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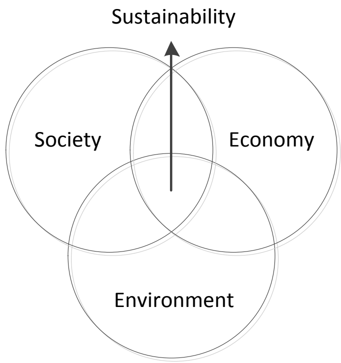

Demand side management strategies for the residential sector

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I dedicate this Thesis to my Family, mainly my Mother, my Father, my sister, Ana and my brother, Guilherme, who hve always been present for me, no matter what, and who inspired me since the day I was born to always search for my positive mark in the world.

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Abstract

This Thesis is contextualized in the Net Zero Energy School (NZES), which is being developed by a IST, LNEC, QUERCUS and ICS partnership, under the framework of the MIT Portugal program. This Project intends to sensitize the students and their families to improve their domestic energy habits and, with that, their efficiency.

This Thesis assesses the potentiality of improving the residential energy efficiency and cost savings through a calculation tool developed by the author, which automates (and enables) the estimate of the respective costs of the different profiles, as well as the daily average profiles. The approaches and main conclusions follow:

- Shifting the consumption of two refrigerators from “peak” times: consumption increase between 4.6 and 9.9% and costs raising between 2.6 and 7.0%, depending on the refrigerator and the schedule;
- Connecting the dishwashing and the washing machines to a pipe in which the water is heated by a gas heater: costs increase 23 and 82.5% and the CO_2 emmissions 18 and 46%, respectively. If consumption to heat the water is not needed, a decrease in 52 and 89% in the costs and in the environmental impact results;
- Analyzing the electricity consumption profiles of four different families (two of which being part of the NZES study-target) and determining the potential savings by changing the tariff, the contracted power, eliminating the standby consumption during the night time and deviating the usage of the washing and dishwashing machines to “off-peak” times: costs decrease between 12.1% and 19.8% just by changing the contracted power, being the overall savings up to 47.1%, and consumption lowering of 5.6%.

By applying the recognized potentialities in the third point, together with those determined in the second one without expenditure in water heating, the national consumption would decrease 2.6%, corresponding to 1.4×10^3 GWh and 3.9×10^3 $tonCO_2e$ per year.

In order to reach more representative values, further experiments with more families, refrigerators and controlled parameters would be required.

Key-words

Energy efficiency, Consumption profiles, School buildings, Behavior change, Sustainable behavior, Refrigerator, Dishwashing machine, Washing machine, Demand side management .

Resumo

Esta dissertação insere-se no âmbito do Projecto Net Zero Energy School (NZES), o qual está a ser desenvolvido por uma parceria entre o IST, LNEC, QUERCUS e ICS,

Este projecto pretende sensibilizar os estudantes e as suas famílias para melhorar os seus hábitos de consumo energético e a sua eficiência.

Nesta dissertação avalia-se o potencial de melhoria na eficiência energética doméstica e redução de custos através de uma ferramenta de cálculo desenvolvida pelo autor, que estima os custos associados a diferentes perfis de consumo, nomeadamente custos médios diários. Seguem-se a abordagem e as respectivas conclusões:

- Alteração do consumo de dois frigoríficos na hora de ponta: o consumo aumenta entre 4,6 e 9,9% e os custos sobem entre 2,6 a 7,0%, dependendo do modelo do frigorífico e do horário.
- Modificação do aquecimento de água nas máquinas de lavar loiça e de lavar roupa, através da ligação destas ao esquentador: os custos aumentam 23 e 82,5% e os impactos ambientais de 18 e 46%, respectivamente. Eliminando o consumo para aquecer a água, poupam-se 52 e 89% dos custos e dos impactos ambientais resultantes, respectivamente;
- Análise dos perfis de consumo de electricidade de quatro famílias (duas incluídas no NZES) e determinação das potenciais economias alterando as tarifas contratadas, as potências contratadas, eliminando os consumos em standby durante a noite e alterando a utilização das máquinas de lavar loiça e lavar roupa para períodos fora do horário de ponta: a alteração da potência contratada permite uma poupança entre 12,1 e 19,8% nos custos, sendo a economia global no máximo, 47,1% e a redução de consumo 4,9%.

Ao aplicar as potencialidades referidas no terceiro ponto, juntamente com as determinadas no segundo e sem incluir as necessidades de aquecimento de água, o consumo nacional reduzir-se-ia em 2.6%, o que corresponderia a uma poupança anual de 1, 4×10^3 GWh e 3, 9 $\times 10^3$ tonCO_2e.

No intuito de se obterem resultados mais consistentes e representativos, dever-se-ão efectuar testes que abranjam mais famílias e modelos de frigoríficos, sendo que deve ser incluida maior variedade de parâmetros.

Palavras-chave

Eficiência energetic, Perfis de consumo, Edifícios escolares, Mudança de comportamento, Comportamento sustentável, Frigorífico, Máquina de lavar a loiça, Máquina de lavar a roupa, Gestão activa da procura

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ADENE	Agência para a Energia
BTN	“Baixa Tensão Normal” (normal low voltage)
CMVM	Comissão do Mercado de Valores Mobiliários
EC	European Commission
EDC	Expansion Device Capacity
EDP	Energias de Portugal
EPBD	Energy Services Directive
ERSE	Entidade Reguladora dos Serviços Energéticos
ESD	Energy Performance of Buildings Directive
ESVG	Escola Secundária Vergílio Ferreira
EU-27	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gases
ICS	Instituto de Comunicação Social
IST	Instituto Superior Técnico
LHV	Lower Heating Value
LNEC	Laboratório Nacional de Engenharia Civil
MIT	Massachusetts Institute of Technology
ME	Ministry of Economy
NZES	Net Zero Energy Schools
RCCTE	Regulamento das Características de Comportamento Térmico dos Edifícios
REN	Rede Eléctrica Nacional
RSECE	Regulamento dos Sistemas Energéticos e de Climatização dos Edifícios
SCE	Sistema de Certificação de Edifícios
SWH	Solar Water Heating
UN	United Nations

Chapter 1 - Introduction

This Chapter frames the economic, environment and social context around energy and environmental concerns under which this Thesis was developed. In particular it describes the scope of the project in which this Thesis is integrated – Net Zero Energy Schools (NZES).

The main research questions to be answered, as the main goals to be achieved, are also enunciated. The overview of the Thesis closes this Chapter.

1.1. Motivation

"And I'm asking you for your good and for your nation's security to take no unnecessary trips, to use carpools or public transportation whenever you can, to park your car one extra day per week, to obey the speed limit, and to set your thermostats to save fuel. Every act of energy conservation like this is more than just common sense -- I tell you it is an act of patriotism."

- Jimmy Carter, 39th USA President,

Speech to the Nation, "Energy and the National Goals—A Crisis of Confidence," 15 Jul 1979

The United Nations definition of Sustainable Development is "(…) *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (UN). This sustainability is being threatened in an unprecedented way due to the social dysfunctionality, the environmental degradation and the global economic crisis that the world is suffering. Indeed, the world is facing an alarming scenario, which can be seen in these following numbers (UNEP, 2011):

- In the last 300 years, the global forest area has shrunk by approximately 40%;
- Since 1900, the world has lost about 50% of its wetlands;
- Deforestation destroys around 2 million hectares of forest, annually;
- Approximately 60% of the Earth's ecosystem services have been degraded in the last 50 years;
- More than 50% of the Chief Executive Officers in Latin America see declines in biodiversity as a challenge to business growth;
- Close to 20% of current global greenhouse gas emissions are linked with deforestation.
- Funds engaged so far are intended to realize over $2 billion dollars of clean energy infrastructure;
- The emission reduction potential of the building sector (at a carbon cost of $20 per ton CO_2e) is larger than the combined potential of industry, transport and forestry;
- The International Energy Agency predicts an increase in fuel consumption and CO_2 emissions from the world's cars will roughly double between 2000 and 2050;
- In Portugal, the energy consumption has risen, since the 1990's, 3.2% per year (*ca.* 0.7% above the Gross Domestic Product (GDP) growth) (ADENE, et al., 2010).

Evidently, these are facts that must be considered in a sustainable matter. The technological growth is increasing each passing day, which can be perceptive by, per example, the growth in internet users: from 16, reached to 1,650 million users in the last 16 years (Stats, 2011), and this growth is linked to the increase of resources expenditure. Indeed, the society has becoming more and more demanding. Some say that new generations are damaged because they are exaggeratedly spoiled (Stillwell, 2011). Even though one must ask if it is all the society, in general, that are "spoiled", the unconcern on wasting is evident through the pollution indicators. The social evolution should lead to decrease in consumption, not the opposite. The overall sustainability to be achieved requires a sustainable consumption, in particular of energy resources.

The inefficient habits of people are the main obstacle in the struggle for achieving energy efficiency. This Thesis aims to take a step forward in the upgrade of the referred energy efficiency in the residential sector, through an active demand-side-management of the energy consumption and with a strong linkage to the Social Sciences. Indeed, this Thesis is directly associated to a Project called Net Zero Energy School (NZES), which is being developed by a partnership Insituto Superior Técnico (IST), the Laboratório Nacional de Engenharia Civil (LNEC), the Associação Nacional de Conservação da Natureza (QUERCUS) and the Instituto de Ciências Sociais (ICS), under the framework of the MIT Portugal program, a research partnership between the Massachusetts Institute of Technology and the Portuguese Universities. This Project intends to sensitize the students and their families to improve their domestic energy habits and, with that, their efficiency. This linkage allows a stronger contribution from this Thesis to the domestic energy efficiency due to the unprecedented association between Engineering and Social Sciences, which opens a new path in the breaking of the friction between the inertia of the human habits and the technology innovation.

The importance of the energy efficiency in a residential level is notorious when one thinks about the share of the building sector in the national electricity consumption, which, in 2008, was 60%: 29% concerned domestic buildings and 31% regarded service buildings (ERSE, 2009). A high share of these buildings consume electricity in BTN ("baixa tensão normal", corresponding to electricity consumption with voltage levels under 1 kV, being the contracted power up to 41.4 kVA), which corresponds to 44.9% of the national consumption (CMVM, et al., 2011).

The national energy policy has been based on a "supply follows demand" (ME, 2003), which leads to an over-installed national power to serve the highest expected consumes, mainly in "peak" time hours , as shown by the national consumption in 2010 (Chart 1.1-1)[1]. This system has the advantage of satisfying the energy needs but it has the disadvantage of allowing that the demand commands the amount of energy produced. By having an active role in the energy demand side – demand-side-management – one can control the consumption so that the national supply can be more efficient. This control must be within certain boundaries and should not decrease the comfort level of the population, but it must be accurate enough in order to incentive the efficiency usage of electricity. The wished national consumption profile must be as homogeneous as possible to reach the best possible efficiency because, in this way, the consumption will dilute from "peak" time to the remaining periods of the day, allowing decrease in the national instant electricity supply power and so the instantaneous pollution generation decreases, as well as in the grid tension, what reduces the electricity loss by heat transmission (CMVM, et al., 2011), as it can be seen in Chart 1.1-2[2], in which is represented the average percentage of energy loss in the grid, concerning the consumption in BTN. Further, demand side management strategies have to look also into energy reduction, which tackles with the use of more efficient equipments, the elimination of superfluous consumptions (e.g.

[1] This chart was determined by running the data referred to 2010 (REN, 2010), in a calculation tool developed by the author, which is explained further and is used several times along the studies in this Thesis. Therefore, this chart gives the exact daily average electricity consumption in Portugal, for 2010 (see Annex II).

[2] This chart was obtained as the ratio between the average of the national daily energy loss in the distribution, predicted for 2011 (CMVM, et al., 2011), and the average national electricity consumption determined in Annex II, multiplied by the share of consumption in BTN (CMVM, et al., 2011). The national average electricity loss is determined by running the data in the calculation tool developed by the author (see Annex II).

stand-by) or changing the energy source for certain types of use (*e.g.* using solar energy to produce hot water).

Reinforcing the urgency of improving the national energy efficiency, the 27 countries of the European Union (EU-27) must accomplish the following goals:

- Reducing 20% of the total energy consumption registered in 1990, until 2020 (EC, 2010);
- Rising up the renewable energy share to 20%, until 2020 (EC, 2010), which means, for Portugal, to raise the renewable energy share to 31% until 2020 (EU, 2011);
- Improving the energy efficiency so that the energy expenditure reduces 20% (EC, 2011).

In conclusion, with this Thesis, one expects to provide some insights regarding the change of the residents' habits through demand-side-management strategies, taking into consideration some knowledge from the social sciences fields in order to reach the families. The youngest people are the main motivation target of the habits changes of NZES Project, hopping that they can serve as an example to the elders. Though the youth is known as belonging to the spoiled generations, they must prove the opposite and show that mistakes from the past only belong to the past and should not continue in the present, which is the onset of the future.

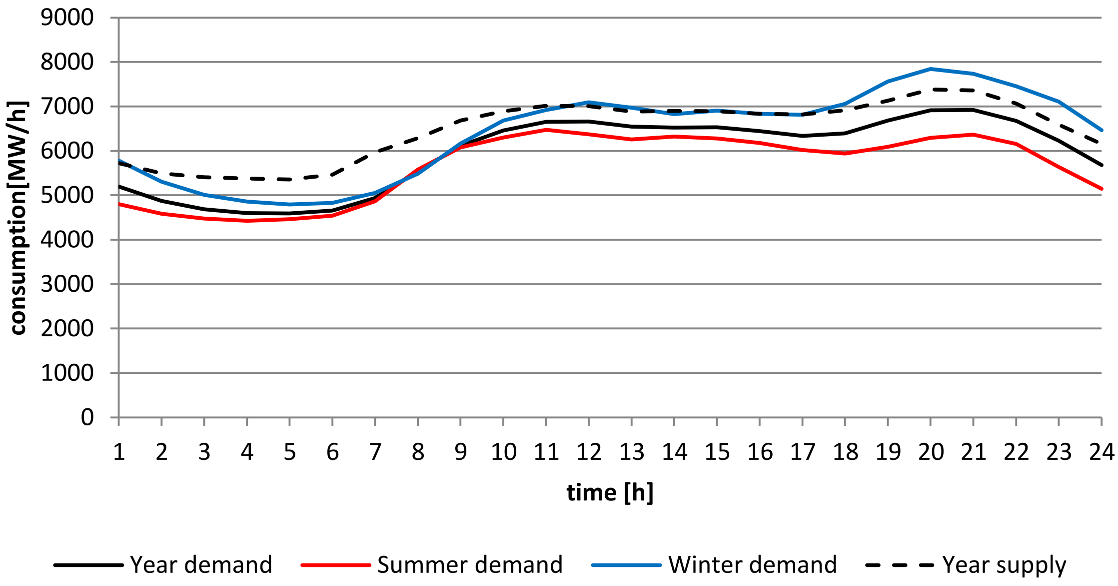

Chart 1.1-1– Average national daily electricity consumption and supply profiles in 2010 (obtained in this Thesis upon processing the data from **(REN, 2010)**, concerned to the electricity consumption in 2010 in intervals of 30min, determining the daily average electricity consumption during the year; winter and summer periods are also evidenced individually, occurring, respectively, from October 31st to March 26th and from March 27th to October 30th, being determined the daily average consumption as well).

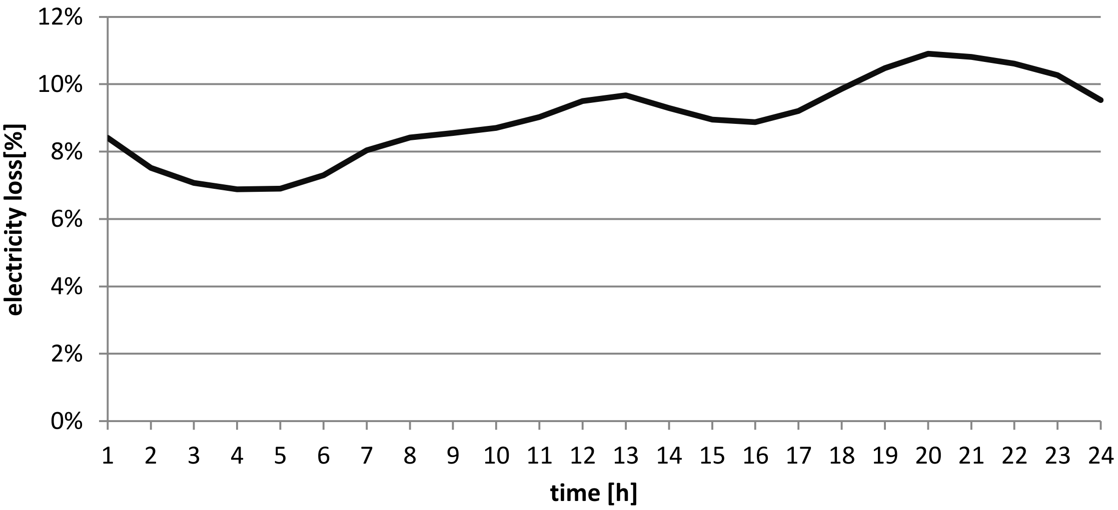

Chart 1.1-2 – Average percentage of electricity loss predicted for 2011, for BTN consumption (obtained in this Thesis through processing the available data, concerning the prediction for electricity loss in the grid in 2011, at **(ERSE, 2011)** and dividing by the BTN share **(CMVM, et al., 2011)** in the registered electricity consumption for 2010 **(REN, 2010)**.

1.2. Research questions and goals

This Thesis has a background motivation that can be described by the following questions:

- Can an active demand-side-management of the residential energy consumption have a perceptible influence in the national electricity consumption?
- Changing behaviors is known to be the main obstacle against energy efficiency. Therefore, can demand-side-management be achieve without influence the people's comfort in an unacceptable way?
    - By applying an automatic induced shut-down of the refrigerator during some periods of the day, has the outcome environment and monetary benefits?
    - By changing the habits of using the dishwashing and washing machines to "off-peak" times, which environment and monetary benefits can be achieved?
    - In order to encourage these behaviors, what are the advantages of changing the electricity tariff?
    - Which environmental and economic advantages can come from turning-off the standby consumption?
- Being the main purpose the establishment of a thinking-line methodology to assess the potential savings according to different electricity consumption profiles, how can an automatic calculation tool enable such studies?
- How can the study-target families by the NZES project can benefit with the studies developed in this Thesis?

1.3. Overview

This Thesis is composed by five Chapters.

Chapter 1 frames the economic, environment and social contexts within energy and environmental concerns under which this Thesis was developed. In particular, it describes the scope of the project in which this Thesis is integrated – Net Zero Energy Schools (NZES).

Chapter 2 summarizes the main "State of the Art" of actions related to energy efficiency undertaken in schools and domestic energy efficiency, focusing the demand-side-management main points: incentives for habit changes and potentiality of consumption changing.

Chapter 3 describes the experimental part of this Thesis, which consists in testing different consumption habits for three utilities (refrigerator, dishwashing and washing machines).

In Chapter 4 the electricity consumption profiles of four different families (two of which belonging to the NZES project study-target) are analyzed, which enables the assessment of the adequacy of the chosen tariff by each family. This Chapter closes with an overall analysis through the average consumption of these families and with an extrapolation of the consumption habits change to a national level, being determined the potential savings.

Chapter 5 depicts the general conclusions of this Thesis and the proposed future work, as well as its limitations.

Chapter 2 - Literature review

This Chapter summarizes the main “State of the Art” of actions concerning energy efficiency undertaken in schools and domestic energy efficiency, focusing the demand-side-management relevant points: incentives for habit changes and potentiality of consumption changing.

2.1. Residential demand side management

2.1.1. Residential energy efficiency

The building sector (not taking in account it's construction phase) is responsible for more than a third of the global annual resource consumption, including 12% of all fresh water use, and produces 40% of solid waste (UNEP, 2011).

The domestic electricity consumption has risen in Portugal in the last years – it represented 15.9% in 1989 and 44.1% in 2010, relatively to the national consumption (INE, et al., 2011), being the residential and the transportation sectors the ones who increased their consumption the most (ADENE, et al., 2010). In Portugal, the percentage of metropolitan citizens has increased from 19% to 68% from 1950 to 2000 (INE, 2007), respectively. Also, 60% of the national electricity consumption is regarded to buildings, being 29% assigned to domestic buildings and 31% concerned to service buildings (ERSE, 2009).

According to Bertoldi, et al. (2009), the residential electricity end-use increased 2.11% from 2007 to 2009. This is a consequence of several factors, such as the growth of electric equipments in the dwellings (*e.g.*, audiovisuals, specially personal computers and air conditionings) (ADENE, et al., 2010). Even though, this growth was smaller than the increase of gas consumption of 9%, from 1999 to 2007. However, the residential final energy consumption in the EU-27 decreased 7.12%. It was the first time, since 1990, that the final energy consumption decreased from one year to the following one. Such fact may be a consequence of the effectiveness of residential energy efficiency policies and measures.

This reduction trend is rather recent, which means that hopeful predictions may still be premature. In fact, the predicted climate changes may also have an impact in energy consumption. According to Pilli-Sihvola, et al. (2010), it is estimated that the electricity use will decrease in Central and North Europe, due to decrease in warming needs but, in Southern Europe, the necessity for cooling will overtake the less needing for warming.

Figure 2.1-1 shows that the residential sector had a share, in 2007, of 18.63% among the EU-27 final energy consumption.

According to Águas (2003), final energy is the energy resulting from the transformation of primary energy (*e.g.*, oil, coal, wind, sun or natural gas) being, in most cases, the electricity (it can also be, *e.g.*, gasoline, diesel, gas or heat). Associated to this transformation, there are performance losses due to processes inefficiency. This final energy is then transported in the electricity grid to the consumption points (*e.g.*, households, service buildings or industry) and, again, with performance losses in these processes. Finally, the energy that comes out of the plug at home is electricity that makes the equipments operating. This working corresponds to the end-use energy (*e.g.*, the light from a lamp, the water pumping and heating in the dishwashing and washing machines, as well as the tambour rotation in the washing machine and the refrigeration liquid compression and heating in the refrigerator).

Finally, linked to the end-use energy, there is the productive energy, which corresponds to the correct way that the former energy is utilized. *E.g.*, room lightning use when no one is in there, the selection of a program in the dishwashing or washing machines that is too intensive for the dirtiness of the dishes or clothes, respectively, or the placement of still warm food inside the refrigerator, instead of previously waiting to cold to the room temperature, constitute bad practices which lead to productive energy waste.

This Thesis assesses the impact of meliorating the consumption habits (end-use and productive energy), as well as the effect of such improvements may have in the grid losses (final energy – electricity). ADENE, et al. (2008) sustain that changing the consumption habits in service buildings, one can reduce up to 35% in energy consumption, without changing the comfort level.

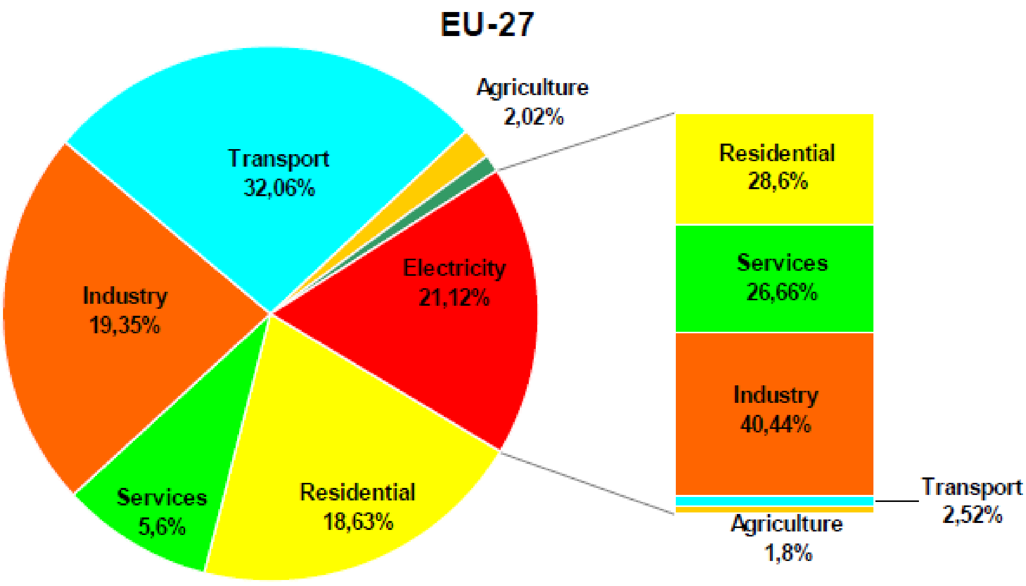

Figure 2.1-1 – Breakdown of the final energy consumption between sectors and final electricity consumption, in 2007 (Bertoldi, et al., 2009).

Together with the EU legislation, the State Members are adopting energy measures concerning financial incentives, supplier obligations, information, *etc.*, that are targeted to accomplish the potential EU savings. Examples of such measures are as follows (Bertoldi, et al., 2009):

- The Eco-design of the Energy-Using Products Framework Directive 32/2005/EC (Eco-design Directive);
- The End-use Energy Efficiency and Energy Services Directive 32/2006/EC (ESD);
- The Energy Performance of Buildings Directive 91/2002/EC (EPBD, under recast);
- The Labeling Directive 92/75/CEE

The national energy policy has been based on a “supply follows demand” (ME, 2003), which leads to an over-installed national power to serve the highest expected consumes. In order to contradict this policy, promising studies concerning “smart grids” are being undertaken (Livengood, et al., 2009). The concept of “smart grid” is linked to “smart metering”, which enables real-time consumption measurement of the different appliances in a household (demand side response) and an interactive management by the electricity retailers or energy service companies to shape the consumption profiles, by shifting loads away from “peak” times into periods when energy supply is constrained (Abreu, et al., 2011). Such consumption displacements are intended for a range of equipments, *e.g.*, refrigerators or dishwashing and washing machines, whose potentiality is assessed in this Thesis. In the overall, these smart grids are believed to lead to demand-sensitive pricing, which encourage a “demand follows supply” policy (Livengood, et al., 2009).

In order to underline the priority in reaching energy efficiency in the EU, the European Directives 2006/32/EC and 2009/72/EC were published. The first Directive on Energy Efficiency promotes an energy efficiency market where suppliers are encouraged to provide consumers with smart electronic meters capable of providing time of use information and appropriate billing, based upon real consumption instead of estimated data. The later sets the goal for smart metering deployment in households (80% coverage, by 2020) (Abreu, et al., 2011). However, in order to succeed in the former goals achievement, several issues concerning the demand side response must be overwhelmed (Jin-Ho, et al., 2011), as well in the metering equipments costs (Abreu, et al (2011) and Swan, et al. (2009)).

2.1.2. Consumption behavior - factors

The consumption habits have deployed in an increased tendency. In fact, the share of the residential sector in the national final energy consumption increased from 13% (ADENE, et al., 2004), in 2001, to 31%, in 2009 (ERSE, 2009).

There are reported inefficient consumption habits in the households, which are rather common, such as the ones referred in ADENE, et al. (2010), QUERCUS (2004) and EcoDP (2011):

- Taking shower without closing the water while soaping;
- Washing the hands with hot water;
- Keep the lights turned on when no one is in the room;
- Place warm food inside the refrigerator;
- Let the equipments on standby consumption;
- Use programs to hot (above that required by dirtiness) in the dishwashing and washing machines;
- Cook without covering the pan;
- Not recycling;
- Recourse the car in short-term routes;
- *Etc.*

In order to accomplish the improvement of the efficiency in the residential consumption habits, the approaches must not only be concerned to Engineering but to Social Sciences as well, what is stressed along this Thesis.

The demand side responses toward new behavior proposals varies according to the approach of the latter. According to Armel (2008), the behavior change can be explained as it is displayed in Figure 2.1-2:

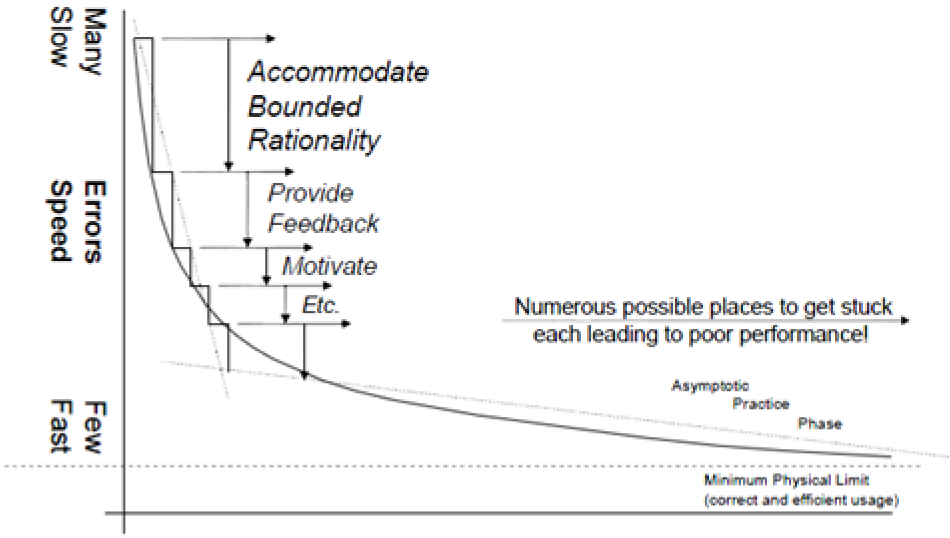

Figure 2.1-2 – "How the user thinks": an approach how practice is linked to efficiency usage **(Armel, 2008)**.

The behavior evolution depicted in Figure 2.1-2 can be explained by the Power Law of Practice, which sustains that "*ca. 80% of improvement along the power function comes from figuring out a good strategy for getting the task done, while about 20% of improvement comes from getting better at the same strategy*" (Armel, 2008). In such is implicit the hardness in adapting new behaviors, whose implementation is linked to the practice (UNEP, 2005), which stretches the need to develop motivation strategies (Ehrhardt-Martinez, et al., 2010).

