Energy Efficiency (2023) 16:88
https://doi.org/10.1007/s12053-023-10170-0

ORIGINAL ARTICLE

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Standby energy consumption and saving potentials in the residential sector in tropical areas: the Caribbean island Curaçao as a case study

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Received: 21 November 2022 / Accepted: 16 October 2023
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Abstract Rising levels of carbon dioxide (CO_2) are of significant concern in modern society, as they lead to global warming and consequential environmental and societal changes. The standby energy consumption of appliances in households is considerable and can be up to 15% of the appliance energy consumption in the residential sector. Overall, standby energy consumption is accountable for roughly 1% of total global CO_2 emissions. When we contrast this impact on global CO_2 emissions with the impact of the transportation sector, standby energy's contribution is minimal. The transportation sector is responsible for about 24% of the global CO_2 emissions arising from the combustion of fuel. Nevertheless, a significant reduction in standby energy consumption in the residential sector is crucial to reduce the CO_2 footprint accordingly. This paper is among the first to assess the magnitude of standby energy consumption and to explore options for reducing standby energy consumption in the Caribbean. The Caribbean island Curaçao was taken as a first case study. Based on a field study of 20 households, the standby energy consumption of about 300 appliances were measured. It was estimated that about 8% of residential electricity consumption was linked to standby energy consumption. The average standby power of the 20 households in Curaçao is 50.3 W. Past research shows that it may be possible to reduce the estimated standby energy consumption by approximately 43%, which is about 6.4 MWh/year in Curaçao. Besides adopting technical solutions, the intended reduction of standby energy consumption can be realized through the introduction of import regulations to favor the selling of appliances with lower standby energy consumption and the creation of public awareness through TV and other media campaigns.

Keywords Standby power · Standby energy consumption · Options to reduce standby energy

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Introduction

Reducing energy consumption and CO_2 emissions are increasingly important cornerstones of sustainable policy development for governments and industry around the world to address grand societal challenges related to sustainability, climate change and energy security (van Oorschot et al., 2021).

As more and more appliances are being used in households and offices and as more appliances are built with features that lead to standby energy consumption, the energy consumption of appliances during standby periods represents a significant share of the energy globally used (Heo et al., 2008; Lebot et al., 2000). In 2014, the International Energy Agency reported that in developed countries, wasted standby energy accounts for around 2% of global electricity use and 10% of national residential electricity use. Overall, standby energy consumption is contributing to around 1% of global CO_2 emissions (Mc Garry, 2004; Pano, 2017; Solanki et al., 2013). When comparing the impact of standby energy consumption on global CO_2 emissions to the impact of the transportation sector, the contribution of standby energy consumption to global CO_2 emissions is minimal. The transportation sector accounts for approximately 24% of worldwide CO_2 emissions resulting from fuel combustion (Solaymani, 2019).

In the past two decades, several studies have been conducted about standby energy consumption and options to reduce standby energy. These studies have mainly focused on developed countries. Unfortunately, there is almost no information available about standby energy use in developing countries. Developing countries have fewer electric appliances, but the appliances that are available are, most of the time, not the state-of-the-art and thus their standby energy consumption can be assumed to be higher for the individual appliances (Clement et al., 2007). But even if the levels of standby energy drawn for a particular appliance are similar to those found in developed countries, the ownership and usage patterns of those appliances may differ.

Another important gap in literature which may be noticed is the lack of information about standby energy use in tropical areas. Households in tropical areas, e.g., often have one or even more air conditioners. This will result in a different composition of appliances per household, and different standby energy consumption and saving opportunities. As a first step to fill this gap in literature, this paper reports on a detailed study that we have conducted on the magnitude of standby energy consumption of home appliances on the tropical Caribbean island Curaçao. We also explore options for reducing the identified standby energy consumption.

The rest of this paper is structured as follows. The next section provides an introduction to standby energy and the type of appliances that consume standby energy. The "Literature on standby energy consumption and saving potentials" section provides a background of the literature on standby energy consumption and saving potentials. The "Method" section outlines the research steps that have been followed to assess the magnitude of standby energy consumption in the residential sector in Curaçao. This is followed by a presentation of the research findings in the "Results and discussion" section. In the "Opportunities to reduce standby energy consumption and by this reduction of CO2 emissions" section, the opportunities for reducing standby energy consumption in the residential sector in Curaçao are discussed. The paper ends with a discussion in the "Contributions and future research" section, on the main contributions, policy implications and limitations of this study and a number of suggestions for further research.

An introduction to standby energy and the type of appliances that consume standby energy

Standby energy consumption, standby loss, standby power, vampire power, and leaking electricity all refer to the electricity consumption of appliances when they are not performing their primary function or are switched off (Bredekamp et al., 2006; Fung et al., 2003; Lu et al., 2011; Meier, 2001; Meier et al., 2004). Standby energy consumption was identified in the 1980s as a significant energy use, and it represents one of the largest end-uses in the residential sector worldwide (Fung et al., 2003; Guan et al., 2011; Hamer et al., 2008; Harrington & Foster, 2021). Standby energy is related to the operational mode of an appliance. To clarify this relationship, Fig. 1 illustrates the several operational modes of an appliance and the standby energy associated with these modes (A. Meier & Lebot, 1999; Shuma-iwisi, 2009; Solanki et al., 2013; Bulbaai, 2019).

As can be seen in Fig. 1, an appliance can first be in the plugged off mode or in the plugged-on mode. An appliance does not consume standby energy in the plugged off mode.

