Energy Efficient Products and Smart Homes

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Abstract

The electricity sector is changing rapidly as we are moving from fossil fuel centralized power stations towards a more distributed and smarter electricity network. The electricity supply must be secured while also lowering the carbon emissions. Smart grid technologies offer the possibility to meet these challenges and develop a "cleaner", more efficient and sustainable energy system enabling also the wider penetration of renewable energy sources. Demand Side Management enables the control of energy exchange between consumers and energy utilities, focusing on the reduction of demand peaks. In this paper we explore the effects of using energy-efficient products and the use of Time Of Use (TOU) pricing on the total energy use, the energy costs for the consumer and the peak-power demand of the house.

We have developed an analytical model which simulates the total homes' energy consumption for specific appliances' use-profiles. The model is built up bottom-up and is composed of different consumer appliances which each have their own power-profile. Three scenarios are investigated and compared the Business As Usual (BAU) benchmark, a standard house without energy-efficient consumer electronics and without any smartness. The first scenario is the Energy-Efficient scenario, where the house is equipped with appliances using Best Available Technologies (BAT). Smart control is introduced in the Smart-TOU scenario, where the effect of TOU pricing on the power demand is investigated. In order to study what would happen if there was a limit in peak power we have simulated the Smart-Peak scenario, where a household does not exceed a certain power threshold during peak-time periods.

The results of the simulation show that a great reduction in energy usage and peak power demand can be achieved when the electrical appliances in a household are replaced by more energy efficient products without compromising on the users' comfort. When smart-controlling is applied a drop in peak power demand is shown of respectively 40% and 50% compared to the BAU scenario. As expected the energy-reduction of both smart scenarios are not significant compared the energy-efficient scenario, but a significant decrease in peak power can be achieved when a certain maximum power threshold is introduced. Unfortunately this does not significantly show a reduction in the users' energy-costs for the household in the specific case simulated, which makes it questionable if there is incentive enough for the household to introduce smart-shifting of appliances.

Introduction

The electricity sector is changing rapidly as we are moving from fossil-fuel centralized power stations towards a more distributed and smarter electricity network. Smart grid technologies offer the possibility to meet these challenges and develop a "cleaner", more efficient and sustainable energy system [1] enabling also the wider penetration of renewable energy sources. In the Netherlands, through smart grid concept, the objective is to reduce energy consumption as well as greenhouse gas emissions [2].

Smart house integration where automation systems are installed monitoring intelligently the daily living of the consumer and its energy use derives as a necessity from the significant changes that the electrical system will foresee while transforming to a smart grid. Smart houses changes the role of the current home, turning it into a more "autonomous block" in a smart grid [3]. That means that the users in a household can decide themselves about their consumption and/or production and with whom they exchange. Electricity consumers not only become more aware of their consumption and relevant subjects, but they also accept a wider installation of smart meters and technologies [4]. The efficiency and sustainability of smart homes is fully exploited through Demand Side Management (DSM), improving in this way the management of the total power grid and enabling the higher penetration of distributed generation.

Smart grid development leads to several emergent technologies each with different impacts on the market [3]. End end-user feedback can help enabling consumers to monitor their energy demand, be informed whether local green energy production is available, at what rate, and to get tips for further reducing energy consumption. The automated decentralized control of distributed generation combined with demand response enables better matching of energy demand and supply conditions. This can be achieved by stimulating users to accept demand management, for example the rescheduling of some of the appliances or other loads, whether this is pre-programmed by themselves or controlled by an external agent. One of the incentives for the consumer to react to this external agent and change its behaviour is lower market prices of electricity. Within this paper we want to investigate if the introduction of smart appliances acting on TOU tariffs will lower the total electricity use and costs of a single household.

A model is developed which generates a household-load profile based on different appliances with their own power profile, and a randomly selected operation time of the appliance. With this generated load profile different strategies decreasing energy- and power-usage are evaluated and compared. A simple home energy management controller is designed which effectively shifts appliances based on total power consumption, pricing variations, user prioritized needs and overload management. This house model forms the basis for testing smart grids in combination with sustainable energy-sources for residential areas, for instance on the island of Vlieland in the Netherlands.

