Energy consumption patterns of residential users: A Study in Greece

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Abstract. Electricity is an integral part of our lives and is directly linked to all areas of indoor human activity. In order to achieve good management of household electricity consumption, it is first necessary to make a correct and detailed measurement of it. Based on that aspect, this paper utilizes smart meters to monitor the electricity consumption of 120 different houses for a year in Greece. The measurements are saved and analyzed in order to gain a perspective of energy consumption patterns in comparison to temperature and personal energy profiling. The results and information of this paper could be used by current and future users as a guide to shift electricity behavior towards energy saving and also create new standardized profiles regarding demand response management to achieve energy efficiency.

Keywords: energy consumption · electricity · behavioral consumption patterns · outdoor environmental conditions · smart meters.

1 Introduction

The need to limit climate change by keeping global warming at a stable level and reducing greenhouse gases is, considering especially nowadays, an imperative necessity. This, combined with the idea that pervasive technologies – such as smart metering, home automation, sensing, and mobile devices - can enable the collective and individual change, is fundamental to activate energy efficiency policies.

The use of studies on the residential electricity profile is becoming more and more crucial. Temperature plays a very prominent role in this subject. Giannakopoulos and Psiloglou [3] on their research for Athens (capital City of Greece), highlights the sensitivity of energy demand to weather conditions and seasonal variation. A relative study was conducted by Pardo *et al.* [7] for Spain.

Hekkenberg *et al.* [5] present the respective results for a colder climate, such as the one in the Netherlands. Gouveia *et al.* [4] demonstrate profiles of electricity consumption for 230 households in Evora, Portugal. Comparative residential profiles between Kenya, Germany and Spain were developed by Stoppok *et al.* [9]. This paper presents results of a study aimed to explore residential energy patterns in Greece, which emanated after an effort to educate household occupants on energy saving behavior as well as how to exploit smart metering equipment for this cause.

In our approach, a newer and more effective approach to energy saving was developed, leveraging data generated from smart sensors and provided energy recommendations by applying advanced consumer behavior models. The aim was to improve the energy consumption habits of people, by always keeping the individual comfort level high and achieve a reduction of resource consumption and a more sustainable society.

To begin with, smart meter technology is described along with the way it is utilized for energy consumption metering (Section 2). Afterward the relationship between energy consumption and outdoor temperature and different behavioral patterns of randomly chosen users are presented and evaluated in Section 3.

2 Smart meters

The first type of electricity consumption meters was manufactured in the 1980s [11]. These meters were hardware driven (electromechanical) and were a very good solution for recording and monitoring consumer habits in energy distribution networks. Although the manual monitoring and restoration, the limited control and the often mechanical failures led over the next decade to the development of a new type of meters, known as electronic meters. Those had more features, in addition to simple energy consumption measurements and could calculate more complex parameters such as the use of energy, power demand in Kilowatt (kW) or Kilovolt-Ampere (kVA), electrical voltage, current, reactive power and other parameters related to energy.

Nowadays, a new kind of meters have emerged, the so-called "smart" meters [10]. Smart Metering or Advanced Metering Infrastructure (AMI) is an integrated system of smart meters, communication networks, and data management systems that enables bidirectional communication between utilities and customers. The smart meter is an advanced energy meter that obtains information from the end users' load devices and measures the real-time energy consumption of the consumers and then provides added information to the system operator (utility access points). These utility access points are commonly located on power poles or street lights. The entire system is referred to as a mesh network allowing for continuous connections among the network [13]. The goal of an AMI is to provide utility companies with real-time data about power consumption and allow customers to make informed choices about energy usage, based on the price at the time of use [6].

Smart meters measure, collect and report data back to utilities in short intervals throughout the day. They can also perform advanced functions such as sending signals to home appliances. A smart meter allows not only remote monitoring but also gives the user the ability to detect possible issues (extreme usage of electricity consumption, theft of electricity, etc.). The basic function of a smart meter is to gather and transmit data. Many methods are used for the transmission of data, such as:

(a) Wired via cables such as fiber-optic and copper phone lines;
(b) Wired via power lines such as power line communication or broadband over power lines;
(c) Wireless via antennas (e.g. GPRS, GSM, ZigBee, WiMax) [8].