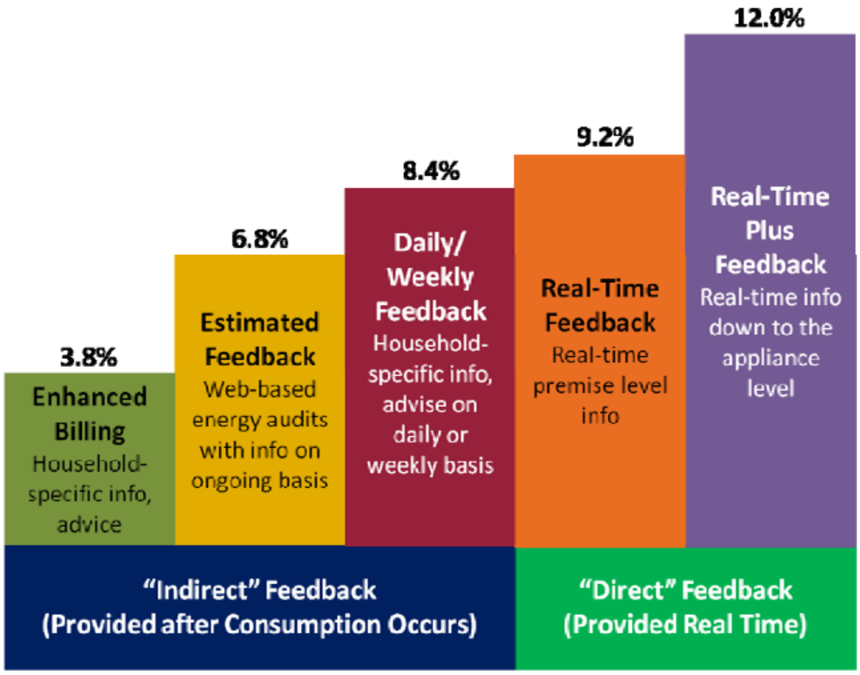

Figure 2.1-3 – Annual percentage on savings resulting from different feedback approaches, based on 36 studies implemented between 1995 and 2010 **(Ehrhardt-Martinez, et al., 2010)**.

Former studies sustain that daily/weekly feedback and real-time plus feedback ("plus" means that useful details on energy use are provided and not just total consumption) tend to have higher corresponding savings per household. However, these estimates result from studies with small sample universes and short duration, which implies a necessity of longer tests durations and larger samples in order to outcome valid conclusions. Studies concerning estimated and real-time feedback strategies reached for savings on *ca.* 7%, while programs that incised on enhanced billing strategies achieved savings of 5.5%, averagely. Hence, feedback is proving to be an important first step toward the consciousness in the residential energy resource management (Ehrhardt-Martinez, et al., 2010).

With the embracement of the demand side response into the demand side management, subchapter 2.1.3 follows with the description of the practical approach in this Thesis, concerning the Engineered potential efficiency to be achieved through the assessment of the energy consumption impact resulting from changes on usage habits of the refrigerator, the dishwashing and washing machines.

2.1.3. Management of appliances: refrigerator, dishwashing and washing machines

The demand side management through smart metering implies deviation of consumption of equipments, as it is referred in subchapter 1. The appliances in which the usage can be displaced to periods with lower energy loads, that are approached in this Thesis, are the refrigerator, the dishwashing and the washing machines.

According to ADENE, et al. (2004), the refrigerator and the freezer utilities represent, respectively, 22 and 10% of the domestic electricity consumption. Concerning the dishwashing and the washing machines, the respective shares in the electricity consumption are 3 and 5 %, respectively. Chart 2.1-1 displays these and other shares.

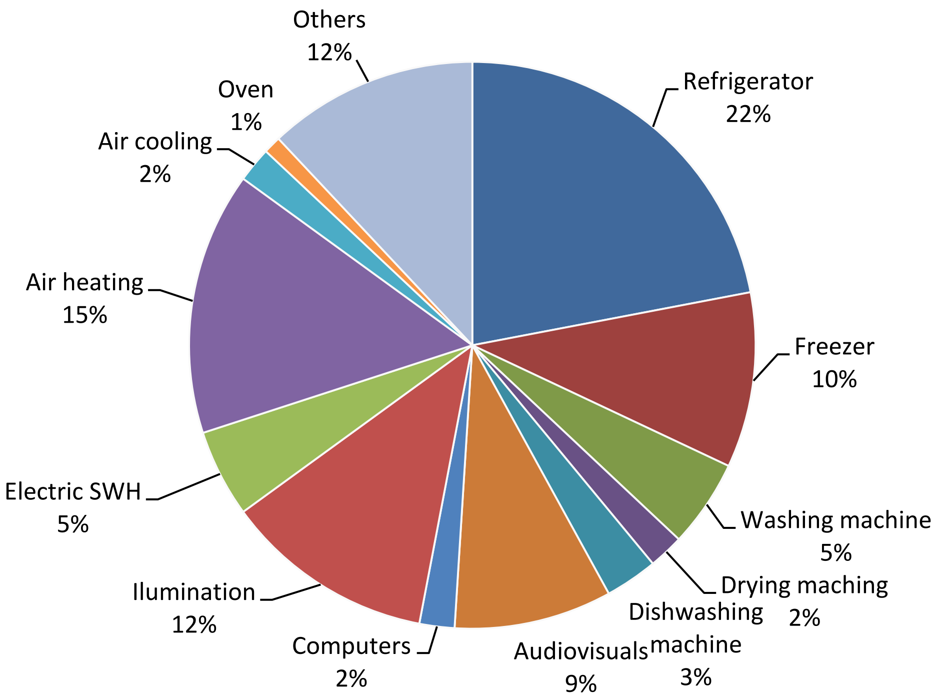

Chart 2.1-1 – Repartition of electricity consumption according to the different final uses in 2002 **(ADENE, et al., 2004)**

The evolution of the energy consumption of the refrigerator and the dishwashing and washing machines is depicted in Figure 2.1-4.

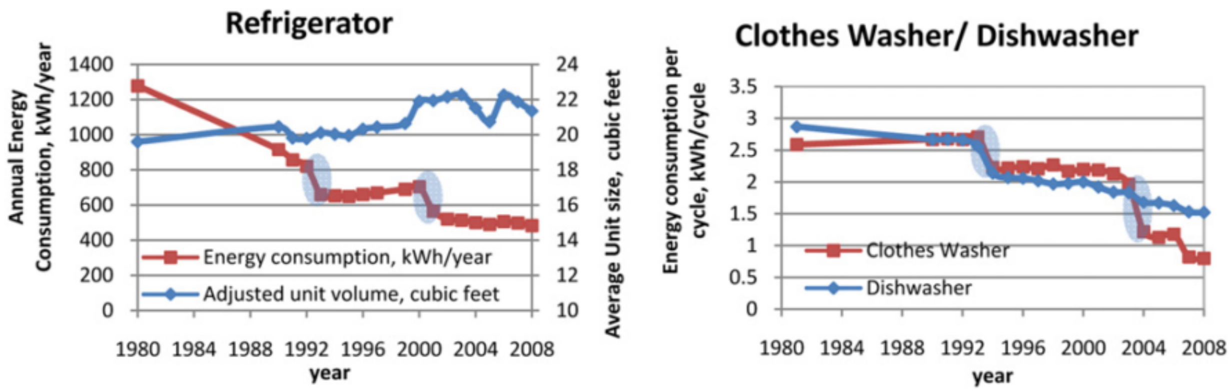

Figure 2.1-4 – Evolution of the refrigerator (concerning the annual consumption per year and the capacity (unit size)) and the washing and dishwashing machines (concerning the consumption per cycle) **(Bansal, et al., 2011)**.

As it can be seen, the performances of these utilities have improved in the last years, more noticeable in 1992 there was an enhanced improve and again in 2000, for the refrigerator, and in 2004, for the washing machine.

The refrigerator is a low powered utility but, once it works continuously, it represents an important share in the residential electricity consumption. Moreover, the consumption varies with the following several factors (ADENE, et al., 2010):

- Isolation (68%);
- Food (13%);
- Door seal (8%);
- Door openings (7%);
- Others (4%)

These factors vary with the dwelling habits and the refrigerator, meaning that before any conclusion be established, it is mandatory to perform several studies in various scenarios, which does not occur in this Thesis. Nevertheless, the refrigerator is dotted with a thermal inertia (Malaquias, 2010) what allows forced shut downs in the refrigerator in "peak" consumption times, without compromising the food quality and with cost benefits. However, it is found in the literature that, in order to benefit from such measures, one must recur to phase-change-materials to maintain the low inside temperature (Bansal, et al., 2011).

Concerning the washing and the dishwashing machines, the water heating corresponds to the highest consumption per cycle: 90 and 80-85%, respectively (ADENE, et al., 2010). Therefore, the assessment of the decrease in the national consumption if suppressing this consumption (*e.g.*, using solar energy to produce hot water), together with the shift of the usage of these two appliances during "off-peak" times, reveals to be quite interesting (Pina, et al. (2011) and Abreu, et al. (2011).

Chapter 3 - Experimental activities

This Chapter describes the experimental part of this Thesis, which consists in testing different consumption habits for three utilities:

- The refrigerator, by turning it off during some daily periods;
- The washing and the dishwashing machines, by connecting them to the hot water pipe (the same as the hot water tap of the kitchen), instead of the regular cold water pipe.

3.1. Methodology

The shares of the refrigerator, the dishwashing machine and the washing machine in the domestic electricity consumption are 22%, 5% and 3%, respectively (Chart 2.1-1).

Two approaches were studied in this Thesis. The first one consists in scheduling different working periods for the refrigerator, instead of the normal continuous work during the day, and the other approach is to connect the dishwashing and the washing machines to the hot water pipe – therefore, the water being heated by the water heater before entering into the machine – and see how it can influence the electricity consumption and balance it with the gas and extra water consumption. The consumptions of the utilities were measured with one PlugMeter® that can register up to thirteen variables regarded to electricity consumption while the appliance is turned on. Concerning the consumption profiles of the four families, they were measured with the iMeter® kit, the PlugMeter of which is a complement but, in this case, the iMeter® registers the overall consumption of the dwelling.

A *calculus* tool was developed through a code in Visual Basic that analyzes the data saved by these gadgets (in format Coma Separated Value – CSV – file), which estimates the average daily consumption (accumulated and by the chosen interval) and the average daily costs according to all different tariffs and in the different tariff seasons of the year, as it is explained in Annex I. This code is used in this Thesis each time are presented a daily average consumption and the associated costs. More than the practical use for this Thesis, this tool will be available to be used during the NZES Project, what provides an added value.

3.1.1. Refrigerators

The study focused on two refrigerators:

- one of them in the house of the author, which is a BOSCH KGN46A03, with energy labeling A^+ , a compressor power of 150 W and a refrigeration power of 220 W. Is a combined refrigerator, meaning that it has a freezer partition bigger than a regular refrigerator;
- and another refrigerator in the MIT Portugal Program offices, at the IST campus TagusPark, which is an INDESIT R 28, with energy labeling B and a total power of 150 W. As it can be seen, this refrigerator has an efficiency performance lower than the BOSCH but less than half of its power.

The chosen schedules were:

(i) Working continuously;

(ii) Disconnected from 9 to 10 h and from 15 to 16 h, which corresponds to the "peak" times in electricity consumption, as it can be seen in Chart 1.1-1;

(iii) Disconnected from 22 to 0 h, which corresponds to the "peak" time at the residential sector.

The reasons why they were chosen are:

(i) ⟶ This is the standard working for a refrigerator and, thus, it is the basic model for the remaining scenarios;

(ii) ⟶ These two periods correspond to "peak" time, which means hours of higher electricity consumption in a national scale, which is represented in Chart 1.1-1. Though the period from 15 to 16 h is not a maximum peak (this is close to 20h30), it is a pre-"peak time" period in the room because that is the time when people go to have a snack and, therefore, the consumption is higher right afterwards, as it is shown in the working normally consumption profile in Chart 3.2-2. The interval between 17 and 18 h corresponds to a "peak time" period.

As it was said, the consumption measured in "peak" time determines the installed power capacity. Decreasing the overall consumption in these periods can lower the installed power capacity and also the electricity losses in the power grid through heat losses in the cables. Having chosen this schedule, positive results are a decrease in the electricity bill, even if it means more accumulated electricity consumption (it will be spread along lower-consumption periods);

(iii) ⟶ This period corresponds to intense national electricity consumption. Following the aim to decrease national peak electricity consumption, this is a potential good schedule to adopt, especially if the user has a "two" or "three rate" tariff, where the energy is cheaper in "off-peak" time (from 0 to 7 or 8 h). This is expected because the bigger consumption of the refrigerator should be right after the perturbation is applied.

All measurements correspond to a period of one week because for each day there is a different usage of the refrigerator. Moreover, the monetary expenditure according to different tariffs was also simulated and, since the tariffs are different in week days and at the weekend (see Annex III), the period of the entire week is also required. In such a way, more representative values are achieved.

The refrigerator consumption is affected by the air temperature (T). In Bjork, et al. (2005), for tests under approximately the same experimental conditions, the consumption varies according to: $(0.05T - 0.47)[\mathrm{kWh}/24\mathrm{h}]$ (see Annex IV) and so this is the variation assumed by the author. Unfortunately, the temperature inside the rooms was not measured because, at the time of the measurements, the author was not available to measure regularly the temperature and there was not any thermometer with data storage availability. So, the approximation made was as follows:

- The temperatures registered during the experimental period were collected in (WeatherUnderground, 2011), using the registered data of the closest stations of TagusPark campus (Barcarena station – 1,5 km) and the author's house (Amadora station – 4 km);
- The previous point was repeated for the first two weeks of September and the room temperature (in TagusPark room and in the author's kitchen) of this period was measured during the day with a thermometer. Then, this temperature was crossed with that registered in WeatherUnderground and a relation was established:
    - For the TagusPark campus, the measured temperature variation, during the day, is very mild (having a constant increase of the temperature until the end of the afternoon). But, as the average weekly temperature increases, the temperature inside the room increases

approximately at the same rate. Thus, the average temperature collected for the tests will be considered as having the same variation as the room temperature, which is a fair approximation because, in that room, the sun strikes directly in the afternoon and the air conditioning is not usually turned on and the window is commonly opened.

- For the kitchen in the author's house, the measured temperature also varies slightly during the day, increasing until the end of the afternoon, but it is not as high as the average registered in WeatherUnderground. The weekly increase of the outside temperature reflects a lower increase of the room temperature. This is a fair approximation because the kitchen does not have the sun striking directly, though the windows are frequently opened and has no air conditioning. Still, the house has a rather good thermal isolation. Therefore, the week variation of the room temperature will be considered as half of the temperature variation registered in WeatherUnderground.

Though this approach does not correspond to the real values that could be measured, it must be understood that, even if the temperatures in the weather stations are not the same as the outside temperature in the studied sets, the weekly amplitude shall be approximate in both places, what gives a reasonable accuracy to this methodology.

The temperature is the only quantified factor by the author. Indeed, the refrigerator is a utility that cannot provide accurate measurements because it depends on how it is used. Influent factors are, *e.g.*, amount of stored food, frequency that the door is opened, initial temperature of the food, type of food (quantity of organic matter, which is in constant metabolic activity and, therefore, in continuous heat release). As a matter of simplification, the author considers that all of these factors are constant.

3.1.2. Dishwashing and washing machines

The dishwashing machine and the washing machine have a common working feature: both have to heat the water that is used to wash the dishes or the clothes, respectively. In fact, there are different programs in each machine with different temperatures – the more intensive is the program, the higher temperature is applied. According to ADENE, et al. (2010), the electricity spent in heating the water is, respectively for the dishwashing and washing machines, *ca.* 90% and 85%. This common feature places these appliances in the same subchapter of the Methodology, being used the same testing procedure for each of them.

The measurements concerned the consumption of:

- one dishwashing machine, which is a BOSCH, model SMS40M02EU,
- and one washing machine, which is a SIEMENS, model WM10E120EE.

Both are from the author's house. Two scenarios were simulated to each machine:

(i) Working normally, in a selected program;

(ii) Working with water coming from the pipe in which the water is previously heated by the water heater by combustion of natural gas[3].

Also, a potential scenario was analyzed[4]:

(iii) Scenario in which all the used water is heated with a non pollutant and "cost-free" energy source and with an approximately ideal efficiency, as for example would be water provided by an ideal solar thermal device – this is the potential accomplished scenario.

The tested programs were:

A. Dishwashing machine, working in program at 70°C;
B. Dishwashing machine, working in program auto at 45-65°C;
C. Washing machine, working in program at 40°C.

For that, each machine had to be attached, at the time, to the pipe in which the water is previously heated by the gas water heater, which is the pipe in which the hot water tap is connected. So, before any measurement could have been done, an adaptation in the hot water pipe had to be undertaken by the author: A "T" adaptor had to be installed, so that the pipe could be connected to the hot water tap and to the testing machine Figure 3.1-2.

After this adaptation being made, the water flow (in the gas heater – detail 2 of Figure 3.1-1 – as well in a regulation tap at the entrance of the kitchen) and the power of the water heater (which influences the gas consumption –detail 1 of Figure 3.1-1) had to be adjusted so that one had the less possible instantaneous gas consumption for the same reached water temperature. Still, the test faced a limitation: it was only known the maximum and the minimum instantaneous gas consumption corresponding to the maximum and minimum power of the water heater, respectively.

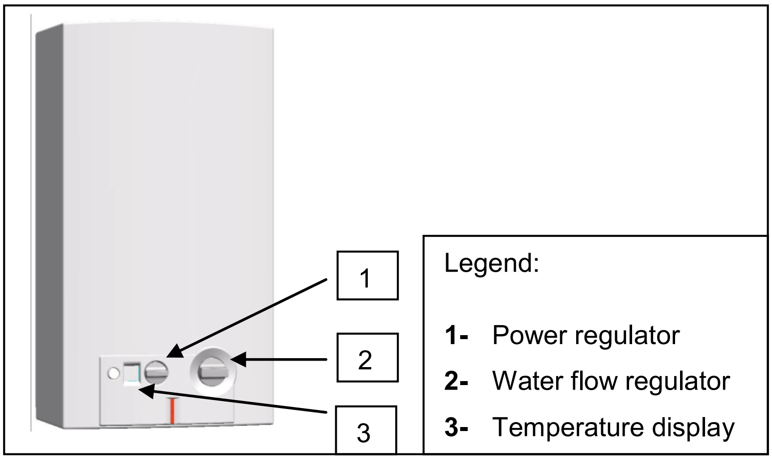

Figure 3.1-1 – Gas water heater used in the tests.

[3] Not all the water that is used is heated because of two factors that are referred some paragraphs below. Thus, this procedure is far from having an ideal efficiency.
[4] Unfortunately, the first selected program for the dishwashing machine – 70°C – has an insufficient water consumption flow, which cannot activate the water heater every time water is consumed and, therefore, it cannot be determined the used water by multiplying the known water flow by the total time the water heater was activated. So, scenario (iii) cannot be determined for this case.

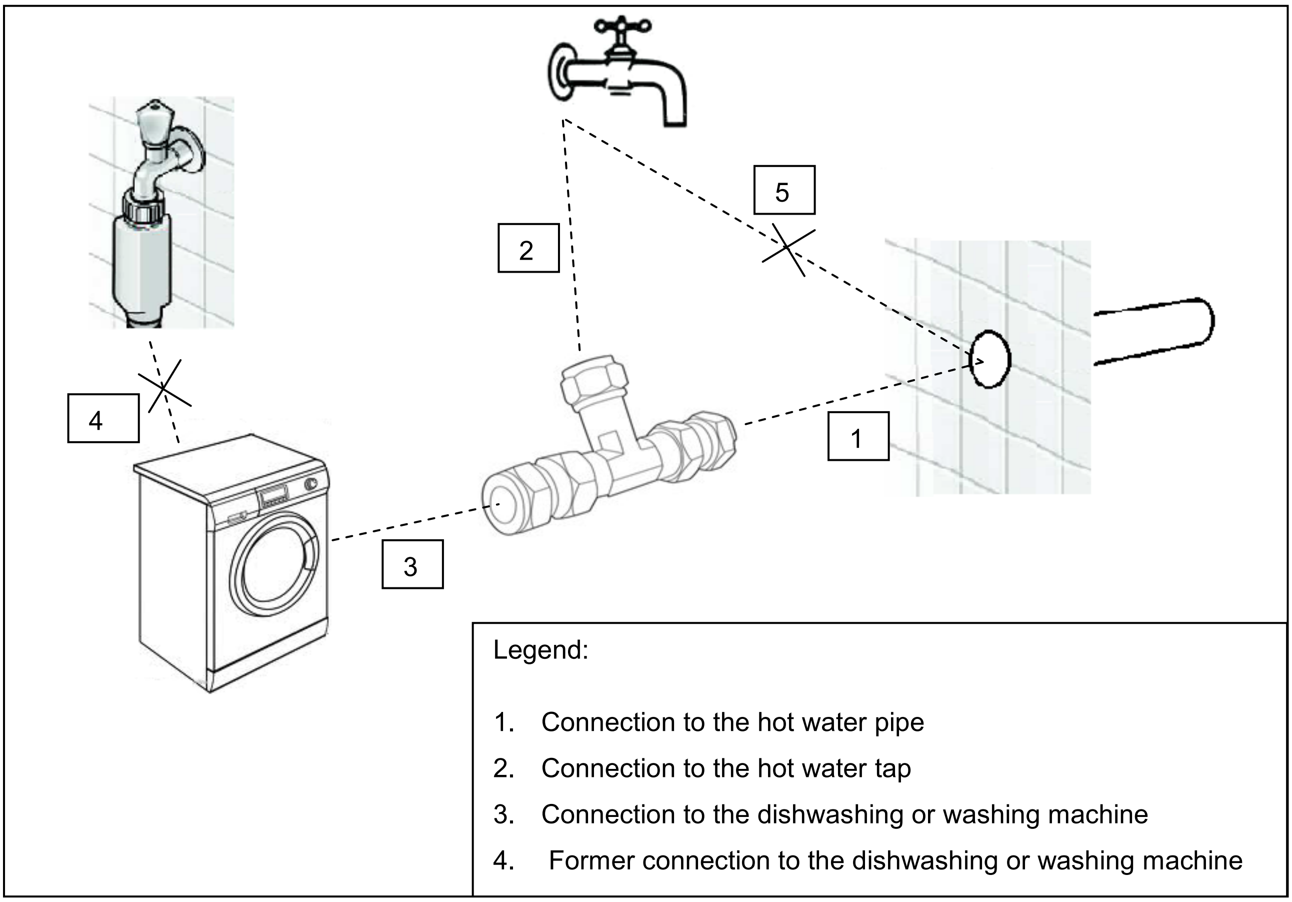

Figure 3.1-2 – Installation made in the hot water pipe to connect the testing machine and the hot water tap at the same time.

In order to adjust correctly the power of the water heater and the water flow, the characteristics of the former had to be known. The water heater used is also in the author's house and it is a JUNKERS, model WRD11-2 KM E23S3505. It is a "smart water heater", which means that the pilot flame is not continuously turned on. It is switched on only when there is enough water flow coming from the pipe to turn it on, through an electric impulse, and extinguishes about two and a half seconds after the tap is closed. The main characteristics to be known for these tests are the consumption and efficiency of the water heater. As it is represented in Figure 3.1-1, the water heater bears two regulators: the power regulator and the water flow regulator (details 1 and 2 of Figure 3.1-1, respectively). With the power regulator at his maximum capacity, the water heater has a gas consumption of 2.3 m^3/h and a capacity of heating a water flow of 5.1 L/min, at 50^{o}C, with an available nominal power of 18.6 kW. At its minimum capacity, the nominal power is 7 kW but, once the gas flow is not known, it is determined in subchapter 3.2.2.

For each measurement under scenario (ii), the *modus operandi* is:

a) Connect the machine to the PlugMeter® and this to the plug;
b) Open the hot water tap during enough time to heat the water from the initial temperature until the desired one is reached (temperature controlled with the display in the water heater – detail 3, Figure 3.1-1; from here, the temperature is 2.3-2.4^{o}C higher than the intended one). The water from the tap is thus already at the desired temperature (measured with a thermometer in the exit of the tap);
c) Press the "start" button of the dishwashing or washing machine and wait until the flow coming from the tap decreases (the machine starts to use the water). At this instant, the tap is closed.

Each measurement was repeated, after enough time to allow the temperature in the machine to decrease to not affect the results. All measurements were also made with no dishes (for the dishwashing machine) or clothes (for the washing machine) inside because a slight variation of weight or dirt would change the working way of the machines, independently of the program or the incoming water temperature. The results presented are the average of each pair of measurements.

The consumed gas in each test is calculated by multiplying the known gas flow with the time that the water heater was functioning – during point b)[5]; and during the period after point c) of *modus operandi*. The measurement of the spent water in point b) of *modus operandi* can be done with a cooking measurement cup.

The potential scenario (iii) concerns only the water heating. Though a solar thermal device is only able to heat the water at temperatures around 60^0C and the heat loss still occurs in the water pipes (Rosa-Clot, *et al.*, 2011), it is still established in this Thesis that such device is enough for the efficient heat purpose. The coupling with a photovoltaic panel is also not studied, which would eliminate the electricity consumption for these appliances and it can be enough to fulfill the energy need of a whole dwelling and, even, be enough to sell it to the grid (Rosa-Clot, *et al.*, 2011), once the study only incises in the difference in the energy consumption for water heating in the dishwashing and washing machines.

3.2. Experimental results

The description of the theory and the concepts which have to be known, in order to proceed with the analysis and the respective conclusions, starts the two following subchapters, concerning, respectively, the refrigerators and the dishwashing and washing machines. Both are concluded with an overall view of the results and the CO_2 emmissions is assessed. For that, the energy consumption has to be reduced at primary energy, which is “kilograms of oil equivalent” – Kgoe – which is the conversion factor used by SGCIE (and it is a universal conversion factor), converting the final energy (*e.g.*, electricity (kWh) or natural gas (m^3)) into primary energy. In this way, it is possible to assess the impact of the energy consumption in final using. For natural gas, the conversion factor is 1.077 toe/ton and for electricity, the conversion factor is 1 MWh = 0.29 toe, according to the International Energy Agency. The energy can be converted into the factor of CO_2 emmissions: kgCO_2e (kg of CO_2 equivalent). Such calculation is made with the conversion factors of the electricity and the natural gas, which are, respectively: 0.47 kgCO_2e/kWh and 2.6837 kgCO_2e/kgoe (Ferrão, et al., 2009).

Concerning the dishwashing and washing machines (subchapter 3.2.2), the conversion to primary energy is made not only in the Overall view but, as well, for each single test for a better comparison between the two different energy sources that are being tested: electricity and natural gas, what does not happen in the tests of the refrigerators (subchapter 3.2.1).

[5] The water and gas spent at this stage will not be taken into account in the balances between the scenarios, once it is suggested that this water can be used and, therefore, not wasted (*e.g.,* to clean the sink, to fill a bucket to recharge the flush, to clean the floor or to fill a pan for cooking).

3.2.1. Refrigerators

Before the results can be discussed, one has to understand how the appliances work.

The refrigerator is an indispensable facility in a house because it makes food conservation possible, which is a primary necessity. As it was said in the previous subchapter, the freezing utilities have a share of 32% of the final domestic energy consumption (ADENE, et al., 2004).

A brief explanation on how a refrigerator works must be given. It operates in a cyclic way, with four stages, as it can be seen in Figure 3.2-1.

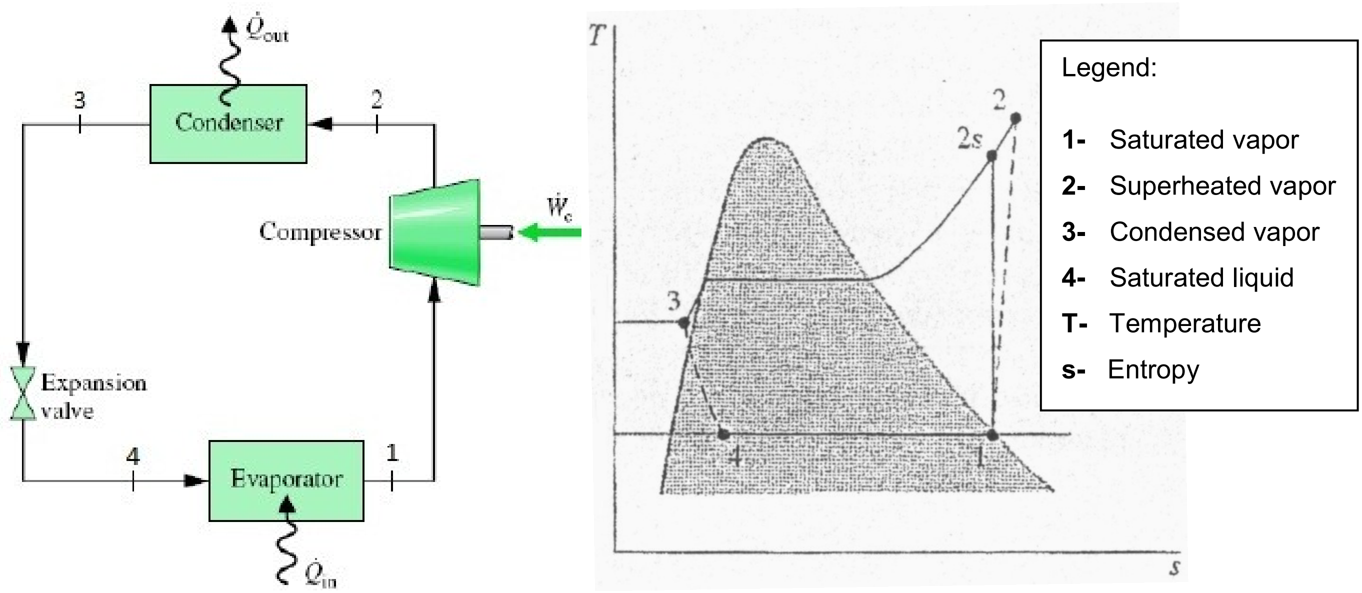

Figure 3.2-1 – Refrigeration cycle by vapor compression: scheme and T-s (temperature-entropy) diagram. SI units: K and kJ/kg, respectively **(Shapiro, et al.)**

The refrigerator uses a refrigerant – in the case of the tested Bosch, is r-600; in the case of the tested INDESIT, is r-134a –, and is this liquid that passes by all the stages.

(4→1): In the evaporator, the refrigerant receives heat from the air in the room and from a resistance placed in the back of the refrigerator. The temperature and the pressure, though, do not increase and, so, there happens an isothermal and isobaric expansion with an increase of entropy and the liquid, first in liquid-vapor stage, increases the vapor title. The incoming heat, Q_{in}, is called the refrigeration capacity of the refrigerator, and the SI unit is kW;

(1→2): The refrigerant (in vapor state) is adiabatically (and isentropically) compressed in a non-irreversible cycle (1→2s, using electricity from the plug to activate the compressor. Here, the temperature of the refrigerant increases and it is only in the vapor state;

(2→3): The temperature of the refrigerant decreases, occurring heat transfer from the condenser to the colder nearby (this is the heat that one feels in the back of the refrigerator);

(3→4): The refrigerant passes through an expansion valve and its pressure and entropy increase in an adiabatic and closely enthalpic expansion, from a saturated liquid state to a two-phase state.