Relative work

Demand Side Management (DSM)

Demand side management includes a number of methods to control the exchange of energy between consumers and suppliers and adapt the power production to the user energy needs. It also focuses on the reduction of demand peaks, which add a significant cost in energy production. According to Long Ha et al. [5] there are two basic forms of DSM: one form is aiming at a direct control of appliances' loads, by cutting off directly those requesting high power or, in other words, by absorbing the sudden variations in demand which cannot be supplied efficiently. This type of DSM is called "emergency DSM". The other form is the "economical DSM", which includes the encouragement of consumers to shift the energy from peak hours to off-peak hours providing financial incentives. With these forms the peak periods are reduced or shifted during the day.

Clastres [2] claims that when additional information about their usage and not just an energy bill is provided to consumers, a reduction of up to 20% in energy consumption can be achieved, consequently leading to significant cost savings. It is claimed that this number comes to 5-15%, while the reduction achieved when just looking at the energy bills ranges between 0-10% showing how low the benefit is when only the consumption status is provided to consumers [6, 7]. When dynamic tariff is applied, energy saving can reach 14% of the consumption. This percentage is twice that of the saving which can be achieved when only meters are adopted [2].

Because of the complexity of the electrical system, the total management and control can be divided in three layers interacting with each other via information flows [5]. The higher level is the load management layer, responsible for the dynamic control of the energy consumption of all the houses, adjusting an upper limit by taking into account customers' feedback and also capacity constraints of the production. The next level is the home automation level, which consists of the Home Automation Systems (HAS) of all houses. A HAS manages the predictions about future user requests and available resources, as well as the variation of market prices. Lastly, the appliance layer, characterized by the fastest dynamics, includes all the appliances and their embedded controls and is responsible for the real-time distribution of energy by taking actions of control like enabling and disabling certain appliances. At this level, the home energy management is one of the current issues nowadays in the market, and maybe the most interesting and promising, since the consumers are trying to save from energy bills and they are encouraged to reduce their consumption not only for decreasing the capital cost for production, but also for limiting the use of fossil fuels the energy of which, mostly goes for generating electricity [6]. Home management systems enable households and utilities to monitor all the appliances, which are connected to each other and to the entire system, control them even remotely and conserve energy. Combined with smart grid technologies, like smart meters home energy management can make us rethink about energy and its usage.

Time Of Use (TOU) Tariffs

Dynamic energy pricing schemes enable the user to decide how and when to use their appliances. Although there might be some people motivated by environmental friendly feelings, most are motivated by economic benefits. Thus, it is really important for the utilities to offer tariffs that can encourage consumers to shift their usage and rethink their daily use habits.

Time Of Use (TOU) tariffs can stimulate consumers to change the use of some appliances by shifting their operation to time periods when rates are lower and of course saving money. The smart appliances respond automatically to utility signals either by shifting the load to non-critical times or "spreading" it, which means extending their operation for longer time and lowering the power demand. Of course the utility, since the appliance cycle will be longer, must reassure that consumer will have an economic benefit for the total cycle [8].

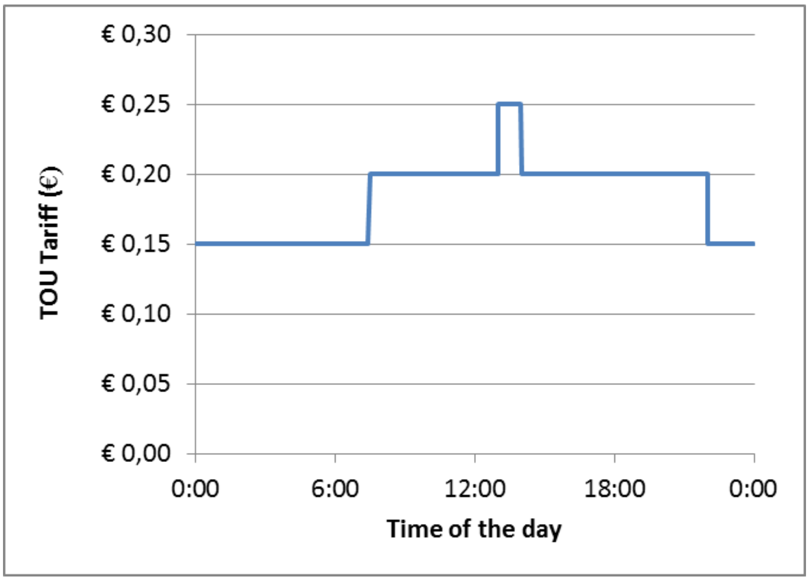

Figure 1: Example of a 3-level TOU tariffs.