2.1 Hardware and Software infrastructure

Measurement equipment is installed to record the energy consumption of each household. This equipment is connected to each central electrical panel of each user. The data is transferred from the measurement point (meter) to a logger/poster using a radio frequency (RF) signal. The poster connects to a modem via an Ethernet port that allows the contents of its memory to be transferred through a wire to an online database using a secure service. At specific set time stamps, the recorded data is transferred from the database to a computer using a suitable computer program. The measurements and the collection of all the data are processed and analyzed in order to produce graphs and indicators for the electrical energy consumption of each dwelling, as well as the whole of the sample. An automation service is retrieving the data from the intermediate server, formats the data correctly and delivers the data via secure FTP protocol to the endpoint. The conceptual architecture of the method described above is shown in the following Figure 1.

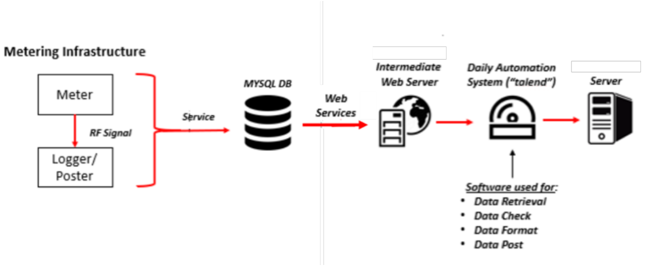

Fig. 1. Conceptual architecture for data integration

The metering devices used for monitoring energy consumption (Figure 2) are clamps. These devices are utilized for the measurement of a live-conductor circuit without damaging its continuity. The "clamp" device as the name suggests uses a clamp or jaw like object, for the measurement of current flow. It is used for measurement of alternative current (AC) / direct current (DC) voltage and AC/DC current, resistance, frequency, capacitance, etc. In general AC clamps operate on the principle of current transformer (CT) used to pick up magnetic flux generated as a result of current flowing through a conductor. Assuming a current flowing through a conductor to be the primary current, one can obtain a current proportional to the primary current by electromagnetic induction from the secondary side (winding) of the transformer which is connected to a measuring circuit of the instrument. This permits to take an AC current reading on the digital display (in the case of digital clamp meters).

Fig. 2. Smart meter hardware

A meter using clamps to measure electricity is similar to a digital panel meter. A digital panel meter has advanced features, such as the detachable display part for easy user handling. Low pass filters provide accurate and stable measurements and use of advanced signal processing software. Some of these measurements include the calculation of power factor, max demand power and total harmonic distortion. Unlike other meters available on the market, this type has Pulse and Modbus communications built in, eradicating the requirement of purchasing extra modules.

For the current study, the meters with the clamp hardware were selected as the most valid option, since the cost can be kept low and also the error in measurements was negligible.

3 Case study: Greek Residential Houses

A random number of Greek residential houses were selected for participation in this study; therefore, they can be considered as a representative sample of Greek energy consumers. The sample size consists of 120 unique houses all situated in Thessaloniki, Greece. All of the participants gave initial information about their profiles, where basic information such as number of occupants, type of household, heating type, as well as the number of rooms was provided. Additionally, they signed a consent form, giving us the approval to use their data.

3.1 User profiles

The demographics of the 120 participating users are available in Table 1. The average persons living in a household is around 2 and most of them have 1 to 2 children.

Table 1. Main user information

Number of houses	**120**
Average persons in the household	2,08
Average number of children under 16	1,55
Average number of pets per household	1,26

The users are mostly people living in apartment buildings such as multistory buildings (Table 2). This is a very common living arrangement for families in Greece, as it provides plenty of space but also keeps the monthly rent cost down, compared to independent houses.

Table 2. Type of households

Type of households	
Apartment	95
Independent House	8
Semi-Detached	2
Terraced House	15

Moreover, according to the users' profiles, most of the houses in this study consist of 3 available rooms but some variation is also apparent (Table 3). Based on this information, the number of rooms can be correlated with the surface area of each household in question, consequently to the amount of energy use.

Table 3. Number of rooms per house

Number of rooms	**Number of houses**
Two (2)	17
Three (3)	60
Four (4)	28
More than five (5)	15

Additionally, in Greece and particularly for Thessaloniki, there are three main heating type methods. The one of those that has become more available because of its efficiency, is heating using natural gas furnace and normal radiators that dissipate heat. Another method is heating oil furnace, likewise, combined with radiators. This is an older version and not as efficient as natural gas. Other methods consist of using a fireplace or more modern ones, like air conditioning systems. This study reveals that most of the users, use either natural gas or heating oil (Table 4).

Table 4. Type of heating method

Heating type	**Number of houses**
Electricity	22
Wood (fireplace)	2
Natural gas	58
Home heating oil	38

Each of the above group of users has its own characteristics as well as a unique energy behavior. The focus of this study is to understand how these different groups of users behave in their everyday lives, considering electricity consumption.

