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Evaluation of household electricity savings. Analysis of household electricity demand profile and user activities

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Abstract

To achieve reduction in electricity consumption, it is vital to have current information about household electricity use. This allows to draw user behaviour profile based on household electricity demand for a specific time of the day. Activities involving the use of electricity for certain purposes, time of use survey and smart metering data of a four people family were analysed in this study. Household energy efficiency performance till 2020 was evaluated based on increase of equipment energy efficiency driven by technological progress. The results of energy efficiency evaluation for particular household shows that 1219 kWh savings can be achieved due to improvements of energy performance of some mostly used appliances until 2020 (i.e., reduction in electricity consumption of 13 % if compared to present scenario). However, the results imply that user behaviour change is also important to implement the measures associated with energy efficiency improvements in households.

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Keywords: Smart meters; household electricity consumption; user behavior; demand side management

1. Introduction

As reported by the European Environment Agency households represent 25 % of the European energy consumption [1]. Despite countless programs, action plans and measures aimed at reducing building energy consumption, still high savings can be achieved in households. The increased attention also in the political context is being paid to promote energy efficiency in household sector. The Climate and Energy target states that energy

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efficiency in all sectors in the EU need to be improved by 20 % till 2020. A high saving potential of 20 % is estimated through interventions in consumer behaviour [1, 2]. The main drivers for energy efficiency are: increased consumer awareness, appliance purchasing change, change in user habits and routines, as well as reprocessing of current programs, measures, policies regarding household appliance energy efficiency with the aim to encourage consumers to use appliances with lower energy consumption [3].

Several modelling methods have been used for household energy modelling. A bottom-up approach is highlighted as one of the most appropriate method for enabling the user demand pattern and ensuring residential demand response (DR) [4]. This allows determination of activity patterns, appliances and their use at home [5], or occupants' behaviour can be assessed based on energy bills and simple surveys [6]. This technique relies on more detailed housing information and provides greater resolution on energy demand in buildings [6]. Some studies used detailed information on household appliances and occupancy to model electricity use [7−9], while others used the data to construct stochastic models [10−14]. A bottom-up approach used to model household electricity use taking into account user activity patterns (it means, when users are located in the home and awake) and daily activity profiles (how people perform certain activities within the house) was presented in Richardson et al. study [15]. A bottom-up model for electricity and hot water consumption based on time of use data was developed by Widen et al [8] which proved that modelled data compares to very realistic reproductions of measured electricity demand for individual households [8, 15]. Kagvic et al. [16] highlighted the main benefits of bottom-up approach, such as: 1) this approach is simplified and easy to use; 2) macro-economic and socio-economic factors can be assessed with this approach; 3) it can be used to determine energy consumption and related parameters; 4) it can almost always be developed to calculate consumption; 5) highly detailed data are not necessary, since consumption can be assessed based on bills and survey responses. The main disadvantages of this approach are that it requires an extensive database of empirical data and consumption is modelled only based on a household's data in isolation from other sectors of the economy [6, 8, 15−16].

Therefore a bottom-up approach is suitable for enabling the user demand pattern, because it takes into account the activities of the occupants and their associated use of electrical appliances [15]. Electricity consumption in households depends on different conditions: user's personal and socioeconomic factors; the type, size and location of the housing; the number of occupants and appliances used, etc. The use of appliances such as refrigerators and freezers does not depend on the number of occupants in the house [3]. It is evident that there is a high correlation of appliance usage with the occupancy of a household [8, 11, 13, 15, 17, 18−20]. Energy efficiency improvements and savings in the household sector in Latvia have been studied previously [21−24]. In this study a four-person family household has been analysed. Electricity savings potential has been calculated based on equipment energy efficiency improvements in the future.

2. Methodology

The energy efficiency of major household appliances is improving all the time. It is clear that energy efficiency improvements promote the energy efficiency of household appliances. As a result, at the constant user behaviour, electricity consumption is lower. Young [25] argue that it takes time for improvements of energy efficiency to reach the desired level. Moreover, the older appliances are replaced with the new ones deliberately, but only for some longer period of time after being available on the market. Borg and Kelly [26] developed a technique that accounts the effects of appliance energy efficiency improvements. The results showed that electricity consumption can be reduced by 23 % due to transition to energy efficiency improvements of appliances. The scaling factor was developed based on the growth of the technology's development [26]. These yearly scaling factors were developed on the basis of the particular appliances representing the change of electricity use of the appliance affected by energy efficiency improvements. For this purpose data from the UK's Department for Environment, Market Transformation Program was used. The estimated scaling factors of energy efficiency for the most common household appliances till 2020 are summarized in Table 1.