According to Stromback et al. [9] a possible scheme of TOU tariffs can include two levels of price, peak and off-peak prices, but there might be also a third level called "partial peak" or "shoulder" level as shown in Figure 1. Peak prices coincide with the time interval where the peak demand of the day appears. Therefore, consumers try to avoid this time period and shift their consumption to earlier or later hours. Furthermore, the TOU tariffs can vary depending on the day and season but consumers should always be aware of them in advance

Models for generating load profiles

Many models have been developed to predict load profiles because of their importance in research of distributed generation and demand side management. Capasso, et al. [10] present a method for load generation based on demographical, socioeconomic data, different functions for the set of appliances involved and probability factors to analyse consumer's consumption behaviour influenced by psychological and behavioural factors. Montecarlo process was used and the approach followed includes two basic steps: the aggregation of individual appliances in order to derive the household load profile and then the aggregation of all the load profiles to extend the model for more houses. However, the measured data used had been taken with 15 minutes time interval.

More recent Paatero et al. [11] used a bottom-up approach where statistics and public reports consist the source for many data needed. The consumption data generated are on an hourly basis while the model makes use of statistical averages and representative samples to overcome the lack of detailed and real data. However, DSM strategies like shifting the appliances to a later time or cutting off the operation of appliances in case of emergency where included for deriving the main demand curve. Novel methods such as generic algorithms and neural networks as well as fuzzy logic are suggested when little information is available about the appliances [11].

Gottwalt et al. [12] have developed a household model where the households are equipped with smart appliances and for which the consumer is charged based on time-based tariffs showing an interest in estimating the potential savings, the investment cost for the additional equipment but also for the amount of load that can be shifted and the peak load that can appear.

Armstrong et al. [13] and in a similar way Esser et al. [14] present a model for the development of which statistical data for the annual power consumption but also probability distributions were deployed. The load curve derived is generated under flat tariffs and then differences in the price for different times of the day are introduced to test the results from load shifting and consumer's response.

Yao & Steemers [15] suggest that the load profiles should be based on residential occupancy and seasonal factors and these methods are mainly based on average household profiles.

This paper proposes a model of a house which generates load profiles by aggregating the appliances in the house and enabling their shifting according to a 3 level TOU pricing scheme, allowing at the same time for different energy reduction approaches and the extension of the model for a wider area or community to be studied.

Design approach and Analysis

The model simulates the impact of energy efficient products and demand side management on the daily energy consumption and the costs of that for a single household. First a study was conducted to examine the potential energy conservation, when energy-efficient appliances replace the existing and less efficient ones in a household, the effects of Best Available Technology (BAT) versus Business As Usual (BAU). Second a simplified home controller was designed in Simulink™ which was used to explore how a home energy management system would contribute to more flexible energy use taking into account the individual consumption profiles of the appliances, the tariff rates and overload management. Technical possibilities such as peak shifting or clipping are inserted in this way, enabling to study what the effects of these scenarios are for the consumer.

The BAU benchmark is considered as a reference scenario depicting the existing trends in households and the energy market, while assuming their continuation in the future. It is also assumed that the structure of the system will be the same for the coming years as well as the consumer's demand behaviour and of course without any reduction in comfort. The houses in this scenario are equipped with a large variety of appliances with only a few of them being highly energy efficient and of the latest technology. Three scenarios are benchmarked against BAU:

1. **Energy Efficient scenario**: using only Best Available Technology (BAT) energy-efficient appliances, at least A-label appliances replace the older less efficient ones in the household. Furthermore three appliances - the dishwasher, the washing machine and the dryer - are chosen not to function at will but only during the low-tariff off-peak time periods (semi-automation).
2. **Smart-TOU scenario:** which uses the BAT appliances together with feedback about TOU tariffs. This scenario focuses on encouraging consumers to change their behaviour. This can be done by giving them feedback about their consumption so they can shift the operation of some appliances to periods when prices are lower. In the model it is assumed that the consumer is willing to change its behaviour based on changing tariffs.
3. **Smart-Peak scenario** where peak shifting and clipping is introduced, by limiting the maximum peak-power consumption of the household [16]. The overload threshold consumption, however, is determined via feedback and information exchange between the supplier and the household.

Modeling the controller

Load Profile generation

The focus of this paper is on developing a model of a house's electricity-use using a predefined load profile based on 25 appliances, and benchmark the different strategies to the BAU scenario. The model was simulated in MATLAB/Simulink just like in [17, 18, 19]. Simulations are performed which help in comparing the energy consumption between the BAU scenario and the Energy Efficient and the two Smart scenarios. Some characteristics of the house model implemented and the inputs that are introduced are summarized and presented later on.