This cycle repeats itself, transferring heat from the inside of the refrigerator to the outside. It happens continuously until the desired temperature is reached (regulated in the refrigerator thermostat) and, after a while, it shuts down until the temperature increases again (because of incoming heat due to lack of isolation or by opening the door or, even, to heat released by the food which is in continuous metabolic activity). This behavior stops the electricity consumption and rests the refrigerator engine. Moreover, as the compressor stops, the pressure homogenizes in the remaining components, which makes a drop in the condenser pressure and slowly approaches the saturation pressure in the evaporator while refrigerant is pushed into the evaporator. Some studies point out that performance losses due to shut-down and start-up of the working cycle of the refrigerator due to this behavior can account for 5% to 37% of performance loss (Bjork, et al., 2005).

In this Thesis, the tests want to prove, or refute, the advantages on forced turn-off of the refrigerator. ISA has done some experiments which said to improve the electricity efficiency of this utility (Malaquias, 2010).

With these working profiles, the accumulated consumption is not expected to be inferior to the one in the normal work, because the refrigerator has to compensate the time it was turned off and, therefore, has to compensate the heat transferred to it. When heat is stopped to be extracted from the refrigerator, there are three components that increase the temperature by natural convection: the structure of the refrigerator, the inside air of the refrigerator and, finally, the food inside the refrigerator. So, when the refrigerator is turned on again, it has to extract the heat gained by those three components, which would not occur if it had been working normally.

A goal of this study is to verify if that consumption increase is also reflected in a cost increase, which depends on how the refrigerator reacts to the applied perturbation. Indeed, it can have a high immediate consumption, after it is turned on again, and have a normal consumption afterwards; or it can have a lower increase in the beginning and dumping smoothly along the day, describing bigger consumption profile amplitudes than before. By analyzing the behavior of the refrigerator, it will be decided which working scenario is the best one, in therms of CO_2 emmissions and costs.

The electricity consumption profiles for each chosen schedule of both refrigerators are analyzed and represented in the following charts. The costs are assessed and compared in the presented tables.

A. Refrigerator INDESIT R 18

This refrigerator is placed at the IST TagusPark campus. The environment in which this appliance is inserted is characterized by a room accessed by the research group of the MIT Portugal, spread along 18 offices and, approximately, 10 people use it to store lunch, snacks, drinks and ice. The room is a spot where people go and take a coffee, some have lunch and, even, from time to time, groups of one, two or three people study in one of the two existing tables. The area is around 25 m^2.

The electricity consumption profiles are depicted in the following charts and their analyses are made at this point. The tables concerning the temperature variation and the electricity consumptions can be consulted in Annexes V and VI, respectively.

Chart 3.2-1 displays the real accumulated daily electricity consumption and Chart 3.2-2 gives the real consumption per hour along one day, each profile corresponding to the average day of the experimental weeks. The charts interpretations are considered together with Table 3-1 analysis, which provides the estimated consumption in each scenario, if the average temperature was the same in each of them (corrected consumption for temperature (i)).

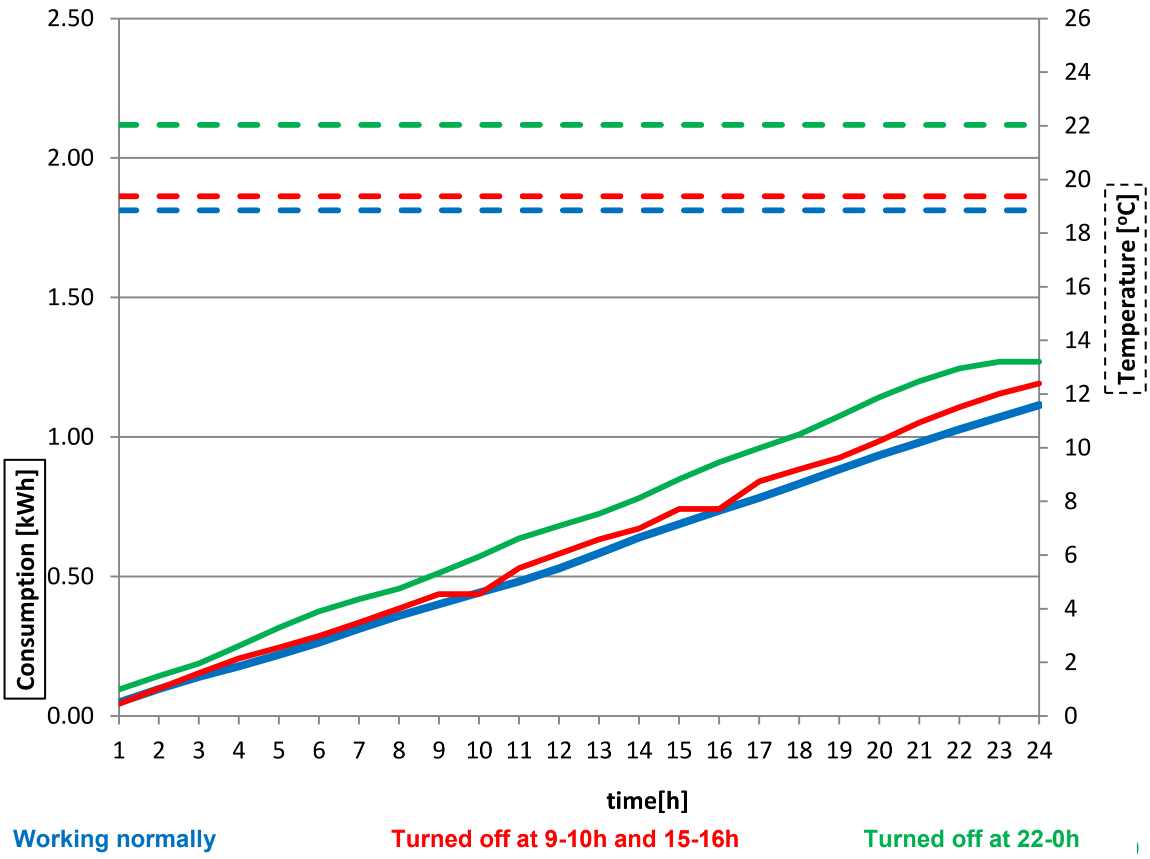

Chart 3.2-1 – Average real accumulated electricity consumption profiles (continuous lines) and average air temperatures (dashed lines) for the measurements of the refrigerator INDESIT R 18, working in the three different schedules.

As it can be seen in the consumption profile of schedule (ii), the accumulated consumption is 0.08 kWh (7%) higher than in schedule (i). Though the refrigerator does not consume electricity during the two periods when it is turned off, immediately upon switching on, it consumes energy at a higher rate than it was consuming before.

A related behavior can be seen for profile (iii), in which the consumption is null during the turned off period, where after the slope of the profile increases in the beginning, and then reduces slightly. The final accumulated consumption is 0.15 kWh (13%) higher than in (i); and 0.08 kWh (7%) higher than in (ii).

A more detailed analysis of the consumption behavior is given in Chart 3.2-2.

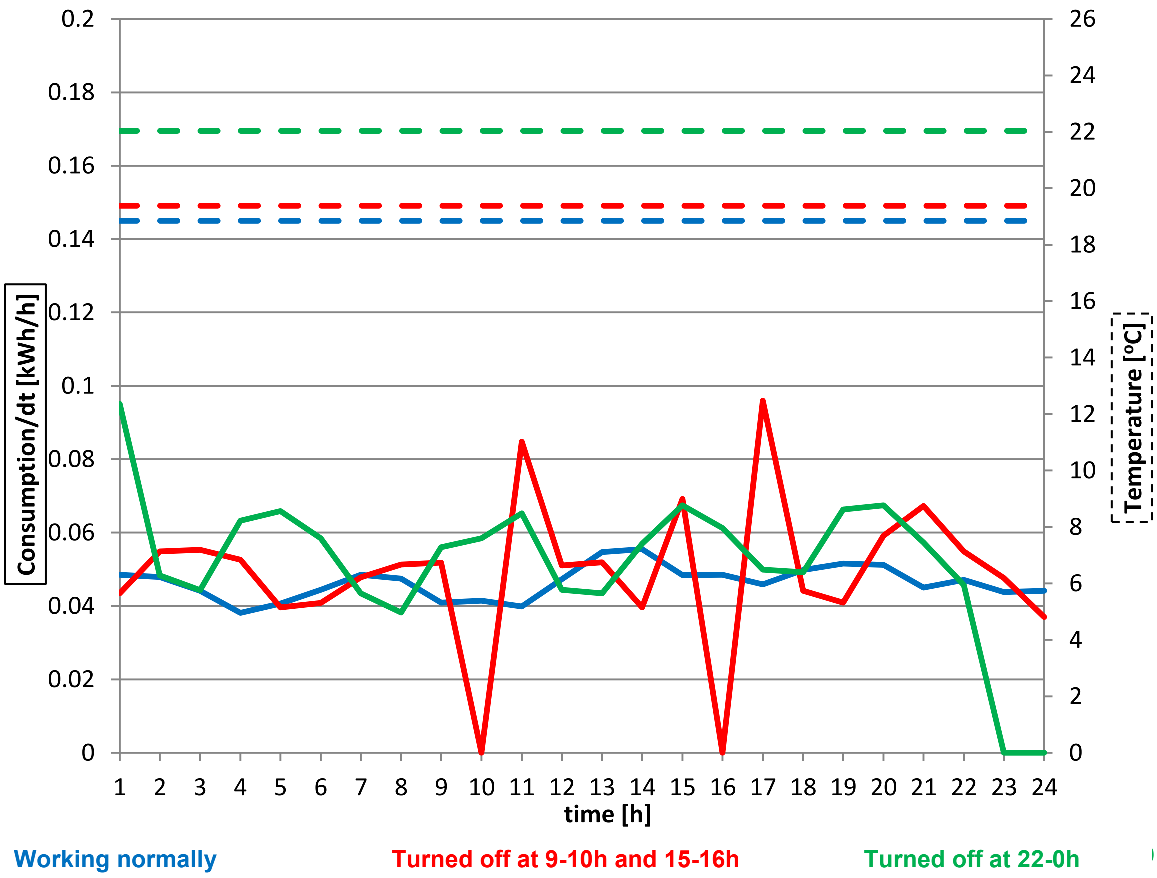

Chart 3.2-2 – Real electricity consumption profiles (continuous lines) and average air temperatures (dashed lines) for the refrigerator INDESIT R 18, working in the three different schedules

In scenario (ii), the peak consumptions occurring after the shut-sown periods are 0.085 and 0.096 kWh for 11 and 17 h, respectively. As for scenario (iii), the peak consumption occurs at 1h and is 0.095 kWh. Therefore, concerning peak consumption, scenario (iii) has a consumption 52.5% inferior to scenario (ii), which may be related to the fact of the most intensive usage occurs during the afternoon and not occurring at night, together with the fact of the room temperature being higher during the afternoon.

Table 3-1 – Accumulated electricity consumption and average temperatures, concerning the refrigerator INDESIT R 18[a].

Schedule	Consumption (real) [kWh]	Temperature [°C]	Consumption (i) (corrected) [kWh]	Consumption (i) (corrected) [kgoe]	Consumption (i) (corrected) [kgCO_2e]
(i)	1.115	18.8	1.115	0.323	0.524
(ii)	1.192	19.4	1.177	0.341	0.553
(iii)	1.269	22.0	1.189	0.345	0.559

[a] The variation of temperature inside the kitchen is considered to be half of the registered one in (WeatherUnderground, 2011), which corresponds to the values in the column "Temperature". The columns "Consumption" and "Consumption (i)" regard, respectively, the average accumulated electricity consumption at the experimental temperature and the average accumulated energy consumption at the same temperature as (i), regard to electricity, primary energy and equivalent kg of CO_2, respectively.

The average temperature in (ii) is 0.6^0C higher than in (i), which induces an increase in its electricity consumption of 0.015 kWh (1.3%). Ergo, if the temperature had remained constant, the accumulated consumption in (ii) would be 1.177 kWh (5.6% higher than in (i)).

In scenario (iii), the temperature is, averagely, 3.2^0C above (i), which reflects in an increase of its consumption of 0.08 kWh (6.3%). Therefore, if the temperature had remained constant and equal to the temperature in (i), the accumulated consumption would be 1.189 kWh (6.6% higher than in (i)).

Within an environmental impact perspective, scenarios (ii) and (iii) have, respectively, an associated increase of 0.029 $kgCO_2e$ and 0.035 $kgCO_2e$, corresponding to the same percentage as the accumulated electricity consumption increase.

Concerning the costs regarded to these tests, they are represented in Table 3-2, being the different electricity tariffs discriminated.

Table 3-2 – Costs associated to the real consumptions in scenarios (i), (ii) and (iii) tested for the refrigerator INDESIT R 28.

Tariff	Scenario[a]		
	(i)	(ii)	(iii)
"Three rate" tariff; Daily cycle	0.087	0.093	0.099
Normal; <2.3kVA	0.115	0.122	0.130
"Three rate" tariff; Weekly cycle	0.131	0.140	0.146
"Two rate" tariff; Weekly cycle	0.133	0.142	0.148
"Two rate" tariff; Daily cycle	0.131	0.138	0.151
Normal; >2.3kVA	0.148	0.158	0.168
Average	0.124	0.132	0.140
Average corrected at temperature (i)	0.124	0.130	0.131

[a] Values in €/day

It can be noticed that scenario (i) has the lowest costs, being approximately 6.8% inferior to scenario (ii) and 13.3% inferior to scenario (iii). Again, the temperature had a considerable influence in the electricity consumption which is proportional to the electricity costs. Hence, taking into account that (ii) had an increase in electricity consumption of 1.3% due to the temperature increase, and (iii) had an increase of 6.3%, this means that, for the same air temperature, the costs in scenario (ii) and (iii) are still, respectively, 4.8% and 5.6% higher than and in scenario (i). The most adequate tariff for this kind of consumption is the "Three rate" tariff with daily cycle and the one with highest associated costs is the Normal tariff with a contracted power of 2.3 kVA.

B. Refrigerator BOSCH KGN46A03

This refrigerator is in the author's home. The environment in which it is located is constant, not having noticed any change in the way of using. The area of the kitchen is around 20 m^2.

The electricity consumption in the author's house was, for the month of May of 2011, 331 kWh. Taking this value as a typical monthly consumption, this means that the refrigerator has a share of 14% of the total electricity consumption, which represents a deviation, in this case, from the normal 22% share of the refrigerator (ADENE, et al., 2004).

The electricity consumption profiles are displayed in the following charts and their analyses are undertaken at this point. The tables concerning the temperature variation and the electricity consumptions can be consulted in Annexes V and VI, respectively.

Chart 3.2-3 displays the real accumulated daily electricity consumption and Chart 3.2-4 gives the real consumption per hour along a day, each profile corresponding to the average day of the experimental weeks. The variation of accumulated consumption with the temperature is represented in Table 3-3 (corrected consumption for temperature (i)).

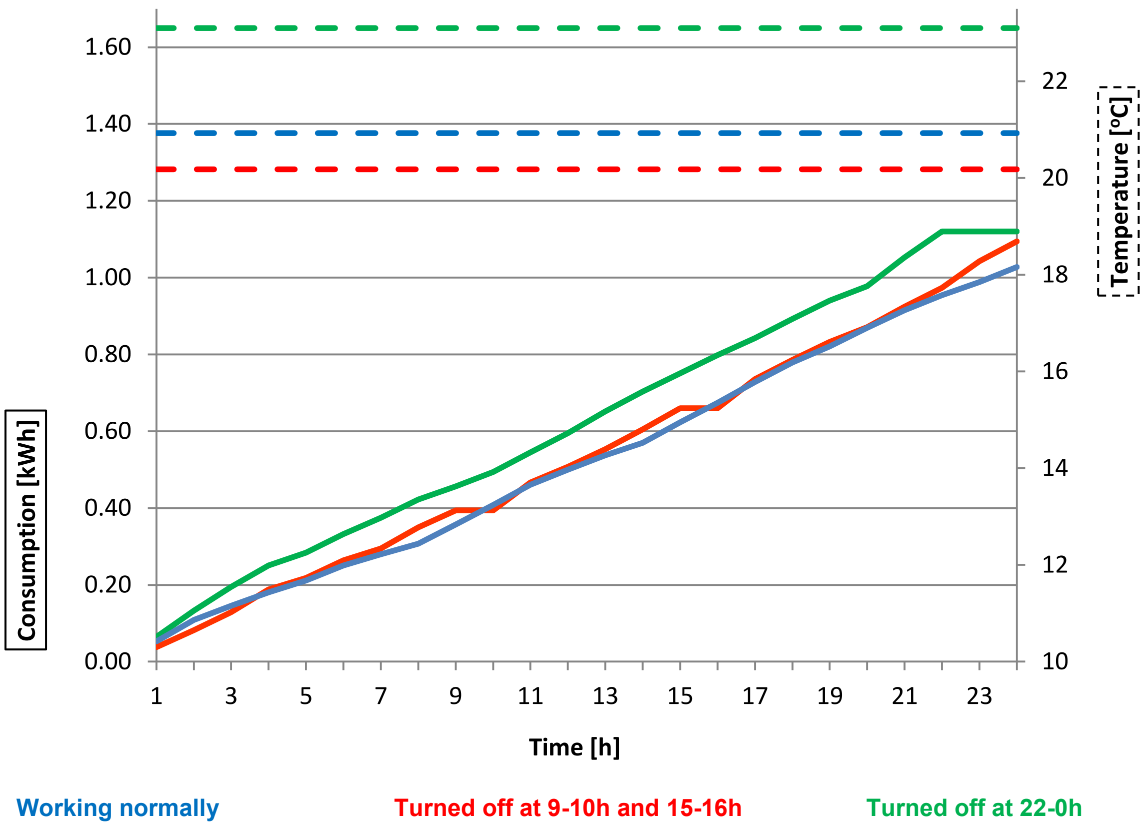

Chart 3.2-3 – Average real accumulated electricity consumption profiles (continuous lines) and average air temperature (dashed lines) for the measurements of the refrigerator BOSCH KGN46A03, working in the three different schedules.

As it can be seen in Table 3-3, the accumulated consumption in (ii) is 0.067 kWh (6.5%) higher than in schedule (i). Though the refrigerator does not consume electricity during the two periods when it is turned off, immediately after being switched on it consumes energy in a higher rate than it was consuming before.

A related behavior can be seen in the profile (iii), in which the consumption is null during the turned off period and, after, the slope of the profile increases evidently in the beginning, and then reduces slightly. The final accumulated consumption is 0.092 kWh (8.9%) higher than in (i); and 0.025 kWh (2.3%) higher than in (ii).

A more detailed analysis of the consumption behavior is possible through Chart 3.2-4.

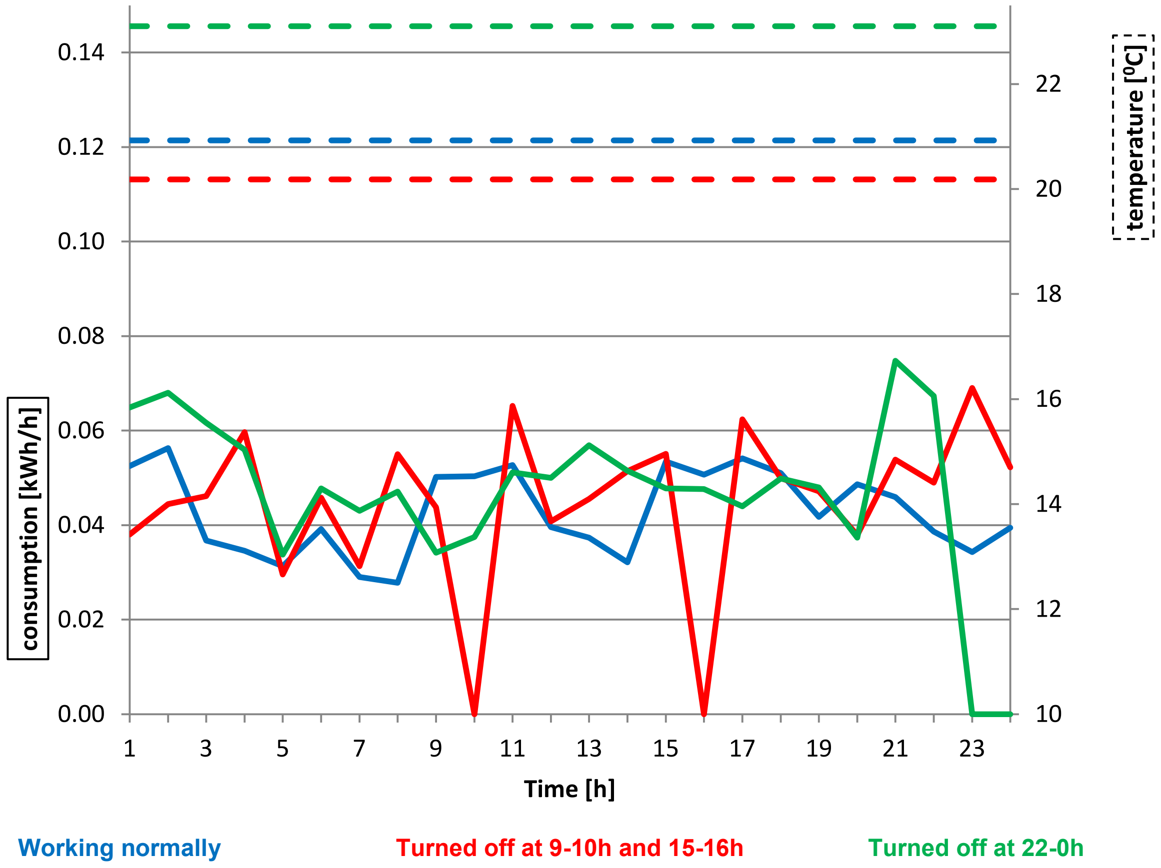

Chart 3.2-4 – Real electricity consumption profiles (continuous lines) and average air temperatures (dashed lines) for the refrigerator BOSCH KGN46A03, working in the three different schedules

In scenario (ii), the peak consumptions that occur after the shut-down periods are 0.065 and 0.062 kWh for 11 and 17h, respectively. As for scenario (iii), the peak consumption noticed at 1h is 0.062 and 0.068 kWh. Therefore, concern the peak consumption resulting from the induced shut-down, scenario (iii) has a consumption 2.3% higher than in scenario (ii). The noticed peak between 20 and 22h concerns the more intensive use during the dinner time.

Table 3-3 – Accumulated electricity consumption and average temperatures, concerning the refrigerator BOSCH KGN46A03 [a].

Schedule	Consumption (real) [kWh]	Temperature [°C]	Consumption (i) (corrected) [kWh]	Consumption (i) (corrected) [kgoe]	Consumption (i) (corrected) [$kgCO_2e$]
(i)	1.028	20.9	1.028	0.298	0.483
(ii)	1.095	20.2	1.113	0.323	0.523
(iii)	1.130	23.1	1.075	0.232	0.505

[a] The variation of temperature inside the kitchen is considered to be half of the registered one in (WeatherUnderground, 2011), which corresponds to the values in the column "Temperature". The columns "Consumption" and "Consumption (i)"

regard, respectively, the average accumulated electricity consumption at the experimental temperature and the average accumulated energy consumption at the same temperature as (i), regard to electricity, primary energy and equivalent kg of CO_2, respectively.

The average room temperature in (ii) is 0.4°C inferior than in (i), which induces a decrease in the electricity consumption of 0.018 kWh (1.6%). Ergo, if the temperature had remained constant from (i) to (ii), the accumulated consumption in (ii) would be 1.113 kWh (8.3% higher than in (i)).

In scenario (iii), the room temperature is, averagely, 1.1⁰C above (i), which is reflected in an increase in the consumption of 0.055 kWh (5.1%). Therefore, if the temperature had remained constant and equal to the temperature in (i), the accumulated consumption would be 1.075 kWh (4.6% higher than in (i)).

Under an environmental impact viewpoint, scenarios (ii) and (iii) have, respectively, an associated increase of 0.040 $kgCO_2e$ and 0.022 $kgCO_2e$, corresponding to the same percentage as the accumulated energy consumption increase.

Concerning the costs regarded to these tests, they are represented in Table 3-3, being the different electricity tariffs discriminated, for this simulated refrigerator.

Table 3-4 – Costs regarded to the real consumptions in scenarios (i), (ii) and (iii) tested for the refrigerator BOSCH KGN46A03.

Tariff	**Scenario**[a]		
	(i)	**(ii)**	**(iii)**
“Three rate” tariff; Daily cycle	0.080	0.085	0.088
Normal; <2.3 kVA	0.106	0.112	0.116
“Three rate” tariff; Weekly cycle	0.121	0.127	0.129
“Two rate” tariff; Weekly cycle	0.122	0.131	0.130
“Two rate” tariff; Daily cycle	0.122	0.127	0.132
Normal; >2.3 kVA	0.136	0.145	0.150
Average	0.115	0.121	0.124
Average corrected at temperature (i)	0.115	0.123	0.118

[a] values in €/day

It can be noticed that scenario (i) corresponds the lowest costs, which are, averagely, 6.2% inferior to scenario (ii) and 8.7% inferior to scenario (iii). However, knowing that (ii) had a decrease of 1.6% and (iii) had and an increase of 5.1% in electricity consumption due to the temperature increase, this means that, for the same air temperature, the costs associated to scenarios (ii) and (iii) are 7.0% and 2.6% higher than in scenario (i), respectively. The most adequate tariff for this kind of consumption is the “Three rate” tariff with daily cycle and the least adequate is the Normal tariff with a contracted power of 2.3 kVA.

C. Overall view and average consumption

The simulations made for the two refrigerators evidence different consumption profiles in the different scenarios. The overall consumption results are expressed in Table 3-5, as well as the CO_2 emmissions of each one.

Table 3-5 – Overall consumption and cost concerning each measured scenario for the tested refrigerators at temperature (i)[a].

	INDESIT			BOSCH		
	(i)	**(ii)**	**(iii)**	**(i)**	**(ii)**	**(iii)**
kWh	1.115	1.177	1.189	1.028	1.113	1.075
kgoe	0.323	0.341	0.345	0.298	0.323	0.312
kgCO_2e	0.524	0.553	0.559	0.483	0.523	0.505
€	0.124	0.130	0.131	0.115	0.123	0.118
Balance relatively to scenario (i)						
∆ kWh	-	0.062	0.074	-	0.085	0.047
∆ kgoe	-	0.018	0.021	-	0.025	0.014
∆ kgCO_2e	-	0.029	0.035	-	0.040	0.022
∆ €	-	0.006	0.007	-	0.017	0.003

[a] Values in €/day

These values require a careful attention and justified interpretations. In fact, they present curious results:

a) After a perturbation, the refrigerator increases the consumption and stabilizes. Such can be noticed in scenario (iii).
   - Reckon the refrigerator INDESIT, the consumption stabilizes after one hour, maintaining a higher amplitude than in (i)
   - Concerning the refrigerator BOSCH, the consumption stabilizes after five hours, maintaining roughly the same amplitude as in (i).

b) The refrigerator INDESIT has a consumption while working normally – (i) –with lower amplitudes than the BOSCH.

c) Scenarios (ii) and (iii) have an associated higher consumption than in (i), corresponding to different values in each refrigerator, proportional to the associated environmental impact.
   - The consumption registered in (ii) is higher than in (i), concerning, respectively, the refrigerator INDESIT and BOSCH, by 5.6% and 9.9%.
   - The consumption registered in (iii) relatively to the refrigerators INDESIT and BOSCH are, respectively, 6.6% and 4.6% higher than in (i).

d) The costs differ between the refrigerators within the same scenario.
   - Concerning scenario (ii), the costs increase 4.8% in the refrigerator INDESIT but, for the refrigerator BOSCH, the costs increase 7.0%.
   - Regarding scenario (iii), the costs increase 5.6% in the refrigerator INDESIT and 2.6% in the refrigerator BOSCH.

Firstly, one must keep in mind that the temperature measurements were not the most accurate ones but the important factor is the temperature variation, which is trusted to be accurately achieved (see subchapter 3 and Annex V). Also, though considering the use of the refrigerators as the same in each simulated period, once the number of users did not change nor the amount or type of stored food, this is a point that is impossible to be precisely controlled in such experimental conditions. Furthermore, one does not know the performance of the engine nor the compressor, which are trusted to be the main influent factors in the consumption and in the performance losses during the “on-off” cycle (Bjork, et al., 2005).

The working way differs in the two refrigerators. Indeed, the refrigerator BOSCH has higher consumption amplitudes, having longer shut-down periods as well (smoothed in Chart 3.2-4 due to the different times in which the shut-down period occurs in the consecutive days, resulting in a compensation in the average) and the INDESIT has a flatter profile, with shorter shut-down periods. The BOSCH is a combined refrigerator, with a power of 370 W, contrasting with the 150 W of the INDESIT, what means a higher consumption, even though it has a higher energetic certification. The dimensioning of the capacity of the refrigerator according to the dwelling’s needs is, therefore, an important factor that must be consider together with the energetic label.

The usage – concerning the induced working periods as well – influences the consumption profiles. In fact, the refrigerator INDESIT has a high usage during the day at lunch time and the BOSCH has generally a high usage at lunch and even higher during dinner time. The effects of such differences are explained, as follows.

Concerning the refrigerator INDESIT, the shut-down periods in scenario (ii) occurred during the day, when the probability of being used is higher and the room temperature was higher as well, and with intervals of five hours, which may not have given enough time to remove the extra heat that got in during the shut-down period. Such contrasts with scenario (iii), in which the probability of being used during, and after, the shut-down period is lower, which did not require such a high effort of the refrigerator to extract the accumulated heat during that period. Indeed, the high consumption periods after the shut-down periods were 52.5% higher in scenario (ii) than in scenario (iii). This is justified by the usage. Indeed, it was expected a higher consumption peak after a shut down period of two hours (scenario (iii)) than in one of one hour (scenario (ii)).

Concerning the refrigerator BOSCH, the consumption profile in (i) evidences an occurrence of the periodical peaks which tend to be intercalated with the ones in (iii). Such may be explained by the fact of the turn off period in (iii) being at the arising of a new peak, which implies a delay in that peak and, as well, an increase afterwards, affecting the remaining peak periods by also delaying them. As for the highest peak noticed in (iii) which occurs before the shut down period, it may have not been a consequence of a different usage but, yet, due to the temperature increase and the fact of that period corresponding to the normal high usage period. Such does not happen in (i) because the consumption peak tends to be earlier. The high consumption periods after the shut-down periods were 2.3% lower in scenario (ii) than in (iii), which evidences a higher need to extract the heat that got inside during the longer continuous turn-off period in (iii).