When the appliance is in the plugged-on mode, it can be in the switched on or the switched off mode. The switched off mode is further subdivided into hard-off and soft-off modes. Appliances have a hard-off mode when the internal power supply circuit of the appliances is connected through a mechanical switch to the power source. In contrast, a soft-off

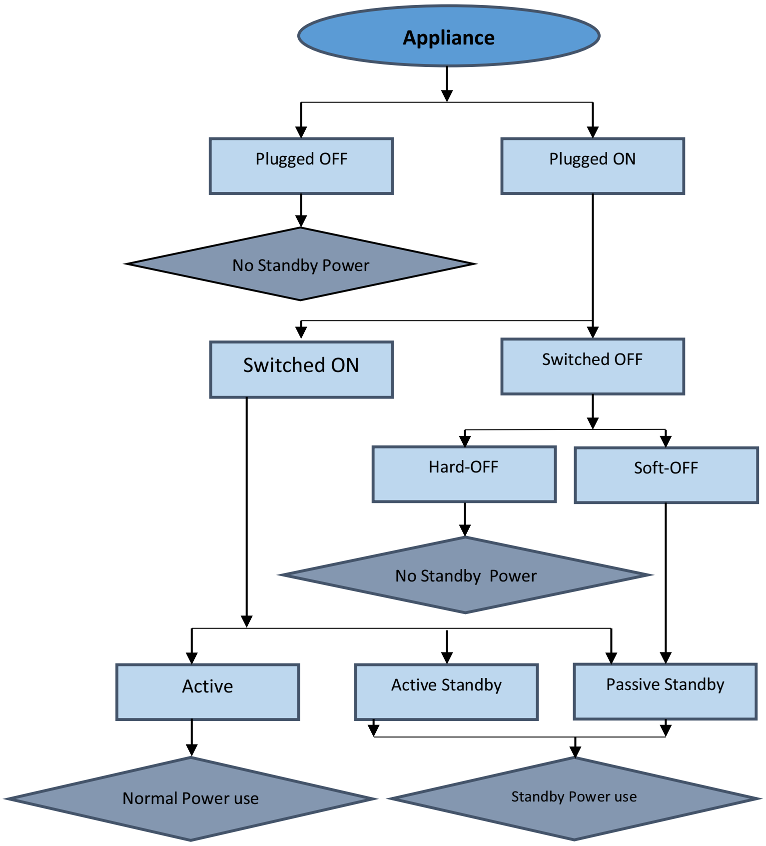

Fig. 1 Block diagram of standby power modes (A. Meier & Lebot, 1999; Shuma-iwisi, 2009; Solanki et al., 2013; Bulbaai, 2019)

mode refers to appliances where the mechanical switch connects the appliance's internal power supply circuit to an electronic circuit. Appliances do not consume standby energy if they are in the hard-off mode; however, they do in the soft-off mode. This latter standby mode is labelled the passive standby mode if the appliance does not provide any function in this mode, but still consumes energy. Appliances in this mode can be powered up remotely (Alan et al., 1999; Clement et al., 2007).

Further, when an appliance is in the on-mode, it can be in active standby mode, passive standby mode or in an active/normal mode. In the active/normal mode, the appliance performs its main function, whereas in the active standby mode, it consumes power but is not providing its main function (Guan et al., 2011; A. Meier & Lebot, 1999). In this mode, appliances are waiting for a command to be activated. For example, an alarm system, an alarm clock, a computer router, and a garage door opener (Alan et al., 1999; Clement et al., 2007). An appliance can be in passive standby mode if the switch is on or if the switch is soft-off. Passive standby is when the appliance is off and can be powered up remotely. An appliance that is in sleep mode or in passive standby mode, when the switch is on, is an appliance waiting to be activated by, for an example, a remote control.

Almost all household appliances with external power supplies consume standby energy. In recent years, the number of appliances with standby energy consumption has increased rapidly. Appliances that consume standby energy are:

1. Appliances that have no power switch;
2. Appliances with a remote control;
3. Appliances with LED status lights;
4. Appliances with a display that includes LED status lights;
5. Appliances with a memory keeping function
6. Appliances with inefficient power supply; and
7. Appliances with an external power supply, which is, in many cases, always connected to the electricity grid.

The electricity power of appliances in the standby mode is generally small, between 0.5 and 10 W (Meier, 2001). Notwithstanding this small consumption, the sum of all the standby energy consumptions represents a considerable amount of power in the residential sector, with households' standby power varying from 23 to 112 W per home.

The rest of this paper is structured as follows. The "An introduction to standby energy and the type of appliances that consume standby energy" section outlines the research steps that have been followed to assess the magnitude of standby energy consumption in the residential sector in Curaçao. This is followed by a presentation of the research findings in the "Literature on standby energy consumption and saving potentials" section. In the "Method" section, the opportunities for reducing standby energy consumption in the residential sector in Curaçao are discussed. The paper ends with a discussion on the main contributions, policy implications and limitations of this study and a number of suggestions for further research.

Literature on standby energy consumption and saving potentials

In the past 25 years, several studies have been conducted about standby energy consumption and the options to reduce standby energy.

Studies published in the period 1995–2010

Studies in Germany (Rath & Hellmann, 1999), Japan (Nakagami et al., 1997), the Netherlands (Siderius, 1998), and the USA (Huber, 1997; Meier & Lebot, 1999) have found that standby energy accounted for as much as 10% of national residential electricity use. These studies (and others) have resulted in standby measurements of thousands of appliances, but few measurements of total standby energy consumption in individual homes. The Jyukankyo Research Institute in Japan (Murakoshi, 2000) and ADEME in France (Sidler et al., 2000) have conducted the first studies of whole-house standby energy consumption. Ross and Meier (2001) investigated the variation in standby energy consumption in ten Northern-California homes. Total standby power in these homes ranged from 14 to 169 W, with an average of 67 W. This corresponded to 5–26% of the homes' annual electricity use. Lebot et al. (2000) provided a global estimate of standby energy consumption in the residential sector of the OECD member countries. These countries represent roughly 65% of the world's electricity use and 54% of global CO_2 emissions. Based on this estimate, Lebot et al. (Lebot et al., 2000) concluded that standby energy in the residential sector accounted for 1.5% of the total electricity consumption (124 TWh) and contributed to 0.6% (68 million tons) of CO_2 emissions. In comparison, this represented the annual CO_2 emissions of 24 million European-type cars.

A first study on standby energy use and its saving potential in China was conducted by Meier et al. (2004). Appliances in 28 urban Chinese homes were surveyed and standby energy consumption was measured. The standby power was about 29 W per home. Many Chinese occupants appeared to unplug their appliances when not in use. This explained the lower level of standby energy consumption in Chinese homes if compared with earlier reported findings of other countries. Still, standby energy consumption appeared to be responsible for about 10% of total electricity use in urban Chinese homes. Clement et al. (2007) investigated the standby energy consumption of ten households in Belgium and reported a standby energy consumption on average of 274 kWh/year, representing 8% of the yearly consumption of an average household in Belgium.