In general the daily load profiles are characterized by power spikes from the different appliances. Averaged data, on the other hand, tend to “lose” information because of the large time intervals they sometimes insert, leading to a considerable reduction in resolution or smoothens out the peaks giving the impression of a low (power) and more constant electricity profile. A typical household may be equipped with 10 up to 60 different appliances, each with its own characteristic and load pattern or use pattern. The household load profile used in this paper is derived from the aggregation of 25 individual appliances (see Table 1). Each household appliance has a unique load profile, which is represented as a pattern. In Figure 2 the load pattern of a three appliances are depicted, the dryer, the dishwasher and the washing machine. The rated power of both the BAU and also the A+ energy-efficient appliances are presented in Table 1, which are collected after a market research.

Table 1: 25 appliances and attributes used for load generation and there rated power.

Appliances	**Power (W) BAU scenario**	**Power (W) EE/Smart scenario**	**User Priority**
Washing machine	2284	1102	3
Dryer	2756	828	3
Dishwasher	1600	807	3
Vacuum cleaner	2200	1250	2
Microwave	1700	900	1
Kettle	3000	2200	1
Laptop	100	50	1
Desktop	300	50[1]	1
Toaster	1000	1000	1
Coffee machine	1000	1000	1
Electric shaver	13	13	1
Hair dryer	1500	1500	1
TV 40”	180	63	1
TV 32”	79	42	1
Food blender	500	500	1
Hob	3000	3000	1
Oven	1400	900	1
Iron	2000	2000	2
Freezer	110	48	1
Refrigerator	90	40	1
Lighting	30-562	30-360	1
CD player	100	60	1
Printer	200	45	1
Phone charger	3.5	4.5[2]	2
Standby of laptop	15	8.9	1

[1] The desktop is assumed to be replaced by a laptop computer in the energy-efficient and the smart scenario’s.

[2] This value is higher than the BAU value because of the higher power consumption while charging new phones as smartphones.

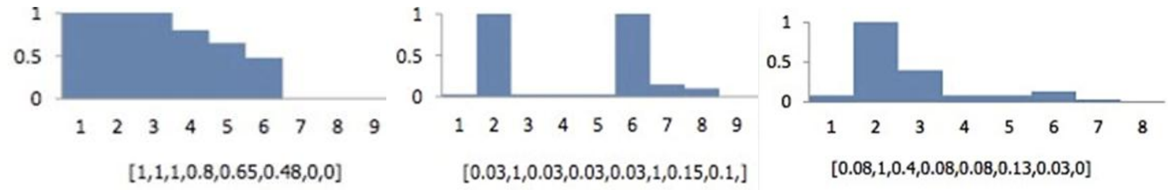

Figure 2: Load patterns for three household appliance, the dryer, the dishwasher and the washing machine, as a percentage of the rated power versus the time in steps of 15 minutes.

Table 2: Level TOU Tariffs used in the house model simulated

	Time period	Tariff (€c / kWh)	percentage per day
Off-peak time period	00:00-07:29; 22:00-23:59	15.00	40%
Shoulder time period	07:30-11:59; 14:00-21:59	20.00	52%
Peak time period	12:00-13:59	25.00	8%

Smart shifting of appliances and control strategy

Nowadays the user prepares the home appliance and after asking for a program, the appliance starts. In smart houses this is not always the case. In both the Energy Efficient and Smart scenario's the user is also asked to set the latest time during the day that he wants the appliance to end its operation. When the user asks for an appliance to operate, the Smart Home Controller (SHC) checks the current market tariff and depending on the appliance's priority level (1, 2 or 3) either it loads the appliance or delays it untill the conditions for price and priority over previously requested appliances are met.

The priorities are set according to user's preference and apart from describing the urgency and consumption needs, they facilitate the shifting to the right price level. For this work, the priorities used for the appliances are based on different previous approaches that can be encountered such as in [16]. The priority numbering is used only in the Energy Efficient scenario, where only priority 1 or 3 appliances are used, and in the Smart Scenarios, where also priority 2 appliances are introduced. The shifting of appliances is based on three different price levels: peak, shoulder and off-peak hours pricing, see Table 2. To be more specific:

1. Priority 1: Appliances that will/have to operate on demand. No shifting is allowed
2. Priority 2: Appliances operate only during off-peak and shoulder periods, like the vacuum cleaner, the iron and the phone charger. The ones that are loaded during peak hours are advised to shift to the first allowed level in the order of appearance first in first out.
3. Priority 3: Appliances which are used only during off-peak hours, like the washing machine, the dishwasher and dryer unless the user has set a prior desired finishing time.