The approach that led to these results must be taken rather cautiously. Indeed, the experiments were performed under some (and fair) considerations on the environments in which the two different refrigerators are placed. Surely, deviations have occurred in the usage that were not perceptive, but that is a feature of a real usage, with no exact routines by the users. Nonetheless, the relation was established concerning the induced shut-down of a refrigerator in two different schedules: an increase in the accumulated consumption at the end of the day and, furthermore, an increase in the costs, depending on the usage, on the refrigerator type and on the tariff. Concluding, the forcing shut-down of a refrigerator may contribute to reduce the peak loads but at the expense of higher energy consumption and clients costs. Thus, this measure *per se* does not lead to better environmental or monetary scenarios.

3.2.2. Dishwashing and washing machines

The dishwashing and washing machines working stages are distinguished, of course, but still they have important resemblances which are represented in Table 3-6:

Table 3-6 – Technical characteristics of the selected testing programs of the dishwashing and washing machines

	Dishwashing machine		Washing machine
Program	70°C	Auto, 45-65°C	40°C
Use of water [a]	12 L	9-19 L	53 L
Water heating	Yes	Yes	Yes
Centrifugation	No	No	Yes
Duration	2h15min	1h25min-2h30min	2h13min
Accumulated specified electricity consumption [b]	1.50 kWh	1.00-1.60 kWh	0.60 kWh

[a] These values depend on the pressure, hardness and temperature of the water, air temperature, amount and kind of dirtiness of the washing objects, electricity tension, and the selected program, in the case of the washing machine.
[b] Values per cycle.

The common stage is the water heating. Indeed, both are connected to a pipe with non heated water through a hose and that water is heated while it enters. After being used, it is expelled through another hose to another pipe in the wall. The consumptions referred in Table 3-6 refer to the cycles in each stage. The detailed stages of both machines are not known but the general way of working is as follows (BOSCH SMS40M02EU and SIEMENS WM10E120EE Instruction manuals):

For the dishwashing machine:

- Heating the incoming water;
- Pumping the water to the inside, while sprinkling with the turning shovels (repeated several times during the program);
- Measure the cloudiness of the water with the Aquasensor (special feature of this dishwashing machine) and, with that, decide on the reuse, or not, of the water during the program;
- Heating the inside of the machine in the sterilization stage (close to the end).

For the washing machine:

- Heating the incoming water (repeated several times during the program);
- Pumping the water to the inside;
- Centrifuging.

Although the maximum and minimum heating powers of the gas water heater (19.2 and 7 kW, respectively) and the maximum gas flow (2.3 m^3) are specified in the supplier manual, the minimum gas flow is unknown and should be determined, by using the following expression in which 7 kW is the minimum heating power, 0.8404 kg/m^3 and 45.1 MJ/kg the natural gas specific weight and lower heating value (LHV) (DR, 2008), respectively:

$$\frac{7\ \mathrm{kW}}{0.8404\ \mathrm{kg/m^3} \times 45.1\ \mathrm{MJ/kg} \times 10^3\ \mathrm{kJ/MJ} \times \frac{1}{3600}\ \mathrm{h/s} \times 1\ \mathrm{kWs/kJ}} = 0.66\ \mathrm{m^3/h}$$

The water flow was regulated to a value of 4.3 L/min, being this the minimum experimental flow able to activate the water heater.

The used water in scenario (ii) is previously heated by combustion of natural gas in the water heater but not all the used water is heated. The heating inefficiency in this scenario results from two important factors:

1. An often insufficient flow for the activation of the water heater (specially noticed in program A);
2. Long intervals between the water consumptions, which causes a drop in the temperature of the stopped water in the pipe and, when the machine consumes water again, it will firstly consume that less heated water and only after a certain continuous consumption, is the recently heated water consumed.

During the working period of the machines, the water heater is activated when sufficient water flow is used but that heating does not occur right at the entrance of the machine but, instead, a distance of four meters connected by a water pipe (length measured by the author, from the water heater to the pipe exit under the sink, following the trace of the pipe). This means that after a certain time, the water at the entrance of the machine that is about to be used, and that has been stopped in the pipe, will not be reheated and, in the meanwhile, it decreased the temperature (Figure 3.2-2). Therefore, it must be done a quantification of the lost heat and if the activation of the gas heater has any effect in the water temperature that is used by the machine.

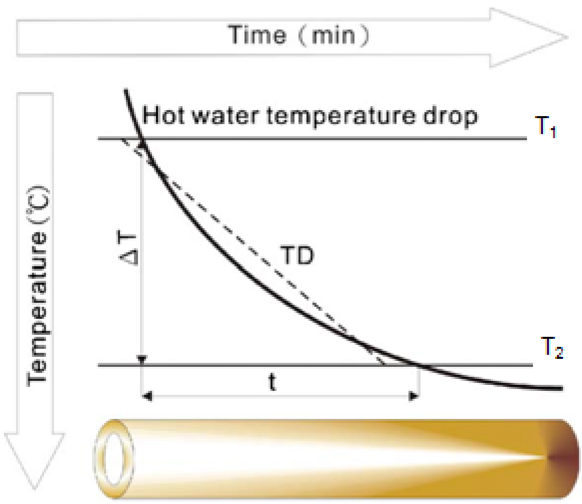

Figure 3.2-2 – Temperature drop of hot water in a pipe, along the time **(Cheng, et al., 2006)**

In Cheng, et al. (2006), this phenomenon is referred and Eq. (1) is given to determine the heat loss (q_p), depending on the length, diameter and material of the pipe. Such equation gives a linear approximation of the heat decay, which is not quite what happens, as it can be seen in Figure 3.2-2. The main inaccuracies are due to the error in the measurement of the pipe length and to eventual fluctuation in the air temperature between the pipe and the wall, which may not correspond to the registered average of 25°C, in the kitchen.

$$q_p = \frac{2\pi k_p L_p (T_1 - T_2)}{ln\left(\frac{D_o}{D_i}\right)} \quad [\mathrm{kJ/h}] \tag{1}$$

In the experiment, the material of the pipe is a non insulated polyvinyl chloride (PVC) and the presented values are (FERSIL, 2011):

- K_p = 0.511 kJ/(m.°C.h) → thermal conductivity
- L_p = 4 m → pipe length
- D_o = 0.0419 m → outside diameter
- D_i = 0.0329 m → inside diameter
- T_1 = 70°C (for test A and B) and 45°C (for test C) → water temperature in the water heater
- T_2 = 25°C → air temperature

The rate of the temperature drop (ΔT/dt) is given by [Eq. (3)] where C_p [Eq. (2)] is the mass thermal capacity of the water, $\partial Q = q_p/dt$ and m is the mass of the water. C_p values for the experimental temperatures are (Shapiro, et al.):

C_p(25°C = 298.15K) = 4.179 kJ/(kg.K)

C_p(45°C = 282.15K) = 4.185 kJ/(kg.K)

C_p(70°C = 343.15K) = 4.193 kJ/(kg.K)

The water mass is given by $m = V \times \rho$ (kg, where ρ = 1 kg/L).

Moreover, C_p is defined by Eq. (2):

$$C_p = \frac{1}{m}\frac{\partial Q}{dT} \ [\mathrm{kJ/kg.K}] \tag{2}$$

Knowing that ∂Q is given by the determined q_p in Eq. (1), the rate of temperature drop is now obtained in Eq. (3):

$$\frac{\Delta T}{dt} = \frac{q_p \times 60^{-1}\mathrm{h/min}}{m \times C_p} \ [\mathrm{K/min}] \tag{3}$$

- For T_1 = 70°C and T_2=25°C: dt = 19min00s; ΔT /dt = 2.36 K/min = 2.36 °C/min

- For T_1 = 45°C and T_2=25°C: dt = 13min00s; ΔT /dt = 2.28 K/min = 2.28 °C /min

This means that, for simulation A, if there is an interval between two gas consumptions of more than 19min00s, the water in the pipe (and that is about to be consumed) is already at the air temperature of 25°C. For simulations B and C, that period is of 11min00s. After these periods, the water heater only has an effect in the temperature of the consumed water if the water consumption lasts for enough time so that all the remaining water in the pipe is consumed and the just heated water passed through the pipe. This period is calculated by dividing the volume of the pipe by the water flow – the regulated water flow is of 4.3 L/min:

$$\text{Time for the water to cross the pipe} = \frac{\pi \times \left(\frac{0.0329\ \text{m}}{2}\right)^2 \times 4\ \text{m}}{4.3\ \text{L/min} \times 10^{-3}\ \text{m}^3/\text{L} \times 60^{-1}\ \text{min/s}} = 47\ \text{s}$$

The potential electricity saving corresponding to the theoretical scenario (iii) can now be estimated. The representation of the water temperature and the consumed volume are represented in Chart 3.2-9 and Chart 3.2-12. The corresponding tables are represented in Annex VIII.

There is, though, an important restriction, which is the minimum incoming water flow for the dishwashing machine: 10 L/min (BOSCH SMS40M02EU Instruction manual). No minimum value is referred for the washing machine. The water flow adjusted for the tests was lower than these values. Still, this fact did not turn on any anomaly indicator in the machines, which would have happened if the water flow was inadequate for the normal functioning.

By feeding the machines with heated water, the thermostat of the machines sees that the water does not need to be heated, or needs to be heated not as much as if it was colder. In this way, the presenting tests aim to verify how much electricity can be spared with the previous heating of the water and if this method – heating the water with the gas water heater – is economically and environmentally better. Concerning the machines, it is expected that the programs spend less electricity and have a shorter duration.

The presented analyses are not taking into account the water and gas spent in stage b) of the procedure described in subchapter 3.1.2 (the stage in which the tap is opened to ensure that the machine starts the program with heated water) because it is intended that this used water is not wasted, as it is referred therein, in footnote 3. Still, the values corresponding to that water and gas spent are mentioned in each test results analysis.

In charts 3-5, 3-6, 3-7, 3-8, 3-10 and 3-11, the gas consumption in the scenario with incoming hot water is also represented with a dashed red line and its consumption values (m^3) concern the scale in the right side of the charts, being complemented by Annex VIII. Each time the gas is consumed, it means that the machine is consuming water as well. As it was said in subchapter 3.1.2, each test was repeated once (with an enough time interval to allow the temperature of the machine to drop to the initial value) and the given results are the average.

Besides the charts of accumulated electricity consumption profile and electricity consumption/min profile, there is also a table for each simulated scenario with the overall balance between scenarios (i) and (ii(i), taking in account three important factors: energy spent in kWh (for the electricity) and in m^3 (for the gas);

energy spent in kgoe; and the costs in €. The costs for different electricity tariffs and gas contracts were also estimated.

In order to assess the economic impact in the different existing electricity tariffs – normal, "two rate" and "three rate" (see Annex III) -, the cost of the accumulated electricity consumption is calculated, as well as the cost of the accumulated gas consumed in the different possible contracts, which depend on the annual accumulated gas consumption – Bands 1 to 4 (see Annex III).

Finally, this subchapter closes with the comparison between the tested programs in the different scenarios and with the balance of the $kgCO_2e$, which represents the equivalent, in a matter of environment impact, kilograms of CO_2 released to the atmosphere with the using of an energy source.

A. Dishwashing machine, working in program at 70ºC

The first test made was the electricity consumption measurement of the dishwashing machine with a c program of 70^{0}C, first with no incoming hot water – (i) – and, after, with incoming heated water – (ii). The gas flow in the water heater is of 2.3 m^3/h, so that the water temperature increased from 25^{0}C to 70^{0}C. Before the machine started consuming water – point b) of the procedure (*modus operandi*) described in subchapter 3.1.2, the hot water tap was opened for 1min20seg and the water and gas consumed were, respectively, 5.6 L and 0.05 m^3.

Chart 3.2-5 gives the accumulated consumption of both simulation scenarios.

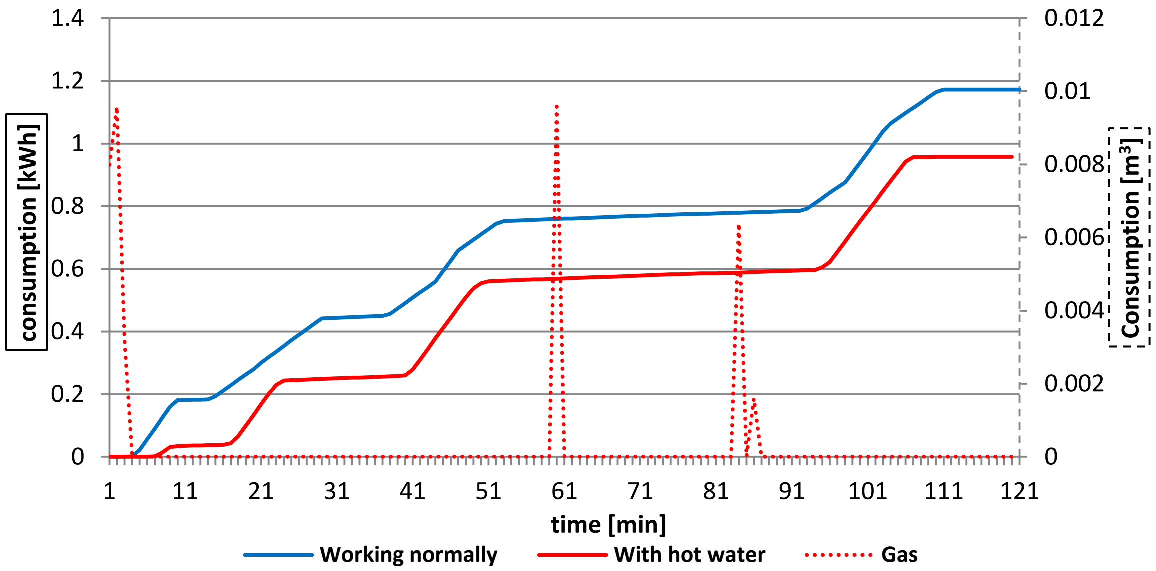

Chart 3.2-5 – Average accumulated electricity consumption profile (continuous lines) and gas consumption (dashed lines) for the dishwashing machine, working in the program at 70^{o}C

As it can be seen, the consumption profiles are similar but with lower values for the scenario with incoming hot water. It is noticed that gas is consumed at the beginning of the program for four minutes, in the middle of the program (around 60 minutes) and *ca.* 85 minutes after the program started. It is also observed that the program of scenario (ii) has a shorter duration of *ca.* 3 min.

The highest consumption periods are better analyzed in Chart 3.2-6, in which the consumption per each minute is represented.

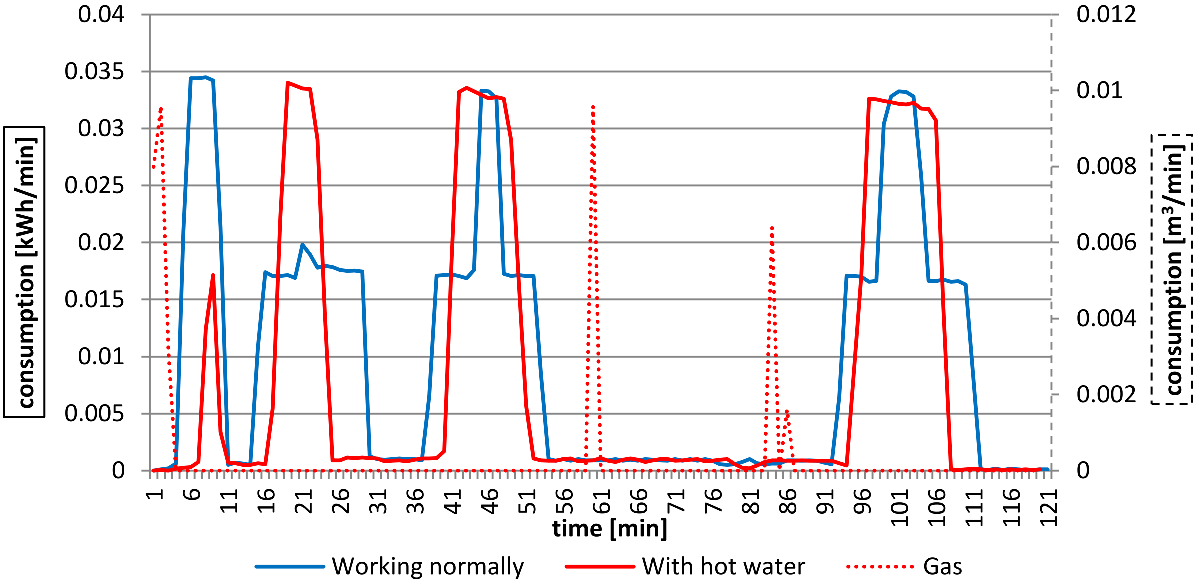

Chart 3.2-6 – Average electricity consumption/min profiles (continuous lines) and gas consumption (dashed lines) for the dishwashing machine, working in the program at 70°C

The first high consumption period is noticed in the first 10 minutes. The consumption in scenario (ii) at this point is 83% lower than in scenario (i) (0.03 kWh in comparison with 0.18 kWh). In the remaining three periods of high electricity consumption – 10, 30, 45 and 100 min after the program started – the consumption is roughly the same in both scenarios, being more intensive and with shorter durations in scenario (ii) but with roughly the same total consumption (0.96 kWh, *i.e.*, less 18% than the value of 1.17 kWh for scenario (i)). This can be explained by the fact of the time intervals between the gas consumptions are longer than 19 min and each one lasts for less than 59 s. Such means that, according to the calculations made in the end of subchapter 3.1.2, all the used water after 19 min the program has started and during four minutes in which the gas heater was activated in the beginning, is at the air temperature (25°C). Therefore, all the consumed gas (due to the water consumption but which occurred in intervals inferiors to 59 s) during that working period is a waste.

The analysis of the values quoted in Table 3-7 leads to the conclusion that this experimental methodology (scenario (ii)) is monetarily worthwhile in 10 different electricity tariffs and gas contracts in percentages between 6% and 11%, out of a range of 24 possible options.

Table 3-7 – Balance between scenarios (i) and (ii), with and without incoming hot water, respectively, for the dishwashing machine operating one cycle in program at 70°C.

Simulation		Accumulated Consumption[a]			Cost by tariff [€][a]					
						"Two rate"		"Three rate"		
		Measured (final energy)	Primary energy		Normal	"Off-peak"	"Peak"	"Off-peak"	"Shoulder"	"Peak"
Scenario (i)	**Electricity (1)**	1.17 kWh	0.34 kgoe		0.16	0.09	0.17	0.09	0.16	0.19
Scenario (ii)	**Electricity (2)**	0.96 kWh	0.28 kgoe		0.13	0.07	0.14	0.07	0.13	0.15
	Gas (3)	0.04 m^3	0.04 kgoe			**Band 1**			0.03	
						Band 2			0.03	
						Band 3			0.02	
						Band 4			0.02	
Electricity saved (4) = (1) - (2) (4)=((1)-(2))/(1); [%]		0.21 kWh (18%)	0.06 kgoe (18%)		0.03 (18%)	0.02 (18%)	0.03 (18%)	0.02 (18%)	0.03 (18%)	0.04 (18%)
Balance between (3) and (4): • **(5) = (3) – (4);** • **(5) = ((3) – (4))/(1); [%]**			-0.02 kgoe (-6%)	**Band 1**	0.00	0.01 (+11%)	0.00	0.01 (+11%)	0.00	-0.01 (-5%)
				Band 2	0.00	0.01 (+11%)	0.00	0.01 (+11%)	0.00	-0.01 (-5%)
				Band 3	-0.01 (-6%)	0.00	-0.01 (-6%)	0.00	-0.01 (-6%)	-0.02 (-11%)
				Band 4	-0.01 (-6%)	0.00	-0.01 (-6%)	0.00	-0.01 (-6%)	-0.02 (-11%)

[a] Values concerned to one cycle

Concerning only electricity, scenario (ii) corresponds to a decrease in costs and energy consumption (0.21 kWh/cycle and 0.02 kgoe/cycle to final and primary energy, respectively) in 18%.

One has to notice that, for "two-rate" and "three-rate tariffs" in "off-peak time" hours, the normal working way is more worthwhile. In a priary energy concern, this methodology presents a positive variation while compared with the normal working way of the dishwashing machine, noticing a decreasing of 0.02 kgoe, from (i) to (ii).

B. Dishwashing machine, working in program auto at 45-65°C

In this experimental test, the dishwashing machine worked in the program auto, at a temperature between 45°C and 65°C. The gas flow was regulated to its minimum, being now 0.66 m^3/h, a value enough to heat the water until 45°C, at the entrance of the machine. The procedure point b) referred in subchapter 3.1.2 lasted for 1min40s and the consumed water and consumed gas were 7.2 L and 0.02 m^3, respectively. Besides the disadvantage of not knowing the exact water consumption due to a not always sufficient water flow for the water heater activation, the temperature required by the machine is also not known since it varies.

Chart 3.2-7 gives the accumulated electricity consumption profiles for both scenarios.

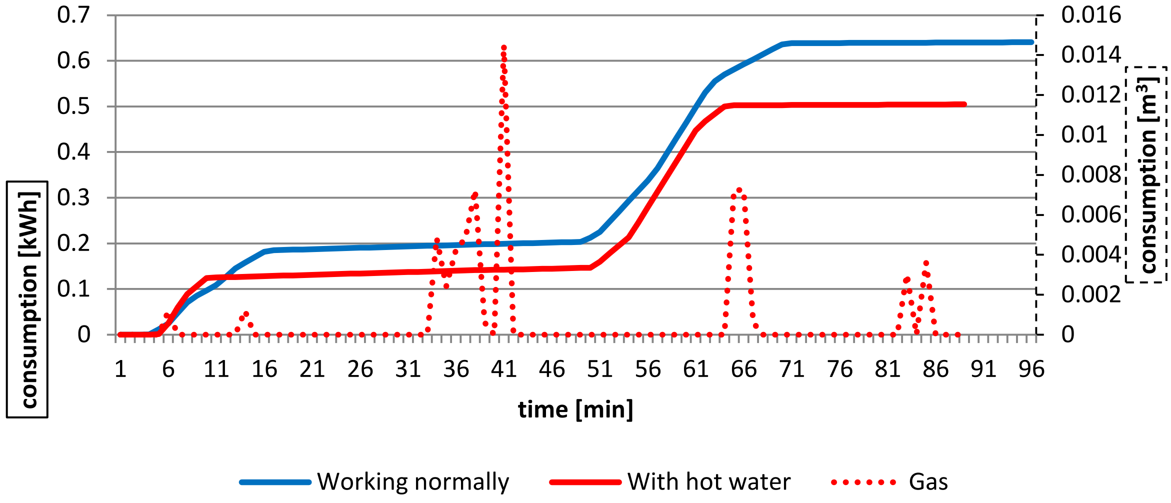

Chart 3.2-7 - Accumulated electricity consumption profiles (continuous lines) and gas consumption (dashed lines) for the dishwashing machine, working in the automatic program at 45-65°C

As it can be seen, scenario (ii) has a saving of accumulated electricity consumption of 0.14 kWh (21%) and, also, a reduction of the program duration in 7 min (8%). Gas consumption occurs during the following periods: 5 min after the program began; again during 10 min after 33 min of the start of the program; again at 65 min; and one last time 85 min after the program started. The periods with high electricity consumption are noticed after 5 and 50 min after the program began. In Chart 3.2-8 it can be seen that these two periods correspond to lower consumptions for scenario (ii) but a peak of 0.035 kWh is noticed *ca.* 7 min after the program started, which is a higher value relatively to the correspondent in scenario (i). This peak in scenario (ii) is immediately compensated by a decrease in consumption higher than the one in scenario (i), reflecting the needless of spending much electricity to heat the water at this point.

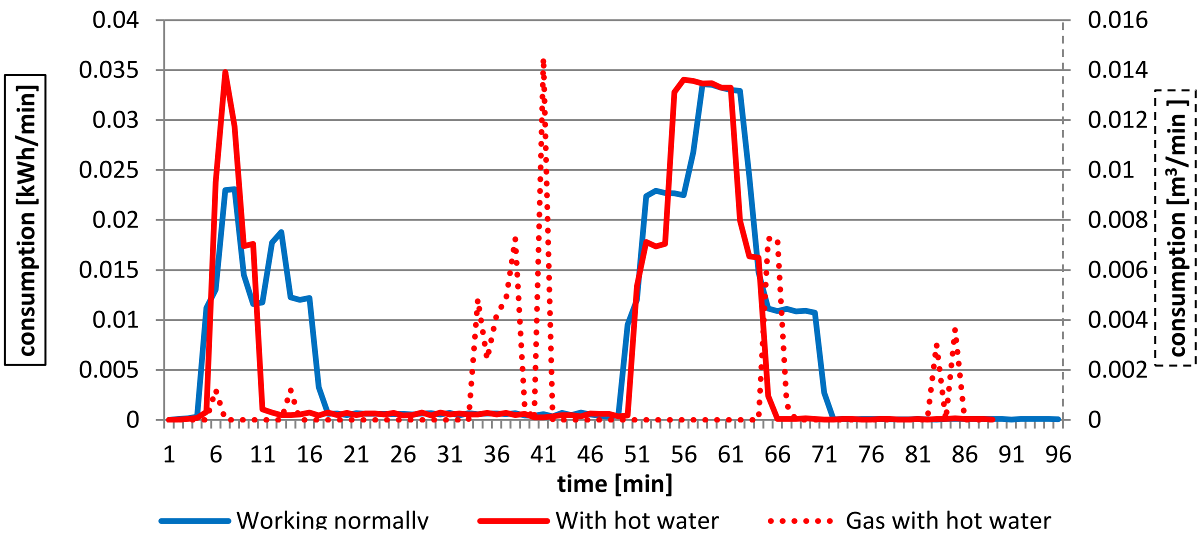

Chart 3.2-8 – Electricity consumption profiles (continuous lines) and gas consumption (dashed lines) for the dishwashing machine, working in the automatic program at 45-65°C

As one can conclude from Table 3-8, this methodology (scenario (ii)) presents worse results under monetary and environmental viewpoints.

It is noticed an increase in primary energy consumption of 0.02 kgoe (11% more than in scenario (i)) and the costs increase from 10% to 40% along the different possible electricity tariffs and gas contracts.

Table 3-8 – Balance between scenarios (i) and (ii), with and without incoming hot water, respectively, for the dishwashing machine operating one cycle in automatic program at 45-65°C

Simulation		**Accumulated consumption**[a] **Measured (final energy)**	**Primary energy**		**Cost by tariff [€]**[a] **Normal**	**"Two rate" "Off-peak"**	**"Two rate" "Peak"**	**"Three rate" "Off-peak"**	**"Three rate" "Shoulder"**	**"Three rate" "Peak"**
Scenario (i)	**Electricity (1)**	0.64kWh	0.19kgoe		0.08	0.05	0.09	0.05	0.09	0.10
Scenario (ii)	**Electricity (2)**	0.50kWh	0.15kgoe		0.07	0.04	0.07	0.04	0.07	0.08
Scenario (ii)	**Gas (3)**	0.05m³	0.05kgoe	**Band 1**	0.04					
				Band 2	0.03					
				Band 3	0.03					
				Band 4	0.03					
Electricity spared (4) = (1) - (2) (4)=((1)-(2))/(1); [%]		0.14kWh (21%)	0.04kgoe (21%)		0.01 (21%)	0.01 (21%)	0.02 (21%)	0.01 (21%)	0.02 (21%)	0.02 (21%)
Balance between (3) and (4): • **(5) = (3) – (4); [€]** • **(5) = ((3) – (4))/(1); [%]**			+0.01kgoe (+1%)	**Band 1**	0.03 (+38%)	0.03 (+60%)	0.02 (+22%)	0.03 (+60%)	0.02 (+22%)	0.02 (+20%)
				Band 2	0.02 (+25%)	0.02 (+40%)	0.01 (+11%)	0.02 (+40%)	0.01 (+11%)	0.01 (+10%)
				Band 3	0.02 (+25%)	0.02 (+40%)	0.01 (+11%)	0.02 (+40%)	0.01 (+11%)	0.01 (+10%)
				Band 4	0.02 (+25%)	0.02 (+40%)	0.01 (+11%)	0.02 (+40%)	0.01 (+11%)	0.01 (+10%)

[a] Values per cycle

The potential scenario (iii), in which there is no electricity consumption for heating the used water, is addressed now. For such purpose, one can analyze Chart 3.2-9, in which is represented the water consumption profile and its temperature at the entrance of the machine. The temperature was calculated according to the Eq. (2) (beginning of this subchapter (see Annex VIII).

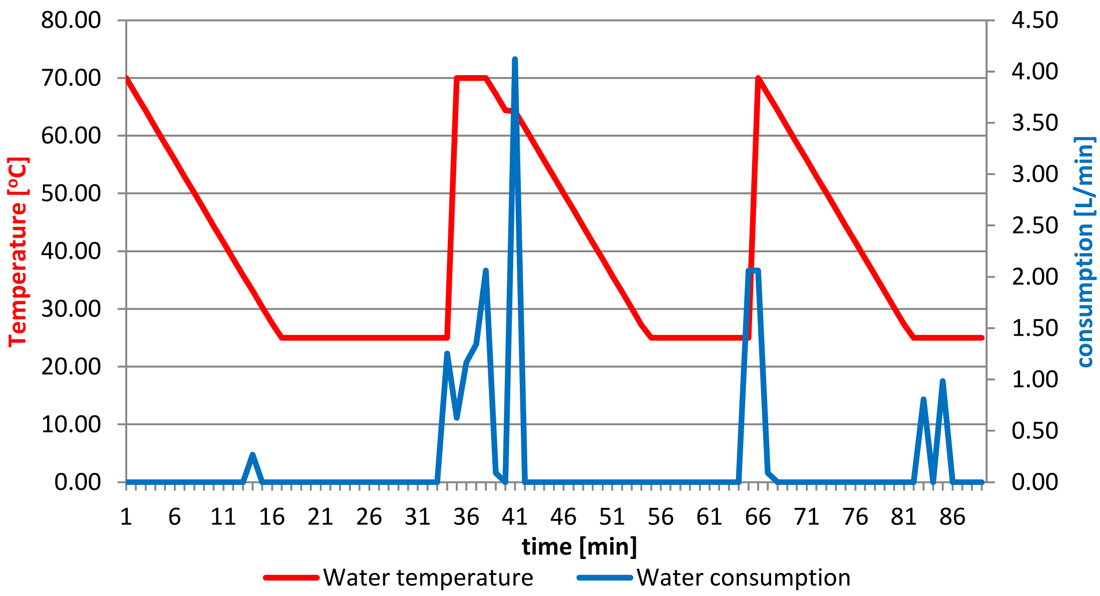

Chart 3.2-9 – Water temperature and consumption profiles concerning the dishwashing machine, in the automatic program at 45-65°C.