Studies published in the period 2010–2023

In Turkey, Sahin and Aydinalp Koksal (2014) investigated standby electricity consumption and savings potential of 260 households in Ankara, Turkey. The estimated average Turkish household standby power and standby energy consumption were estimated as 22 W and 95 kWh/year, respectively. It was also found that the standby electricity consumption constituted 4% of the total electricity consumption in Turkish homes. Pano (2017) measured standby energy consumption in five homes in Korça city in Albania. Standby energy accounted for 3–20% of total electricity consumption of these five homes. All five homes used wood stoves and natural gas for space heating. Based on data provided by the National Institute of Statistics of Spain, Escobar et al. (2020) succeeded to determine electricity consumption profiles in the domestic sector in Spain and found a standby electricity consumption reaching over 5%.

With respect to European Union countries as a whole, Vasiliu et al. (2021) reported an average annual electricity consumption in standby mode of nearly 7% of the total annual energy consumption per household in the European Union. This finding is based on recent measurements of about 1300 households across the European Union.

In the last few years, also a number of studies about standby energy consumption and the options to reduce standby energy consumption were conducted in Africa. Using a self-reporting approach, electricity use behavior of low-income households in South Africa was assessed against a list of common household electricity use actions (Mutumbi et al., 2021). The findings show that among low-income households, there is evidence of both electricity saving and wasteful practices. Key areas of concern relate to the potential prevalence of standby energy consumption and the use of kitchen appliances such as the refrigerator. In a survey with 387 households, Tete et al. (2023) investigated the actual domestic electricity use in Burkina Faso. Their findings demonstrate an average electricity use of 2395 kWh/year by households. Cooling accounts for almost 40% of the domestic electricity use, followed mainly by cooking and food preserving (23%) and information-communication entertainment activities (19%). Tete et al. (2023) also specifically investigated the standby electricity consumption as percentage of the household's total annual electricity consumption and found that this constituted 1.2% of the total electricity consumption in households in Burkina Faso. ICE appliances were found to account for the majority (96%) of standby energy consumption. As income levels increase in future, ICE appliances will become more affordable and consequently a higher share for standby energy consumption could be expected in Burkina Faso (Tete et al., 2023). Olatunji et al. (2019) observe that in Nigeria, little attention has been paid so far to energy conservation. Standby energy consumption accounts for 13–44% of the annual electricity consumption across households. In response to this, several studies have been tailored to ensure a rapid reduction in energy consumption in Nigeria.

In the last few decades, considerable progress in reducing standby energy consumption in specific products has been achieved through a variety of policies and technologies. However, as Meier (2019) and also Gerber et al. (2023) rightly observe, we have also seen in the last 20 years an explosion in the number of devices that rely on power supplies and continuous power consumption. This growth can be attributed to the proliferation of devices that require DC power, traditional AC-powered devices that now have electronics, and mobile devices with batteries. Many of these devices fall into the miscellaneous electrical loads (MELs) category, which continues to grow rapidly in terms of both population and energy use. The need to reduce standby energy therefore continues to be an important policy and technical challenge.

Method

Curaçao is an Antillean island in the Southern Caribbean Sea, about 65 km north of the Venezuelan coast. Curaçao has a population of just over 150,000 in an area of 444 km^2. The island extends from 68 to 70° west of the Greenwich meridian and from 12 to 13° north of the equator. Curaçao is located in the southern Caribbean dry zone, and it is characterized by a semi-arid to arid climate, with distinct dry and rainy seasons (Bulbaai, 2019).

To estimate the magnitude of standby energy consumption in Curaçao's residential sector, a field study was conducted involving about 300 appliances and devices in 20 households in Curaçao. The selection of these 20 households was based on a stratified random selection. This means that the selection was based on the inclusion of a variety in the sizes of the households and the number of appliances per household. This study therefore includes houses with many appliances as well as houses with fewer appliances.

There are three methods for estimating standby energy consumption (Bertoldi et al., 2002; Meier, 2001; Tselekis, 2012):

1. New-product measurement;
2. Bottom-up estimates approach; and
3. Whole-household measurement.

New product measurement

New-product measurement involves visiting a store or factory and measuring the standby power of new appliances. The main advantage of this approach is that the measurements of many appliances can be taken in a short time. However, the measured standby power will not match the standby power in the residential and commercial sectors because the standby power of new appliances is often lower than older existing appliances (Bertoldi et al., 2002; Meier, 2001; Tselekis, 2012).

The bottom-up estimates approach

The bottom-up approach is more appropriate when the appliance saturation and standby power data are available, and the average standby power corresponding to a country is then the estimated average standby power of the appliances multiplied by the appliances' saturation data (Lu et al., 2011; Meier, 2001; Sahin et al., 2011; Yu et al., 2017). This method cannot be applied in Curaçao due to the lack of standby power information on the appliances found in Curaçao.

Whole-household measurement

The whole-household measurement approach consists of different actions, namely visiting a number of households; registering the type, model, and size of each appliance; measuring the standby power of the appliances in the households; and conducting a survey about the electricity consumption of the participants (Lu et al., 2011; Meier, 2001; Sahin et al., 2011; Yu et al., 2017). The standby power is the power [W] of the appliances in the standby mode, and the standby energy consumption [Wh] is the standby power of the appliances multiplied with the time the appliance is in standby mode.

The average standby power and the household standby power are calculated as follows:

The average standby power is the sum of the measured standby powers of the appliances divided by the number of appliances, as given in Equation (4.1).

$$\boldsymbol{Y_i} = \frac{\sum_{i=1}^{n} \boldsymbol{X_i}}{\boldsymbol{n}} \tag{4.1}$$

where:

Y_i is the average standby power of appliance i

X_i is the standby power per appliance i

i is the type of appliance

n is the total number of appliance i

To illustrate, if the appliance is a television, the variable "I" represents the television and the average standby power of the television is represented by $Y_{television}$. As mentioned earlier, X corresponds to the standby power of the appliance in Watts, which, in this example, is the standby power of a television.

The average household standby power and the standby energy consumption are calculated in the same way. The average household standby power or standby energy consumption is the total household standby power or standby energy consumption divided by the number of appliances, as given in Equation (4.2).

$$\boldsymbol{ST_i} = \frac{\sum_{i=1}^{n} \boldsymbol{H}}{\boldsymbol{n}} \tag{4.2}$$

where:

ST_i is the average household standby power or standby energy consumption.