Table 1. Scaling factors for selected appliances till 2020 compared to 2008 present scenario under the future Best Practice Scenario (Adapted from [26]).

Appliance	Scaling factor	Explanations and assumptions for change
Refrigerator	0.467	Mainly A++ technologies available.
Fridge freezer	0.650	Shift towards more efficient technology.
Electric oven	0.690	Shift towards reduction in cooking time and more ready-made meals.
Electric water heater	0.943	Slight improvement brought about by better insulation.
Television	0.782	Technology evolution leading to LED which provide an automatic disconnection stand-by periods or motion sensors if no signs of movement or use.
Domestic lighting	0.502	Increased use of compact fluorescent lamps and LEDs.
Computer	0.364	General improvement in energy-efficiency.
Dishwasher 65 °C cycle; 55 °C cycle	0.845; 0.902	Improved technology and better detergents.
Washing machine 90 °C cycle; 60 °C cycle	0.958; 0.895	Improved technology with better laundry load management.

3. Results

3.1. Analysis of household consumption

For the purpose of our study we analysed one particular 4-person household (2 adults, 2 children) enrolled in the recently launched smart metering project “Promoting energy efficiency of household using smart technologies”. Highly detailed hourly consumption data (even with 5 minute interval) from smart meter during the first year of the project (in a 12-month period from April 1st, 2013 till March 31st, 2014) have been obtained and used for the analysis. In order to clarify consumption pattern household characteristics, number of appliances, time of use and daily usage habits has been carried out due to in-depth household survey. In particular, the number, type, power of home appliances, usage frequency, the exact use of the time during the day, as well as specific usage habits and modes were clarified during the questionnaire. Activities and active occupancy profiles of this household were differentiated between weekdays and weekends, as well as summer and winter time. Distinguishing between weekdays and weekends, as well as summer and winter time, was chosen in order to evaluate what similar and different aspects can be observed based on the type of day, or season of the year and how associated people’s activities and behaviour can affect the pattern of electricity use.

The investigated household is a private house, with an area of 160 m^2, built in 1990, the average time of staying home for all household members per day is 16 h, the living room and kitchen are resided in most when users are at home and awake. The average consumption in the summer is 480 kWh/month, while in the winter – 360 kWh/month. Electricity expenses accounts for 10−15 % of the total monthly housing payments. Heat supply in the household is provided with a pellet boiler (capacity of 15 kW used only during the heating season). The heating season usually begins in October and lasts until March or April (depends on the weather). During the heating season water in the storage water heater is heated by accumulated heat form the pellet boiler. In the summer time (when the pellet boiler is not operating), the storage water heater is set to electrical network and water is heated using electricity. The list of home appliances, power, usage habits is summarized in Table 2. Electricity consumption in the household differs between weekends and weekdays, as well as between summer and winter. In total, 34 different electrical appliances and 52 different light bulbs are used in the household. Outdoor lighting (efficient bulbs) runs on a motion sensor, which is adjusted based on daylight availability. The refrigerator is used continuously throughout the day, followed by LED TV set (150 h/month) and PC (120 h/month). Small kitchen appliances (such as printer, juice dispenser and toaster) are among the least frequently used items. The largest share of total monthly consumption in the summer is accounted for by the storage water heater, electric oven, washing machine, air conditioner, and air humidifier. While in the winter: electric oven, washing machine, floor heating, electric self-consumption of wood pellet boiler and lighting.

Table 2. Survey sheet - user-reported appliance use for the household studied.