For scenario (ii), the average water temperature increase is of 22°C (41°→61°C) and in scenario (i) it is of 36°C (25°C→61°C) (Annex VIII). The difference in the electricity consumption is 0.14 kWh (21%, as it is referred in Table 3-8). It is noticed an increase in primary energy consumption of 0.02 kgoe (33% more than in scenario (i)) and the costs increase from 10% to 40% along the different possible electricity tariffs and gas contracts.

The total gas consumption (0.05 m^3) occurred during 3min50s. Since the water flow was 4.3 L/min, the total amount of water that was heated by the gas combustion in the water heater was 17 L. This value is in accord with that in the catalog (9-19 L, Table 3-6) and this is the assumed value, which means that, for this program, the water flow is constant (4.3 L/min) and all the consumed water activates the gas water heater. The fact that the amount of the consumed water is close to its maximum cataloged value means that the Aquasensor (feature referred in Table 3-6) regulated the machine to its maximum water consumption and, so, it can be guessed that the water temperature is also close to the maximum specified value (65°C). This is close to the value obtained by the interpolation between the temperatures and water consumption: 61°C. In scenario (ii), the average water temperature increase is of 22°C (39°→61°C) and in scenario (i) it is of 36°C (25°C→61°C) (Annex VIII). The difference in the electricity consumption is 0.14 kWh (21%, as it was referred above). This means that this spared energy is related to a decrease of 14°C in the heating necessity for the same volume of consumed water, 17 L. Therefore, this electricity can be related to the temperature variation by the following expression:

$$\frac{0.14\ \text{kWh} \times 10^3\ \text{Wh/kWh}}{14\ \ ^{\text{o}}\text{C} \times 17\ \text{L}} = 0.55\ \text{Wh/(}\ ^{\text{o}}\text{C. L)}$$

This allows to estimate the spent energy, in scenario (i), just concerning the water heating:

$$0.55\ \text{Wh/(}\ ^{\text{o}}\text{C. L)} \times 10^{-3}\ \text{kWh/Wh} \times 36\ \ ^{\text{o}}\text{C} \times 17\ \text{L} = 0.33\ \text{kWh}$$

This value corresponds to **52%** of the total electricity consumption. This is the potential accomplished electricity saving for this dishwashing machine with no need for heating the water, which corresponds to scenario (iii). This percentage also corresponds to the decrease in the costs and in primary energy consumption – 0.03 kgoe. It is not worthwhile to present the values in a table because the costs become too low and with no meaning, as three decimal places are not inside the precision of the calculations. Still, the value that has to be taken in consideration is the percentage of 52. This value contradicts, though, the 90% depicted in (ADENE, et al., 2010), accusing some inaccuracies in the assumptions considered by the author.

C. Washing machine, working in program at 40ºC

In this experimental test, the washing machine worked in the program at 40ºC. The gas flow was maintained at the minimum value of the previous simulation, 0.66 m^3/h, being this value enough to heat the water until 45ºC. The water flow also kept its value of 4.3 L/min. The procedure point b) (of *modus operandi*) referred in subchapter 3.1.2 lasted for 1 min 35 s and the consumed water and consumed gas were, respectively, 6.9 L and 0.02 m^3.

The main difference between the washing machine and the dishwashing machine is that, in the former, the water consumption is made with a sufficient flow to activate the water heater each time the machine consumes water. The water consumption can be estimated by multiplying the water flow (4.3 L/min) by the total amount of time that the gas heater was functioning – subtracting 2.5 s in each operation period (as it was said in subchapter 3.1.2, that is the time the water heater remains in its activated status after the water stops being consumed) – which corresponds to the period of time 11min 38s, giving a final volume of 50 L. This value is 3 L lower than the cataloged one but it is also said that this value varies with the pressure, hardness and temperature of the water. Therefore, it is considered that the total water consumption was of 50 L. With this, the potential scenario (iii) can be determined.

The washing machine displays different consumption profiles that are distinct from those for the dishwashing machine, as it can be seen in Chart 3.2-10 and Chart 3.2-11: instead of having two or three periods of higher consumption, it shows one at *ca.* 8 min after the program started (Chart 3.2-10).

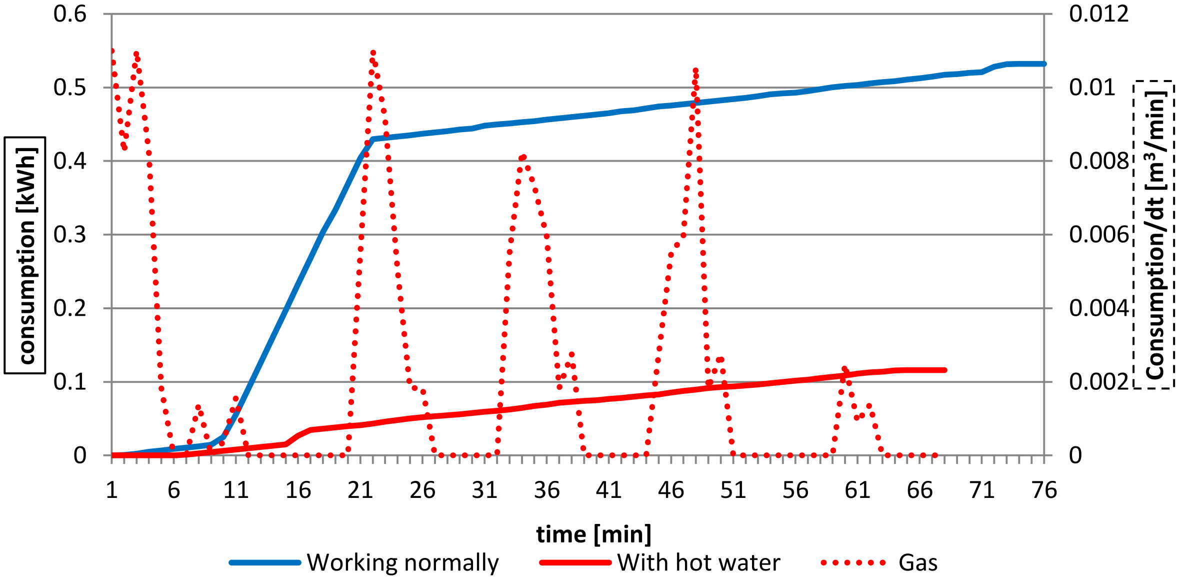

Chart 3.2-10 – Accumulated electricity consumption profiles (continuous lines) and gas consumption (dashed line) for the washing machine, working in the program at 40°C

The accumulated electricity consumption profile of scenario (ii) is much lower than in scenario (iii), corresponding to a decrease of 0.41 kWh (78%), and the duration of scenario (ii) is shorter by 8 min (11% of the total time).

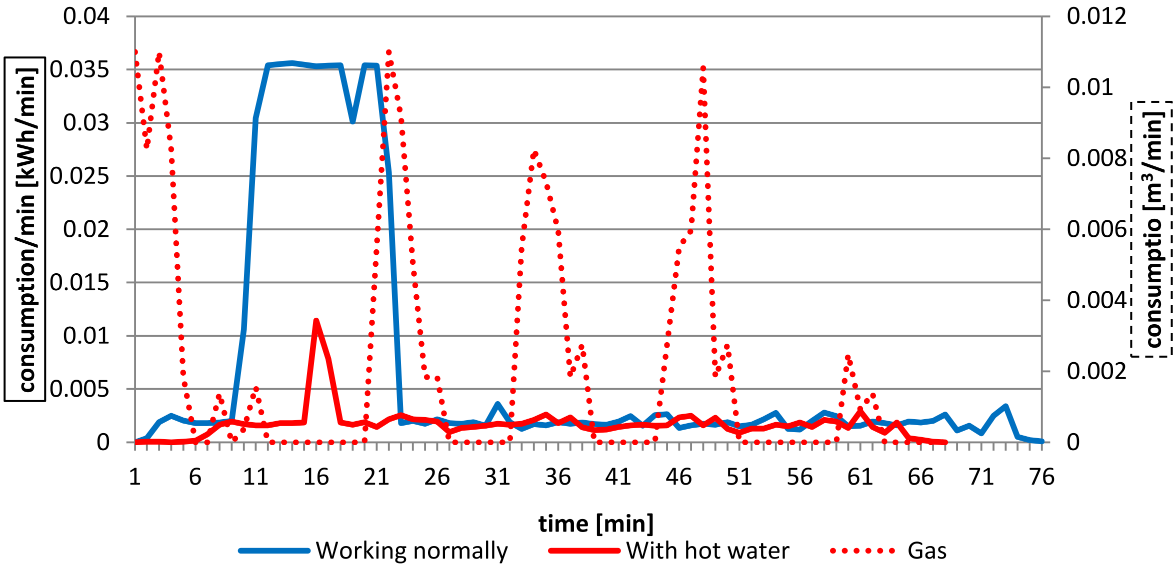

Chart 3.2-11 – Electricity consumption profiles (continuous lines) and gas consumption (dashed line) for the washing machine, working in the 40°C program.

The high consumption period in scenario (i) lasts until 22 min after the program has started. In the same working period in scenario (ii), a decrease in electricity consumption of 0.39 kWh (90%) is observed, with a gas consumption until 11 min after the program started. Following this period, it is noticed a reduction of 0.02 kWh (7% of the remaining electricity consumption) between both scenarios ((i) and (ii)), and four more consumption periods of gas around 20, 32, 44 and 58 min after the program has started, corresponding also to periods of water consumption. This reduction is not much significant and can represent a low electricity consumption in maintaining the water temperature. The main consumption results from centrifuging and other processes.

Clearly, the influence of the incoming heated water has an impact on the electricity consumption of the washing machine, but, in order to assess the environmental and economical impacts of this methodology, one must analyze Table 3-9.

Table 3-9 - Balance between the scenario with and without use of incoming hot water in the washing machine operating one cycle for the program at 40°C.

Simulation	Accumulated consumption[a]				Cost by tariff [€][a]					
		Measured (final energy)	Primary energy		Normal	"Two rate"		"Three rate"		
						"Off-peak"	"Peak"	"Off-peak"	"Shoulder"	"Peak"
Scenario (i)	**Electricity (1)**	0.53kWh	0.15kgoe		0.07	0.04	0.08	0.04	0.07	0.08
Scenario (ii)	**Electricity (2)**	0.12kWh	0.04kgoe		0.02	0.01	0.02	0.01	0.02	0.02
	Gas (3)	0.14m³	0.13kgoe	**Band 1**	0.11					
				Band 2	0.10					
				Band 3	0.09					
				Band 4	0.09					
Electricity saved (4) = (1) - (2) (4)=((1)-(2))/(1); [%]		0.41kWh (78%)	0.12kgoe (80%)		0.05 (78%)	0.03 (78%)	0.06 (78%)	0.03 (78%)	0.05 (78%)	0.06 (78%)
Balance between (3) and (4): • (5) = (3) – (4); [€] • (5) = ((3) – (4))/(1); [%]			+0.02kgoe (+13%)	**Band 1**	0.06 (+86%)	0.08 (+200%)	0.05 (+63%)	0.08 (+200%)	0.06 (+86%)	0.05 (+63%)
				Band 2	0.05 (+71%)	0.07 (+175%)	0.04 (+50%)	0.07 (+175%)	0.05 (+71%)	0.04 (+50%)
				Band 3	0.04 (+57%)	0.06 (+150%)	0.03 (+38%)	0.06 (+150%)	0.04 (+57%)	0.03 (+38%)
				Band 4	0.04 (+57%)	0.06 (+150%)	0.03 (+38%)	0.06 (+150%)	0.04 (+57%)	0.03 (+38%)

[a] Values concerned to one cycle

The analysis of this table leads to the conclusion that, as for the previous scenarios, this methodology (scenario (ii)) is environmentally and economically worse than the normal working way (scenario (i)). Indeed, though a decrease in electricity consumption and electricity costs of 78% are noticed, the consumption in primary energy (kgoe) increases in 7%. Moreover, the final costs increase boost from 50% to 200%.

As it was mentioned above, it is possible to determine the potential savings for this test – if, for example, an environmental "clean" and no cost charged energy source is applied to heat all the water used in the machine – scenario (iii). For that purpose one should analyze Chart 3.2-12, in which the water consumption profile and its temperature at the entrance of the machine are depicted.

The temperature was calculated according to the Eq. (2) (beginning of this subchapter) (see Annex VIII).

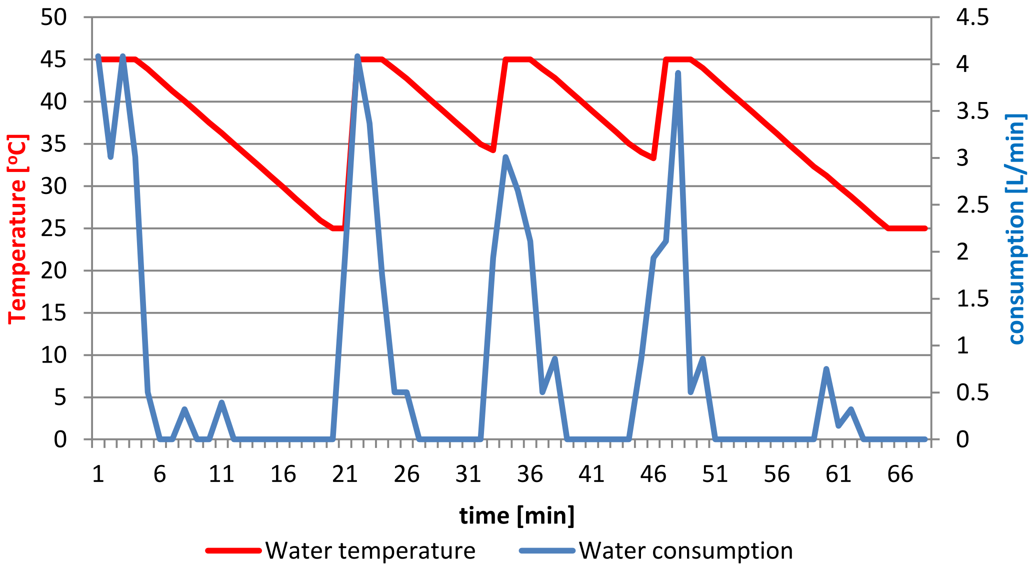

Chart 3.2-12 – Temperature of the incoming water and water consumption profiles for the washing machine, working in the 40°C program.

In scenario (ii), the average water temperature increase is of 2°C (38°→40°C) and in scenario (i) it is of 15°C (25°C→40°C) (Annex VIII). The difference in the electricity consumption is 0.41kWh (78%, as it was referred above). This means that this spared energy is related to a decrease of 13°C in the heating necessity for the same volume of consumed water, 50L. Therefore, this electricity can be related to the temperature variation in the following way:

$$\frac{0.41 \text{ kWh} \times 10^3 \text{ Wh/kWh}}{12 \text{ °C} \times 50 \text{ L}} = 0.63 \text{ Wh/(°C. L)}$$

This allows to estimate the spent energy, in scenario (i), just regarded to the water heating:

$$0.63 \text{ Wh/(°C. L)} \times 10^{-3} \text{ kWh/Wh} \times 15 \text{ °C} \times 50 \text{ L} = 0.47 \text{ kWh}$$

This value corresponds to **89%** of the total electricity consumption. This is the potential accomplished electricity saving for this washing machine. This value also corresponds the decrease in the costs and in primary energy consumption – 0.04 kgoe. It is not worthwhile to present the values in a table because the costs become too low and meaningless, as three decimal places are not out of the precision of the calculations. Still, the value that has to be taken in consideration is the percentage of 89.

D. Overall view

For the sake of simplification, the programs are now referred as follows: **A –** dishwashing machine, working in program at 70°C; **B –** dishwashing machine, working in program auto at 45-65°C; **C –** washing machine, working in program at 40^{0}C, intensive. In this way, one can better percept the efficiency of this methodology (scenario (ii)) in the different tested programs for dishwashing and washing machines.

Table 3-10 – Overall consumption and cost per cycle, concerning each measured scenario in subchapter 3.2.2. The presented costs are the average in all calculated tariffs.

	A		B		C	
	(i)	**(ii)**	**(i)**	**(ii)**	**(i)**	**(ii)**
Electricity	1.17 kWh 0.34 kgoe 0.55 kgCO_2e 0.143 €	0.96 kWh 0.28 kgoe 0.45 kgCO_2e 0.115 €	0.64 kWh 0.19 kgoe 0.30 kgCO_2e 0.077 €	0.50 kWh 0.15 kgoe 0.24 kgCO_2e 0.062 €	0.53 kWh 0.11 kgoe 0.25 kgCO_2e 0.063 €	0.12 kWh 0.03 kgoe 0.06 kgCO_2e 0.017 €
Gas	- - -	0.04 m^3 0.04 kgoe 0.10 kgCO_2e 0.025 €	- - -	0.05 m^3 0.05 kgoe 0.12 kgCO_2e 0.033 €	- - -	0.14 m^3 0.13 kgoe 0.34 kgCO_2e 0.098 €
Water	12 L	12 L	17 L	17 L	50 L	50 L
Average water temperature	25^{0}C	- [a]	25^{0}C	39.7^{0}C	25^{0}C	37.1^{0}C
Balances (ii) - (i)	- 0.21 kWh -0.02 kgoe + 0.04 m^3 - 0.003 € 0.0 kgCO_2e		- 0.14 kWh + 0.01 kgoe + 0.05 m^3 + 0.018 € + 0.06 kgCO_2e		- 0.41 kWh + 0.02 kgoe + 0.14 m^3 + 0.052 € + 0.15 kgCO_2e	
Electricity spent in water heating	-	-	0.33 kWh 0.07 kgoe 0.16 kgCO_2e (52%)	0.17 kWh 0.04 kgoe 0.08 kgCO_2e	0.47 kWh 0.10 kgoe 0.22 kgCO_2e (89%)	0.06 kWh 0.01 kgoe 0.03 kgCO_2e

[a] could not be measured

One can see that the increase in consumption in program A, comparing with B, in scenario (i), is due to the higher water temperature for that program (70^{0}C *vs.* 61^{0}C). Once it was not possible to measure the heated water in program A, as the water flow was insufficient to activate the gas water heater (therefore, the periods in which the dishwashing machine consumed water were not measured), one could not determine the heated water in scenario (ii) and, thereby, the potential scenario (iii).

Concerning programs B and C, it is assumed that all the used water activated the gas water heater but, as it is referred in Chart 3.2-9 and Chart 3.2-12, as well as in Annex VIII. Such does not mean that all the used water is at the desired temperature. In fact, the average temperature of the used water, at the entrance of the machine for B and C, is 39.7 and 37.1^{0}C, respectively, which means that the machine had to heat the water at 21.3^{0}C and 2.9^{0}C, respectively. This reflects the inefficiency of this experimental methodology. In fact, the primary energy that is spent in scenario (ii) increases in program B and C, 11 and 1%, respectively, though it represents a corresponding decrease in electricity consumption of 21.9 and 77.4%. In A, the balance between primary energy consumption shows a decrease in 6%, and occurs a spare in electricity consumption of 17.9%.

As far as the costs are concerned, scenario (ii) corresponds, averagely, to an associated increase of 2.1, 2.3 and 82.6% for programs A, B and C, respectively.

The potential scenario (iii) concerns the machines working without spending energy on water heating. For that, it is assumed the adoption of a technology that surely most people are not investing and, furthermore, it is assumed that it is capable to provide heat enough for no resource to other energy source, which it is known that such does not exist. Nevertheless, this is the potential scenario and it is referred as such. The potential electricity savings, if no need for heating the water in the tested machines, are 52 and 89% for programs B and C, corresponding to an equal percentage reduction in the costs and in the CO_2 emmissions decrease (0.16 and 0.22 kgCO_2e, respectively).

The value concerning the dishwashing machine (52%) contradicts, though, the 90% depicted in (ADENE, et al., 2010). Though the later value cannot be compared with our because the conditions in which it was obtained are not known, such value makes sense in a way that the electricity share, for the dishwashing machine, for heating water must be superior to that (89%) for the washing machine. Inaccuracies in the experimental conditions eventually can account for this.

Moreover, the CO_2 emmissions of this methodology (scenario (ii)) is defined, respectively for programs B and C, by an increase of 0.06 and 0.15 kgCO_2e. As for program A, it is not registered a variation.

Chapter 4 - Demand Side Management

In this Chapter, electricity consumption profiles of four different families (two of which belonging to the NZES project study-target) are analyzed and the daily average costs are determined according to the different possible tariffs, which enables the assessment of the adequacy of the chosen tariff by each family. Two behavior changes are proposed:

- Change the dishwashing and washing machines consumption to “off-peak” periods;
- Extinguishing the standby consumption during the night time.

This Chapter closes with an overall analysis through the average consumption of these families and it is introduced another behavior change proposal:

- the implementation of, *e.g.*, a solar thermal device so that the consumed water in the dishwashing and washing machines does not require electricity to heat.

Having this, an extrapolation of the consumption habits change to a national level is undertaken and the potential savings determined with this Thesis is assessed.

4.1. Residential consumption profiles

At this section, general residential electricity consumption profiles are analyzed and studied. The goal is to apply a methodic thinking-line in order to assess the costs according to the chosen electricity tariff and the savings potentiality on changing consumption habits – in the use of the dishwashing and washing machines only in "off-peak" time – and applying a "Two-rate" or "Three-rate" tariff for each profile, as it is explained at the end of this introduction.

The analyzed profiles are not annual, meaning that not all the seasons are represented and, therefore, not all the consumption fluctuations are shown. Hence, in order to generalize the measured profiles to an annual level, it was considered that:

(i) During the winter period, the consumption increases 13% and with a constant profile (explained in the following paragraph);
(ii) The annual vacation period is of 30 days, being 22 days (approximately three weeks) enjoyed in the summer period and 8 days (approximately one week) enjoyed in the winter period;
(iii) The standby consumption during the vacation period is lower than the standby consumption during the normal period;
(iv) All the houses, once they have Normal tariff, use the dishwashing and washing machines randomly during the day. The consumption of these appliances is considered to be 8% of the total electricity consumption – 5% for the washing machine and 3% for the dishwashing machine (ADENE, et al., 2004).

(i)--> It was not found a correlation between the national electricity consumptions in the summer and in the winter. Many factors affect the electricity consumption in the winter, such as holiday time (which is normally higher in the summer time), lighting, heating appliances (*e.g.,* drying machine) or air and water heating. However, the following was assumed on the basis available of data (REN, 2010), being represented in Chart 1.1-1:

a. the daily electricity consumption increased 13% in the winter (from 135.6MWh/day to 153.5MWh/day), in 2010. The national consumption is divided in five different sectors: Residential, Services, Transport, Industry and Agriculture. Among these, Transport and Agriculture are considered not having significant fluctuation in the electricity consumption between the summer and the winter. Therefore, the increase of 17.9 MWh/day in the winter is regarded to Residential, Services and Industry sectors, being considered that the increase is similar across sectors – 13%. This approach is not very precise because the appliances and social level of the families in the analyzed houses vary, a fact that will be taken into account during the analysis. This increase of consumption in the winter is considered to be homogeneous, maintaining the shape of the profile measured in the summer.

(ii)--> It is known that the summer period is from March 27th to October 30th, being divided in the normal (196 days – 53.7%) and the vacation (22 days – 6.0%) periods; and the winter period is from October 31st to March 26th, split also in the normal one (139 days – 38.1%) and the holiday (8 days –

2.2%) ones. These values are the basis for the extrapolation of the analyzed profiles for the whole year, and, furthermore, allow the determination of potential savings of turning off the standby consumption.

(iii)--> The difference between the standby consumptions during the normal and the vacation periods is established after the first analyzed profile because it includes both of the periods during the measured time. For the profiles in which there is no measured vacation period (hence not measured standby during this period), that established difference (in the first analyzed profile) is applied to the standby in the normal period.

(iv)--> The assessment of the potentiality in the change of consumption habits, deviating the "peak" time to "off-peak" and "shoulder" times, allied to the change from Simple tariff to "Two rate" or "Three rate" tariff, is undertaken by reducing the consumption percentage of 8% homogeneously and then transferring it to an "off-peak" time. The chosen time is 00h00min and it is considered that the consumption concentrates during that hour. That is not what happens in reality because the programs of the machines last for more than one hour but, for a matter of analysis and calculation, this is the same as if the consumption was spread along the remaining "off-peak" time, so this approximation is followed for the sake of simplicity.

The main accounted features for each house are represented in Table 4-1:

Table 4-1 – Main features of the analyzed houses

	House 1	House 2	House 3	House 4	Average
dishwashing machine	Yes	Yes	Yes	Yes	100%
washing machine	Yes	Yes	Yes	Yes	100%
refrigerator	Yes	Yes	Yes	Yes	100%
freezer	Yes	Yes	No	No	50%
electric water boiler	Yes	No	No	No	25%
oil radiator	Yes	Yes	No	Yes	75%
air conditioning	No	No	Yes	No	25%
number of rooms	4	4	3	4	3.75
number of people	4	6	4	5	4.75
existing tariff	Simple	Simple	Simple	Simple	Simple
contracted power (kVA)	- [a]	10.35	3.45	6.9	6.9

[a] Unknown

Regarding to contracted power, it is not possible to know if the house has, or not, the adequate one because the interval between each value is one hour and, so, it is not known the instantaneous power in each minute, being this factor the decisive one in this matter. Indeed, the instantaneous power may vary significantly during one hour. Nevertheless, one can compare the consumption profiles and, if any house has a contracted power higher than another one with a similar profile, it may be assumed that this family has a contracted power too high.

There are two profiles – A and B – that have periods of holidays and normal periods (are considered as normal the periods when the house has the family living there, consuming electricity) and those periods are analyzed separately. Concerning the remaining families, this distinguish is determined but the periods are not analyzed separately.

Following the method mentioned in subchapter 3.1 (see Annex I), the data analysis in this Chapter is undertaken by the recourse to a *calculus* tool developed by the author, through a code in VBA that organizes the registered data (CSV files) of the PlugMeter® and separates then into consecutive days, calculating also the average data per day. Therefore, all the analyzed data are the daily averages over the entire simulated period. Moreover, the corresponding costs and consumption are the daily averages, as well.

For each house, the analysis focus firstly on the measured periods, following to the extrapolated annual periods. Lastly, all the four analyzed houses are aggregated in order to result in an average scenario to allow general conclusions.

A. House 1

The fist analysis concerns "House 1". This house corresponds to one of the study-target families in the NZES Project, which means that this family is of a student at the Vergílio Ferreira high school. Unfortunately, it is not known the contracted power but this house has the normal electricity tariff (Table 4-1). The measurements were taken from July 10th to September 18th, including vacation and normal periods:

Normal period	Vacation period	Normal period	Vacation period
July 10th to July 23rd	July 24th to August 7th	August 14th to August 28th	August 29th to September 18th

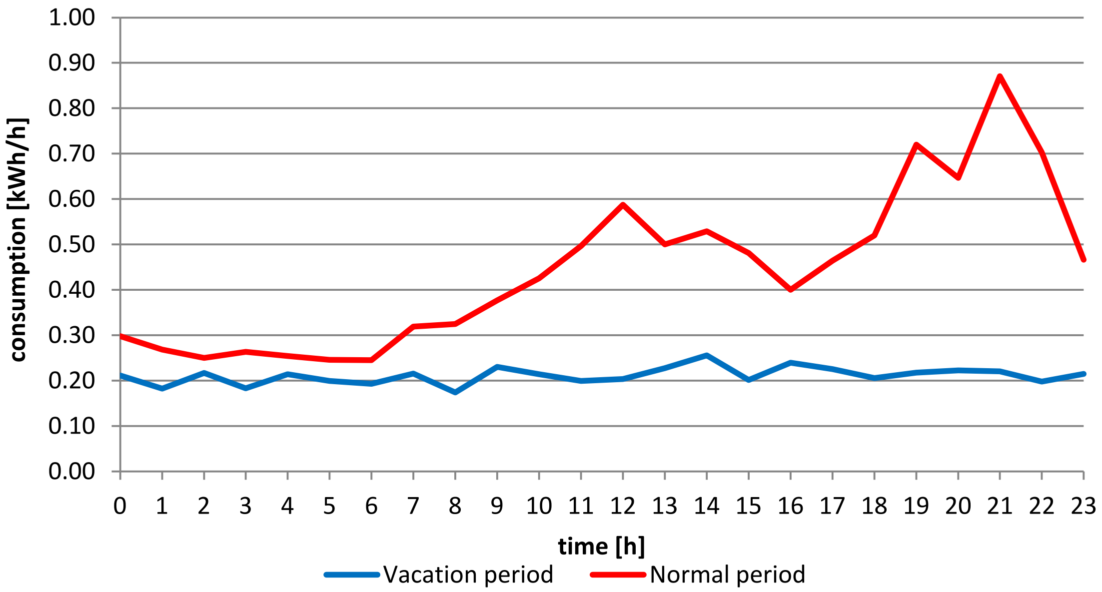

Chart 4.1-1 – Average daily electricity consumption profiles measured in House 1 for the summer period, distinguishing the normal and the vacation periods.

As it can be seen, during the vacation period, the consumption of electricity has a low fluctuation along the day, having a value of 0.21 kWh per hour, which is reflected in a daily accumulated consumption of 5.07

kWh. For the normal period, the daily accumulated consumption is 10.66 kWh, corresponding to an increase of 110% relatively to the vacation period. It can also be noticed that the lowest consumption, in the normal period, occurs from 1 to 6h and is 0.25 kWh per hour. This value is 19% higher than in the vacation period, which may be the consequence of the increase of the standby consumption of the refrigerator and the freezer and, eventually, other appliances that stay turned on or in “hibernate” state (*e.g.*, computers, printers or cell phones charging during the night). This percentage of 19 is the considered value for the estimate of the vacation period consumption for the following houses in which the vacation period is not registered. It is noticed that the “peak” consumptions occur at *ca.* 12h and between 19 and 22h, which corresponds to meal periods. This house has always someone therein because the electricity consumption during the day is practically always above 0.4 kWh, which represents some activity.

The costs associated to this profile – which occurred in the summer – were calculated and the costs associated to the winter period have been determined as well, being both collected in Table 4-2.

Table 4-2 – Costs associated to the all periods regarded to “House 1”. The values are in €/day [numbered from the lowest (1) to the highest (6) one].