Priority 1 appliances have priority over priority 2, which in turn have priority over priority 3 appliances. In every case, priority 1 describes those appliances that need to be loaded on request, even if there is no "room" below the power threshold. The appliance needs to wait for the total consumption to be restored under the acceptable power limit. The user can set the latest time that he desires the appliance to end and if the appliance is not loaded by that time, the appliance skips the shifting and it is loaded at the end of that margin. Switching off the appliances while operating is not always desirable, so, this is not an option in the simulation model. Different control strategies are incorporated in the controller for the simultaneous request for operation of several appliances. For example, if more than one appliance at the same time and with the same priority are asked by the consumer to operate, the SHC enables the one with the higher power demand to be loaded first. However, it is unlikely that more than one or two appliances start at the same time.

Main Characteristics

Based on the analysis presented in [20] the main characteristics of the house model can be distinguished:

- It is event driven, meaning that it interacts in a dynamic way with the user's request for using an appliance. The controller decisions are based on the power level and price at the moment of request. If the time is appropriate for the appliance to be used or it needs to be delayed till a later time in the day when conditions of usage will be met.
- It takes into account the market prices. The controller shifts the appliances according to the price level that can be provided by the energy provider. It can be understood that the price levels can change from time to time, since the cost and availability of varies, especially for renewable sources
- Time varying signals: Power level showing the peak load demand, consumption profiles of the appliances, and price levels vary during the day. Load limits could also vary according to local renewable sources or in-house generation, for example. However, more variation in pricing and load limits can also be considered.

Results

Business as Usual (BAU) scenario

In Business as Usual (BAU) scenario where most of the appliances in the household are of low energy efficiency, the daily household load curve simulation is shown in Figure 3. According to the load curve depicted in the figure the peak power demand is 6228W while the daily energy consumption is estimated to be 20.1kWh. The energy bill that the consumer has to pay to the energy utility, according to the given TOU tariffs, as described in Table 2, the energy consumed will cost the household around 4,33 €/day.

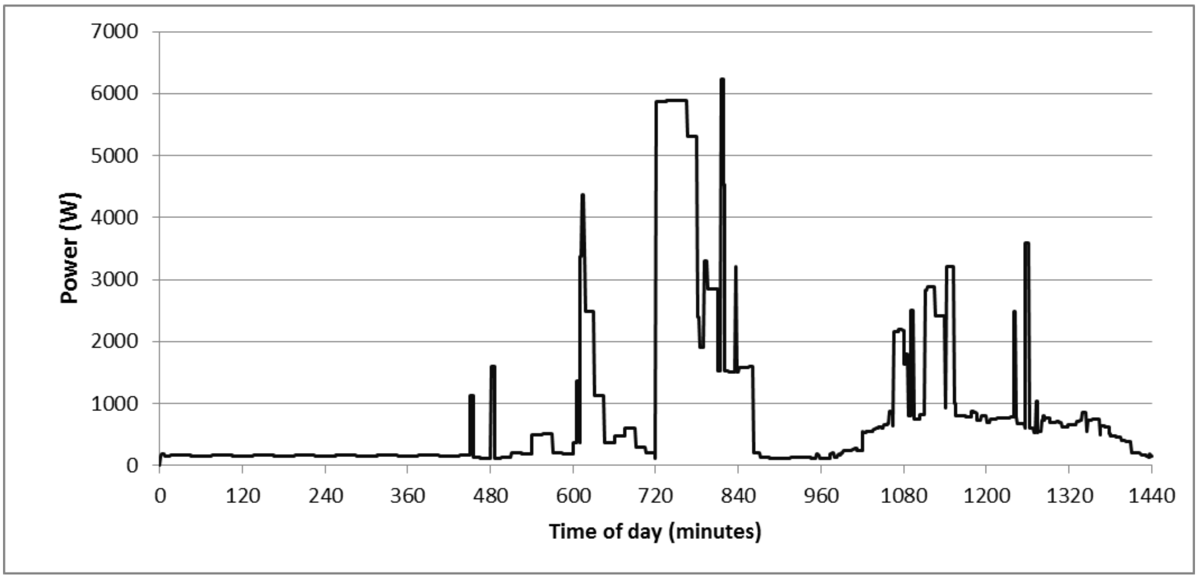

Figure 3: Daily load profile for benchmarked BAU scenario.