Appliance	N°	Power consumption, W	Use of appliances	
			Weekdays	Weekends
CFL light bulbs	12	15	Winter: 6:30−7:30; Winter: 19:00−22:00; Summer: 19:00−22:00	Winter: 8:30−10:00; Winter: 19:00−23:00; Summer: 19:00−23:00
LED bulbs	14	4		
Halogen light bulbs	12	20		
Incandescent light bulbs	6	185		
Daylight bulbs	6	20		
Outdoor lighting	2	9	Periodically for a few minutes during morning and evening	
Refrigerator	2	56	Continuously, 24 hours a day	
Electric oven	1	3500	19:00−20:00	11:00−12:00; 19:00−20:00
Cooker hood	1	170	19:30−20:00	11:30−12:00; 19:30−20:00
Dishwasher	1	2200	1x every two days at 24:00−2:00 (mainly 65 °C cycle)	Every weekday at 12:00−14:00
Coffee machine	1	1050	7:00−7:05	8:00−7:05
Toaster	1	950	–	9:00−9:10
Juice dispenser	1	20	19:00−19:20	11:00–11:20
Blender	1	500	19:30−19:35	19:30−19:35
Bread baking oven	1	600	–	1x month, at different times
Personal computers	1	29	1x every two days at 21:00−23:00	13:00−15:00
Telephone	2	4.5	Charging 1x every 3 days at 21:00−23:00	
Notebook	1	5	1x a week for 2 hours in the evening	
LED TV set	1	13	6:30−7:30; 19:00−22:00	8:30−12:00; 15:00−18:00; 19:00−23:00
Digital TV decoder	1	4.7		
Acoustic sound centre	1	60	19:00−19:30	11:00−12:00; 18:00−19:00
DVD player	1	0.9	20:00−21:30	13:00−15:00; 18:00−21:00
Washing machine	1	2200	2 times every Thursday (mainly 60 °C cycle) at different times between 9:00−18:00	-
Vacuum cleaner	1	2200	2−3 hours every Thursday at different times between 9:00–18:00	-
Iron	1	1310		-
Hair dryer	1	2000	1x every 2 days at 6:50−7:00	8:50−9:00
Printers	2	29	Periodically for a few minutes per day	
Storage water heater (boiler)	1	2000	Only in the summer: 24 hours a day	
Air humidifier	1	72	Only in the summer: Periodically for 30 minutes several times a day	
Ventilation hood	2	26	Only in the summer: Periodically for few minutes several times a day	
Air conditioner	1	1020	Only in the summer: Periodically for 30 minutes several times a day	
Thermo ventilator	1	2200	Only in the winter: Periodically for some minutes several times a day	
Floor heating	1	700	Only in the winter: located in the lobby at the entry in a 10 m^2 area, used	

			approximately 50 hours a year
Self-consumption of pellet boiler	1	150	Only in the winter: operates 24 hours a day to ensure the continuous operation of the pellet boiler for heating purposes

User habits of some appliances' usage is quite similar in the summer and winter time, as well as on weekdays and weekends, such as, refrigerator, PC and notebook, some small kitchen appliances, hair dryer, printer, ventilation hood, TV and others. A different pattern of use is for lightning – in the winter it is used more frequently due to shorter periods of natural daylight (solar irradiation). Seasonal appliances are thermo ventilator, floor heating and electrical self-consumption of wood pellet used in the winter, but storage water heater, air humidifier and conditioning system are used in the summer. It can be noted that cleaning equipment, such as, washing machine, iron, vacuum cleaner are used only on a particular day of the week – every Thursday. Some appliances are used more often on the weekend than on weekdays: lightning, electric oven, cooker hood, some small kitchen appliances (toaster, bread baking oven), entertainment equipment (LED TV set, digital TV decoder, acoustic sound centres, DVD player). This, of course, can be explained by the users' lifestyle and routines. On weekdays the family gets up early in the morning, prepares breakfast, and at around 8:00 the adults go to work, the children – to kindergarten, and at 19:00 or 19:30, the family returns home. On the weekends, however, the family spends more time at home.

When reviewing smart metering data it is evident that the daily electricity load curve over a one hour period differs considerably among the 12-month period (April 1st, 2013 – March 31st, 2014). Based on the information obtained, we made a comparison of measured consumption (i.e., smart metering data) and simulated consumption (consumption is calculated based on user profile using bottom up approach taking into account each appliance power, their number, usage duration under the same principles as described in previous studies [4−10, 13, 15, 18−20]). Also standby consumption (for example for coffee machine, washing machine, DVD player, acoustic sound centre, etc.) have been taken into account for calculations. The aggregate electricity consumption of 4 typical daily profiles (weekends, weekdays, summer and winter) in case of measured data (MD) and simulated data (SD) scenarios is shown in Figure 1.