Tariff	Summer		Winter (calculated)	
	Normal period	Vacation period	Normal period	Vacation period
“Three rate” tariff; Daily cycle	**1-** 0.88	**1-** 0.44	**5-** 1.47	**5-** 0.67
“Three rate” tariff; Weekly cycle	**2-** 1.08	**2-** 0.44	**1-** 1.19	**1-** 0.48
Simple; <2.3 kVA	**3-** 1.09	**3-** 0.52	**2-** 1.24	**2-** 0.59
“Two rate” tariff; Daily cycle	**4-** 1.24	**4-** 0.58	**3-** 1.40	**4-** 0.66
“Two rate” tariff; Weekly cycle	**5-** 1.34	**5-** 0.60	**4-** 1.44	**3-** 0.64
Simple; >2.3 kVA	**6-** 1.41	**6-** 0.67	**6-** 1.60	**6-** 0.76

The increase of 13% in electricity consumption in the winter means an accumulated consumption of 12.04 kWh in the normal period and 5.72 kWh in the vacation period. The accumulated consumption for the vacation period in the summer is 5.07 kWh. One must notice that the relative cost of the tariffs differs according to the period.

The average daily costs for this house, concerning the whole year, are represented in Table 4-3, as well as the associated costs when using the dishwashing and the washing machines only during “off-peak” time.

Table 4-3 – Costs associated to the calculated annual consumption for “House 1”, distinguishing the use of the dishwashing an washing machines during “off-peak” time. The values are in €/day [numbered from the lowest (1) to the highest (6) one].

Tariff	All year	
	Normal use of dishwashing and washing machine	Dishwashing and washing machines working in “off-peak”
“Two rate” tariff; Weekly cycle	**1-** 1.02	**1-** 0.99
“Three rate” tariff; Daily cycle	**2-** 1.09	**2-** 1.07
Simple; <2.3 kVA	**3-** 1.10	**3-** 1.10
“Two rate” tariff; Daily cycle	**4-** 1.25	**4-** 1.22
“Three rate” tariff; Weekly cycle	**5-** 1.41	**5-** 1.36
Simple; >2.3 kVA	**6-** 1.42	**6-** 1.42

The consumption profiles for the normal and “off-peak” operations are represented in Chart 4.1-2.

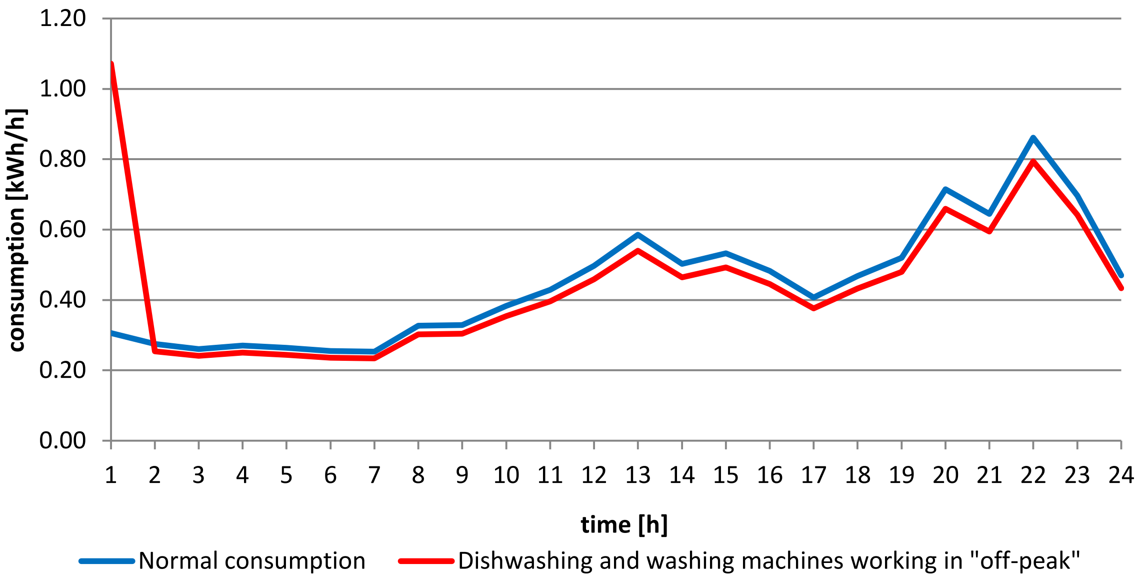

Chart 4.1-2 – Average daily electricity consumption profiles of “House 1”, determined for the whole year, using the washing machine and the dishwashing machine normally and during “off-peak” time.

Knowing that this family has Simple electricity tariff and assuming that it has a contracted power higher than 2.3 kVA (which is almost certain because a peak consumption of 0.72 kWh (from 19 to 22h) surely means that the 2.3 kVA are overcome during some periods during the year, especially in the winter), it can be seen that this represents the worst tariff for this family. Therefore, just by choosing a different tariff, this family may benefit from a cost saving from 0.7% to 28.2% (Table 4-3). If this house only used the dishwashing and washing machines during “off-peak” time, this would correspond to an average saving up to 3.4% in the costs in the same tariff and, though the electricity consumption increases during “off-peak” time, the consumption in “peak” and “shoulder” times decreases 8%.

The potential saving in the costs is 30.3%, corresponding to the scenario with “two rate” tariff with weekly cycle and with the machines being consumed during “off-peak” time.

B. House 2

This house has the same interesting feature as “House 1”, which is being one of the study-target of NZES Project. The contracted power is 10.35 kVA and the existing tariff is the Simple (Table 4-1). Relatively to the pervious house, it differs in the household composition (six people, *i.e*,. two more) and in the gas water heater, which is the only water heating appliance.

The measurements undertaken from July 7th to September 19th, comprising both vacation and normal periods:

Normal period	Vacation period	Normal period
July 7th to August 3rd	August 4th to August 17th	August 18th to September 19th

By fortune, the two normal periods are complementary. Indeed, August 18th is a Thursday, which follows August 3rd, which is a Wednesday. There is, though, a period of three days – from August 10th to August 12th (21.4% of this vacation period) – in which consumption is noticed. This means that this period corresponds to a three day break in the "home away" vacation. Nevertheless, this period is treated as part of the vacation period because this is how this family enjoys the vacation time. The consumption profiles are represented in Chart 4.1-3. Similarly, in the normal periods we detect four days in which only standby consumption is noticed, which corresponds to 6.6% of this normal period and concern full days in which the family was absent.

The first analyses from these consumption profiles are that they don't have an evident tendency and there is an irregular point – at 19h – that is intriguing because it is noticed the highest consumption during the vacation period and a drop down before a peak period during the normal period. The explanation for these atypical profiles is as follows:

- Regarding to the non evident tendency of the profiles, it can be explained, for the vacation period, by the 21.4% of the time in which is consumption noticed and, for the normal period, 6.6% the time in which the house is empty. The latter percentage for the normal period is not much significant, but by considering also the registered days with inconstant consumptions, which may reflect the high number of occupants (six), it can eventually account for this profile.
- During the vacation period, for the three days in which the family returned from holidays, as it is assumed, the dinner time might have been earlier than in the normal period, which is a common behavior. During the normal period, the consumption drops at that time (19h) maybe because part of the family has outdoor activities during that period, returning at dinner time (*e.g.*, sports practice for the children or late working hours for the parents).

The consumption fluctuation during the vacation period is 0.16 kWh per hour, which corresponds to 40.2% of the consumption for this period (0.39 kWh per hour), resulting in an accumulated consumption of 9.31 kWh. As for the normal period, the daily accumulated consumption is 12.16 kWh, corresponding to an increase of 131% regarding to the vacation period. The lowest consumption, for this period, occurs from 4 to 7h and is 0.38 kWh per hour. This value is just slightly higher (7.7%) than the one in the vacation period, which is 0.37 kWh per hour and occurs from 0 to 8h.

The "peak" consumption in the normal period is not well defined, just being defined two drop down periods in the consumption, one at 14 and other at 19h.

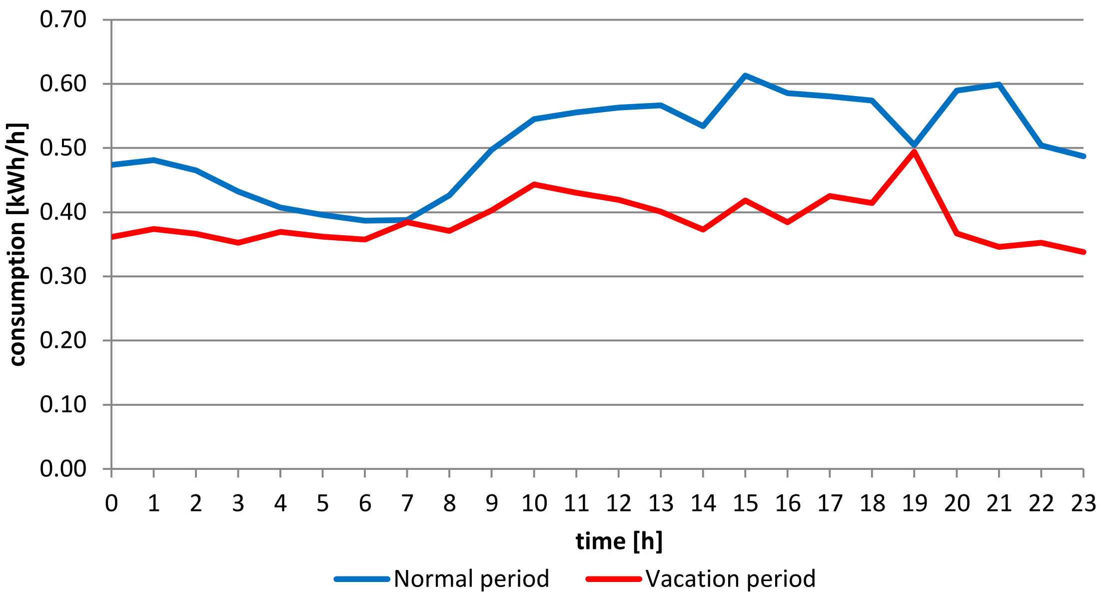

Chart 4.1-3 - Average daily electricity consumption profiles measured in House 2, for the summer period, distinguishing the normal period and the vacation periods.

The costs associated to this profile (which occurred in the summer) were also calculated. These associated to the winter period estimated as well, by increasing the consumption in 13% and repeating the analysis as previously. These costs are given in Table 4-4.

Table 4-4 – Costs associated to all the periods concerning "House 2". The values are in €/day [numbered from the lowest (1) to the highest (6) one].

Tariff	Summer		Winter (calculated)	
	Normal period	Vacation period	Normal period	Vacation period
"Three rate" tariff; Daily cycle	1- 1.04	1- 0.79	3- 1.63	3- 1.23
Simple; <2.3 kVA	2- 1.25	2- 0.96	1- 1.41	1- 1.08
"Two rate" tariff; Daily cycle	3- 1.41	3- 1.08	2- 1.59	2- 1.22
"Three rate" tariff; Weekly cycle	4- 1.49	4- 1.13	4- 1.64	4- 1.23
"Two rate" tariff; Weekly cycle	5- 1.52	5- 1.14	5- 1.64	5- 1.23
Simple; >2.3 kVA	6- 1.61	6- 1.23	6- 1.82	6- 1.40

Regarding to the determined consumption in the winter period, accumulated consumption is 12.04 kWh in the normal period and 5.72 kWh in the vacation period. The accumulated consumption for the vacation period in the summer is 9.31 kWh.

The average daily costs for this house, regarded to the whole year, are represented in Table 4-5, as well as the associated costs when using the dishwashing and washing machines only during "off-peak" time.

Table 4-5 – Costs associated to the calculated annual consumption for "House 2", distinguishing the use of the dishwashing an washing machines during "off-peak" time. The values are in €/day [numbered from the lowest (1) to the highest (6) one].

Tariff	All year	
	Normal use of dishwashing and washing machine	Dishwashing and washing machines working in "off-peak"
"Two rate" tariff; Weekly cycle	1- 1.15	1- 1.11
"Three rate" tariff; Daily cycle	2- 1.27	2- 1.25
Simple; <2.3 kVA	3- 1.29	3- 1.29
"Two rate" tariff; Daily cycle	4- 1.46	4- 1.42
"Three rate" tariff; Weekly cycle	5- 1.59	5- 1.54
Simple; >2.3 kVA	6- 1.66	6- 1.66

The respective profiles are depicted in Chart 4.1-4.

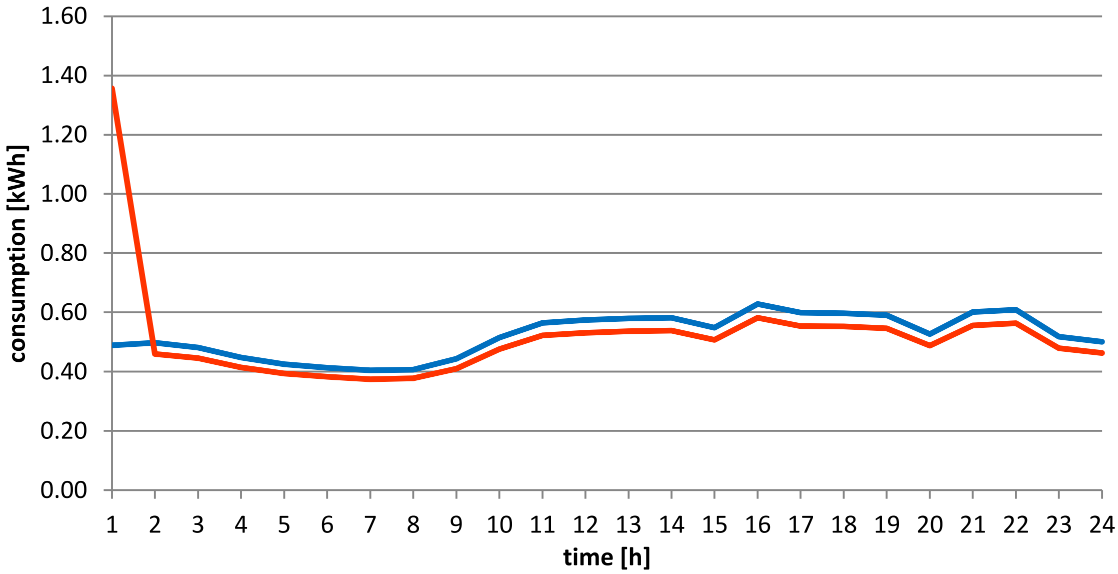

Chart 4.1-4 – Average daily electricity consumption profiles of "House 2", determined for the whole year, using the washing machine and the dishwashing machine normally and during "off-peak" time.

Knowing that this family has the Simple electricity tariff and a contracted power of 10.35 kVA, it can be seen that this represents the worst tariff. Therefore, just by choosing a different tariff, this family could benefit a cost saving from 4.2% to 30.7% (Table 4-5). In addition, if this house only used the dishwashing and washing machines during the "off-peak" time, this would represent an average saving up to 3.1% in the costs and, though the electricity consumption increases during "off-peak time" periods, the consumption in "peak" and "shoulder" times would decrease 8%.

The potential saving in the costs is 33.1%, corresponding to the scenario with "Two rate" tariff with weekly cycle and with the machines being used during the "off-peak" time.

C. House 3

This house concerns a household characterized by four people, being two of them babies. The contracted power is 3.45 kVA and the existing tariff is the Simple one (Table 4-1).

The measurements were made from November 19th (2010) to February 22nd (2011), without having being noticed any vacation period. So, the represented profile that was measured corresponds to the normal period and is represented in Chart 4.1-5.

This profile is very typical for a household with active people, with two evident consumption “peaks”, corresponding to the periods when the family gets up (from 8 until 10h) and has dinner (from 21 to 22h). It is noticed some consumption during the day, higher than during the night, which represents the weekends and the days when someone stays in the house (*e.g.*, a housekeeper).

The referred highest consumption periods correspond, respectively, to 0.98 kWh and 0.93 kWh. The lowest consumption period occurs from 1 to 6h, with an average consumption per hour of 0.13 kW. The daily accumulated consumption is 12.21 kWh.

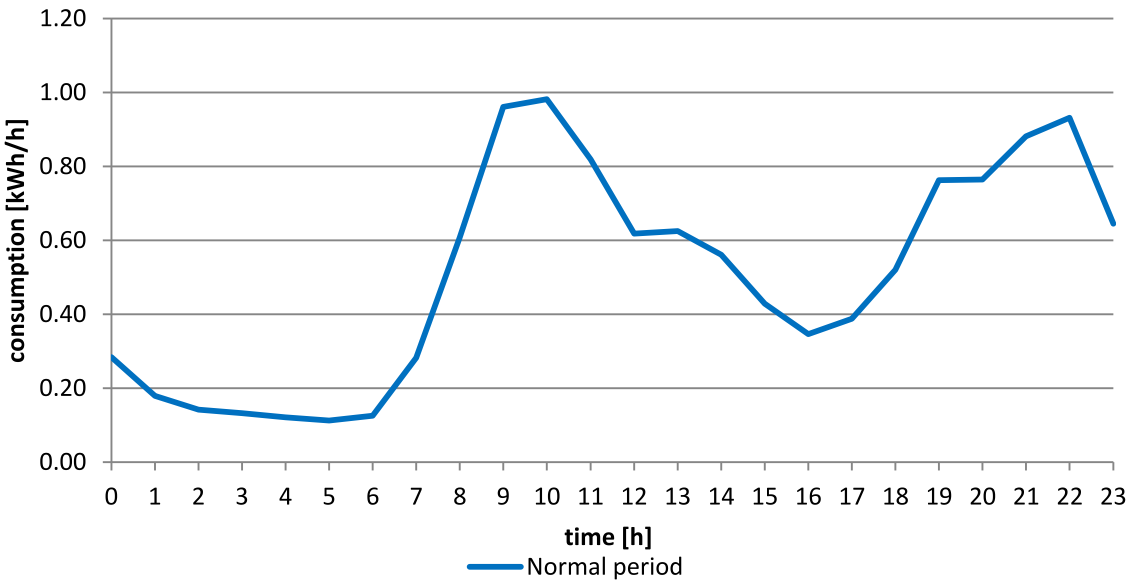

Chart 4.1-5 – Average daily electricity consumption profile measured in “House 3”, for the normal period in the summer.

The costs associated to this profile (which occurred in the summer period) were estimated. Those associated to the winter period have been determined as well, by increasing the consumption in 13% and repeating the analysis as previously. These costs are represented in Table 4-6.

Table 4-6 – Costs associated to all the periods regarded to "House 3". The values are in €/day [numbered from the lowest (1) to the highest (6) one].

Tariff	Summer		Winter (calculated)	
	Normal period	Vacation period	Normal period	Vacation period
"Three rate" tariff; Daily cycle	**1-** 0.97	**1-** 0.26	**4-** 1.42	**4-** 0.35
Simple; <2.3 kVA	**2-** 1.25	**2-** 0.31	**1-** 1.67	**1-** 0.39
"Two rate" tariff; Daily cycle	**3-** 1.48	**3-** 0.35	**2-** 1.75	**2-** 0.39
"Three rate" tariff; Weekly cycle	**4-** 1.60	**4-** 0.36	**5-** 1.75	**5-** 0.39
"Two rate" tariff; Weekly cycle	**5-** 1.60	**5-** 0.37	**3-** 1.76	**3-** 0.39
Simple; >2.3 kVA	**6-** 1.62	**6-** 0.40	**6-** 1.83	**6-** 0.45

Regarding to the determined consumption in the winter period, the accumulated consumption is 13.80 kWh in the normal period and 3.40 kWh in the vacation period. The accumulated consumption for the vacation period in the summer is 3.03 kWh.

The average daily costs for this house, concerning the whole year, are given in Table 4-7, as well as the associated costs when using the dishwashing and washing machines only during "off-peak" times.

Table 4-7 – Costs associated to the calculated annual consumption for "House 3", distinguishing the use of the dishwashing an washing machines during "off-peak" times. The values are in €/day [numbered from the lowest (1) to the highest (6) one].

Tariff	All year	
	Normal use of dishwashing and washing machine	Dishwashing and washing machines working in "off-peak"
"Two rate" tariff; Weekly cycle	**1-** 1.19	**1-** 1.15
"Three rate" tariff; Daily cycle	**2-** 1.23	**2-** 1.21
Simple; <2.3 kVA	**3-** 1.24	**3-** 1.24
"Two rate" tariff; Daily cycle	**4-** 1.46	**4-** 1.42
Simple; >2.3 kVA	**5-** 1.59	**5-** 1.60
"Three rate" tariff; Weekly cycle	**6-** 1.66	**6-** 1.61

The respective profiles are depicted in Chart 4.1-6.

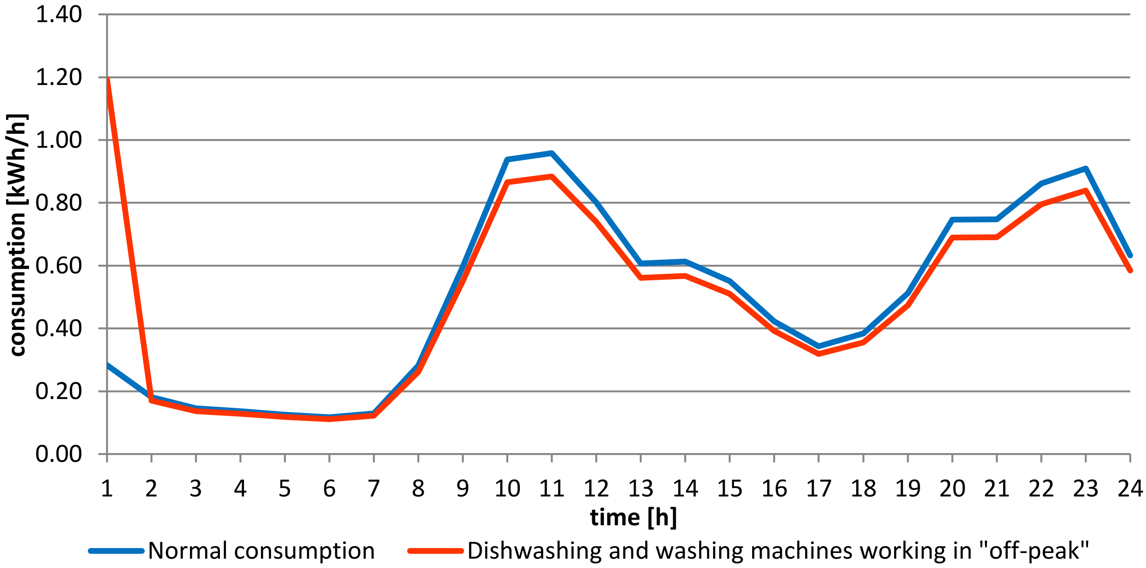

Chart 4.1-6 – Average daily electricity consumption profiles of "House 3", determined for the whole year, using the washing machine and the dishwashing machine normally and during "off-peak" time.

Knowing that this family has the Simple electricity tariff and a contracted power of 3.45 kVA, it can be seen that this represents the second worst tariff. It must also be highlighted the fact that this house has the lowest contracted power in the minimum available power in the Normal Low Tension tariff. Nevertheless, just by choosing a different tariff, this family could benefit a cost decrease from 4.2 to 28.3% (Table 4-7). Moreover, if this house only used the dishwashing and washing machines during "off-peak" time periods, this would represent an average saving up to 3.2% in the costs and, though the electricity consumption would increase during "off-peak" times, the consumption in "peak" and "shoulder" times would decrease 8%.

The potential saving in the costs is 30.7%, corresponding to the scenario with "Two rate" tariff with weekly cycle and with the machines being used during "off-peak" times.

D. House 4

This house concerns a household characterized by five people. The contracted power is 6.9kVA and the existing tariff is Simple (Table 4-1).

The measurements were taken from May 1st to June 30th without any vacation period. So, the represented profile that was measured corresponds to normal period and is shown in Chart 4.1-7.

This profile is similar to the previous one, differing in the periods of the consumption "peaks", corresponding now to meal periods from 11 to 13h and from 20 to 22h. These "peaks" correspond to 0.73 and 0.71 kWh/h, respectively. It is also noticed some consumption during the day, higher than during the night, which represents the weekends and the days when someone stays in the house (*e.g.*, a housekeeper). The lowest consumption period occurs from 4 to 9h, with an average consumption of 0.22kWh/h. The daily accumulated consumption is 10.26 kWh.

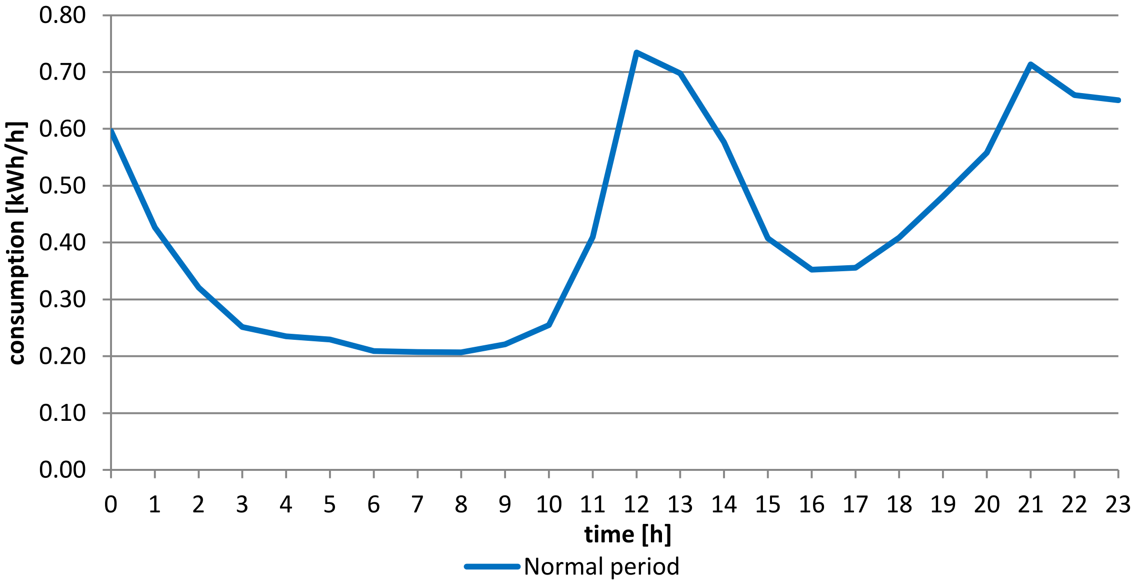

Chart 4.1-7 – Average daily electricity consumption profile measured in “House 4”, for the normal period in the summer.

The costs associated to this profile (which have occurred in the summer period) were calculated. Those associated to the winter period have been determined as well, by increasing the consumption in 13% and repeating the analysis as previously. These costs are represented in Table 4-8.

Table 4-8 – Costs associated to all the periods regarded to “House 4”. The values are in €/day [numbered from the lowest (1) to the highest (6) one].

Tariff	Summer		Winter (calculated)	
	Normal period	Vacation period	Normal period	Vacation period
“Three rate” tariff; Daily cycle	**1-** 0.84	**1-** 0.43	**4-** 1.42	**5-** 0.35
Simple; <2.3 kVA	**2-** 1.04	**2-** 0.52	**1-** 1.67	**2-** 0.39
“Two rate” tariff; Daily cycle	**3-** 1.08	**3-** 0.53	**3-** 1.75	**3-** 0.39
“Three rate” tariff; Weekly cycle	**4-** 1.15	**4-** 0.58	**2-** 1.75	**1-** 0.39
“Two rate” tariff; Weekly cycle	**5-** 1.25	**5-** 0.61	**5-** 1.76	**4-** 0.39
Simple; >2.3 kVA	**6-** 1.35	**6-** 0.67	**6-** 1.83	**6-** 0.45

Regarding to the estimated consumption for the winter period, the accumulated consumption is 11.48 kWh in the normal period and 5.73 kWh in the vacation period. The accumulated consumption for the vacation period in the summer is 5.07 kWh.

The average daily costs for this house, concerning the whole year, are given in Table 4-9, as well as the associated costs when using the dishwashing and washing machines only during “off-peak” times.

Table 4-9 – Costs associated to the calculated annual consumption for "House 4", distinguishing the use of the dishwashing an washing machines during "off-peak" times. The values are in €/day [numbered from the lowest (1) to the highest (6) one].

Tariff	**All year**	
	Normal use of dishwashing and washing machine	**Dishwashing and washing machines working in "off-peak"**
"Two rate" tariff; Weekly cycle	**1-** 0.95	**1-** 0.92
"Three rate" tariff; Daily cycle	**2-** 1.02	**2-** 1.00
Simple; <2.3 kVA	**3-** 1.05	**3-** 1.05
"Two rate" tariff; Daily cycle	**4-** 1.16	**4-** 1.13
"Three rate" tariff; Weekly cycle	**5-** 1.30	**5-** 1.26
Simple; >2.3 kVA	**6-** 1.36	**6-** 1.35

The respective profiles are represented in Chart 4.1-8.

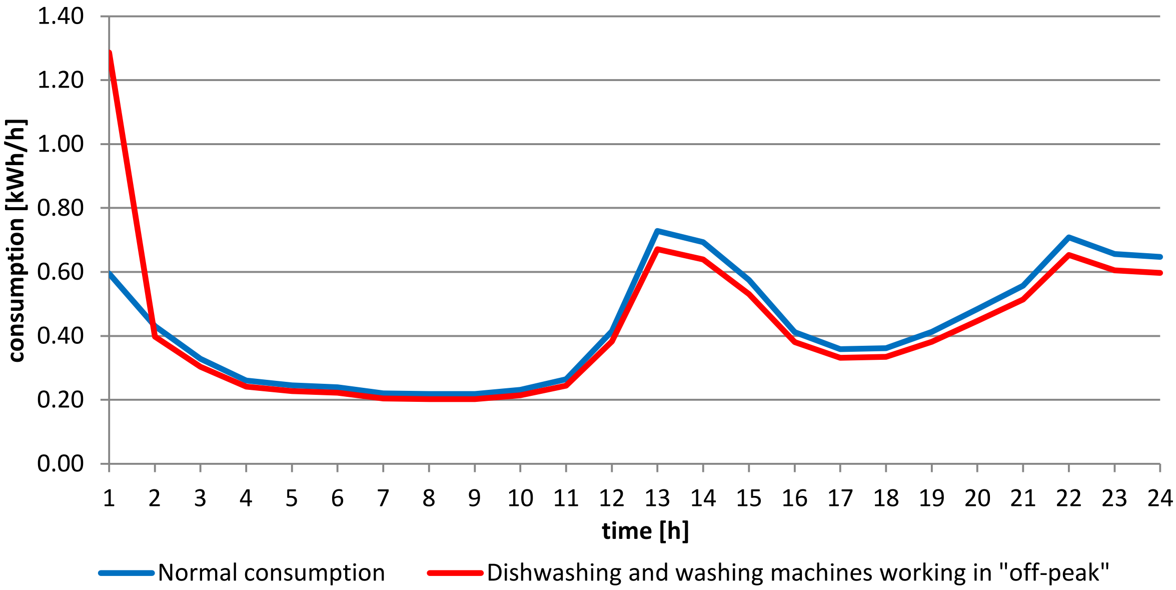

Chart 4.1-8 – Average daily electricity consumption profiles for "House 4", determined for the whole year, using the washing machine and the dishwashing machine normally and during "off-peak" times.

