Decreasing the Residential Energy Consumption: Habitual Behaviours of Occupants

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Abstract
In the residential sector, energy demand may be divided mainly into six different types of final energy use: cooking, air heating, water heating, air cooling, lighting and other electric equipment. The energy consumption associated with the different energy services is influenced by the way consumers use each of them, making consumers playing an important role on residential energy consumption. Up to 20 % energy savings can be achieved by actions targeting behaviour. Accordingly, this work aims to identify, considering the Portuguese reality, the residential equipment with more potential for behaviour change actions in the residential sector as well as the most relevant energy saving behaviour associated with each one. Four criteria were defined to identify the set of equipment to be analysed: the ownership rate of the equipment, its annual energy consumption, its load diagram shape and the availability of general quantitative data. Considering these criteria, it was concluded that, among 25 different residential equipment, the most suitable for actions targeting behaviour are lighting systems, washing machine, refrigerator, television, computer and dishwasher. Each type of behaviour was linked to demand-side management actions by considering the type of loads it represents: investment dependent loads (all the identified equipment except the television and computer), deferrable loads (washing machine and dishwasher), loads responding to changeable parameter settings (refrigerator) and loads prone to energy conservation actions (all the identified equipment). In this work, special attention is given to loads prone to energy conservation actions.

Keywords: energy saving behaviours, residential equipment, behaviour change, energy conservation

Introduction

In the residential sector, energy demand may be divided mainly into six different types of final energy use: cooking, air heating, water heating, air cooling, lighting and other energy services. In Portugal, a big fraction uses electricity, which fulfils the total demand of air cooling, electric equipment and lighting systems (INE, 2011).

To reduce the energy consumption in this sector, improving the energy efficiency of equipment is crucial. However, the way consumers use the different energy services also plays an important role. General energy efficiency policies in OECD countries have focused essentially on increasing the energy efficiency of buildings, appliances, vehicles and industrial equipment and operations. Less attention has been paid to changing consumer behaviour (Geller et al., 2006) and there is a growing evidence in the literature demonstrating that there is a potential of energy savings up to 20 % due to measures targeting behaviour (European Environment Agency, 2013), such as behaviour change programs and Demand-side Management (DSM) actions.

Despite the Portuguese population already adopt some energy saving behaviours, their adoption rates may have potential to be enhanced. The aim of this work is to identify, considering the Portuguese reality, the residential equipment with higher potential for actions targeting behaviour and the most common energy saving behaviours associated with each one. Moreover, values of the behaviours' adoption rates are also explored, based on studies conducted in Portugal during the last years.

This work is organized as follows: section 2 describes the methodology employed to select the equipment and the behaviours, section 3 presents the results regarding the selection of the equipment with higher potential for actions targeting behaviour, in section 4 the most common energy saving behaviours are presented, as well as some of their impacts on energy consumption and their adoption rates obtained from several Portuguese studies. The main conclusions of the work are presented in section 5.

Methodology

This section is divided in two parts. The first part presents the methodology employed to identify the equipment with higher potential for actions targeting behaviour. In the second part the methodology is presented regarding the identification of the most common energy saving behaviours associated with each equipment.

Selection of Residential Equipment

Twenty five (25) different residential equipment were analysed. To identify the ones with higher potential for actions targeting behaviour, four criteria were used: 1) the ownership rate of the equipment, 2) its annual energy consumption, 3) its availability of quantitative data, namely from past projects and monitoring programs and 4) its load diagram shape, more precisely, the difference between the time of occurrence of the typical daily global load diagram peak, in Portugal usually around 11 am and 8 pm, and of the typical daily load diagram peak of the equipment. The criteria were analysed for Portuguese households. When Portuguese data were not available, European values were used wherever there was not a significant difference between the two realities.

The decision analysis procedure was accomplished using the JSMAA decision analysis tool (Tervonen, 2014). No preference among the criteria was established, having all the same weight.

