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RANKING OF ENERGY SAVING DEVICES FOR SMART HOMES ACCORDING TO THEIR PAYBACK TIME

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ABSTRACT
This paper discusses the average energy savings of various smart devices in connection with their average price. By calculating the devices' payback times, a ranking of the tools can be given. The whole study focuses on the average household within the EU-28 in terms of climate as well as in terms of user behaviour. The purpose of the research was to provide a win-win situation for users' wallets and the environment by showing the device which suits both players best. As a result of the research, it was found that the greatest reduction in energy consumption can be reached by an interaction of the smart device and the inhabitants of a smart home. By giving users feedback on their energy consumption through smart meters, average savings of 7.5% are reached. As a smart meter is available for about € 80, it has a payback time of only 4.24 months.
Keywords: Smart home devices, payback time, energy consumption, energy saving, smart homes.

1 INTRODUCTION

The EU 20-20-20 targets were determined by the heads of the governments of the European Union (EU) members in 2007. They firstly stipulated a reduction of greenhouse gas emissions of 20% until 2020 in comparison with the measures of 2005. Secondly the use of renewable energy should be 20%. Lastly, energy efficiency is ought to rise by 20% [1]. Concerning the climate change in general and specifically the agreement of the European Union it is obvious that energy saving is a highly accurate concern. Given the current distribution of energy consumption within the EU it is evident that households are a key factor concerning this topic. Households account for about a quarter (24.8%) of the whole energy expenditure [2]. Other statistics show, that buildings in general account for 40% of total energy consumption within the EU [3].

This paper analyses the current situation regarding devices for smart homes, which can provide a basis for higher energy efficiency. Research was conducted in form of a document analysis. The type of research conducted for this paper can be classified as descriptive and qualitative research. The data for this paper were collected in two different ways. First data about average energy savings of the different smart home devices were collected through whitepapers of companies selling those tools and studies from universities. Second, the average prices of these devices were calculated out of the first page of hits on eBay [4]. The eBay Corporation is a great player in leading the worlds' online marketplace. A huge variety of products are offered on its platforms. With the use of an average energy price for the different energy products such as electricity and gas, the average payback times of the various tools were calculated. Last but not least, the tools were ranked according to their payback time.

2 SAVING ENERGY WITH SMART HOMES

The idea and the phenomenon of so called "smart homes" are not exactly new. Marsh wrote in his article "Taking Control of Energy Use" in 1998" [5]:

> *"Advanced home control systems go by several names, including smart home, home automation and integrated home systems. By any name, these systems*

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conveniently control home electronics and appliances including audio/video, home office, telecommunications, intercom, security, lighting, HVAC, and lawn sprinklers. Control systems can also provide information – residents can find out how much electricity they've used on specific appliances or systems, and utilities can read meters remotely. The systems can be accessed from remote locations by phone or computer, allowing residents to turn on the heat, for example, on their way home from work."

The definition of smart homes by Harper and Aldrich [6] has lost nothing of its actuality. The single devices were developed a lot further and now suit their tasks better, but the overall concept has not changed:

"A "smart home" can be defined as a residence equipped with computing and information technology which anticipates and responds to the needs of the occupants, working to promote their comfort, convenience, security and entertainment through the management of technology within the home and connections to the world beyond."

2.1 Energy saving potentials

A lot of research has been done on the topic of smart homes in general and on its ability to save energy. As presented by Harper and Aldrich [6] the idea of smart homes has a relatively long history. The process of home automation started in about 1915. The introduction of the term "smart" into homes was conducted in the nineties of the last century.

According to Louis' paper from 2015 [7], the general energy saving potential of smart systems in Finland is a reduction of 14% of the total energy consumption. He further claims the payback time for smart meters to be 3.5 months. Nevertheless, only little studies can be found which calculate average saving potentials. Most of the studies and whitepapers focus on maximum values. However, a sufficient amount of studies and whitepapers can be found that give an average value of savings in order to calculate the payback times of the various devices. The Nest White Paper published in 2015 [8] gives explicit average savings concerning the smart thermostat and so does for example the study conducted in 2011 by Williams et al. for lighting control systems [9]. Summing up, the field of smart home devices is in general well explored, but there is a certain lack of research concerning average saving potential and payback times.