H is the total standby power or standby energy consumption per household.

The average standby power or standby energy consumption of a country is equal to the number of households multiplied by the average standby power or standby energy consumption of the households, as presented in Equation (4.3).

$$\boldsymbol{STC_i} = ST_i * N \tag{4.3}$$

where:

STC_i is the average standby power or standby energy consumption per country

N is the total number of households

The standby energy consumption of an appliance is equal to its standby power multiplied by the standby time in hours, as given in the following equation:

$$\boldsymbol{X_c} = \boldsymbol{x} * \boldsymbol{t_{ST}} \tag{4.4}$$

where:

X_c is the standby energy consumption of an appliance.

X is the standby power of an appliance.

t_{ST} is the standby time in hours.

For clarity, the variables and the formulas, along with their explanations, are included in Tables 1 and 2.

Another method of measuring the entire household is to measure the entire dwelling power, after all appliances are turned off or disconnected so that

Table 1 Symbols, expressions and their corresponding explanations

Symbols/expressions	Description
Y_i	The average standby power of appliance i
X_i	The standby power per appliance i
i	The type of appliance
n	The total number of appliances i
ST_i	The average household standby power or standby energy consumption
H	The total standby power or standby energy consumption per household
STC_i	The average standby power or standby energy consumption per country
N	The total number of households
X_c	The standby energy consumption of an appliance
X	The standby power of an appliance
t_{ST}	The standby time in hours
X_c	The standby energy consumption of an appliance

Table 2 Equations accompanied by their elucidations

No	Equations	Description
4.1	$Y_i = \frac{\sum_{i=1}^{n} X_i}{n}$	The sum of the measured standby powers of the appliances divided by the number of appliances
4.2	$ST_i = \frac{\sum_{i=1}^{n} H}{n}$	The total household standby power or standby energy consumption divided by the number of appliances
4.3	$STC_i = ST_i * N$	The number of households multiplied by the average standby power or standby energy consumption of the households
4.4	$X_c = x * t_{ST}$	Standby power of the appliance multiplied by the standby time in hours

the remaining load is all standby. The main drawbacks of this method are that it can contain appliances that might not otherwise be found (e.g., in basements, attics or in walls, such as electrical controls), or appliances that are left on accidentally. However, this method offers a significant advantage as it allows rapid measurement of household standby energy consumption.

A review of the available literature addressing standby energy consumption made clear that in most of the studies, the 'bottom-up estimates approach' or the 'whole-household measurement' approach are applied (Heo et al., 2008; Sidler et al., 2000; Ross and Meier, 2001). Given the shortcomings of both the 'new product measurement' and the 'bottom-up estimate approach', we decided to apply the 'whole-household measurement approach' and followed the prescribed steps of this approach. Therefore, we visited each of the 20 selected households and registered per household, the type, model and size of each appliance, and measured the standby power of the appliances. Depending on the number of appliances per household, the measurements took between two and five hours. The measurements were carried out over a period of five months. In this period, the standby energy consumption of about 300 appliances, that were identified in the selected 20 households, were determined. Nineteen of the households were owner occupied, and one was a rented apartment. The occupancy of these households varied from one to five persons, with an average of four people per household. Appliances such as doorbells, security alarms, and garage door openers were excluded from the measurements since most houses in Curaçao do not have such appliances. During all the standby power measurements, the appliances were either in the 'off mode' or in the 'on mode' but not performing their main task. In addition to the measurements, a survey consisting of 17 questions was carried out within the 20 households (Appendix). The survey was conducted by a student of the faculty of engineering of the University of Curaçao. This survey was conducted to determine the electricity consumption behavior of the residents and the average time their appliances were in standby mode.

A large number of standby power measurements are not easy to obtain. Because it is difficult to get participants, because of the privacy of the participants, and measuring standby power in a dwelling is an intensive exercise. In our studies, we do take the size of the dwellings into account. This means that the dwellings we have chosen are small, medium and large. In addition, all the literature we examined used the number of dwellings, which is not representative of the total number of homes.

Standby power is often low and, therefore, the measurement of standby energy requires a meter with sufficient resolution to take an accurate reading. A digital KPM1000 power meter was used in this study. This meter has a resolution of 0.01 mW for a low range and 0.1 W for a high range, and it can perform standby power measurements in compliance with IEC62301. The accuracy of the measurements is ±0.1% of the reading (Bulbaai, 2019).

Results and discussion

The "*Research findings of the conducted field study*" subsection provides an overview of the main research findings of the conducted field study. This is followed by a discussion of the research findings in the "*The average standby power and average standby energy consumption of the residential sector in Curaçao*" subsection. Based on the outcome of the field study, an estimation is made in the "*Discussion of the findings in the case study*" subsection of the average standby power and average standby energy consumption of the residential sector in Curaçao.

Research findings of the conducted field study

Table 3 provides an overview of the type and number of the identified appliances in the 20 households, the average standby power per type of appliance and the average standby energy consumption of the respective appliances. Appliances with negligible standby power are not shown in this Table. The appliances are classified into five product categories: Entertainment; Communication; Cooking; Food cooling and; Various with different types of appliances such as, Transformer, Air conditioner, Washing machine, and Fan. Figure 2 and Fig. 3 respectively illustrate the average standby power and the average standby energy consumption of the more than 300 appliances that were included in the field study. The appliances with the highest average standby power are the set-top box 1 (13.4 W), followed by the refrigerator (12.4 W), and the transformer (12.2 W), see Table 3 and Fig. 2.

As shown in Table 3 and Fig. 3, the appliances with the highest average standby energy consumption are respectively the set-top box 1 (90.5 kWh/year), followed by the transformer (51.5 kWh/year), and the set-top box 2 (50.3 kWh/year). In this study, a distinction was made between set-top box 1 and set-top box 2 based on the fact that set-top box 1 is provided by a television company in Curaçao, while set-top box 2 is sold by retail outlets.

The total standby power per household (see also Table 4) was calculated by adding the standby powers of all the appliances of each specific household. The households are listed in a descending order of standby power, ranging from 101.4 W standby power to 11.2 W standby power. This fluctuation is primarily caused by a variation in the number of appliances per household, the type of installed appliances, the household size, and the number of occupants present in the house during the day. The household with the smallest standby power (11.2W) is a small household with just a few appliances. The average standby power of the 20 households is 50.3W.