Taking into account that this family has Simple electricity tariff and a contracted power of 6.9 kVA, one concludes that this represents the worst tariff for this family. Hence, just by choosing a different tariff, this family may enjoy a cost decrease from 4.4 to 30.1% (Table 4-9). In addition, if this house only used the dishwashing and washing machines during "off-peak" time, this would represent an average saving up to 3.4% in the costs and, though the electricity consumption increases during "off-peak" time, the consumption in "peak" and "shoulder" times decreases 8%.

The potential saving in the costs is 32.4%, corresponding to the scenario with "Two rate" tariff with weekly cycle and with the machines being used during "off-peak" time.

E. Overall view and average consumption – Introduction of standby consumption reduction

The profiles analyzed above present features that do not differ much, as it is referred in Table 4-1. Still, the electricity consumptions differ, as it is represented in Table 4-10. At this point, the CO_2 emmissions are addressed as well, by determining the correspondent $kgCO_2e$ in each house. The overall analysis is completed with the calculation of the average results.

Table 4-10 – Overall electricity consumptions and associated costs of the analyzed families. The values are in €/day.

	House 1	House 2	House 3	House 4	Average[a]
Accumulated consumption [kWh]	10.74	12.55	12.02	10.26	11.39
Accumulated consumption [kgoe]	3.11	3.64	3.49	2.98	3.30
Accumulated consumption [$kgCO_2e$]	5.05	5.90	5.65	4.82	5.35
Average consumption [kWh/h]	0.45	0.52	0.50	0.43	0.47
Maximum consumption [kWh/h]	0.86	0.63	0.96	0.73	0.76
Minimum consumption [kWh/h]	0.25	0.41	0.12	0.22	0.25
Actual cost [€]	1.42	1.66	1.59	1.36	1.51
Potential cost [€]	0.99	1.11	1.15	0.92	1.00

[a] The values concern the average of the analyzed profiles obtained with the average consumption in each hour, being these values obtained by the calculation tool developed by the author, resulting in these average costs (as it is represented in Chart 4.1-9, Table 4-11 and Annex IX).

It can be noticed that the highest consumption is in “House 2”, being 4.4% higher than in “House 3” (the second highest consumption) and 22.3% higher than in “House 4” (the lowest consumption). It is also known that “House 2 “ has the greatest number of people (six) and the number of existing rooms is four, which is the same for the remaining houses with exception of “House 3”, which has three. These factors may justify the highest consumption for this house but it can easily be noticed that the number of people and the number of rooms are not the only factors of the consumption, once “House 3” has the second highest consumption and has the lowest number of people (four) and the lowest number of rooms (three). This stretches the neediness of a larger study sample for establishing a relation between consumption and dwelling features (Wiesmann, et al., 2011), namely, for this case study, the income in each house, which is unknown but constitutes a major determining factor (Frankhauser, et al., 2006).

If considering the minimum consumption in each house as the standby consumption, it can be seen that “House 2” has, again, the maximum value among these houses, being 64% higher than in “House 1” (the second highest standby consumption) and 142% higher than in “House 3” (the lowest standby consumption), which may correspond to a higher number of equipments and a disregard in the usage as well, by not turning off them completely during the night. This standby consumption has a share that cannot be turned off (*e.g.*, the refrigerator, some air cooling or heating equipments that are turned on during the night and, thereby, not wished to be turned off by the users). However, there is a share that can be turned off (*e.g.*, audiovisuals and computers). In order to assess this consumption, one must know the periods during the day in which no one is in the house. Such cannot be known with these results. Indeed, the minimum consumption during the day, for the average of the analyzed houses, is 0.43 kWh, which represents consumptions that were noticed during the measured days. Therefore, an estimate is made, according to the estimated standby consumption for Portugal (QUERCUS, 2004): 5% of the overall consumption (11.39 kWh in the overall average scenario). This consumption occurs mainly during vacation time and during the sleeping time; during the day, it is not possible to predict when this consumption occurs but one can suppose that it happens during hours of lower consumption. Therefore, this share is subtracted to a considered period, the sleeping period – from 1 to 7h. This is a rough approximation, mainly because the standby consumption occurring during the day cannot be securely predicted. The resulting consumption profile follows, being the calculations and the corresponding values represented in Annex IX.

Ergo, by taking the results obtained in this Thesis regarding these four dwellings, one obtains an average daily consumption during a year and the associated costs that are represented in Chart 4.1-9 and in Table 4-11, respectively. The potential scenario with the dishwashing and washing machines working during "off-peak" times and with turning off the determined unnecessary standby consumption during the night is also given.

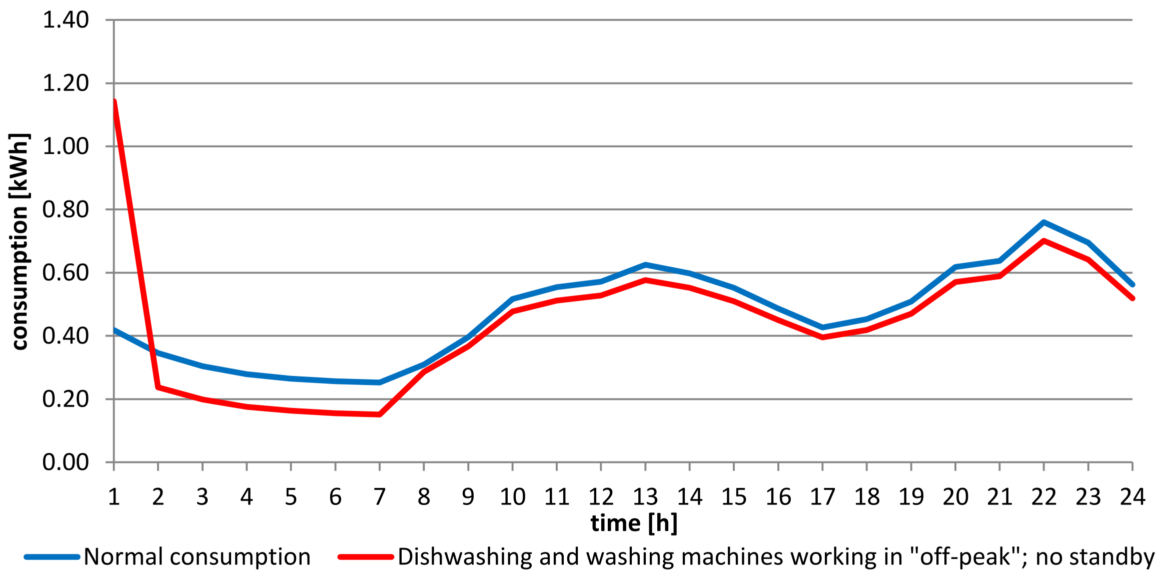

Chart 4.1-9 – Average daily electricity consumption profiles for the four studied houses, determined for the whole year, using the washing machine and the dishwashing machine during "off-peak" time and by elimination the unnecessary standby consumption during the night time.

The average consumption for these families displays an overall consumption of 11.39 kWh, with a "two-peak" consumption profile, one during the lunch time (from 11 to 13 h) and another during dinner time (from 19 to 22 h). The "peak" consumptions are, for the normal consumption, 0.63 kWh, at 12 h, and 0.76 kWh, at 21 h. The lowest consumption occurs from 3 to 6 h and is 0.26 kWh, in average, being this the considered standby consumption for these houses during a normal period. The lowest consumption during the day time occurs from 15 to 17 h and is 0.43 kWh, in average.

The associated costs were calculated and are displayed in Table 4-11.

Table 4-11 – Costs associated to the calculated annual consumption of the four presented houses, distinguishing the use of the dishwashing an washing machines during "off-peak" time. The values are in €/day [numbered from the lowest (1) to the highest (6) one]..

Tariff	All year	
	Normal use of the appliances	**Dishwashing and washing machines working in "off-peak" and no disposable standby**
"Two rate" tariff; Weekly cycle	**1-** 1.08	**1-** 1.01
"Three rate" tariff; Daily cycle	**2-** 1.15	**2-** 1.09
Simple; <2.3 kVA	**3-** 1.17	**3-** 1.11
"Two rate" tariff; Daily cycle	**4-** 1.33	**4-** 1.25
"Three rate" tariff; Weekly cycle	**5-** 1.49	**5-** 1.40
Simple; >2.3 kVA	**6-** 1.51	**6-** 1.43

For the analyzed houses, the Simple tariff, with a contracted power above 2.3 kVA corresponds to the worst cost scenario (1.51€ per day). Just by changing the tariff, these families could enjoy a save between 1.3% and 28.5%. Moreover, if only the consumption habits concerning the use of the dishwashing and washing machines were changed to the "off-peak" time as well as by eliminating the disposable standby consumption during the night and the vacation period, this would correspond to a save up to 5.6%, maintaining the same tariff. Furthermore, "House 3" has a contracted power of 3.45 kVA, which is the lowest contracted power within these families, and, more than that, this is the family with the highest registered "peak" consumption (0.96 kWh). Such means that the "House 2" and "House 4" have an over-contracted power (as it was said, it is not known the contracted power in "House 1"). Consequently, they are paying, respectively, 89% and 179% more than "House 3". This increases the electricity bill in 9.86 € (19.8%) and 4.93 € (12.1%) per month, respectively (Annex III).

The potential costs saving is **45.2%**, corresponding to the scenario with "Two rate" tariff with the potential scenario conditions and with a benefit of 12.1% by changing to the sufficient contracted power. Associated to this, there is a consequent reduction of 8% in consumption in "peak" and "shoulder" times during the normal period. The total consumption reduction that can be achieved is **5.6%** (10.79 kWh against 11.39 kWh).

At this stage of the Thesis, following the determined potentialities in subchapter 4.1 and 3.2, one has collected the tool to try to extrapolate them to a national scale. Such is attempted in the following subchapter 4.2.

4.2. Behaviors to change and saving potentialities

In Chapter 3, the potential savings resulting from a habit change in the usage of three appliances (the refrigerator, the dishwashing and the washing machines) were determined. In subchapter 4.1, it was established the average daily electricity consumption profile for four houses, two of which being a study-target of the NZES Project. Therefore, in this Chapter, the determined saving potentialities are applied to this average electricity consumption profile and an extrapolation to a national scale is assessed. The numbers that must be known (or remembered) for this extrapolation are the following ones:

- Percentage of consumers with Simple tariff: 78.4%, corresponding to 26.5% of the national electricity consumption (CMVM, et al., 2011);
- Percentage of electricity consumption in BTN: 44.9% (CMVM, et al., 2011);
- Percentage of energy loss by GWh in the distribution in BTN (ERSE, 2011) and (REN, 2010):
    - "Peak" time: 9.2%;
    - "Off-peak" time: 6.9%.
- Percentage of the electricity consumption by appliance (ADENE, et al., 2004):
    - Refrigerator: 22%;
    - Dishwashing machine: 3%;
        - The potential scenario allows a saving in electricity consumption of 52%.
    - Washing machine: 5%.
        - The potential scenario allows a saving in electricity consumption of 88%.

Moreover, the following relevant factor must also be taken into account: the potential scenarios for the dishwashing and washing machines are dependent on an alternative energy source beyond natural gas and electricity. Hence, these scenarios require an investment that varies according to the chosen technology, but the corresponding cost quantification is not estimated, once it is not within the scope of this Thesis. If a dwelling adopts this kind of measurement, the overall water heating energy consumption decreases (not only in these appliances), resulting in a lower expenditure in electricity and/or natural gas. These savings are just referred but not quantified because, again, they do not fall in the scope of this Thesis.

This Thesis studied three behaviors that could be adopted in order to lower the consumed electricity (concerning the refrigerator, the dishwashing and washing machines and by using these last two appliances in "off-peak" times), which are now aggregated and, thus, the potential overall scenario for a dwelling can be determined at this point.

Concerning the refrigerator, it is established in the conclusions of the results analysis (subchapter 3.2; C) that none of the tested scenarios bring any environmental and economical benefit. Thus, the habits in this appliance must be maintained.

Regarding to the dishwashing and the washing machines, the potential scenarios require an investment in a technology that does not consume natural gas nor electricity (*e.g.*, solar panels). Putting aside this investment (that is not inferior to 2,000 € (SANILUZ, 2009)), the potential savings are, for the dishwashing

machine (program auto, with temperatures between 46°C and 65°C), 52%, which correspond to an overall 1.6%, and for the washing machine (program at 40°C), they are 88%, which correspond to an overall 4.4%. The potential savings in electricity consumption by extinguishing the needless standby consumption during the "sleeping period" (0 to 07h), are 39%, corresponding to an overall 6.7%.
Adding the potential savings determined in this Thesis, which are referred in these previous paragraphs, the concerned potential scenario is established, as it is represented in Chart 4.2-1.

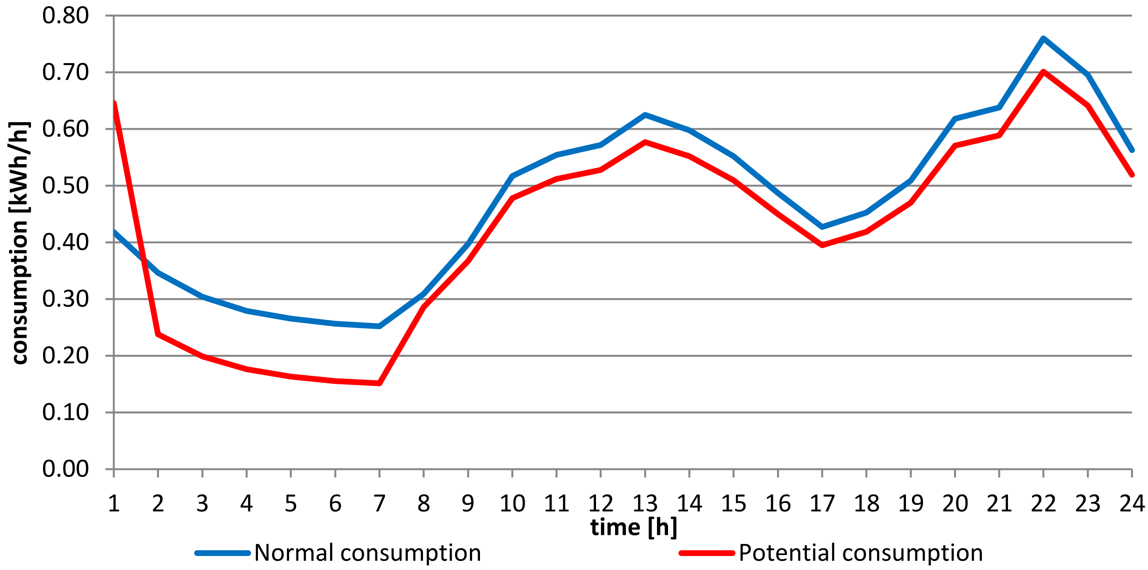

Chart 4.2-1 - Average daily electricity consumption profiles of the four presented houses, determined for the whole year, concerning the normal and the determined potential consumption.

Table 4-12 – Costs associated to the calculated annual consumption of the four presented houses, distinguishing the normal and the potential consumption. The values are in €/day [numbered from the lowest (1) to the highest (6) one].

Tariff	All year	
	Normal consumption	Potential consumption
"Two rate" tariff; Weekly cycle	1- 1.08	1- 0.98
"Three rate" tariff; Daily cycle	2- 1.15	3- 1.05
Simple; <2.3 kVA	4- 1.17	2- 1.06
"Two rate" tariff; Daily cycle	5- 1.33	4- 1.21
"Three rate" tariff; Weekly cycle	6- 1.49	6- 1.36
Simple; >2.3 kVA	7- 1.51	5- 1.36

The accumulated consumption reduces, in the potential scenario, from 11.39 kWh to 10.29 kWh (9.7%). Keeping the same tariff, the costs can decrease up to 9.7% and the best scenario is the "Two rate" tariff with weekly cycle, corresponding to a lowering in 28.5% in the costs, as it was seen in subchapter 4.1-E. Adding to this, it must be considered a lack of dimensioning of the contracted power. As it was observed in point E of this subchapter, this can correspond to an increase from 12.1% to 19.8%. Considering the minimum percentage and the adoption of the potential behavior, the cost reduction can reach **47.1%** in a family bill.

The percentage of consumers that have the Simple tariff is 78.4%, corresponding to 26.5% of the national consumption (CMVM, et al., 2011). This is the population in which the determined saving potentialities in this

Thesis are meant to be applied (those with the remaining tariffs are expected to use generally the dishwashing and washing machines in “off-peak” times). This means that, at a national level, the potential electricity consumption can decrease 2.6%, corresponding to a saving in 1.4 TWh (4.1 x10^5 toe and 6.6 x10^5 tonCO_2e) per year.

A better understanding of the impact of such measures have in the national electricity consumption, Chart 4.2-2 displays the variation of the electricity consumption profile if all the 78.4% of the domestic sector (corresponding to the percentage with Simple tariff) adhere and if 6 or 3 million inhabitants adhere to these consumption behaviors.

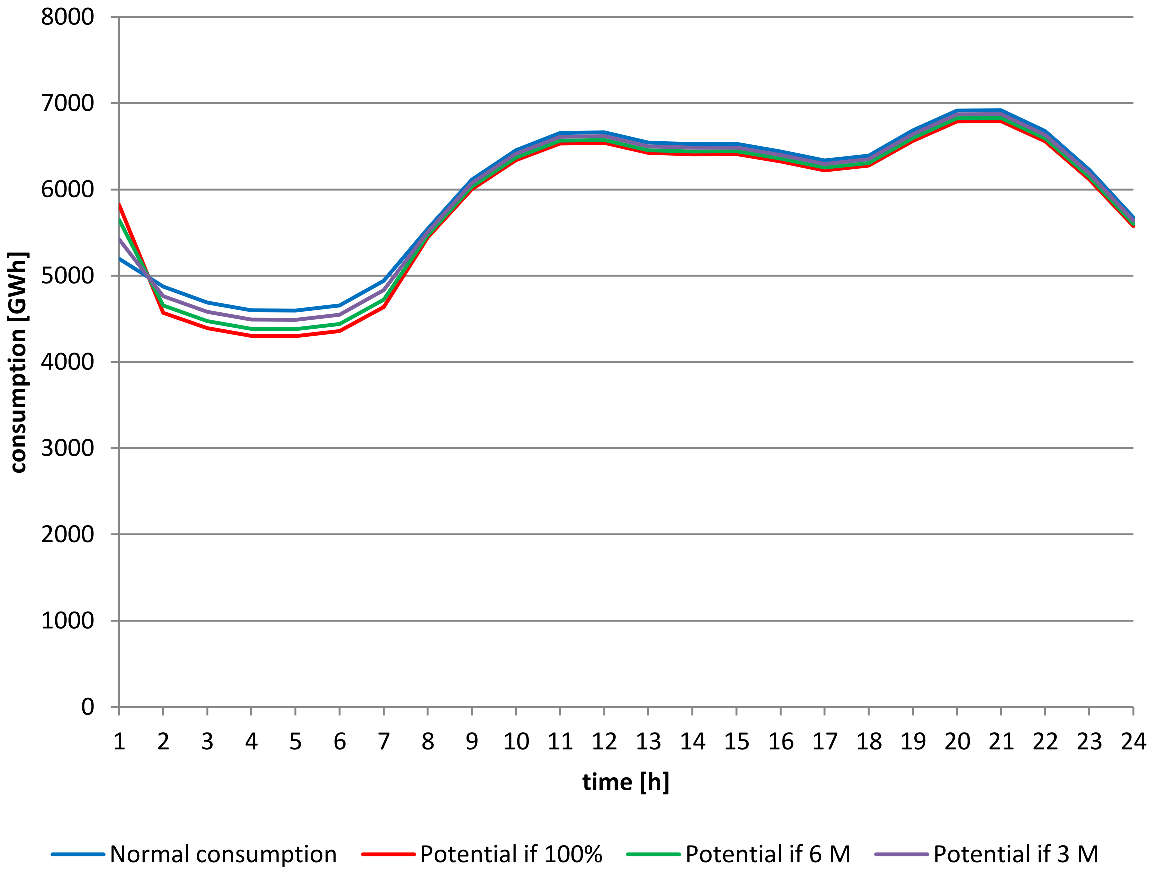

Chart 4.2-2 – National daily average electricity consumption and impact of the potential consumption scenario in the national average daily electricity consumption, concerning three hypothesis: one with adhesion of 100% of the residential sector; one with the adhesion of 6 million (M) inhabitants; and another one with the adhesion of 3 M inhabitants (the total number of inhabitants is 10,555,853 **(INE, 2011)**)

Chapter 5 - Conclusions and future work

The general conclusions of this Thesis and the proposed future work are depicted in this Chapter, as well as the limitations concerning the approaches.

5.1. General conclusions

This Thesis is the result of a detailed data analysis of several electricity consumption profiles. Such could not be achieved without the development of an automation analysis and calculation tool. The author developed a tool that analyzes each consumption profile, divides it into consecutive days and estimates the daily average accumulated consumption, the daily average consumption in each hour and the daily average costs according to the ruling tariffs in Portugal for BTN.

Concerning the refrigerator, the presenting tests showed that a forced turn-off period results in a higher daily accumulated consumption, as well as higher costs, which demystifies the belief sustained in (Malaquias, 2010). Indeed, the consumption increase depends on the working schedule and on the refrigerator type, reaching values between 4.6% and 9.9%. Furthermore, the costs do not increase at the same rate as the consumption, being this within 2.6% and 7.0%.

The applied methodology had the purpose of testing real scenarios, having obtained realistic results. However, more detailed experiences must be done in order to analyze the real effects that an induced shut-down may affect the functioning of the refrigerator It may induce a deregulation of the engine and compressor and, also, it may cause a temperature drop which may affect the stored food. The tests in this Thesis concerned two different refrigerators in two different environments, which constitutes a limited sample. Hence, more experiments must be done in order to prove irrefutably if this behavior is, or is not, benefic or harmful to the refrigerator, the food, the environment and in costs. Nevertheless the practical results sustain that such actions induce a consumption increase, as well as a costs boost, within general controlled usage and temperature.

Concerning the dishwashing and washing machines, the general results of the tested methodology (scenario (i)) show worse environmental an economic scenarios than in the normal working way (scenario (i)), once the consumed gas for heating the water has a high impact.

As far as the costs are concerned, only in the program at 70°C in the dishwashing machine the overall costs reduce, but still only in 2.1%, being the main reason the electricity consumption in this program, which is higher and the gas consumption is lower than in the remaining tested programs, which means that the gas consumption does not have the impact that has in the other two tested programs. Such means that, in the dishwashing machine working in program auto, at 45-65°C, the costs increase 23.4% and in the washing machine working in program at 40°C, increase 82.5%.

Moreover, the CO_2 emmissions of this methodology (scenario (ii)) is defined, respectively for programs B and C, by an increase of 0.06 and 0.15 kgCO_2e. As for program A, it is not registered a variation.Such means that, indeed, this methodology is worse environmentally (in a matter of CO_2 emmissions) and economically, being also due to the temperature loss in the water pipe between periods with no water consumption. Nevertheless, the electricity spent in heating the water by the machines was determined and a potential scenario was established, assuming an investment in a technology that does not need a non-renewable energy source to heat the water (*e.g.*, solar panels). Such scenario is known to be unlikely at a large scale due to the costs in a house that does not have such a kind of technology. Moreover, this device is known to be not enough to heat the water of these machines without resourcing another energy source, once heat is loss in the pipes and, furthermore, it is unlikely that in a cloudy day and at midnight the temperature of the water can reach a desired high temperature (*p.e.* 70^0C) (Rosa-Clot, *et al.*, 2011). The water heating can be coupled with a photovoltaic panel, which eliminates the electricity consumption for these appliances and it can be enough to fulfill the energy need of a whole dwelling and, even, be enough to sell electricity to the grid (Rosa-Clot, *et al.*, 2011). This is the potential (and hypothetical) scenario, which results in a saving in the electricity consumption and in the CO_2 emmissions of 52% (0.33 kWh and 0.16 kgCO_2e) and 89% (0.47 kWh and 0.22 kgCO_2e), for the dishwashing and the washing machines, respectively. The value concerning the dishwashing machine (52%) contradicts, though, the 90% depicted in (ADENE, et al., 2010), accusing some inaccuracies in the assumptions considered by the author.

Concerning the electricity consumption profiles of the analyzed families, the consumption differences were perceptible but, only with such a small sample, it was not possible to establish a relation between the consumption and the dwellings features. Nevertheless, it was noticed that exists a lack of dimensioning of the contracted power, resulting in a cost increase between 12.1 and 19.8%. Moreover, in the overall analysis, two behavior proposals were presented, one by using the dishwashing and the washing machine only during “off-peak” times and another one by shutting down the unnecessary standby consumption during the nighttime. That reflects in a potential reduction in costs – together with changing from Simple tariff to the lowest associated cost, “Two rate” tariff, with weekly cycle – of 45.2% and a reduction of 8% of consumption during “peak” and “shoulder” times, as well as an overall lowering of 5.6% in the consumption (10.79 kWh against 11.39 kWh).

According to the results observation, the number of people and the number of rooms are not the only factors of the consumption. This stretches the neediness of a larger study sample for establishing a relation between consumption and dwelling features (Wiesmann, et al., 2011), namely, for this case study, the income in each house, which is unknown but constitutes a major determining factor (Frankhauser, et al., 2006).

Concluding, the overall potential scenario has four associated positive changes determined in this Thesis: adapting a technology that heats the water and, therefore, does not imply electricity spent in heating the water in the dishwashing and washing machines; deviate the consumption of these appliances to “off-peak” times; eliminate the assumed standby consumption (5%); and changing the tariff from Simple with contracted power above 2.45 kVA to “Two rate” tariff with weekly cycle, as well as dimensioning properly the contracted power. The outcome benefits from these behavior changes are a cost reduction up to **47%** and a consumption reduction of **9.3%**, which traduces in a national consumption reduction of **2.6%**, reflecting in a decrease in the year consumption of **1.4 TWh** in final energy and **4.1 $\times 10^5$ toe** in primary energy. Such means a lowering of the CO_2 emmissions of **6.6 $\times 10^5$ tonCO_2e** per year.

5.2. Future work

The developed work in this Thesis has revealed interest in the energy efficiency research. The experimental activities undertaken by the author had the purpose of testing the environmental and economical impact of energy consumption behavior changes, which resulted in new research perspectives. In fact, the automated analysis is mandatory for the achievement of scientific and representative results. This is one research field that must be in continuous improvement, by developing the "smart metering" and consumption simulation logarithms, in an energy and cost matter.

The applied methodologies in this Thesis followed considerations and calculated approximations in order to define the most realistic conditions as much as possible. However, concerning the tests to the refrigerators, in order to assess more precisely the influence of the forced turn-off during the day, further tests have to be done, evaluating the performance of the engine and the compressor, as well as extending the studies to a wider range of different equipments. Only in this way one can relate the main influence factors in the refrigerator consumption with the induced turn-off. Indeed, the author could not find any bibliography with such tests and, even so, some registered statements are found (Malaquias, 2010) defending that such usage way traduces in environment an economic benefits, contradicting the conclusions of the two tests made in this Thesis.

The water heating technology must improve, so that it can be more economically reachable by a normal family, as a cheap solar panel costs more than 2,000 € (SANILUZ, 2009). The efficiency of the heating equipments and water pipes isolation is suggested to be improved as well, once a solar panel cannot convert all the heat power of the sun to the water, reaching efficiencies of 50%, and, also, accumulate it perfectly during the night or colder and cloudy periods (Rosa-Clot, *et al.*, 2011). Also, the heat loss in the pipes is considerable and the cold water remaining in the pipes is often wasted before the heated water reaches the tap. In this way, the energy spent in water heating may decrease, reflecting as well in the dishwashing and the washing machines.

The benefits referred above must now be implemented in the NZES project in the families' consumption habits changes. This is an exciting point, once the presented results in this Thesis can be soon validated in the dwellings of the students of the ESVF.

All the conclusions on a potential environment benefit accomplishment are dependent on the human behavior. Indeed, 78.4% of the users in BTN have Simple tariff (CMVM, et al., 2011), which means that people are not sensitive to consume more energy in "off-peak" time. Therefore, more studies must be undertaken with different approaches, so that more (environment and economic) benefits can be determined and, in this way, motivate people to change their consumption behavior. Allied to the deviation of consumption from "peak" time, there is a rooted energy spare concern. These kind of reactions and thoughts must be well studied by Social Sciences and be coupled with Engineering. Indeed, not many studies can be found that link Social Sciences with Engineering, and that's why the NZES Project has so much social and scientific values. Being this Thesis a complement to this Project, is it now reinforced the importance of such “marriage”, without which the results presented in this Thesis could not be achieved, as expected for any other studies that depend on behaviors (Black, et al. (2007) and Ramalho (2009).

Energy efficiency is mandatory for the accomplishment of sustainability. In a global matter, the best possible efficiency should be searched for. Concerning the residential sector, studies must continue toward that aim, for all the resources expenditure. Energy efficiency must have engineering accomplishments but, even more important, it cannot exist without efficient – sustainable – behavior.

Science must accomplish the best scenarios in a way that is sustainable and embraced by the humans.

“We need to be the change we wish to see in the world”

-Mahatma Ghandi, Indian political and spiritual leader (1869 - 1948)

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I. Calculation tool developed by the author

This Thesis includes the data analyses based in a program developed by the author, in VBA programming. A brief explanation of this program follows.

The input is the data recorded by the PlugMeter® or the iMeter® kit, which is in format CSV, having parameters established by the user (*e.g.*, the time interval, which can be from 1 to 30,000 min, accumulated consumption, consumption and power). The chosen parameters for the tests were the accumulated consumption and the consumption. Although the data analyzed in Chapter 4 -Chapter 4 included only the consumption, the program is prepared for that, creating a column with the accumulated consumption as well. The mandatory condition is that the data have no gaps between intervals and that complete days are inserted. The data entries can, indeed, reach high numbers, which makes very difficult to process the data manually.