Identification of Energy Saving Behaviors

Taking into account the selected equipment, a review was carried out of studies which, in one of the phases, surveyed a certain sample of the Portuguese population about energy saving behaviours. It must be noted that, in Portugal, there is no systematic study addressing energy saving behaviours. Moreover, the scopes and methodologies of the surveys reported by the studies reviewed were different. Briefly, Energaia (2011) launched a survey during 2010 among 1014 households spread throughout the country; INE (2011) launched a survey during 2010 among the 3773956 households existing in Portugal at that year; Ferreira et al. (2008) launched a survey during 2007 among 206 households spread throughout the country, although the participation in this project was voluntary; Carvalho (2013) launched a survey during 2013 among 30 households in Amadora, Sintra, Oeiras and Cascais regions; Rebelo et al. (2011) launched a survey during 2010 among 731 students in Lisbon with ages between 12 and 20 years old; Costa (2011) launched a survey during 2011 among 562 individuals, with ages between 30 and 50 years, working or studying at universities, spread throughout the country. ADENE (2011) launched a survey during 2011 among 1005 individuals, with ages between 18 and 65 years old, spread throughout the country; Ferreira (2009) launched a survey during 2009 among 3371 households spread throughout the country, however, mostly located in Lisbon and its outskirts. Pinheiro (2008) launched a survey during 2007 among 89 washing machines and 91 dishwasher's users from a building complex in Lisbon. Morais (2009) launched a survey during 2009 among 32 households in an urbanisation in Vila Real region. János (2011) launched a survey during 2011 among 1582 students of the University of Coimbra.

Based on the studies reviewed, possible energy saving behaviours with room for improvement were identified as well as their adoption rates in samples of Portugal.
Commonly, energy saving behaviours are divided into investment and habitual behaviour. Investment behaviour is related to the adoption of new technology, occurring occasionally and is commonly related to the adoption of new equipment. Habitual behaviour is a routine, being automatically repeated by consumers without a previous evaluation of its consequences. However, in this work, the behaviours are categorized according to the type of electricity load they represent: investment dependent loads, deferrable loads, loads responding to changeable parameter settings and loads prone to energy conservation actions.

The next sections present the results of the decision analysis procedure accomplished to identify the equipment with higher potential for actions targeting behaviour, followed by the identified behaviours associated with those equipment.

Residential Equipment

The 25 residential equipment were evaluated according to the criteria described previously. The load diagram criterion was analysed only for equipment with an ownership rate higher than 10 %. For this reason, a pre-evaluation of the equipment was carried out according to the ownership rate criterion. **Table 1** presents the set of equipment having an ownership rate higher than 10 % and weighing more than 1 % in the household annual electricity consumption.

Table 1: Selected equipment to be analysed under the load diagram criterion

Equipment	Ownership > 10 %	Annual consumption > 1 %	Data availability
Television (plasma, CRT or LCD)	✓	✓	✓
Refrigerator (with or without freezer)	✓	✓	✓
Washing machine	✓	✓	✓
Computer (desktop or laptop)	✓	✓	✓
Dishwasher	✓	✓	✓
Lighting	✓	✓	✓
Microwave oven	✓	×	✓
Separate Freezer	✓	✓	✓
HVAC	✓	✓	×
Water heating	✓	-	×
Electric stove/oven	✓	-	×
Clothes dryer	✓	✓	×
Vacuum cleaner	✓	✓	×

The load diagram criterion was only analysed for the equipment listed in **Table 1**. In **Table 2** it is presented the temporal deviation of the peak consumption of each equipment from the daily global peak consumption, which was the measure of the load diagram criterion.

Table 2: Deviation from daily peaks (hours)

Equipment	1st peak (≈11 am)	2nd peak (≈8 pm)
Microwave oven	0	2
Refrigerator (with or without freezer)	0	-
Electric stove/oven	2	-
Vacuum cleaner	2	-
Water heating	2	3
Washing machine	2	0
Television (plasma, CRT or LCD)	2	-
Lighting	2	3
Computer (desktop or laptop)	2	-
Dishwasher	2	-
Clothes dryer	2	4
HVAC	4	5
Separate Freezer	N/A	-

Taking into account the four criteria, it can be concluded that the lighting systems, the washing machine, the refrigerator, the microwave oven, the television, the computer and the dishwasher are the equipment which have a higher probability of being ranked in the first positions of the decision analysis procedure, corresponding to the most suitable equipment to be analysed. In the opposite way, the printer, the stereo system, the dehumidifier, the washing/drying machine, the central vacuum cleaner and the separate freezer represent the set of equipment with no particular relevance to this

study. Among the other equipment, the potential is relatively indifferent. However preference should be given to HVAC systems (electric heater, heat pump, air conditioner and fan) followed by the remaining: clothes dryer, electric boiler, electric stove, vacuum cleaner, iron, electric oven, DVD player and radio. Regarding the microwave oven, despite its relevance to this study it was excluded from further analysis due to lack of available data.