The minimum number of the measured appliances of the households was found to be 19 for households nr 11 and 18, and the maximum was 33 appliances for household nr 12. The standby energy consumption per year of a household was calculated by multiplying the standby power of the appliances per household and the corresponding standby time per appliance.

As shown in Table 4, the minimum standby energy consumption of the households was found to be 40.2 kWh/year for household nr 13, while the maximum was 484.0 kWh/year for household nr 1. The average standby energy consumption of the measured households is about 212.9 kWh/year.

The average standby power and average standby energy consumption of the residential sector in Curaçao

To determine the ratio between total energy use and standby energy consumption in the household sector in Curaçao, it was first necessary to determine the

Table 3 Results of measurements of average standby energy consumption

No	Product category	Appliance	No	Standby power min [W]	Standby power max [W]	Y_i = Average standby power [W]	SX_c/year = Average standby energy consumption [kWh/year]
1	Entertainment	Set-top box 1	23	5.5	23.6	13.4	90.5
		Television	28	0.003	5.8	0.6	4.9
		Radio	14	0.005	4.7	1.9	13.8
		DVD player	8	0.003	2.1	0.6	6.3
		Set-top box 2	2			6.9	50.3
2	Communication	Computer	6	0.9	6.7	3.2	20.8
		Speaker	4	0.6	7.4	4.4	7.5
		Printer	15	0.002	10.8	1.0	14.1
		Router	10	1.9	5.8	3.5	17.2
		Modem	18	0.3	7.9	5.1	33.9
		Wireless Phone	9	0.4	4.5	2.0	16.3
		Phone charger	30	0.008	0.3	0.1	1.3
		Laptop charger	18	0.3	1.4	0.1	1.0
3	Cooking	Microwave	13	0.003	3.9	2.2	21.9
4	Food cooling	Refrigerator	3	9.1	18.2	12.4	43.5
		Freezer	1	0.2	0.2	0.2	0.8
5	Various	Transformer	5	3.9	24.3	12.2	51.5
		Air conditioning room/wall	12	0.01	11	3.2	24.0
		Clothes washer	4	0.002	3.9	0.2	6.8
		Fan, portable	7	0.002	2.5	0.3	6.7
		Set-top box Game console	3	0.3	0.9	0.5	3.6
		IPad charger	4	0.1	0.1	0.1	0.0
		Control station “Click on/off”	1	3.0	3.0	3.0	26.4
		Receiver “Click on/off”	8	0.6	0.6	0.6	33.1

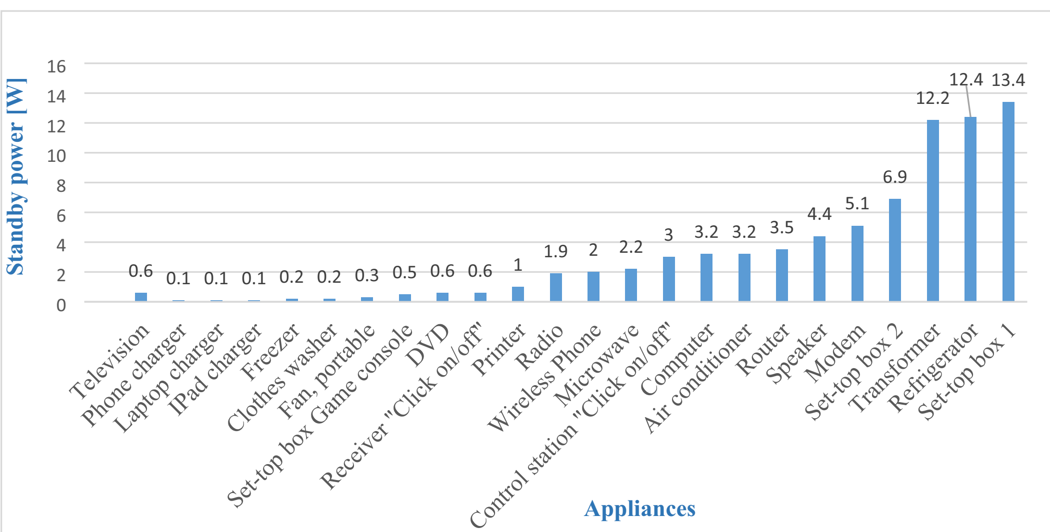

Fig. 2 Average standby power of appliances

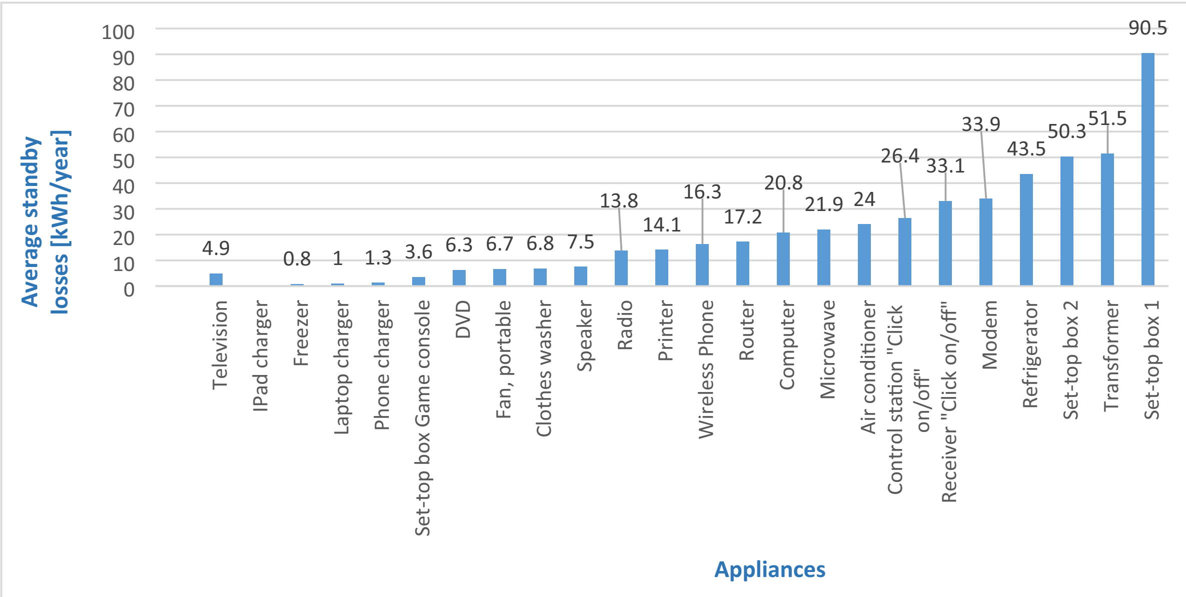

Fig. 3 Average standby energy consumption of appliances

Table 4 Total standby power per household and standby energy consumption per year per household