3.2 Climate in Thessaloniki

Greece is located in Southern and Southeast Europe. The mainland consists of mountains, hills, and sea. It has the 11th longest coastline in the world. he climate of Greece is predominantly Mediterranean, featuring mild, wet winters and hot, dry summers. However, there is a range of micro-climates because of the country's geography. Generally, there are four main types of climate in Greece: Mediterranean, Alpine Mediterranean, transitional continental – Mediterranean and Semi-arid climate. Thessaloniki is the second largest city of Greece with a population over 1.000.000 and the capital of Macedonia. Thessaloniki is located on the Thermaikos Gulf, at the northwest corner of the Aegean Sea. Because of the sea, Thessaloniki's climate is affected by it. Its climate is humid subtropical that borders to the Mediterranean climate and also semi-arid climate. During winter the climate is dry with morning frost. The coldest month is January. During the summer the climate is hot with humidity during the night. The hottest month is July.

3.3 Use of energy related to the outside temperature

The current sample is compared with the outside temperature. An average value of the temperature per month has been acquired for Thessaloniki from an external weather provider application programming interface (API) for the sampling period of April 2018 to March 2019. Data is also available for the previous year of 2017 which shows a similar condition of the weather (Figure 3).

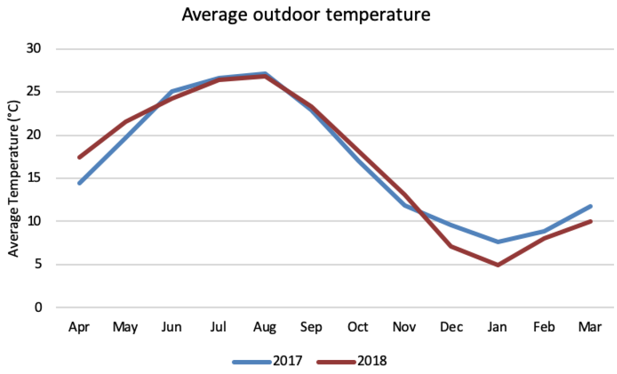

Fig. 3. Average outdoor temperature for Thessaloniki, GR

According to other studies and published papers [1], [12], there is an outdoor temperature "comfort zone" between 15 and 18 degrees (°C) where the average energy consumption is at its lowest.

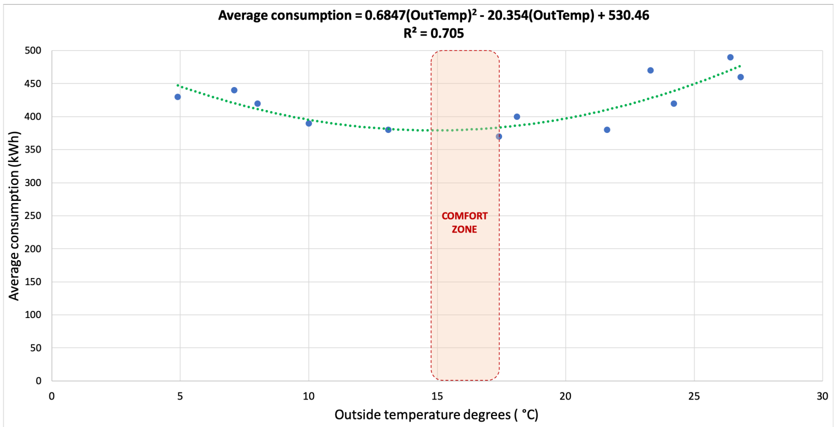

Fig. 4. Relationship/correlation of average consumption in regard to outdoor temperature

The correlation between outdoor temperature and monthly average consumption is depicted in Figure 4. A nonlinear regression [2] was used to test the relationship. The R-squared (R^2) is a statistical measure that represents the proportion of the variance for a dependent variable that is explained by an independent variable or variables in a regression model. The R^2 analysis reveals that the model fits well the data. Within the comfort zone, which is 15 to 17.5 °C it is apparent that energy consumption is at its lowest. The heater it gets, the higher the heating ventilation and air conditioning systems (HVAC) system usage. On the other hand, within the comfort zone, it is apparent that energy consumption is at its lowest. In such cases, households maintain an average temperature that makes the users feel more comfortable, which leads to less usage of HVAC.

The statistical analysis of average consumption along with the standard deviation is as described in Table 5 and depicted in Figure 5.