Energy Saving Behaviors

In this section, the most common energy saving behaviours associated with each equipment are presented. Energy saving behaviours related to lighting systems are related to turning off the lights when not necessary, replacing inefficient light bulbs, which can reduce up to 80 % of the lighting energy consumption of a household, using sensors and/or light intensity regulators, and using daylight instead of artificial light.

Associated with the washing machine, the most common saving behaviours are the use of low temperature cycles, the use of the total capacity of the washing machine and the deviation of its usage to off-peak periods. In fact, the difference between washing at 30 and 60 ºC implies a consumption increase of 200 to 400 %. Shifting the usage of the washing machine to off-peak periods, in spite of not contributing directly to energy savings, contributes indirectly by reducing the daily peak demand at the country level.

The refrigerator is the equipment to which the largest number of different behaviours can be applied. The most common are related to its operating temperature, the number of times and period of door openings (for each time a door of a refrigerator with freezer/combined refrigerator-freezer is open for 10 seconds, its energy consumption can increase from 0.2 to 2 %), the non-existence of a layer of ice in its internal surfaces (a layer of ice higher than five millimetres can increase the consumption to around 30 %), its location (surrounding environments with less 5 ºC reduces the refrigerator's consumption up to 30 %), the habits of unfreezing and do not keeping warm food inside it (keeping warm food inside it can increase its consumption from 10 to 15 %). Moreover, behaviours related to its maintenance, such as keeping the seals, the condenser and the auxiliary ventilator in good operating conditions can be seen as saving behaviours.

Associated with the television and computer there are two similar behaviours which should not be confused. One of them consists of interrupting the equipment operation when not necessary (either by turning it off completely or leaving it in stand-by mode), and the other consists of actually switching off the supply, avoiding the stand-by mode. The stand-by mode consumption can represent around 30 % of the electricity consumption of the equipment.

The behaviours associated with the dishwasher are related to using low temperature washing cycles, fulfilling its total capacity, allowing natural drying by skipping the drying phase and deferring its usage to off-peak periods. In fact, the electricity consumption of a 60 ºC cycle exceeds by 30 % that of a 50 ºC cycle, and interrupting the washing process before the drying process, allowing a natural drying, can reduce up to 50 % the electricity consumed per cycle.

Table 3 summarizes the described behaviours and categorizes them according to the type of load they represent: investment dependent loads (INV), deferrable loads (DEF), loads responding to changeable parameter settings (PAR) and loads prone to energy conservation actions (CON).

Table 3: Common behaviors and types of loads associated with each by type of equipment

	Energy Saving Behaviour	Type of load
Lighting systems	Turning off the lights when not necessary	CON
	Replacing inefficient light bulbs	INV
	Using sensors and/or light intensity regulators	INV
	Using daylight instead of artificial light	CON
Washing machine	Using low temperature cycles	CON
	Using at full load	CON
	Deferring the usage to off-peak periods	DEF
	Replacing for a more efficient one	INV
Refrigerator	Adjusting the operating temperature	PAR
	Reducing the number of times and period of door openings	CON
	Removing the layer of ice in the internal surfaces	CON
	Changing the location	CON
	Avoiding placing warm food inside	CON
	Keeping the seals, the condenser and the auxiliary ventilator in good operating conditions	CON
	Replacing for a more efficient one	INV
Television and Computer	Interrupting the operation when not in use (either by switching it off or leaving it stand-by)	CON
	Switching off the supply (avoiding the stand-by mode)	CON
Dishwasher	Using low temperature cycles	CON
	Using at full load	CON
	Allowing natural drying by skipping the drying phase	CON
	Deferring its usage to off-peak periods	DEF
	Replacing for a more efficient one	INV

Regarding energy saving behaviours associated with loads prone to energy conservation actions, **Table 4** present the average adoption rate obtained from the studies reviewed. The average values were determined by using as weighting factor the sample size considered by each individual study. Accordingly, the sample size presented in **Table 4** corresponds to a virtual sample size which corresponds to the sum of the samples sizes of each individual study. In terms of the individual studies, the samples sizes referring to number of households were converted to number of individuals, by considering an average of 2.6 individuals per household. Studies using different scales of adoption frequency of a certain behaviour (e.g. from always to never or from most times to rarely) were combined by considering the cumulative values up to the middle point of the scale (e.g. from always to sometimes). As a result of such considerations some information was lost.