Household	Number of appliances	H = Total Standby power [W]	ST_i/Year = Standby energy consumption per year [kWh/year]
Household 1	19	101.4	484.0
Household 2	14	97.0	346.1
Household 3	16	95.2	278.6
Household 4	12	86.9	260.8
Household 5	15	84.5	192.7
Household 6	13	76.4	295.0
Household 7	18	66.3	401.9
Household 8	13	53.1	311.1
Household 9	20	50.2	326.0
Household 10	10	38.7	233.2
Household 11	9	36.7	252.5
Household 12	33	31.2	111.2
Household 13	11	28.5	40.2
Household 14	13	28.2	65.1
Household 15	18	27.3	118.4
Household 16	11	26.0	186.4
Household 17	21	25.8	146.9
Household 18	9	25.5	46.3
Household 19	19	15.3	95.2
Household 20	10	11.2	66.0
Total	*304*	*1005.4*	*4257.5*
Average per household	*15*	*50.3*	*212.9*

total number of occupied dwellings. In total, 69,416 dwellings appeared to be occupied (Bulbaai, 2019). To estimate the average standby power of Curaçao, the average standby power of the households must be multiplied by the total number of households in Curaçao. This means that the average standby power in Curaçao is about 50.3 W * 69,416 dwellings is 3.5 MW.

The average standby energy consumption of the measured households multiplied by the total number of households in Curaçao provides the total standby energy consumption of Curaçao, which is roughly: 69,416 households * 212.9 kWh/year is about 14.8 MWh/year. To estimate the fraction of standby energy consumption in the total household electricity consumption, the total standby energy consumption of Curaçao in the residential sector is divided by the total household electricity consumption. In 2021, the total household electricity consumption was 195.5MWh (Aqualectra, 2022). This means that the total standby energy consumption is about 8% of the total annual household electricity consumption in Curaçao.

Discussion of the findings in the case study

Research into standby energy consumption in the Caribbean SIDS is important. There are several reasons for this. The use of some devices is different from the use of devices in other countries. For example, the use of air conditioning, the use of air conditioning in the Caribbean SIDS is intensively compared with the use of air conditioning in Europe. Generally, the number of devices used in the developed countries is much greater than the number of devices used in the developing countries. This also applies to awareness. In developed countries, awareness of standby energy consumption is greater than in developing countries.

In the early 1990s, a pioneering study on standby energy consumption was conducted by a Swedish energy agency, focusing on the energy usage of audio equipment and TVs. The results of this study were published in 1993 in the ECEEE procedure (Meier & Siderius, 2017). During this time, there were numerous publications on standby energy consumption. In 1997, Meier established a guideline advocating for reducing the standby energy consumption of all future appliances to 1 W. Subsequently, in 1999, Meier and Lebot introduced the "global 1-W plan," which was later recommended by the International Energy Agency as a standby power strategy (Meier & Lebot, 1999). As a result, many innovations were introduced to minimize standby energy consumption in a wide range of devices, focusing on improving the efficiency of AC-DC power supply, reducing the power consumption of device circuits, and minimizing the power consumption of displays. After the introduction of the "global 1-W plan", a number of additional efforts were made to further reduce standby energy consumption limits. In particular, there were initiatives to lower the standby power limit to 0.5 and 0.3 W, representing an ongoing commitment to minimizing standby energy consumption in various types of appliances (Meier and Siderius, 2017).

The study of Sahin and Aydinalp Koksal (2014) indicates that the results of some whole-house measurement studies to be very wide. The ranges for the number of homes surveyed, average standby power, average standby energy consumption, standby energy consumption fraction, number of appliances with standby per household and number of appliances with standby power measured, are between 1–1300 homes, 14–125 W, 95–1015 kWh/year, 4–15%, 3.2–19 appliances per household and 80–11,500 appliances measured per study, respectively. According to Sahin and Aydinalp Koksal (2014), these differences are caused by the fact that the whole-house measurement approach involves uncertainties mainly due to defining and measuring of standby power. Each study apparently has its own definition for standby power and conducts measurements based on the appliances that fit in their definition. Some studies included continuous and hard-wired appliance standby loads, which resulted in a higher estimate for the household standby power. In some studies, only major appliances are measured and smaller electronic appliances are ignored, which led to lower estimates of standby power. In addition, one may argue that the economic welfare of a country influences the number and type of appliances that are possessed by the inhabitants. Also, the year in which a specific whole-house measurement study was conducted to be of influence since the standby power of new appliances is generally lower than the standby power of older appliances.

In our field study, the total standby power per surveyed household ranges from 11.2 to 101.4 W, with an average standby power of 50.3 W per household. And the standby energy consumption per year per household ranges from 40.2 to 484.0 kWh/year. The results of the findings of our study are therefore within the wide range as indicated by Sahin and Aydinalp Koksal (2014).

However, a notable exception in our field study concerned the composition of appliances. In many countries, it is unusual to use transformers in the residential sector. But, in Curaçao, almost all households have one or more transformers to step up or down the voltage, due to the different voltage levels of 127 V 50 Hz and 220 V 50 Hz in the dwellings. The mains power supply frequency is 50 Hz and mains power supply voltage is 127 V and many imported appliances are 120 V and 60 Hz and/or 220 V and 50 Hz. Furthermore, the households have a mix of 120 V 60 Hz and 220 V 50 Hz appliances. Transformers are used in Curaçao households when the appliance and supply voltages and frequency do not match. The transformers are usually for a single device. However, the number of transformers per household in Curaçao is nowadays decreasing because many modern electronic appliances can run on any voltage in the 100–240 V range and also with 50 or 60 Hz supplies. Another difference in the composition of appliances is the inclusion of air conditioners. Due to the tropical climate in Curaçao, different households have one or even more air conditioners.