Table 5. Statistical analysis of the average consumption of residential houses

Average monthly consumption	419,8 kWh
Average daily consumption	13,5 kWh
Average monthly consumption per person	201,9 kWh
Average daily consumption per person	6,5 kWh
Standard monthly deviation per household	38,5 kWh
Standard daily deviation per household	3,6 kWh

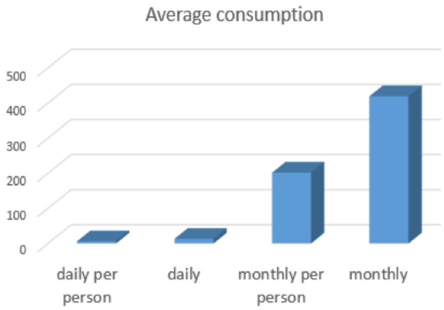

Fig. 5. Average consumption

The change in the relationship between consumption and temperature does not follow a seasonal pattern. The assumption that consumption changes per season is not eligible according to Figure 6. For example, during the month of April, which is Spring, the average consumption is the same as in the case of the month of November, where the temperature is similar, but the season is different (Autumn). The demand of energy consumption is not season dependent. In case the consumption was affected from season, then the same season the consumption would be the same no matter what the outdoor temperature was.

3.4 Energy consumption patterns

Individual energy consumption patterns may differentiate on regards to daily average consumption, demand during peak hours and motifs. Some characteristic

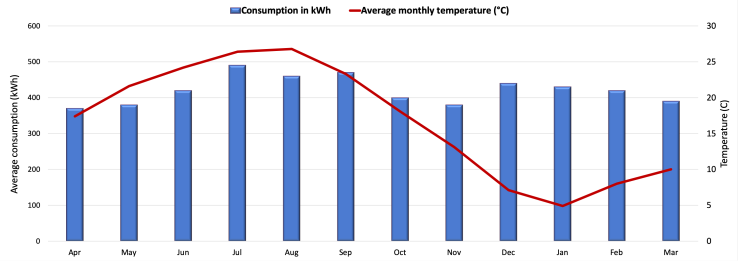

Fig. 6. Outside temperature compared to consumption for one year

behavioral patterns of families with one to three children are as depicted in Figure 7. The number of occupants within a house affects the amount of total daily energy used. In the figure below, the user with the higher peak value (green line) has three children.

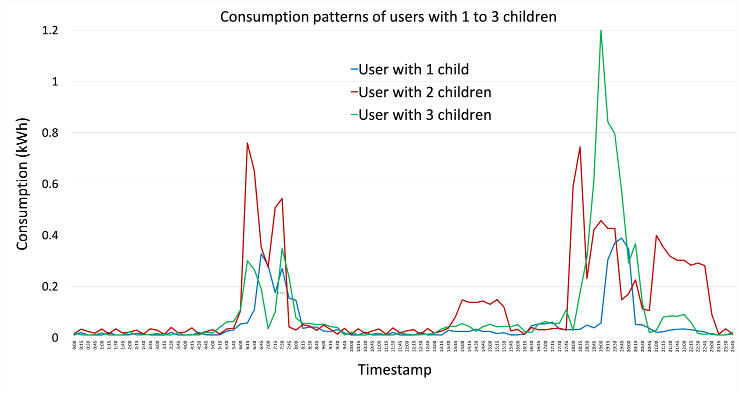

Fig. 7. Daily consumption patterns

Another pattern that is studied is the relationship between consumption (in kWh) and the number of rooms in the household. In Figure 8 it is apparent that the differentiation in the number of available rooms does not have a big impact on the total amount of energy consumption during a single day. Nonetheless, a small increase does occur where the number of rooms is more than three.

A significant divergence in energy consumption is visible when comparing two users with non-identical types of heating in the household. In Figure 9 one of the users has the option to heat the house using a natural gas heater and an air conditioning unit (A/C), whereas the other one can only use natural gas. The user with the extra A/C unit has an average daily consumption of 3,65 kWh more if compared to the user without A/C. Moreover, this user's daily peak value

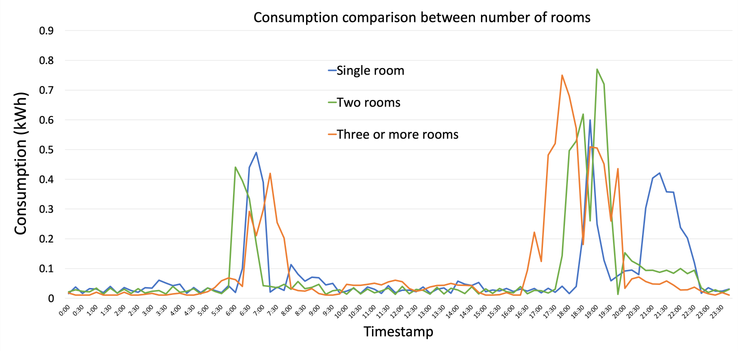

Fig. 8. Patterns of consumption between different number of rooms

is calculated at 0,30 kWh over the analogous peak value of the second user in question.