Energy Efficient Scenario

In Energy Efficient Scenario the appliances are replaced by energy efficient ones and semi-automated appliances which can be shifted in time (priority 3). The scenario also opperates without loss of comfort. A significant reduction in the daily demand curve can be observed in Figure 4 where the line represents the resulted load from the Energy Efficient scenario and the dashed line the load curve from the BAU.

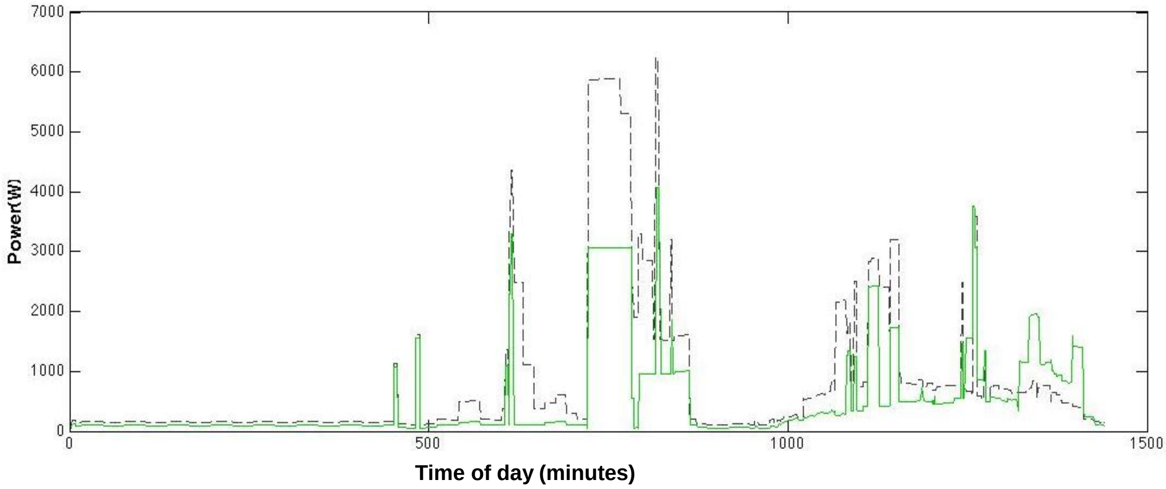

Figure 4: Daily load profile for the Energy Efficient Scenario compared to the BAU benchmark.

The load curve presents an outstanding daily reduction in energy used from 20.1kWh to 12.3kWh (39%), while the peak power was reduced to 4066W (35% of that of the BAU), mainly caused by the lower consumption of the electrical equipment and to a lesser extinct by shifting the semi-automated appliances. Also a significant drop was observed in the energy bill, which was found to be 2.54 €/day, almost 41% of that of the BAU, which could be appealing to the consumer to shift to BAT appliances.

Smart-TOU scenario

For the first smart scenario, the consumer's contribution is necessary in order to reduce the energy consumption and peak power demand. The *Smart-TOU scenario* demonstrates how the Smart Home Controller plans smart appliances (and appliances equipped with smart sensors and smart plugs) starting times based on economic savings (lower operation cost). This is achieved by loading each appliance according to priority number and the first in first out waiting order. So appliances characterized by 2 or 3 priority number are shifted to off-peak hours, instead of being loaded at high-cost peak hours. Figure 5 represents the resulted load from the Smart-TOU scenario compard to the Energy Efficient scenario.

