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A simplified model for the electrical energy consumption of washing machines

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ABSTRACT

In order to develop a software that aims at helping reducing the electrical energy consumption in the domestic sector of the European Union, it becomes necessary to model the electrical energy consumption of the main home appliances as a function of their features such as energy class, capacity and operating set-ups. This paper focuses on the modeling of electrical energy consumption of the washing machines and its validation through experimental measurements. The model is based on the consumption data of a large number of washing machines – data available on the datasheets of the different devices, freely downloadable from the website of the suppliers and also taking into account the washing cycle temperature. For the oldest washing machines where datasheets are not available we estimate the energy consumption from historical consumption data found in literature. The results obtained by our model are promising.

1. Introduction

In the frame of the "20–20–20" Plan set by the European Union, member states are required to mitigate the climate change due to intensive use of fossil fuels. They are also required to reduce the energy dependence and spending on imports. The three targets that are to be met are briefly summarized below [1]:

i. A 20% reduction in EU greenhouse gas emissions from 1990 levels.
ii. Raising the share of EU energy consumption produced from renewable resources to 20%.
iii. A 20% improvement in the EU's energy efficiency.

Reducing the energy waste in all European economic sectors is the way to increase efficiency and decrease energy consumption, keeping the level of economic activity and welfare constant. Fig. 1 [2] shows that the domestic sector is among the most energy intensive sectors responsible for more than 25% of the total energy consumption hence presents a substantial room for improvement.

As highlighted by Wood and Newborough [3] to reduce the energy consumption in the domestic sector is possible to intervene on the following points:

i. replacing the existing housing stock with low-energy buildings designed primarily to minimize heating and cooling loads.
ii. developing and achieving widespread replication for low-energy consuming domestic equipment (e.g. appliances, lighting and IT).
iii. promoting and achieving "energy-conscious" behavior among end users.

Wood and Newborough [3] states that in order to reduce energy waste in the domestic sector of the European Union it can be useful to intervene by changing inefficient electrical appliances and people's behavior. To foresee the effects on energy reduction due to change in energy behavior and use of energy efficient appliances, reliable energy models are then necessary. Note that it has been demonstrated [4, 5] that the user engagement with models/tools that give an indirect (not in real time) feedback about electrical energy consumption contribute with a reduction of 3.8–8.4% in energy consumption in domestic sector.

This paper is focused on the energy consumption model of a specific appliance, the washing machines, and its validation through measurements on devices. Washing machines were selected among other appliances because their energy consumption is not negligible and, according to Pakula and Stamminger [6], the ownership rate of washing machines is very high: washing machines exist in more than the 90% of the households located in West Europe.

There are many studies about residential energy use modeling but only few are focused on washing machines. Ortiz et al. [7]

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Nomenclature

C	washing machine capacity [kg]
ε	washing machine energy efficiency class [dimensionless]
e	electrical energy consumption per washing cycle [kWh/cycle]
T	water temperature [°C]
Y	device age [year]
K	correction coefficient [dimensionless]
R	ratio between energy consumption at different Y
d	relative error [%]
$RMSE$	root mean square error [%]

subscript

$_T$	Water temperature [°C]

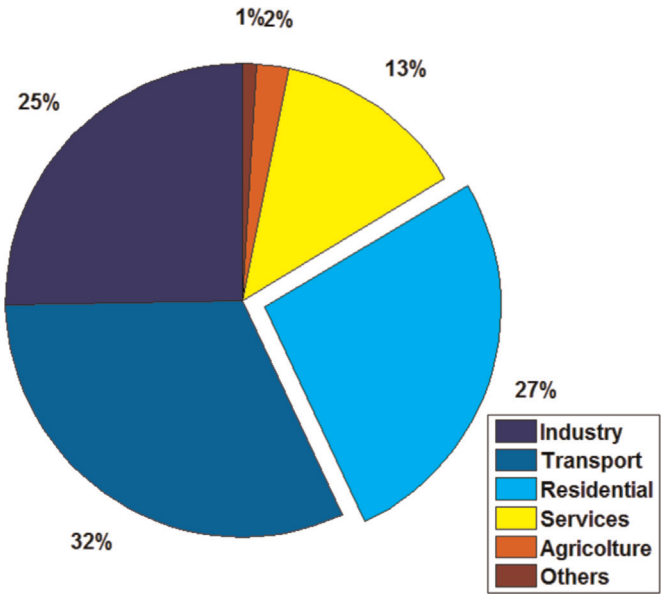

Fig. 1. Final energy consumption breakdown into sectors in the EU 27 [2].