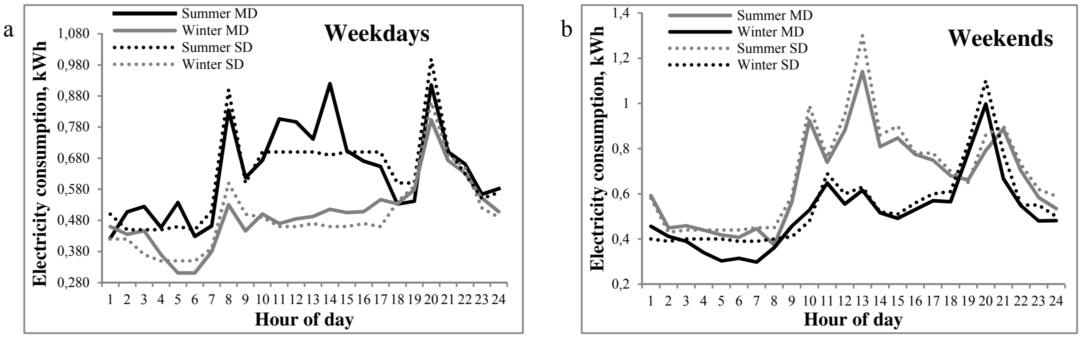

Fig. 1. Electricity consumption curves of measured and simulated scenarios for a) weekdays and b) weekends.

The average electricity consumption for winter is calculated based on average electricity consumption among the winter months from November till February, while for the summer – from May till August. In general, the profiles of all 4 typical cases follow a similar pattern. However some difference can be observed between measured and simulated data. Higher consumption is on weekends due to fact that the family stays at home for a longer time. The household's consumption in the summer is higher and the main reason for this is due to continuous use of the storage water heater. We used the following simplified assumptions for calculations:

1. The nominal power of particular appliance was assumed for the calculations. However, in reality, they do not always work with the same nominal power, but it depends on the specific mode of use.

2. We rely on information provided by the respondent about the time of use of appliances. Nevertheless, users' behaviour is not exactly the same every day.

The higher differences between measured and metered data can be observed on weekdays. At night when the family is sleeping, the amount of electricity used in household is minimal. However, metered data shows higher consumption at night. For weekdays we assume that after 9:00 the family is outside the house and at 23:00 they go to sleep, but metered data shows much higher consumption at these times. This is related to a different rhythm of lifestyle –not always parents arrive at home or go to sleep at the same time. Simulated data better fits in case of weekends. It can be explained that we obtained more accurate information on the use of appliances on weekends. It also explains the increased accuracy of consumption simulation for weekends. In overall, the curves reflect the consumption pattern of households with typical user behaviour. At night when everyone is sleeping (00:00 to 6:00) and when people are at work (from 9:00 to 17:00) electricity consumption is much lower if compared to the time, when the majority of people are at home. Higher consumption is always in the morning, when the family gets up, are taking showers, and preparing breakfast. Then consumption falls in the middle of the day and in the evening consumption again increases when people return home after work (turning on lights, watching TV, preparing dinner, etc.). The horizontal sections of the load schedule show the base consumption created by the refrigerator and appliances operating in standby mode.

3.2. Assessment of energy efficiency improvements in the household

In this section household energy efficiency performance till 2020 are evaluated. Comparison of annual consumption data serves as a basis for assessing increase or decrease of energy efficiency in household. Household consumption in the first year of the project implementation (April 1st, 2013 – March 31st, 2014) was 4791 kWh. It should be noted that before the project, the most commonly used method for monitoring was based on user self-declaration. Household consumption before the project (April 1st, 2012 – March 31st, 2013) was adjusted on the basis of meter readings and user payments, resulting in 6220 kWh which means that decrease in consumption is on average 23 %.

It was found that several energy-efficient measures have been implemented prior to the project, such as, insulated exterior walls and roof, installed efficient lightning and alternative energy sources used for heating purposes (i.e., pellet boiler). The decrease in consumption is quite large. The interview reveals that since participation in the pilot project replacements of 4 incandescent light bulbs to LED were performed as an energy efficient measure. The total investments in energy efficiency measures were ~ 60 EUR. None of the electrical appliances were replaced with new ones or eliminated, or not used. People's attitudes regarding smart meters are positive. It was found that residents look at smart meter readings relatively often at the beginning of the project, but the interest falls with time. Respondents confirmed that they were interested to follow their electricity consumption, but it was not attractive to change behaviour or to undertake some energy efficiency measures.