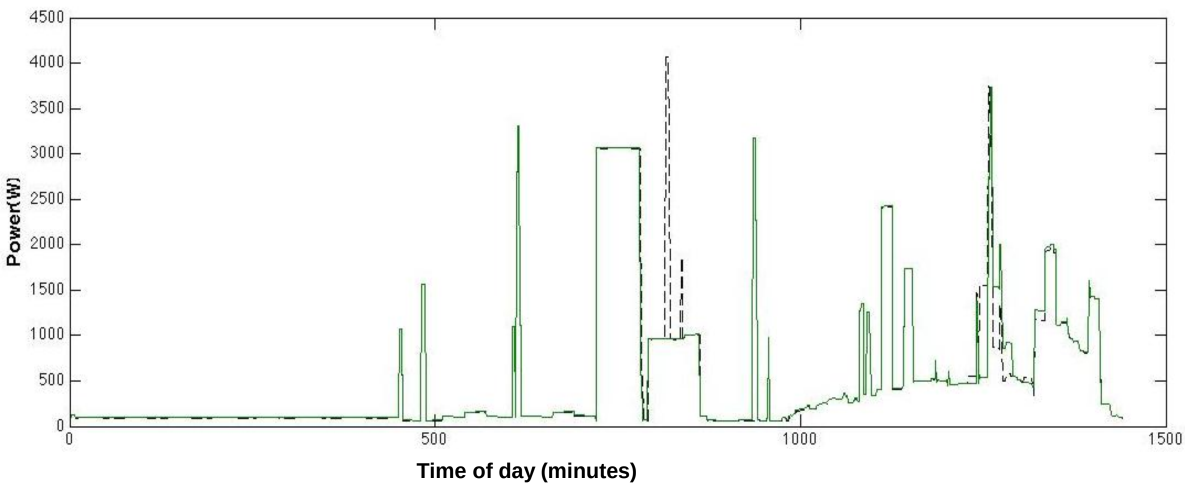

Figure 5: Daily load profiel for the Smart-TOU Scenario compared to the Energy Efficient Scenario.

As expected the total energy consumption does not drop below the energy-consumption of the energy-efficient scenario (12.3kWh). However, since the home controller is now responsible for the efficient and cost-effective management of the electrical equipment, the power demand dropped to 3734W, which equals to 40% of BAU. The total energy costs are estimated to be 2.52€ er day, 42% of BAU, which barely shows a reduction compared to the energy-efficient scenario.

Smart-Peak scenario

In the second smart scenario a 3700W power threshold is introduced together with the TOU tariffs as for the Smart-Peak scenario. Here, the simulation shows how the system allows the appliances to be loaded according to the lower execution cost, while assuring the overload management.

The results from the calculations show that the peak power is reduced to almost 3100W, 50% of the BAU scenario, despite the high threshold limit equal to 3700W (just below the maximum of the smart-TOU scenario). This can be explained, since some of the appliances that were to be loaded would exceed the power threshold if added to the total system's power and is thus shifted to a low-power region. Despite the reduction in the peak power there is no significant cost saving compared with both the Energy Efficient as the Smart-TOU scenario. What is more, a delay between the two load curves presented is observed. This is because the integrators used in the model hold the priority "queue" and the total consumption of the house every sample time, adding a quite remarkable delay in the load profile generation.

Table 3: Results overview of the different scenario's.

	Energy consumption [KWh/day]	Peak load [kW]	Energy costs [€/day]	Reduction in Energy use [%]	Reduction in peak load [%]
BAU	20.146	6228	4.33	-	-
Energy Efficient	12.285	4066	2.54	39%	35%
Smart-TOU	12.285	3734	2.52	39%	40%
Smart-Peak	12.285	3107	2.53	39%	50%

In Table 3 an overview is given of all scenario's compared. Based on this test it shows that energy-efficient appliances will introduce a great reduction in the energy-consumption for households. Other "smart" appliances only introduce a reduction in the peak load, and not significantly in the total energy costs. It must be taken into account this simulation was only based on one on/off

Discussion and conclusions

In this paper we have designed a model which is used to evaluate the potential for reduction of the total energy consumption of a household by introducing energy-efficient appliances and smart control of some of the appliances. The smart home controller was able to effectively control the appliances taking into account the pricing tariffs provided and the feedback received, associated to the prioritized needs set in the model and the total consumption level signals.

Although the simulation results look quite promising, only when more user-profiles and more specific appliance' load-profiles are inserted in the model the true potential of these efforts can be revealed. The model developed can be considered as a showcase, which aims to demonstrate the influence of the scenarios evaluated.

A significant reduction in energy use and peak power can be achieved by replacing the existing appliances with more energy-efficient ones, and by introducing shifting the time of use of washing machines, cloth dryers and dishwashers, allowing their latest possible end times to be set. The energy savings were 39 % of BAU, while the peak power demand dropped by almost 35%.

In both the Smart-TOU and Smart-Peak scenario the peak power reduced by 40% and 50% respectively, compared with the BAU benchmark, while energy savings and the energy costs remain about the same as in the Energy Efficient scenario. The results of the calculation indicate that introducing smart shifting in houses does not give any incentive for the user to introduce this level of smartness into their own home. Introducing it will contribute to lowering the peak-power load of the grid, and to give the user incentive to reduce its peak-power he/she should be rewarded for it, for instance, by lower connection fees.

Recommendations

To underpin the preliminary conclusions the model has to be evaluated with more randomized use-scenario's where every application is used within certain time bandwidth or even excluded from the list based on penetration percentage. After producing this large amount of load-profiles different TOU tariffs settings can be evaluated and optimized for low peak-power load and/or the tariffs can be optimized for low total energy-costs for the home.