It is clear that smart homes are giving the society the chance to save energy while nevertheless maintaining the comfort people are used to. It would be beneficial for the successful spreading of energy saving smart devices, if users know what kind of benefit can be achieved by implementing them without decreasing comfort. As in general every individual has a limited budget, a short payback time and therefore not only energy, but monetary savings as well, will be interesting for potential users. Due to the limited budget, users may not be willing or able to implement a multitude of devices. A ranking of the smart devices according to their payback time would help users to decide which tools are best for the environment and at the same time best for their own economic interests. Therefore the research question of this paper is: "With which tools should a smart home in the EU-28 be equipped in order to reduce its energy consumption and how can these tools be ranked according to their payback time?" The research objective is to set up a ranking of the smart devices which is a combination of profits for the user, namely monetary savings, and profits for the environment, namely less energy consumption. This ranking will be set up by using literature which provides average energy savings of smart devices. In connection with the average energy use of households in the EU-28 and average prices for the various devices

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calculated from the listings eBay [4]. In order to assure the win-win situation, the paper only takes devices into account which are likely to preserve the comfort of the users.

2.2 Differences between the energy consumption of private households and offices within the EU-28

In order to compare the findings and data of the different papers about energy savings in private homes and offices, the average energy consumption on lighting, heating, cooling etc. has to be compared.

The energy used in private households is distributed as follows. The majority, namely 64.7% of the total energy expenditure, is used to heat the space. 13.9% are consumed for water heating. Lighting and most electrical appliances account for 13.8% of the household's consumption and cooking for 5.7%. As air conditioning uses 0.5% of the energy, 1.5% are left for other things. Electric energy accounts for 25% of the total energy consumption and lighting uses 18% out of these 25%. Therefore 4.5% of the whole energy consumption of a household is used for lighting [10], [11].

According to Jandrokovic an average office uses 57.14% of its energy for heating. Another 9.52% are used for cooling and lighting accounts for 10.12% of its total energy consumption. The office equipment consumes 17.86%, and 5.36% are left for power-consumers without drive [12].

As the energy consumption is distributed on the different categories like heating, lighting etc., the paper tries to match each category with a smart device which may save energy. There was no smart device found concerning water heating and cooking. Electrical appliances and "else" are too wide as a category to find a device which would be suitable for the aim of the paper. Therefore smart energy saving tools for space heating, lighting and air conditioning are described and taken into account in the calculations for the ranking.

3 DEVICES FOR SMART HOMES

Smart home technologies are more and more accepted and used by residential consumers. The most common devices are described in this capter. The conditions for a listed tool to be considered in the calculations were:

- new product (not from a private seller who bought but did not use it)
- an unambiguous price
- first page of listings
- appropriate to the target word
- each device is counted once, even if it appears several times on the list

3.1 Smart thermostat

Various features may be integrated in a smart thermostat. One of the most common ones is an occupancy sensor. Plus smart thermostats may realise or learn their user's behaviour, such as when they go to sleep and get up. Therefore the heat can be turned down by the thermostat during the user's sleeping time. In such a manner energy consumption is decreased while users comfort rises. It has to be pointed out that energy savings of smart thermostats vary depending on climate zone, isolation and the overall heating habits of the users. An average is presented in the Nest White Paper of 2015 [8]. There it is claimed that the average savings for heating are 11% and 15.5% for electric HVAC (heating, ventilation, and air conditioning). Therefore the Smart thermostat saves 7.117% (64.7% x 0.11 = 7.117%) of the total energy consumption through savings of heating and 0.078% (0.5% x 0.155 = 0.078%) through savings of air conditioning. A Nest Learning Thermostat is actually available for £191.33, which equals €222.739 at current exchange rates of €1 equaling £0.859 on May 19, 2017 [13], [14].

3.2 Smart air conditioner

Between 1982 and 2016 smart air conditioning in a combination with occupancy and thermo-fluidic sensors has attained constantly increasing energy savings. Due to successful development and research of the field, the rise in savings range from 11% in 1982 up to 30% in 2016. Chen and Lee further claim that users who can be better detected because of their use of wearable sensing devices would on average reduce energy use by 46.3% in comparison to an average air conditioner and to average user behaviour. Such a sensing device can for example collect data about the owner's psychology and his core temperature. Furthermore, the user is able to provide additional data like clothing properties to the system by entering them into his smartphone. Having access to this data, the smart air conditioner is able to adapt the cooling effort. Therefore, well developed devices not only can reduce the environmental impact but also enhance users' comfort [15]. In the interest of comparing the energy savings achieved with an air conditioner with other devices, the percentage of the total energy consumption has to be calculated. Air conditioning accounts for 0.5% of the whole energy use of a private household [10]. Therefore a smart air conditioner gains savings of 0.232% of the full energy consumption. The price for a smart air conditioner on eBay [4] is on average £565.88, equaling €658.71 by the use of the exchange rate of May 19, 2017 [14].