The assessment of energy efficiency improvements in the studied household till 2020 was performed. For this purpose we used calculations similar to Borg and Kelly [26] for comparing the present scenario and future scenario. The scaling factor of a particular household's appliances was applied in order to model electricity consumption in the future (until 2020). We assumed that all household's appliances are not older than 7−10 years. Due to lack of studies regarding energy efficiency improvements of other household appliances, it was not possible to assess decrease in consumption of all appliances. The results of electricity consumption based on the use of appliances for the present and future scenario are presented in Figure 2. The results show that electricity consumption can be reduced by 13 % for this particular household by 2020 through the use of more energy efficient appliances than those currently used in the household. It is not surprising, that electricity consumption of the electrical water heater accounts for the largest share of final electricity consumption (of course, it is due to the fact, that the heater has a quite high power demand and is used for 24 hours a day in the summer). However, as few improvements are planned for the electrical water heater, if we look at the year 2020, one can expect only a 6.7 % reduction of electricity consumption from the water heater. In order to improve energy efficiency of water heating, it may be recommended to change the current technology to a more effective one. Amore significant reduction can be achieved in regard to the electrical oven (results show the greatest savings). Also considerable reduction in electricity consumption from therefrigerator can be observed, which is the appliance with the third highest consumption in the household.

PC's and lighting allows for 36 % and 50 % electricity reduction, respectively.

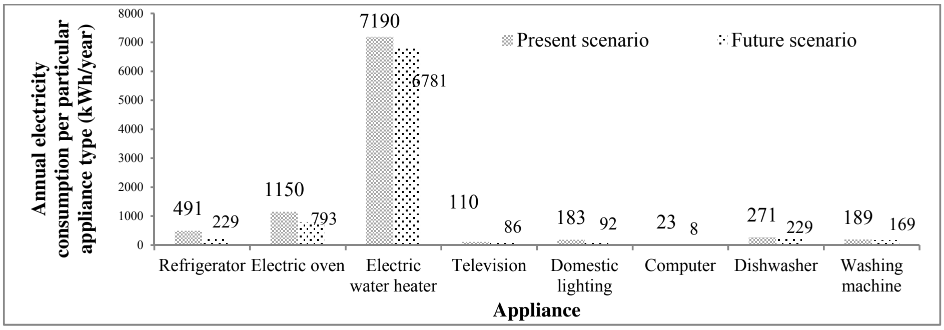

Fig. 2. Annual electrical energy consumption aggregated for household based on the use of appliances.

4. Conclusions and discussion

The purpose of the study was to analyse electricity consumption for one four-person family household. This household is participating in a recent smart metering project in Latvia. A household survey was carried out with the aim to obtain information about the particular household's characteristics (personal, socio-economic data of family members), number of appliances, time of use and daily usage habits.

The results of the energy efficiency evaluation show that electricity consumption can be reduced by 13 % until 2020 in comparison to the present scenario. If we look to the forecasts of future improvements, it can be concluded, that electricity consumption will tend to be less. Whereas electric water heater (boiler) accounts for the largest share of total electricity consumption in the summer and forecasts for technology improvements are not impressive, change in technology or fuel may be more useful. For example, installation of solar collectors can serve as a good solution. As noted by the members of the household, they would be willing to make such a change.

The development of smart systems should be promoted using the experience of European countries and standards. It allows for the consumer to better monitor their electricity consumption by seeing and thinking they can be able to adjust their behaviour and thereby also lower energy bills. For the future DR, focus should be directed to existing experience of user behaviour change to sustainable consumption use based on consumer preferences and expectations. First of all, comparative information on similar households needs to be provided as this information provides feedback for households to compare whether their own consumption might be excessive by comparison. Different consumer education programs need to be targeted to increase the skills and understanding on how to correctly interpret monitoring data. These skills depend particularly on age and education level. Generating behaviour change through community engagement that could be adopted by an increasing number of programmes need to be fostered in the policy context.

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