According to **Table 4** the energy saving behaviours with more room for improvement are using low temperature cycles in both the washing machine and the dishwasher, followed by using the dishwasher at full load, switching off the supply of the television (avoiding the stand-by mode) and turning off the lights when not necessary.

It is important to note that this values may not represent the Portuguese reality mainly for two reasons: i) the studies reviewed analysed samples with quite varied characteristics and ii) the answers provided by the respondents of each individual survey correspond to what they claim their own behaviour to be, which may not correspond to their reality.

Table 4: Loads prone to energy conservation actions: adoption rate of behaviours and virtual sample size

Equipment	Energy Saving Behaviour	Sample size	Adoption rate (%)
Lighting systems	Turning off the lights when not necessary	4332	62
Washing machine	Using low temperature cycles	1092	16
	Using at full load	11577	83
Refrigerator	Closing the refrigerator's door quickly	731	96
Television and Computer	Interrupting the operation when not in use (switching it off or leaving it stand-by)	814	95 (PC), 88 (monitor) and 97 (TV set)
	Switching off the supply (avoiding the stand-by)	All the population	57 (TV set) and 90 (PC)
Dishwasher	Using low temperature cycles	1014	14
	Using at full load	10015	56

The following paragraphs present, the behaviours associated with loads prone to energy conservation actions, more detailed values of adoption rates obtained by the different studies.

Lighting Systems

Several studies reported conclusions about the habit of turning off the lights when not necessary. In one of them it was concluded, that 62 % of the respondents almost always adopt this behaviour (Energaia, 2011). Other studies present similar values. For example, Rebelo (2011) concluded that 57 % of the respondents claim to almost always turn the lights off when leaving a room and it becomes empty. However, in another study slightly higher values were found, varying from 75 to 85 % (ADENE, 2011). When analysing the adoption rate of the complementary of this behaviour, i.e., leaving the lights on when nobody is in the room, the values seem to be in agreement with the referred previously. According to Rebelo et al. (2011), 61 % claim to almost never leave the lights on when nobody is in the room (Rebelo et al., 2011). According to the approach used by János (2011), on average the respondents often turn off the lights when leaving a room for more than 5 minutes or before leaving it, and they claim it to be probable to try to behave in that way in the next 2 months.

Washing Machine

Some studies evaluated the behaviour associated with washing cycle temperatures of the washing machine. However, for this type of behaviour, it was observed that the results particularly depend on the sample. For example, one of the studies concluded that 61 % of the households habitually use low temperature washing cycles (between

30 and 40 ºC), whereas almost 20 % of them use 60-degrees washing cycles (Carvalho, 2013). However, in another study it was concluded, that only 12 % of the households use low temperature washing cycles (Energaia, 2011). Both studies contrast with a third study, which concluded that among all the households, 87% of them use washing cycles limited to 40 ºC (F. Ferreira et al., 2008). However, the participation in this last study was voluntary, probably biasing the results.

Several studies addressed the habit of using the washing machine at its full capacity. One of the studies evaluates this type of behaviour for different Portuguese regions. The variation among the regions is not significant, being the adoption rate of 21 %, on average (ADENE, 2011). Even lower, was the adoption rate of 9 %, obtained by Energaia (2011), which also evaluated different regions. On the contrary, Pinheiro (2008) concluded that 80 % of the respondents use the washing machine at its full capacity. However, this study is referent to a building complex in Lisbon, a strict sample, in opposition to the other two studies referred. Two other studies, besides evaluating the adoption rate of this behaviour, also considered its frequency of adoption. This fact, apart from hampering the comparison with the previous studies, may conduct to different results. Despite that, the results obtained in the two studies are reasonably in agreement: one of them concluded that 79 % of the respondents declare to always use the washing machine at its full capacity, 19 % sometimes and only 2 % of them claim to almost never use it full (Costa, 2011); the other concluded that around 85 % of the respondents declare to always use the washing machine at its full capacity and around 10 % of them to usually use it even if not full (A. G. Ferreira, 2009).

Refrigerator

Despite the large number of potential energy saving behaviours associated with the refrigerator, compared to the other energy services analysed, little information could be gathered. No studies were found concerning the habit of unfreezing food and storing warm food inside the refrigerator, as well as the habits related to the refrigerator's maintenance. Regarding the habit of opening the refrigerator's door, Rebelo (2011) concluded, that more than half of the respondents almost always close the refrigerator's door quickly when using it, avoiding keeping it open for long periods. However, this was the only study addressing energy savings behaviours specifically related to the refrigerator's use, as a result no comparison of values is possible with other studies.