Low peak-power houses are not only interesting for larger utilities but also for smaller energy-initiatives at district level where sustainable energy is introduced in combination with temporarily energy storage. Lower peak-power and a more distributed energy consumption over the day will decrease the amount of costly power generators (like PV cells) and temporary storage systems (like batteries).

Bibliography

[1] International Energy Agenc, "Technology Roadmap, Smart Grids.," 2011.

[2] C. Clastres, "Smart grids: Another step towards competition, energy security and climate change objectives," *Energy Policy,* vol. 39, no. 9, pp. 5399-5408, 2011.

[3] C. Warmer, S. Karnouskos, K. Kok, A. Weidlich, D. Nestle and P. Selzam, "Web services for integration of smart houses in the smart grid," *Grid-Interop Forum,* 2009.

[4] EOLAS Magazine, "Rethinking electricity, smart generation, smart networks, smart users," in *Energy Ireleand Conference*, Ireland, 2011.

[5] D. Long Ha, Ploix, E. Zamai and M. JAcomino, "Realtimes dynamic optimization for demand-side load management," *International Journal of Management Science and Engineering Management,* vol. 3, no. 4, pp. 243-252, 2008.

[6] Aricent Group, "Home energy management - beyond the numbers," Aricent Group, 2011. [Online]. Available: www.aricent.com. [Accessed 2011].

[7] S. Darby, "The effectiveness of feedback on energy consumption," Environmental Change Institute , university of Oxford, Oxford (UK), 2006.

[8] Association of Home Appliance Manufacturers, *Smart grid white paper, the home appliance industry's principles & requirements for achieving a widely accepted smart grid,* Washington : AHAM, 2009.

[9] J. Stromback, C. Dromacque and M. Yassin, "The potential ofr smart meter enabled programs to increase energy and systems efficiency: a mass pilot comparison," VaasaETT, European Smart Metering Industry Group, 2011.

[10] A. Capasso, W. Grattieri, R. Lamedica and A. Prudenzi, "Bottom-up approach to residential load modeling," *IEEE Transactions on Power Systems,* vol. 9, no. 2, pp. 957-964, 1994.

[11] J. Paatero and P. Lund, "A model for generating household electricity profiles," *International Journal of Energy Research,* 2006.

[12] S. Gottwalt, W. Ketter, C. Block, J. Collins and C. Winhrdt, "Demand side management - A simulation of household behavior under variable prices," *Energy Policy,* vol. 39, no. 12, pp. 8163-

8174, 2011.

[13] M. Armstrong, M. Swinton, H. Ribberink, I. Beausoleil-Morrison and J. Millette, "Synthetically derived profiles for representing occupant-driven electric loads in Canadian housing," *Journal of Building Performance Simulation,* vol. 2, no. 1, pp. 15-30, 2009.

[14] A. Esser, M. Franke and A. Kamper, "SESAM Arbeitspaket 3.7: Simulation und Einplanung dezentraler Energieerzeugungsanlage," Karlsruhe, 2006.

[15] R. Yao and K. Steemers, "A method of formulating energy load profile for domestic buildings in the UK," *Energy and Buildings,* vol. 37, no. 6, pp. 663-671, 2005.

[16] G. Veerabadhra, “Agent based economic framework for resource distribution in household smart grid,” Delft University of Technology, department of Electrical Engineering, Delft, the Netherlands, 2011.

[17] G. Haines, A. McGordon, P. Jennings and N. Butcher, “The simulation of vehicle-to-home systems - using electric vehicle battery storage to smooth domestic electricity demand,” University of Warwick, ARUP, Blythe Gate, Blythe Valley park, United Kingdom, 2009.

[18] N. Hatziargyriou, A. Dimeas, S. Hatzivasiliadis, M. Vandenbergh, R. Geipel and S. Tselepis, “Avanced architectures and control concepts for MORE MICROGRIDS,” 2009.

[19] S. Rahman and M. Pipattanasomporn, “Modeling and simulation of a distributed generation - integrated intelligent microgrid,” DoD Strategic environmental research and development programm (SERDP), Virginia, USA, 2010.

[20] A. Di Giorgio and L. Pimpinella, “An event driven smart home controller enabling consumer economic saving an dautomated demand side management,” 2012.

[21] International Energy Agency, “Technology Roadmap, Smart Grids.,” 2011.