3.3 Smart meter

There are different ways of providing feedback about energy consumption to users. Direct feedback can be gained contemporaneous from a meter or a display monitor. The user gets information about where and how much energy is used. According to Darby the savings from this method vary between 5% and 15%. Darby further claims that the saving occurring from indirect feedback, which is modified for example through billing, before it can be seen by the user, differs between 0% and 10% [16]. As this paper is about smart devices, the focus will be set on direct feedback, namely smart metering. Users being informed more precisely about their energy consumption by the use of smart meters are likely to achieve savings from 5% to 10% of their overall energy consumption [17]. By comparing the listed new smart meters on eBay [4], an average price of £68.73 was found. According to the exchange rate of the mentioned date the average price of a smart meter would be approximately €80 [14]. In order to calculate the payback time average savings of 7.5% are assumed.

3.4 Lighting control

Williams et al. differentiate between savings occurring from occupancy strategies, daylighting strategies, institutional and personal tuning [9]. Their work analyses 88 papers and case studies about lighting controls in commercial buildings and studies their saving estimations. In order to calculate the average energy savings potential of various lighting devices for offices, several filters are applied to select just those findings which occur from lighting control. Plus data which is not comparable is avoided. As a last filter only data from actually conducted case studies, and not just simulations, are used. The findings differ according to the various devices that are described in the papers and case studies used for the research. For this paper only devices which suit to the definition of "smart" are taken into account [9]. Their final findings include 22% lighting energy savings for offices which are equipped with occupancy sensors. These sensors regulate lighting in confirmation with user's presence. Furthermore, the energy used for lighting can be cut by 27% if a daylighting system is implemented. This system adapts light levels in line with the incidence of natural light by using photo sensors, automatic timers or daylight harvesting sensors. Third, institutional tuning aiming to meet individual requests for different locations saves on average 36% of the energy used for lighting. Institutional or task tuning reaches these requests by the use of dimmable ballasts which change the level of light with the aid of technology and through commissioning. The difference between institutional tuning and daylight harvesting is therefore the cause of turning on or off or for dimming the lights. The authors of the paper conclude with 40% savings for multiple approaches where several energy saving methods are used simultaneously.

To use these findings and data for the stipulated outcome of this paper some calculations are necessary. Williams et al. wrote about energy savings in offices. By comparing the average energy use on lighting in offices and in private households, the data will be brought in line with the other findings of this paper. Therefore the data of the various devices can be compared. In private households 4.5% of the total energy consumed is used for lighting, whereas in offices lighting accounts for 10.12% [10]–[12].

- Occupancy sensors: 22% of 4.5% means 0.99% savings of the household's total energy consumption
- Daylighting system:
- 27% of 4.5% means 1.215% savings of the household's total energy consumption
- Institutional tuning:
- 36% of 4.5% means 1.62% savings of the household's total energy consumption
- Multiple approaches:
- 40% of 4.5% means 1.8% savings of the household's total energy consumption

The lighting control devices which are introduced above, definitely have the potential for saving energy within a household. Nevertheless it is difficult to calculate an average price for equipping a household with occupancy sensors, because the situation where several devices of this type would be needed in order to cover the whole area of the home can occur easily. As the number of needed sensors can differ widely, the occupancy sensor will not be taken into account for the ranking. Moreover the possible additional costs for installing dimmable light bulbs will not be considered.

On eBay [4] an average price for smart dimmers of £45.4 can be calculated. This corresponds to €52.84 according to the exchange rate of May 19, 2017. Concerning daylight harvesting sensors surprisingly few occupancy sensors for lighting control are available. The average calculated equals £37.46 or €43.6. As there was no serious output found on eBay [4], by looking for keywords for multiple approach devices, the EasySense Fixture-Mount Sensor was found on http://www.usa.lighting.philips.com/products/oem-components/new-product-releases/easysense. This tool combines a daylighting harvesting sensor with an occupancy sensor and institutional tuning. It is available on eBay [4] for $19.95, which equals €17.85 at the exchange rate of May 19, 2017. Apparently the device cannot be found on the site of the United Kingdom. Therefore the site where it could be found was used in order to consider the device in the ranking, although it cannot be compared equally to the other devices because of the lack of information for the average price.

According to the housing statistics in the European Union of 2010 an average of four rooms per dwelling, and by that the need for 4 dimmers per household, can be assumed [18].

