa electricity load[15], current geyser load[14][1], estimated efficient geyser load, and estimated HPWH load.

[1] There are more recent studies that give geyser use profiles that were also consulted, but are based on a low number of households, so this older profile was used for our estimates.

For this reason, HPWH presents an opportunity to reduce both overall electricity demand and peak electricity demand.

3.4 WATER HEATER PROGRAMMES

Over the last few years, South Africa's government and Eskom have been actively implementing demand side management, after a series of blackouts in 2008. Demand side management programs are now being funded with an environmental levy on electricity tariffs and energy efficiency is now included as a resource of choice in integrated planning for future energy resources[16].

Water heating has been a particularly difficult appliance to address for energy efficiency programs, primarily because they are generally not self-installed and are often replaced on an as-needed basis.

3.4.1 Standby Losses

Standby losses are generally addressed with MEPS, with standard testing procedures including a standing loss test. Eskom and other utilities have historically given out geyser blankets or wraps. In the US, this is no longer a standard practice as internal insulation is required to meet MEPS and insulation added during manufacturing can be more effective as it is not dependent on a customer installing it correctly, or paying for it

3.4.2 Heat pumps

HPWH have been on the market for a number of years, but have seen poor market penetration. The primary reason is high upfront cost, which can be several times that of a traditional geyser. Other reasons include lack of consumer awareness and education, lack of domestic production, lack of midstream market actors, and uncertainty in savings.

South Africa, the US, and Australia all have HPWH incentive programs to defray the upfront cost. A few are summarized with the estimated value of the cost of the electricity conserved in Table 4.

Table 4- Summary of select heat pump water heater incentive programs

Country	Incentive (Rand)	Estimated Savings/yr	CCE (Rand, 15 yr, 10%)	Electricity Retail Rate (Rand)	Estimated COP
USA, Puget Sound	5,000	1,828	0.36	0.86[17]	1.6
USA, Georgia	2,500	2,553	0.13	0.53[18]	2.1
Australia	6,000	2,357	0.33	2.40[19]	2.1
South Africa	4,490	2,500	0.24	0.89[13]	2.0

As shown, the South African program can save an estimated 2,500 kWh at a COP of 2.0 at a cost of around 0.24 Rand/kWh. This is in line with other programs in the US and Australia.

4 CONCLUSIONS AND DISCUSSION

While an international survey of electric water heating standards is not an entirely novel analysis, an up to date quantitative assessment of performance requirements is timely, since the South African government is newly embarking on a labelling and MEPS program for geysers.

The goal of an EES&L program, such as being developed in South Africa, is to move the market incrementally by removing the lowest efficiency equipment and encourage gradual innovation and improvement via the labelling system. As Figure 1 above shows, the labelling levels chosen by the government to be harmonized with those of the EU cover a wide range, with A and B levels exceeding the Indian 5-star level and the EU MEPS, but not the U.S. MEPS. The adoption of the EU labelling system provides ample range to drive improvement to levels on par with international best practices. The MEPS themselves are not particularly stringent, being roughly equivalent to those in India, but much less than those found in the U.S. and EU. In addition to comparison with international benchmarks, the stringency of MEPS can be evaluated in terms of how significantly they are likely to move the market from the current status quo. An evaluation of the current geyser efficiency baseline in South Africa is difficult to estimate precisely, due to the lack of publicly available data on the industry. An indication of this was provided, however in comments to the FRIDGE report. In this document, a representative of the South African Bureau of Standards stated:

"There should be no technical problem in requiring Standard (electrical only) geysers to be labeled 'D' and phasing them out over time to meet label 'C'. Banning 'D' geysers will have a significant effect on the production plant of the 'D' level manufacturers."

This statement, and partial evidence implies that most of the South African market lies at the D or E level. Since the D level is not required as a minimum, the likelihood is that the current MEPS will have little or no effect on the market. This situation suggests the need for further investigation on the feasibility of South African manufacturers to upgrade their production to accommodate a higher MEPS level, including an analysis of resulting increases in consumer equipment prices and cost-effectiveness.

In addition to reduction of standing losses through an EES&L programme focusing on geysers, this paper demonstrates a large potential for reduction of peak load, particularly through the encouragement of uptake of HPWH. Some strategies being employed to achieve this throughout the United States include manufacturer promotions, retailer promotions, installer promotions, and energy efficiency programs at the federal, state, and utility level.

The South African government and Eskom can put more emphasis on heat pump water heaters by ramping up the awareness of the benefits of the appliances and help offset the initial higher product cost to consumers, similar to current programs. Further market momentum could be gained through retail advertising or Eskom communications, similar to the programming for the solar water heating rebates, which resulted in a marked increase in the number of solar water heating system manufacturers, suppliers, and installers. While this paper does not consider solar water heaters, the authors accept that solar water heaters are an alternative technology that can also yield high overall and peak savings.

Further, South Africa can put tools in place to develop a capable and motivated domestic manufacturing sector and supply chain to deliver high quality products that will lead to high customer satisfaction. While South Africa does not currently have a domestic heat-pump water heater industry, there is a domestic base for heat-pump manufacturing in South Africa's refrigerator industry. More research should be conducted to provide data on heat pump water heaters performance throughout the country and develop a realistic customer expectation of savings. This research could also provide insight into how the national EES&L programme could be expanded to include heat pump water heaters.

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