Television & Computer

Considering the electric equipment in general, and not specifically the television and the computer, several studies presented values about the habit of switching off the equipment's supply (avoiding the stand-by mode). From the reviewed studies, the adoption rate of this type of behaviour varies between 35 and 61 %. However, in three of them, this range is shortened to values between 40 and 49 % (ADENE, 2011; Energaia, 2011; A. G. Ferreira, 2009). Two other studies evaluated the habit of leaving the equipment on stand-by mode instead of using the on/off button (Costa, 2011; Rebelo et al., 2011), i.e. the complementary habit of switching off the supply (avoiding the stand-by mode). The results presented are quite similar to the ones referred before. Assuming that "never leaving the equipment on stand-by mode" is

equivalent to “always switching off the supply”, it is possible to conclude that between 31 and 36 % of the respondents usually switch off the equipment’s supply (i.e., almost never, never or sometimes leave the equipment on stand-by mode).

Regarding the television individually, it is known that from the 7475656 televisions existing in the Portuguese households in 2011, 43 % of them were usually left on stand-by mode (INE, 2011), existing on average two televisions per household, as national statistics at country level show. When studies are targeted to small samples, different values may be obtained. According to Morais (2009), around 30 % of the respondents claim to switch off the television supply, avoiding the stand-by mode.

In the case of the computer, according to national statistics, from the 3102548 computers existing in the Portuguese households in 2011, only 10 % of them are usually left on stand-by mode, existing on average one computer per household (INE, 2011). Similarly to the case of the television, this value varies with the sample considered. Morais (2009) concluded that around 90, 70 and 50 % switch off the supply of the desktop, the monitor and the laptop, respectively, avoiding the stand-by mode.

Dishwasher

There are some studies concerning the dishwasher’s washing temperature. However, similarly to the case of the washing machine, the adoption rate of a certain temperature considerably varies with the study. Besides, the different questions used in the surveys used by each study make it difficult to make a comparison among the values obtained.

For the sample analysed by Carvalho (2013), temperatures between 30 and 45 ºC are used by 35 % of the respondents. However, in other study it was concluded that only 12 % use low temperature washing cycles, not specifying the temperature values (Energaia, 2011). And in another study, it was concluded that 44 % use temperatures higher than 60 ºC (F. Ferreira et al., 2008).

According to the study performed by Ferreira (2009), the use of the dishwasher at its total capacity is a habit always adopted by around 60 % of the respondents, declaring only 5 % of them to usually use it even if not at full capacity. A slightly higher adoption rate was presented in another study, which concluded that 80 % of the users use the dishwasher at its full capacity (Pinheiro, 2008). However, in this study no frequency of adoption is referred, making it quite difficult to compare with the former. On the other hand, according to another study, only 9 % of the users claim to adopt such behaviour (Energaia, 2011).

Conclusions

The residential equipment with higher potential for actions targeting behaviour and a set of common consumers’ behaviour related to each one were identified, for the Portuguese reality. To identify the most relevant equipment, four criteria were assessed under a decision analysis procedure. Considering these criteria, the results indicate that, among 25 different equipment, lighting systems, washing machine, refrigerator, television, computer and dishwasher are the equipment with higher

potential for actions targeting behaviour. Printers, stereo systems, dehumidifiers, washing-drying machines, central vacuum cleaners and separate freezers belong to the group of equipment with lower potential for actions targeting behaviour.

Different types of behaviour associated with the referred equipment were identified for the Portuguese reality. Studies which employed surveys launched in Portugal during the last years, addressing each behaviour, were reviewed. For the majority of the identified behaviours, studies were found with relevant information. However, most of the times that information varies significantly from study to study, mainly due to the sample considered by each one. Moreover, the use of different types of questions to obtain similar information, make the comparison among the studies a challenging task. From the identified types of behaviour, no relevant data could be collected regarding behaviours related to daylight use, the removal of the layer of ice in the internal surfaces of the refrigerator, interrupting the television and/or computer operation when not in use (either by switching it off or leaving it stand-by) and allowing the natural drying of dishes when using the dishwasher.

According to the data collected from the studies, the energy saving behaviours with more room for improvement are using low temperature cycles in both the washing machine and the dishwasher, followed by using the dishwasher at full load, switching off the supply of the television and turning off the lights when not necessary.

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