As a result average costs of €52.84 x 4 = €211.36 can be calculated. The same holds true for multiple approach devices, €17.85 x 4 = €71.4. For the sake of completeness it has to be mentioned that the reduction of lighting has an effect on the energy which has to be spent on heating and cooling. Plus, a change of the light bulbs may reduce the energy consumption cost-efficiently by using for example an LED instead of an incandescent lamp.

4 RANKING OF ENERGY SAVING DEVICES

Depending on climate, former habits of the users, housing characteristics and equipment of the building, savings differ. Payback times can be calculated by setting average energy savings in context with average energy prices and average prices for the different devices. According to Eurostat an average household within the EU consumes a quarter of its energy in the form of electric energy [10]. For the first ranking the value of the electricity savings were used in the calculations. Eurostat claims that the total amount of electricity consumed by all the households of the EU-28 together in 2014 equals 67.577,600 tonnes of oil equivalent [2].

67,577.6 times 1000 tonnes of oil equivalent = 67.577,600 tonnes of oil equivalent 1 ton of oil equivalent = 11,630 kWh 67.577,600 tonnes x 11,630 = 7.859E+11

The total number of households within the EU-28 in 2014 was 216.769,800 [19].

7.859E+11 kWh / 216.769,800 = 3,625.63 kWh per household in 2014 3,625.63 kWh / 365 = 9.93 kWh per household and day in 2014

The average electricity price within the EU-28 in 2014 for households was €0.208 per kWh [20]. Therefore 9.93 kWh equal €2.07. Concerning the smart thermostat, the savings which are shown here account only for energy savings occurring of air conditioning. Table 1 gives an overview of the prices of the different devices for smart homes as well as of the respective percentage share of savings from total energy consumption.

The part of electricity of the total energy consumption is 25%, the electricity costs per day are 2.07 €. Calculation example concerning metering:

2.07 € = 25% 0.08 € = 1% 0.62 € = 7.5%

Table 1: Overview of the prices of the different devices and the savings in per cent for electricity. *(Source: [8]–[12], [14]–[17].)*

Electricity		
	Savings from total energy consumption in %	Price in €
Thermostat	0.078	222.74
Metering	7.500	80.00
Air conditioner	0.232	658.71
Daylight harvesting	1.215	43.60
Dimmers	1.620	211.36
Multiple lighting approaches	1.800	71.40

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Table 2: Overview of the savings by using different devices per day and per year in € for electricity. *(Source: [8]–[12], [14]–[17].)*

Electricity		
	Savings per day in €	Savings per year in €
Thermostat	0.006	2.36
Metering	0.620	226.24
Air conditioner	0.019	6.98
Daylight harvesting	0.100	36.65
Dimmers	0.134	48.87
Multiple lighting approaches	0.149	54.30

In order to calculate the savings of heating costs of the smart thermostat average heating costs have to be calculated. According to Gynther et al. an average European household consumes 43% of its heating energy in electricity, 20% out of wood and 16% out of solar energy, geothermal heat etc., 9% of the heating energy are gas, 7% are oil and another 5% are gained from coal [21].

In this paper the average price for heating energy will be calculated among the variable costs of the energy. Fixed costs like the price of boilers etc. will not be taken into account because they normally do not occur once a year.

4.1 Electricity

43% of heating energy are electricity [21]. 43% out of 64.7% (percentage of energy which is consumed from heating out of the total energy consumption [10]), so 27.82% of the total energy consumption of an EU-28 household is used for heating with electricity. This finding stands in conflict with the statistics concerning the division of the households total energy consumption of heating products. Considering the lack of trustable statistics whose findings fit together better, the paper will nevertheless calculate with this value.

64.7% x 0.43 = 27.81 [10]
3,625.63 kWh per household in 2014 …. 25% of the total energy consumption
145.03 kWh per household in 2014 …. 1% of the total energy consumption
4,034.75 kWh per household in 2014 …. 27.82% of the total energy consumption
4,034.75 x € 0.208 = €839.23 per year for electricity for heating

4.2 Wood

20% of heating energy come from wood [21]. According to Rakos in 2014, 1 kWh out of pellets costs on average € 0.052 [22].