The references used in this study span a long period of time over 20 years. Given the technological progress of recent years, the standby energy consumption in the residential sector should fall drastically. However, the falling prices of electronic devices, leading to more devices being used, are having a negative effect on the reduction of standby energy consumption. Standby energy consumption of some appliances will also decrease in countries that do not have a standby power consumption standard. This is because the standby power of a number of new appliances will decrease. But, as mentioned earlier, standby energy consumption in these countries will increase as more appliances will be used.

Opportunities to reduce standby energy consumption and by this reduction of CO_2 emissions

This section is based on a literature review about opportunities for reducing standby energy consumption and consequently CO_2 emissions. The main options to reduce standby energy consumption are to change consumer behavior, technological innovations, and through policy measures and arrangements.

A change in consumer behavior

During our field study, we noticed that hardly any of the residents were aware of the standby energy consumption. A first option to reduce standby energy consumption therefore seems to increase consumer awareness and knowledge on standby energy consumption. Utility companies and/or governments can lead campaigns to encourage consumers to reduce their standby energy consumption (Clement et al., 2007; Hamer et al., 2008). An easy and cost-effective way for consumers to reduce standby energy consumption is to unplug appliances when they are switched off, fully charged, or not performing their main functions. An electrical power bar is a useful option for easily unplugging home electronics, for instance TVs, computers, printers, CD and DVD players, and decoders when they are not being used. Another way for consumers to lower their standby energy consumption is to purchase appliances with lower standby power. In countries like Germany, Switzerland, Denmark and the Netherlands, some local utilities have conducted information and motivation campaigns to raise consumers' awareness and to encourage the purchase of appliances with reduced standby energy consumption (Mohanty, 2001). However, as argued by Mohanty (2001), these campaigns may also have their drawbacks. It is not an easy task to convince the end-user about the benefits of adopting energy efficiency practices, when the quantum of saving is not high at the individual level. In addition, reaching out to all the target households, will require considerable human and financial resources. Buchanan and Russo (2019) provide an overview of the many studies that have been conducted to examine whether giving people feedback about their energy use can lead them to decrease it and concluded that to date no consensus has been reached about which type of eco-feedback is the most effective. To test the efficacy of different feedback techniques, Buchanan and Russo (2019) measured the impact of different feedback strategies and found that all the feedback strategies led participants to report significant gains in knowledge of standby power. However, these knowledge gains, were not sufficient to inspire behavior changes. This left them to conclude that pecuniary feedback and knowledge gains alone appear insufficient in the quest of inspiring householders to reduce their standby energy consumption.

The adoption of technological innovations

An effective way to reduce standby energy consumption is through the adoption of technological innovations. Mohanty (2001) estimated that redesigning appliance circuits can reduce standby energy consumption up to 90%. In fact, in the last two decades, manufacturers have introduced many power-saving features, such as by improving the efficiency of low-voltage transformers and using intelligent switches. The low-voltage transformers can be both internal and external power supplies, which convert the AC voltage into DC voltage. New generation power transformers are capable of reducing the standby power from 5 W to as little as 0.1 W. These transformers are also far more energy efficient (Mohanty, 2001).

In general, power bars are used to switch off units such as computers, printers, scanners, televisions, TV boxes, and DVD players. Smart power bars are designed to prevent unnecessary waste of energy, as they turn off peripheral devices when the main device is not being used. Various devices can be plugged into the power bar into specially marked sockets. One socket is for the main (master) device, such as a computer or TV, and the others are for peripherals (slaves). When the power bar detects that the main device is off or on standby, it cuts the power to all the peripherals, such as printers or loudspeakers. When the computer or TV is turned back on again, the peripherals are reconnected.

An apparent trend in the field of electric/electronic devices in homes is that they will function in a network setting. As a consequence of this trend, the total consumption of standby energy will greatly increase. To reduce this total consumption of standby energy, Heo et al. (2008), Byun et al. (2013) and Chen and Lin (2019) have proposed the use of a control mechanism for standby power reduction. To reduce standby energy consumption in a networked setting, this home automation system generates control commands to isolate or to connect the available appliances.

Residential energy is commonly categorized into six major end uses (Burgett, 2015): Lighting, Water heating, Space cooling, Space heating, Major appliances (including white goods and televisions), and the Various electrical load. Over the past 30 years, the intensity (watts per meter) of all major energy use categories has decreased in the residential sector, with the exception of MEL, which has increased steadily over time (US Energy Information Agency, 2011). Therefore, reduction of the MEL is a key area of research for global energy reduction and for achieving zero-net-energy homes. The whole-house switch (WHS) is an energy efficiency measure that can reduce the MEL by eliminating much of the standby energy consumption (Burgett and Chini, 2013; Burgett, 2015). A study conducted among 12,000 respondents in the USA, found that the WHS would save the average US household 282 kWh/year, or 7.0–23.6% of the home's total residual MEL which corresponds to an approximate savings of 1.2–3.7% of the home's total electrical consumption (Burgett, 2015).

Technological innovations have proven to be an important method to reduce standby energy consumption. Despite this rosy prospect, due to the economic conditions of a subset of the households, it may take a relatively long time to replace existing appliances. This will apply more in particular to the households in developing countries.

Governmental regulations

From the late 1990s, governments in different parts of the world are implementing standby power policies with success (Bertoldi et al., 2002). Four policy tools have shown their effectiveness (Mohanty, 2001): Setting standby power efficiency standards; Voluntary agreements between industry and government; Appliance labelling; and other complementing policies such as Market transformation initiatives, Technology procurement programs and the introduction of Economic instruments and Awareness campaigns.