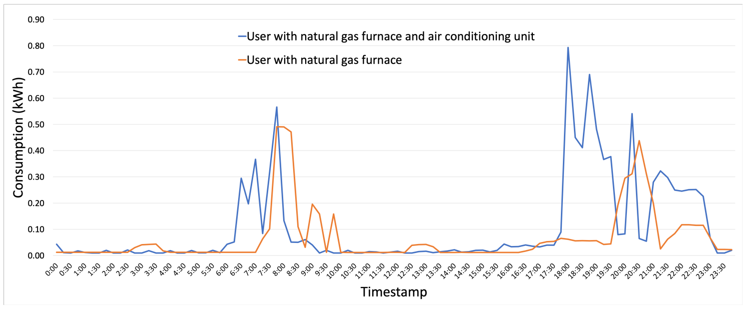

Fig. 9. Patterns of consumption between different heating type

In general (Figure 10), it may be seen that consumption is never zero, because there are always devices, either active or on standby, for example, a working fridge or LED lights. There are also several time stamps during the day, where a higher consumption is apparent, that concurs with the users' morning routines as well as evening occupancy of the household. Moreover, lower consumption may be due to user absence.

Contrarily, none of the daily patterns overlap with any other. This case may be observed throughout the whole sample. There is a time shift on morning routines, household occupancy and absence. Additionally, electricity consumption is shifted quantitatively, depending on each users' energy consumption profile.

As it may be observed, in Figure 11 each day has a unique consumption instance, both in the total kWh used and the time of usage. A deeper look reveals how the user is consistent during the weekdays, such as the sleeping routine, the absence during work hours and the evening occupancy. Furthermore, from Friday

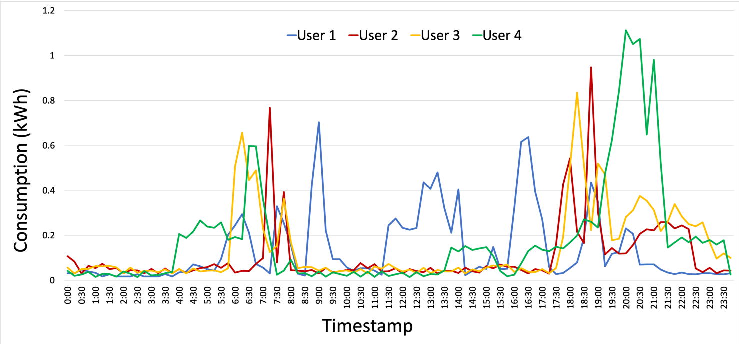

Fig. 10. Daily consumption patterns of four random users

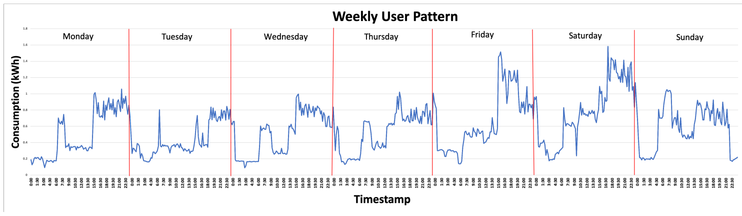

Fig. 11. Weekly consumption patterns

afternoon to Saturday evening the consumption is at its highest, because the user might be using home appliances, like washing machine and dryer.

4 Conclusions

This study aims to establish a better understanding of the patterns of residential energy consumption. The relationship between energy demand and the temperature is examined, which in turn reveals that there is an apparent correlation between them, at least for average monthly measurements. An analysis of the average values concludes that even though the monthly average standard deviation (stdev) is low, the daily stdev value is really significant. This, in turn, leads to the assumption that consumption should be analyzed through individual profiling of users. To this extent, both outdoor temperature and indoor temperature are to be taken into account while analyzing data.

Results showed that consumption is affected basically from daily routines. Energy behavioral patterns are not only affected by outdoor temperature but also depend on the day of the week. To sum up, consumption monitoring can help users to observe their energy usage and improve their behavior towards more efficient load management.

Acknowledgements

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