proposed a model aimed at describing the energy consumption (including home appliances) of building clusters and neighborhoods for the Mediterranean regions and Richardson et al. [8] develop a similar model for UK. These models use a stochastic approach to simulate more than one household at the same time. During the simulation, the energy uses are selected and modeled for each household through a stochastic approach. In other words, the model defines stochastically which and how much equipment is present in each simulated dwelling. Then energy consumption is computed choosing randomly which equipment is ON or OFF (or Stand-by), using the probability values for each of them. Considering on statistical base the home appliances installed in a dwelling and their time of operation, these models are able to carefully forecast the energy consumption of a cluster of household with features homogenous to the statistical data utilized. However, these kinds of models are not able to compute the real energy consumption of a household because the home appliance really installed in the dwelling and the habits of the family which live in may be different from the average data used by the model. So it is not possible to compute the real consumption of a family, suggest some interventions to reduce consumption and supply a correct feedback in order to obtain a reduction in energy consumption due to the above mentioned people engagement with tool. The model presented in this paper is able to increase the level of detail moving from the cluster of households to the single home. It makes use of the real features of the washing machine and the user habits in such a way to evaluate the actual electrical energy consumption due to washing machine and to recommend actions to reduce the electrical energy consumption.

Porteous et al. [9] and Pakula and Stamminger [6] are more focused on washing machines. Porteous et al. [9] evaluate the average energy consumption for washing machines through an analysis of 100 households in Glasgow. Pakula and Stamminger [6] present a comparison between the average energy and water consumption for automatic laundry washing in different parts of the world. The results of those analyses are not useful for our purpose because, utilizing an average consumption value equal for all washing machines, independently from their real features and from the habits of the family who use it, become impossible to evaluate the actual consumption and forecast the saving due to the substitution of the devices and change in habits.

A model similar to what we are presenting here is implemented in a tool called Home Energy Saver Software Tool, available on REMODECE website [10]. This software enables to evaluate the consumption of households and to display it split between the different appliances. Moreover, it gives advices on how to reduce the consumption [11]. For every home appliance it evaluates electrical energy consumption utilizing few input data. In particular, for washing machines it uses: weekly number of cycles at 40 °C, 60 °C and 90 °C and device age (grouped in macro groups: less than 5 years, between 5 and 10 years, more than 10 year) [10]. This model utilizes average consumption values from REMODECE measurements campaign, made in 2008. The REMODECE tool does not take into account the energy efficiency class and the capacity of washing machine. These parameters are strictly correlated with energy consumption of a washing machine.

The model of electrical energy consumption for washing machine proposed in this paper allows evaluating the electrical energy consumption utilizing more input data (energy efficiency class, capacity and the exact year of purchase) which are easily available. In fact here they are not taken from experimental data, but they are derived directly from the datasheets of the devices supplied by the washing machines manufacturers. The greater number of input data enables a greater device customization; this allows the users describing its home appliance features in a more complete way.

2. Method and results

According to [6] in the European Union the most common ($>98\%$) type of washing machine is with the horizontal axis. For this reason the model described in this paper is developed for and applicable to washing machines of the horizontal axis type. Moreover we decide to limit the analysis to the devices in which the water is heated by electrical energy and not through other means of heat source, an assessment of the energy consumption for external water heating is difficult because it can be done by other energy sources than electricity, e.g., gas, coal, oil, or solar power. The model estimates the electrical energy consumption per washing cycle of each washing machine, based on the data reported on devices datasheets, which are freely downloadable from supplier website.