64.7% x 0.2 = 12.94% of the total energy consumption [10]
3,625.63 kWh per household in 2014 …. 25% of the total energy consumption
145.03 kWh per household in 2014 …. 1% of the total energy consumption
1,876.63 kWh per household in 2014 …. 12.94% of the total energy consumption
1,876.63 kWh x € 0.052 = €97.59 per year for wood for heating

4.3 Heating

As the category heating, which covers solar energy and geothermal energy, has no variable costs like for example gas, this paper will not take it into account for the calculations of an average energy price per household.

4.4 Gas

According to Gynther et al. 9% of the energy consumed for heating consist of gas [21]. The average gas price per kWh within the EU-28 in 2016 for households was € 0.062 [23].

64.7% x 0.09 = 5.823 [10]
3,625.63 kWh per household in 2014 …. 25% of the total energy consumption
145.03 kWh per household in 2014 …. 1% of the total energy consumption
844.48 kWh per household in 2014 …. 5.82% of the total energy consumption
844.48 x € 0.062 = €52.36 per year for gas for heating

4.5 Oil

In 2015 1,000 liters of oil cost € 694 [24]. 1 ton of oil equivalent is 11,630 kWh, therefore 11,630 kWh cost € 694 and 1 kWh costs € 0.06. 7% of the heating energy are oil [21].

64.7% x 0.07 = 4.53% [10]
3,625.63 kWh per household in 2014 …. 25% of the total energy consumption
145.03 kWh per household in 2014 …. 1% of the total energy consumption
656.82 kWh per household in 2014 …. 4.53% of the total energy consumption
656.82 x € 0.06 = €39.20 per year for oil for heating

4.6 Coal

Calculated out of the prices of the nine different types of coal given in the chart of the Seai's publication in 2017 [25], the price of 1 kWh out of coal is on average € 0.058. 5% of the heating energy are coal [21].

64.7% x 0.05 = 3.23% [10]
3,625.63 kWh per household in 2014 …. 25% of the total energy consumption
145.03 kWh per household in 2014 …. 1% of the total energy consumption
469.16 kWh per household in 2014 …. 3.235% of the total energy consumption
469.16 x €0.184 = € 86.14 per year for coal for heating

4.7 Final ranking

Summing up the costs per year and household for heating with electricity, wood, heating, gas, oil, and coal make €1,114.50. Smart thermostat saves 11% of the heating energy, so 1,114.50 x 0.11 = €122.60 per year.

The cooling energy savings per year are €2.34, the heating energy savings per year are € 122.60, all together € 124.94 per year. As the price of the Smart Thermostat is €222.74, the payback time is 1.78 years. Table 3 shows the final ranking of the different devices regarding the payback time, therefore metering is ranked as number 1.

Table 3: Final ranking of the different devices regarding the payback time. *(Source: [8]–[12], [14]–[17].)*

Final ranking		
	Payback time in years	Ranking
Thermostat	1.78	4
Metering	0.35	1
Air conditioner	94.33	6
Daylight harvesting	1.19	2
Dimmers	4.33	5
Multiple lighting approaches	1.32	3

5 CONCLUSION

Analysing the ranking, the smart meter can be found on the first position. This means that providing feedback to users and making them aware of their own energy use has not only a great impact of −7.5% on the total energy consumption of the household but is also cost efficient. Concerning the third position of the ranking, multiple lighting approaches, it has to be clarified that the price is not an average value but a single price taken by chance. Additionally, it is not certain that no additional costs in terms of new light bulbs would occur in order to use this strategy. Therefore it would be appropriate to be careful with its position. Another conspicuous position is the one of the air conditioner. It has to be pointed out that the air conditioner is not on the last place because of its weak performance, but because of the rare usage by households within the EU-28. The smart thermostat, which saves a relatively large amount of energy, is in the second half of the ranking, on fourth position. Nevertheless, it is within the small range of one to two years of payback time with the three tools ranked above the smart thermostat.

It is obvious that not necessarily the single devices have to become more energy efficient, but the users themselves can have a great impact on their own consumption if they know more about it by receiving feedback. As this paper revealed payback times of single smart devices it shows the kinds of device which combine the users' interest in saving money in connection with savings of energy. By this means the ranking provides win-win situations for the wallet of the user and the environment.

The different devices influence each other and by reducing the time used on one tool, the amount of time needed for another tool might change. This paper did not focus on these devices as a whole system because of the changes in the payback times that might have occurred. Seeing a smart home as a system of smart tools in order to document the influences between the different devices would nevertheless be a highly interesting topic to focus on. Furthermore there would be other ways of ranking the devices: according to the energy savings. By using this ranking method in a heating dominated region, the thermostat would definitely be on top of the list because heating accounts for a large part of the total energy consumption.

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