Concerned with the huge monetary consumption and environmental impacts of standby energy consumption, governments in several countries have initiated programs to address this issue. The International Energy Agency (IEA), the Organization for Economic Cooperation and Development (OECD) Paris-based autonomous intergovernmental organization with 30-member countries, launched in 1999 the One-Watt initiative to ensure through international cooperation that by 2010, all new appliances sold in the world would use only 1 W in standby mode. This would reduce CO_2 emissions by 50 million tons in the OECD countries alone by 2010; the equivalent to removing 18 million cars from the roads (Lebot et al., 2000). Later, the IEA ambition was further raised to 0.5 W in 2013. The IEA initiative has given rise to regulations in many countries and regions. The IEA initiative has been successful (Fung et al., 2003; Heo et al., 2008; Pano, 2017; Siderius, 1998). By 2010, the participating IEA member countries banned the production of all appliances with a standby power above 1 W. Similarly, non-member countries could choose to ban the import of all appliances with a standby power above 1 W.

Voluntary agreements between industry and government enables industry to negotiate goals that are achievable and cost-effective within the proposed time-frame. As more and more products are being sold across borders, industry is evolving voluntary standards in an international setting. Some widely recognized international organizations such as the International Standardization Office (ISO) and the International Electro-technical Commission (IEC) are often instrumental in making technical product specifications which are followed by most manufacturers.

The introduction of standby power labels helps consumers to purchase an appliance with a lower standby power. Public authorities, e.g. can prescribe the use of eco-labels such as the Energy-star-label to enable customers to make comparisons between appliances with respect to their standby power efficiency (Clement et al., 2007). In addition, market incentives such as tax credits and energy taxes can increase the demand for energy-efficient appliances (Chakraborty & Pfaelzer, 2011).

Policy implications for the Curaçao case study

Until today, Curaçao, has no appliance manufacturing industry. Therefore, it will be difficult to implement technological innovations that can help to reduce standby energy consumption. In addition, considering the meager results that were so far obtained to inspire end-users to reduce their standby energy consumption, it is expected that governmental regulations which are directed to reduce standby energy consumption will be the most effective. Given the findings of the field study, regulations that encourage the exclusive import of only 50 Hz appliances would considerably reduce the standby energy consumed by the widespread transformer use. Furthermore, the local government should also favor the purchase of appliances with an operating voltage that matches with its intended location. This can be enabled by implementing import duties that significantly favor the demand for energy-efficient appliances in general and the demand for appliances with low standby power more specifically.

Furthermore, setting minimum standards for the market in general plays an important role in ensuring that the devices sold have low standby power, with the overarching goal of ensuring that all devices meet the same basic requirements. This, in turn, not only reduces household energy consumption and cost savings for consumers, but it also has environmental benefits, while at the same time incentivizing sellers to sell appliances that are both environmentally sustainable and financially profitable.

Contributions and future research

Contributions

To the authors' knowledge, this is the first study, in which average standby power and standby energy consumption of households in tropical areas are determined. Households in tropical areas often have one or even more air conditioners. This results in a different composition of appliances. But also, the usage patterns of appliances, if compared with other regions, may differ. As a first step to fill this gap in literature, a detailed study has been conducted to measure the magnitude of standby energy consumption of home appliances on the tropical Caribbean island Curaçao. It has been estimated that the total standby energy consumption in the household and the total energy use in the household are 4272.9 kWh/year and 195.5 kWh/year, respectively. This means, that standby energy consumption is responsible for about 8% of residential end-use of electricity in Curaçao. As such, standby power ranks among the largest end-uses of electricity in households.

In addition, based on a detailed literature review, we have explored options for reducing standby energy consumption. This review revealed that standby options can be significantly reduced through the adoption of technological innovations, the implementation of governmental regulations and by increasing awareness and knowledge among consumers how to reduce standby energy consumption. For small islands like Curaçao, without an appliance manufacturing industry, the local government should play a principal role by implementing import duties which significantly favor the demand for energy-efficient appliances in general and appliances with low standby energy consumption in specific.

In general, the establishment of minimum standards for the market plays an important role in ensuring that the devices sold have low standby power, as it results in a reduction in household energy use, improves cost savings for consumers and contributes to environmental benefits.

The introduction of a standby power grant program would benefit eligible Curaçao residents such as low-income households. For example, this program could help low-income households to purchase appliances with low standby power. The government of Curaçao, the utility company, or other organizations could finance this program.

Encouraging behavioral changes in students and teachers in Curaçao is another critical aspect of a standby power program. This may include educating students and teachers on energy conservation practices, such as to unplug appliances when they are switched off, fully charged, or not performing their main functions.

Future research

This study is not without its limitations and from these various directions for future research can be derived. First, a main limitation of this study relates to the size of the conducted field study. The field study was conducted within 20 households in Curaçao and focused only on the technical aspects related to the household appliances. It is recommended to extend the field study by extending the number of households and to focus on more aspects like studying variables such as the awareness of standby energy consumption per household, income level per household, education level, and the number of occupants per household. This will not only help to determine the standby energy consumption more accurately but will also be helpful to set up targeted standby power policy programs.

The economy of Curaçao can be defined as a high-income economy. The island has a well-developed infrastructure with strong tourism and financial services sectors. Shipping, international trade and other activities related to the port of Willemstad (like the Free Trade Zone) also make a significant contribution to the economy. To build up a more complete overview about standby energy consumption in the Caribbean, it is recommended to extend this research by including other countries in the Caribbean with a much lower standard of living. It is expected that countries such as Cuba, Haiti and Venezuela will not only have fewer electric appliances, but also, that the appliances that are available, are most of the time not state-of-the-art. Consequently, higher standby energy consumption may be assumed for the individual households in the Caribbean with a lower standard of living.

Declarations

Conflict of interest The authors declare no competing interests.

Appendix. Survey questions to measure standby energy consumption in Curaçao

1. What is standby energy consumption?
2. Do you switch off your computer, when you are not using it?
3. Do you use power strip to switch off your computer, and printer, when they are not performing their main task?
4. How much time do you use your computer per day?
5. Do you unplug the charger of your laptop, when you are not using the laptop?
6. How much time do you spend on your laptop per day?
7. Do you unplug the charger(s) of your telephone, when it is not in use?
8. Do you unplug your printer when you are not using it?
9. How much time do you use your printer per day?

10. Do you unplug your wireless router when it is not performing its main task?

11. How much time do you use the wireless router per day?

12. Do you unplug your microwave, when you are not using it?

13. How much time do you use the microwave per day?

14. Do you unplug your television and decoder when they are not performing their main task?

15. How much time do you watch the television per day?

16. Do you unplug your stereo set/radio when it is not performing its main task?

17. How much time do you listen to your radio per day?

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