The program is working in the following stages:

A User Form is filled by the user with the characteristics presented in Figure A I-1. The entry "kWh consumed in the previous day" is concerned to the accumulated consumption registered before the desired period but that is recorded in the PlugMeter from a previous measurement. In the data analyzed in Chapter 4, this entry was filled with "0".

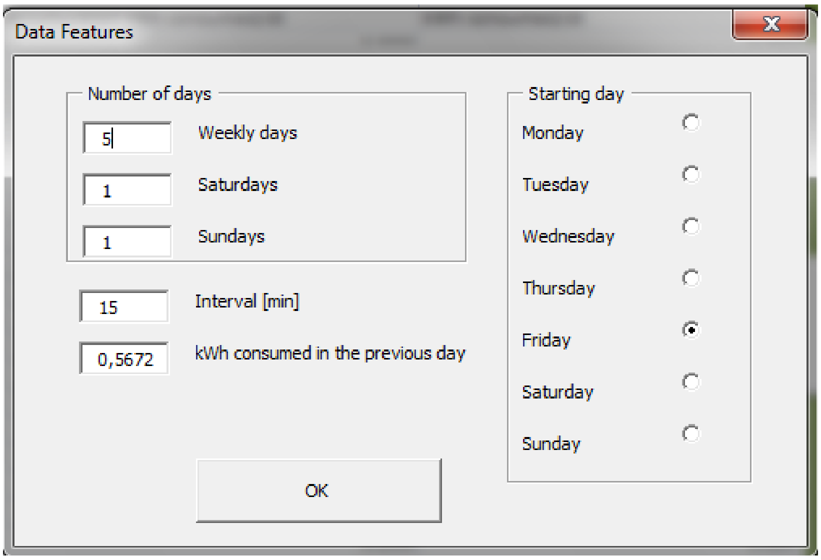


Figure A I-1 – User Form in which the data entries are introduced (example for the simulation of the refrigerator BOSCH KGN46A03 in scenario (i)).

- Then, another User Form arises, in which the tariffs are selected for the costs calculation (Figure A I-2).

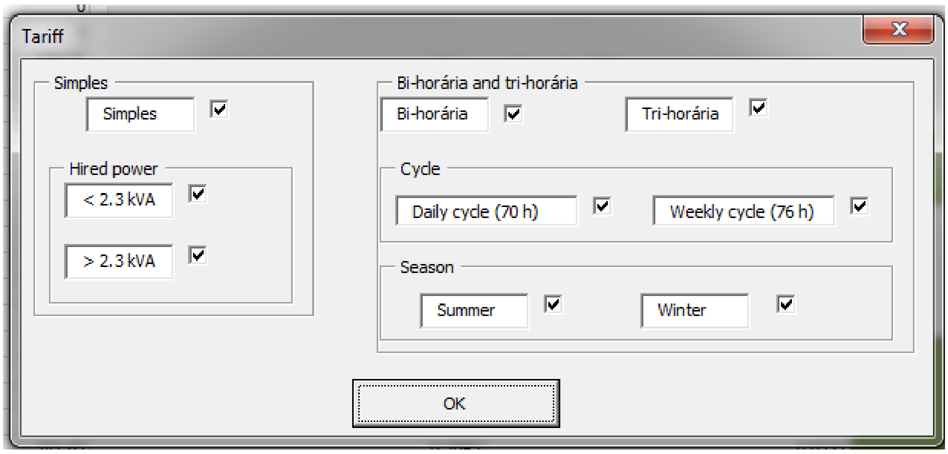
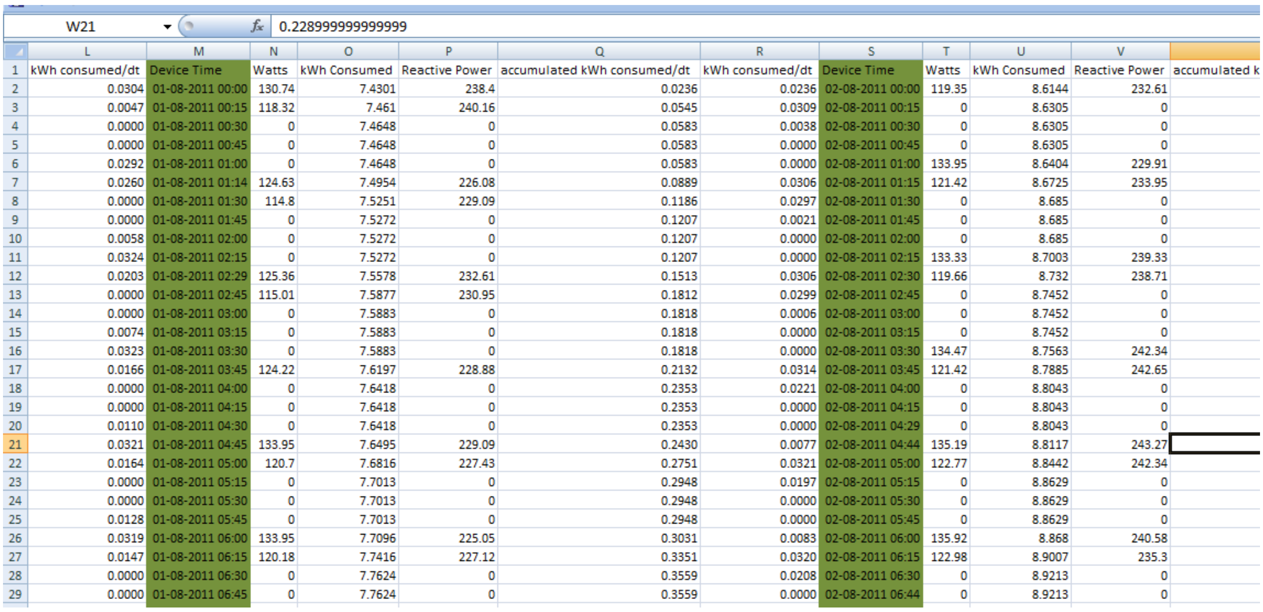


Figure A I-2 – User Form in which the tariffs are chosen (notice that all of them can be chosen at the same time).

- The program processes the recorded data, which is separated into consecutive groups of columns, having each group the selected data entries. In each group, it is also calculated the accumulated consumption, when it was not registered by the PlugMeter®, by adding the consecutive consumption registered before each time interval in which the accumulated consumption is being calculated (Figure A I-3).



W21 0.228999999999999

	L	M	N	O	P	Q	R	S	T	U	V	
1	kWh consumed/dt	Device Time	Watts	kWh Consumed	Reactive Power	accumulated kWh consumed/dt	kWh consumed/dt	Device Time	Watts	kWh Consumed	Reactive Power	accumulated k
2	0.0304	01-08-2011 00:00	130.74	7.4301	238.4	0.0236	0.0236	02-08-2011 00:00	119.35	8.6144	232.61	
3	0.0047	01-08-2011 00:15	118.32	7.461	240.16	0.0545	0.0309	02-08-2011 00:15	0	8.6305	0	
4	0.0000	01-08-2011 00:30	0	7.4648	0	0.0583	0.0038	02-08-2011 00:30	0	8.6305	0	
5	0.0000	01-08-2011 00:45	0	7.4648	0	0.0583	0.0000	02-08-2011 00:45	0	8.6305	0	
6	0.0292	01-08-2011 01:00	0	7.4648	0	0.0583	0.0000	02-08-2011 01:00	133.95	8.6404	229.91	
7	0.0260	01-08-2011 01:14	124.63	7.4954	226.08	0.0889	0.0306	02-08-2011 01:15	121.42	8.6725	233.95	
8	0.0000	01-08-2011 01:30	114.8	7.5251	229.09	0.1186	0.0297	02-08-2011 01:30	0	8.685	0	
9	0.0000	01-08-2011 01:45	0	7.5272	0	0.1207	0.0021	02-08-2011 01:45	0	8.685	0	
10	0.0058	01-08-2011 02:00	0	7.5272	0	0.1207	0.0000	02-08-2011 02:00	0	8.685	0	
11	0.0324	01-08-2011 02:15	0	7.5272	0	0.1207	0.0000	02-08-2011 02:15	133.33	8.7003	239.33	
12	0.0203	01-08-2011 02:29	125.36	7.5578	232.61	0.1513	0.0306	02-08-2011 02:30	119.66	8.732	238.71	
13	0.0000	01-08-2011 02:45	115.01	7.5877	230.95	0.1812	0.0299	02-08-2011 02:45	0	8.7452	0	
14	0.0000	01-08-2011 03:00	0	7.5883	0	0.1818	0.0006	02-08-2011 03:00	0	8.7452	0	
15	0.0074	01-08-2011 03:15	0	7.5883	0	0.1818	0.0000	02-08-2011 03:15	0	8.7452	0	
16	0.0323	01-08-2011 03:30	0	7.5883	0	0.1818	0.0000	02-08-2011 03:30	134.47	8.7563	242.34	
17	0.0166	01-08-2011 03:45	124.22	7.6197	228.88	0.2132	0.0314	02-08-2011 03:45	121.42	8.7885	242.65	
18	0.0000	01-08-2011 04:00	0	7.6418	0	0.2353	0.0221	02-08-2011 04:00	0	8.8043	0	
19	0.0000	01-08-2011 04:15	0	7.6418	0	0.2353	0.0000	02-08-2011 04:15	0	8.8043	0	
20	0.0110	01-08-2011 04:30	0	7.6418	0	0.2353	0.0000	02-08-2011 04:29	0	8.8043	0	
21	0.0321	01-08-2011 04:45	133.95	7.6495	229.09	0.2430	0.0077	02-08-2011 04:44	135.19	8.8117	243.27	
22	0.0164	01-08-2011 05:00	120.7	7.6816	227.43	0.2751	0.0321	02-08-2011 05:00	122.77	8.8442	242.34	
23	0.0000	01-08-2011 05:15	0	7.7013	0	0.2948	0.0197	02-08-2011 05:15	0	8.8629	0	
24	0.0000	01-08-2011 05:30	0	7.7013	0	0.2948	0.0000	02-08-2011 05:30	0	8.8629	0	
25	0.0128	01-08-2011 05:45	0	7.7013	0	0.2948	0.0000	02-08-2011 05:45	0	8.8629	0	
26	0.0319	01-08-2011 06:00	133.95	7.7096	225.05	0.3031	0.0083	02-08-2011 06:00	135.92	8.868	240.58	
27	0.0147	01-08-2011 06:15	120.18	7.7416	227.12	0.3351	0.0320	02-08-2011 06:15	122.98	8.9007	235.3	
28	0.0000	01-08-2011 06:30	0	7.7624	0	0.3559	0.0208	02-08-2011 06:30	0	8.9213	0	
29	0.0000	01-08-2011 06:45	0	7.7624	0	0.3559	0.0000	02-08-2011 06:44	0	8.9213	0	

Figure A I-3 – Fragment of the data arranged after the program run (example for the simulation of the refrigerator BOSCH KGN46A03 in scenario (i)).

- After the last column, the average accumulated consumption and the average consumption concerning all the measured days are calculated and, then, these values are arranged into following columns at time intervals of 1 hour, resulting in 24 lines.
- At this stage of the program, the costs are estimated, according to the ruling tariffs in Portugal (see Annex III). The most complicated part concerns the weekly cycle, in which the cost varies, for the same tariff, with the week period (if it is week day, Saturday or Sunday). The explanation on how the costs are calculated follows.
    - In the daily cycle, the columns with the costs (Normal tariff, "Two rate" tariff – summer and winter and "Three rate" tariff – summer and winter) are calculated with the search in the time cursor (lines) of the hours of the different periods ("off-peak", "shoulder" and "peak") from the

- Column with the average consumption in each hour, which results in the average cost of the whole period. Analyzing Figure A I-4, one can see the calculation is quite simple, in which the cursor "i" crosses the 24 hours and, whenever it corresponds to an "0ff-peak" period, the cost is 0.0778 € is applied, whereas 0.1448 € (Annex III).

```
If UserForm2.CheckBox2.Value = True Then                          '"Two rate" tariff

    If UserForm2.CheckBox6.Value = True Then                      'daily cycle
        j = (ds - (-sab - dom)) * (data + 2) + 10   'column cursor set in column with the cost calculation
        i = 2                                                     ' line cursor in first hour
        Cells(1, j) = "Average €/day (Bi-horária; Daily cycle)"

        While i <= 24 * 60 / dt + 1
            Cells(i, j).Select
            Selection.NumberFormat = "0.0000"
            If i < 8 * 60 / dt + 1 Or i >= 22 * 60 / dt Then      '"off-peak" period
                Cells(i, j) = Cells(i, j - 7) * 0.0778
                i = i + 1
                Else
                    Cells(i, j) = Cells(i, j - 7) * 0.1448        'Remaining time
                    i = i + 1
            End If
        Wend
    End If
```

Figure A I-4 – Code used for the calculation of the costs concerned to the "Two rate" tariff, in daily cycle.

- Concerning the weekly cycle, the development of the code had to follow a different approach. Indeed, now the costs cannot be calculated only with the costs of the average consumption day (as it is done for the daily cycle). The influence factors are the hour, day and season, meaning that the costs also vary with the first day of the week (remembering that the data may not be of one whole week, only the day has to be complete).
  gives the code for the calculation in the "Two-rate" tariff for a period which begins in a Monday.
  The daily cursor "j" has to pass through each column with the consumption in the time interval. When a Saturday or a Sunday is encountered, the cost may be different and so the days are discriminated. When the week is over, the "j" cursor jumps to the first day of the following week (so, the next day to be analyzed) and the week cursor "n" adds one value. When the last day is analyzed, the time interval cursor "I" adds one number. The final results are columns with the same intervals as the analyzed day and the presented values in this Thesis are the sum of the respective values for each tariff in each considered season, concerning the weekly cycle.
  One must notice that this code is repeated seven times for the "Two-rate" tariff (which was not difficult, just had to be changed the definition of week days, Saturdays and Sundays) and it had to be adapted to the "Three-rate" tariff, which was slightly more complicated due to the different daily periods (three instead of two) and the consequent addition of one cycle "if".

The code is now generally explained and the possibility of all the concretized data analysis in this Thesis is now understood. As it was previously said, it would not be possible to analyze such amount of data for a Master Thesis automatic means would not be available.

Moreover, it must be stretched that the author tested manually the code, several times for several data of one week and the results proved to be correct.

```
If UserForm2.CheckBox7.Value = True Then                                                                    'weekly cycle
    Cells(1, (ds - (-sab - dom)) * (data + 2) + 11) = "Average €/day (Bi-horária; Weekly cycle; Summer)"
    Cells(1, (ds - (-sab - dom)) * (data + 2) + 12) = "Average €/day (Bi-horária; Weekly cycle; Winter)"
    If UserForm2.CheckBox8.Value = True Or UserForm2.CheckBox9.Value = True Then    'winter or summer - "off-peak" equal for the week days
      If seg = True Then                                                                                    '1st day: monday
        While i <= 24 * 60 / dt + 1                                                                         'number of time periods
          n = 1
          j = data + 2                                                                                      'column with consumption
          Cells(i, (ds - (-sab - dom)) * (data + 2) + 11).Select                                            'column with cost in the summer
          Selection.NumberFormat = "0.0000"
          Cells(i, (ds - (-sab - dom)) * (data + 2) + 12).Select                                            'column with cost in the winter
          Selection.NumberFormat = "0.0000"
            While n < (ds - (-sab - dom)) / 7 + 1
              While j <= (ds - (-sab - dom)) * (data + 2)
                If j < n * 6 * (data + 2) And j > (n - 1) * 7 * (data + 2) Then                             'week days
                  If i > 7 * 60 / dt + 1 Then                                                               '"Shoulder" in week days
                    If UserForm2.CheckBox8.Value = True Then                                                'summer
                      Cells(i, (ds - (-sab - dom)) * (data + 2) + 11) = Cells(i, (ds - (-sab - dom)) * (data + 2) + 11) + Cells(i, j) * 0.1448 / (ds - (-sab - dom))      'average €/day; week days; "Shoulder"; summer
                    End If
                    If UserForm2.CheckBox9.Value = True Then                                                'winter
                      Cells(i, (ds - (-sab - dom)) * (data + 2) + 12) = Cells(i, (ds - (-sab - dom)) * (data + 2) + 12) + Cells(i, j) * 0.1448 / (ds - (-sab - dom))      ' average €/day; week days; "Shoulder"; winter
                    End If
                    Else
                    If UserForm2.CheckBox8.Value = True Then                                                'summer
                      Cells(i, (ds - (-sab - dom)) * (data + 2) + 11) = Cells(i, (ds - (-sab - dom)) * (data + 2) + 11) + Cells(i, j) * 0.0778 / (ds - (-sab - dom))      ' average €/day; week days; "0ff-peak"; summer
                    End If
                    If UserForm2.CheckBox9.Value = True Then                                                'winter
                      Cells(i, (ds - (-sab - dom)) * (data + 2) + 12) = Cells(i, (ds - (-sab - dom)) * (data + 2) + 12) + Cells(i, j) * 0.0778 / (ds - (-sab - dom))      ' average €/day; week days; "0ff-peak"; winter
                    End If
                  End If
                  ElseIf j = n * 6 * (data + 2) Then                                                        'Saturday
                    If UserForm2.CheckBox8.Value = True Then                                                'summer (does not exist "Off-peak" on Saturdays)
                      Cells(i, (ds - (-sab - dom)) * (data + 2) + 11) = Cells(i, (ds - (-sab - dom)) * (data + 2) + 11) + Cells(i, j) * 0.1448 / (ds - (-sab - dom))      'average €/day; Saturdays; "Shoulder"; summer
                    End If
                    If UserForm2.CheckBox9.Value = True Then                                                'winter (does not exist "Peak" on Saturdays)
                      If i <= 9.5 * 60 / dt + 1 Or (i > 13 * 60 / dt + 1 And i <= 18.5 * 60 / dt + 1) Or i > 22 * 60 / dt + 1 Then      '"Off-peak " on Saturdays
                        Cells(i, (ds - (-sab - dom)) * (data + 2) + 12) = Cells(i, (ds - (-sab - dom)) * (data + 2) + 12) + Cells(i, j) * 0.0778 / (ds - (-sab - dom))    'average €/day; Saturdays; "Off-peak"; winter
                        Else
                        Cells(i, (ds - (-sab - dom)) * (data + 2) + 12) = Cells(i, (ds - (-sab - dom)) * (data + 2) + 12) + Cells(i, j) * 0.1448 / (ds - (-sab - dom))    'average €/day; Saturdays; "Shoulder"; winter
                      End If
                    End If
                  ElseIf j = n * 7 * (data + 2) Then                                                        'Sunday ("off-peak" the whole day)
                    If UserForm2.CheckBox8.Value = True Then                                                'summer
                      Cells(i, (ds - (-sab - dom)) * (data + 2) + 11) = Cells(i, (ds - (-sab - dom)) * (data + 2) + 11) + Cells(i, j) * 0.0778 / (ds - (-sab - dom))      'average €/day; Sundays; "Off-peak"; summer
                    End If
                    If UserForm2.CheckBox9.Value = True Then                                                'winter
                      Cells(i, (ds - (-sab - dom)) * (data + 2) + 12) = Cells(i, (ds - (-sab - dom)) * (data + 2) + 12) + Cells(i, j) * 0.0778 / (ds - (-sab - dom))      'average €/day; Sundays; "Off-peak"; winter
                    End If
                End If
                j = j + data + 2
              Wend
              j = n * (data + 2) * 7                                                 'n * (data+2) variables * 7 days of the week →the cursor "j" leaps one
week
              n = n + 1                                                                                     'the cursor "n" jumps one week as well
            Wend
          i = i + 1                                                                                         'the cursor "i" jumps one "dt" (time interval)
        Wend
      End If
    End if
```

Figure A I-5 – I Fragment of the calculation tool developed by the author, concerning the costs calculation with the "Two-rate" tariff and weekly cycle, being Monday the first day of the week.

II. Electricity demand for 2010 and electricity losses in the grid for 2011

The presented electricity demand is the registered one in (REN, 2010) for the year 2010. The BTN consumption is 44.9% of the overall electricity consumption (CMVM, et al., 2011) and the predicted electricity losses for 2011 are available at (ERSE, 2011).

Table A II-1 – Electricity demand for 2010, with indication of the electricity demand in BTN – 44.9% of the overall consumption – and the average percentage of losses in the grid for one period in “off-peak” and two periods in “peak” time.

t [h]	Demand [GWh]	BTN demand [GWh]	BTN losses [GWh]	BTN losses [%]	
1	5196.56	2333.26	181.69	7.8	Average in “off-peak” time: 6.9
2	4872.35	2187.69	152.29	7.0	
3	4688.39	2105.09	137.84	6.6	
4	4600.30	2065.54	131.59	6.4	
5	4595.30	2063.29	131.81	6.4	
6	4656.04	2090.56	141.36	6.8	
7	4941.15	2218.58	165.28	7.5	
8	5542.05	2488.38	194.14	7.8	
9	6111.37	2744.01	217.40	7.9	
10	6455.42	2898.49	233.67	8.1	
11	6653.72	2987.52	249.77	8.4	Average in “peak” time: 8.7
12	6661.59	2991.05	263.35	8.8	
13	6542.45	2937.56	263.23	9.0	
14	6526.08	2930.21	252.36	8.6	
15	6528.79	2931.42	243.14	8.3	
16	6441.21	2892.10	237.82	8.2	
17	6336.06	2844.89	242.56	8.5	
18	6391.23	2869.66	262.21	9.1	Average in “peak” time: 9.7
19	6684.07	3001.15	291.36	9.7	
20	6915.16	3104.91	313.76	10.1	
21	6919.48	3106.85	311.05	10.0	
22	6678.28	2998.55	294.83	9.8	
23	6229.35	2796.98	266.05	9.5	
24	5676.75	2548.86	224.96	8.8	

III. Tariffs

The tariffs used in this Thesis are the ones ruling in Portugal, defined by ERSE and applied by EDP (EDP, 2011).

Table A III-1 – Costs per period for the different tariffs, as well as the cost for the rent of the counter concerning different contracted powers.

Tariff				Rent of the counter		
	[kVA]	Time	€/kWh	[kVA]	[€/month]	[€/day]
Simple	< 2.3		0.1027	**3.45**	5.51	0.1813
	> 2.3		0.1326	**4.6**	7.16	0.2353
"Two rate"		"Off-peak"	0.1448	**5.75**	8.8	0.2893
		"Shoulder"	0.0778	**6.9**	10.44	0.3434
"Three rate"		"Peak"	0.1593	**10.35**	15.37	0.5054
		"Shoulder"	0.1373	**13.8**	20.3	0.6675
		"Off-peak"	0.0778	**17.25**	25.23	0.8295
				20.7	30.16	0.9916

Table A III-2 – Daily cycle Schedules (corresponding to 70 h) **(EDP, 2011)**.

	Schedule (70 h)	
Time	**Summer**	**Winter**
"Peak"	10:30 - 13:00; 19:30 - 21:00	9:00 - 10:30; 18:00 - 20:30
"Shoulder"	8:00 - 10:30; 13:00 - 19:30; 21:00 - 22:00	8:00 - 9:00; 10:30 - 18:00; 20:30 - 22:00
"Off-peak"	22:00 - 8:00	22:00 - 8:00

Table A III-3 – Weekly cycle Schedules (corresponding to 76 h) **(EDP, 2011)**.

		Schedule (76 h)	
Day	**Time**	**Summer**	**Winter**
Week days	"Peak"	9h15 – 12h15	9h30 - 12h; 18h30 - 21h
	"Shoulder"	7 – 9h15; 12h15 – 24h	7 - 9h30; 12 – 18h30; 21 – 24h00
	"Off-peak"	0 – 7h	0 – 7h
Saturday	"Peak"	9 – 14h; 20 – 22h	-
	"Shoulder"	0 – 9h; 14 – 20h; 22 – 24h	9h30 – 13h; 18h30 – 22h
	"Off-peak"	-	0 – 9h30; 13 – 18h30; 22 – 24h
Sunday	"Peak"	-	-
	"Shoulder"	-	-
	"Peak"	0 – 24h	0 – 24h

The range of schedules vary during the day and, even, during the week (in daily cycle) and during the season (in weekly cycle). Therefore, it can be understood the necessity to create an analysis and calculation tool through some kind of program, being, in this case, developed in VBA. Only with this, it was possible to analyze several electricity consumption profiles recorded by the PlugMeter® and systematize them, by arranging into average daily consumption profiles and calculating the average of the different costs of the different consumptions during the day, the week and the year, transposing then to one chart and one table.

Concerning the gas tariffs, those considered in this Thesis are the tariffs from the company Lisboagás, that is the gas supply in Lisbon associated to the Galp Energia group, which is the chosen gas trader company to the author's house. Thus, the ruling tariffs are:

Table A III-4 – Natural gas tariffs practiced in the author's house **(GALP, 2010)**.

Band	Consumption (m^3/year)	Fixed tariff term [€/month]	Energy [€/kWh]
Band 1	0 - 220	1.80	0.0661
Band 2	221 - 500	3.57	0.0614
Band 3	501 - 1.000	5.38	0.0517
Band 4	1.001 - 10.000	5.82	0.0517

IV. Variation of the electricity consumption of the refrigerator with the air temperature

In (Bjork, et al., 2005) was tested the electricity consumption of a refrigerator by changing some factors, *i.e.*, charge, expansion device capacity (EDC) and air temperature. The main conclusion of this work is that the electricity consumption is not sensitive to a variation of charge and EDC, within a wide range of settings. Still, the experimental results of the tests must be analyzed (Table A IV-1).

Table A IV-1 – Analyzed factors for the electricity consumption of the refrigerator, in **(Bjork, et al., 2005)**

16°C			25°C			31°C		
Charge [g]	**EDC [LN$_x$/min]**	**Energy [kWh/24h]**	**Charge [g]**	**EDC [1N$_x$/min]**	**Energy [kWh/24h]**	**Charge [g]**	**EDC [1N$_x$/min]**	**Energy [kWh/24h]**
22	3.06	0.39	23	3.06	0.76	22	3.06	1.18
22	2.00	0.39	23	2.28	0.78	22	2.00	1.33
22	0.15	0.48	23	0.15	0.87	32	0.15	1.02
36	3.06	0.27	31	3.06	0.62	32	3.06	1.01
36	2.00	0.28	31	2.28	0.61	32	2.00	1.09
36	0.15	0.4	31	0.15	0.76	42	0.15	1.51
50	3.06	0.32	40	3.06	0.87	42	3.06	1.35
50	2.00	0.32	40	2.28	0.8	42	2.00	1.09
50	0.15	0.31	40	0.15	0.71	22	0.15	1.18

As it can be seen, the energy consumption varies slightly with a change of charge and EDC. Therefore, the approach made is to choose the consumption for the closest values of charge and EDC for each temperature and calculate a relation between the consumption for those values with the temperature (T). So, the closest values are: 22 g for charge (for the temperature of 25°C this value is 23 g but, still, it is close to 22 g) and 3.06 LN$_z$/min. The relation established is:

$$\frac{0.39\ \mathrm{kWh/24h}}{16\ {}^{0}\mathrm{C}} = 0.024\ \mathrm{kWh/(24h \times\ {}^{0}C)}$$

$$\frac{0.76\ \mathrm{kWh/24h}}{25\ {}^{0}\mathrm{C}} = 0.030\ \mathrm{kWh/(24h \times\ {}^{0}C)}$$

$$\frac{1.18\ \mathrm{kWh/24h}}{31\ {}^{0}\mathrm{C}} = 0.038\ \mathrm{kWh/(24h \times\ {}^{0}C)}$$

Applying a linear regression, the following relation with a correlation factor r^2=0.977 is:

$$\Delta Energy\ consumption = 0.05\Delta T - 0.47\ [kWh/24h]$$

The consumption variation with the temperature can be determined, replacing ΔT by $T_2 - T_1$.

V. Registered temperatures during the tests in the refrigerators

The downloaded values for the temperature registered in (WeatherUnderground, 2011) concerning the station of Barcarena (the closest to TagusPark campus), have time intervals from 2min to 5min, which correspond to data with more than 300 entries. Therefore, the tables are not shown but only the charts with the daily average temperature:

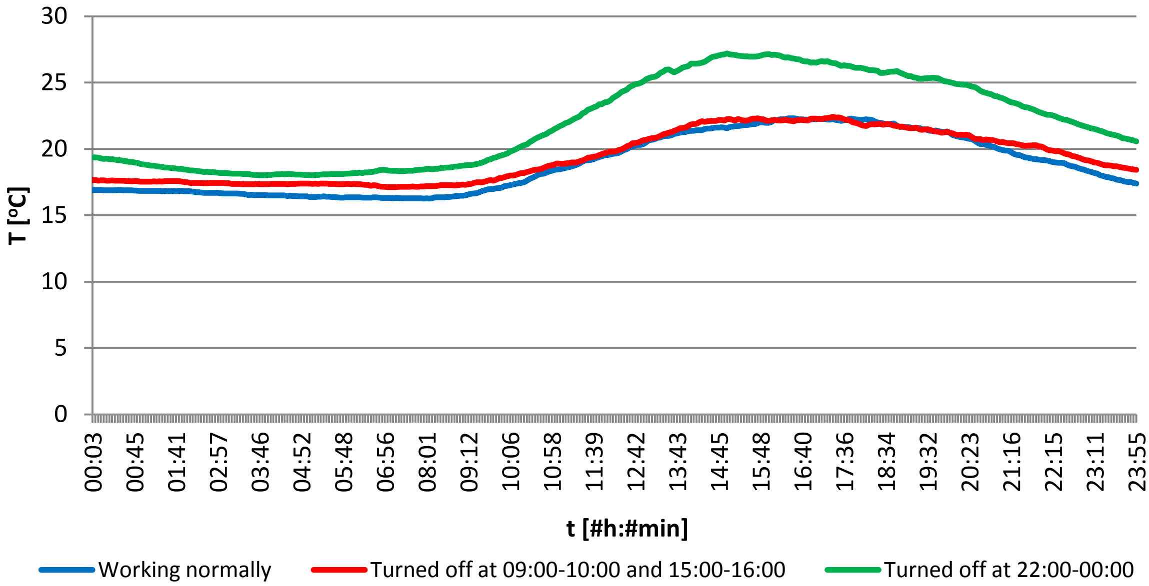


Chart A V-1 – Average temperatures measured in **(WeatherUnderground, 2011)** during the tested periods in the refrigerator INDESIT R 18

The average temperatures, which are those represented ones in subchapter 3.2A, are downloaded from (WeatherUnderground, 2011) and, as it can be concluded in Table A V-1, the room temperature varies at the same rate as the outside temperature. Therefore, the air temperature registered in (WeatherUnderground, 2011) is related to the room temperature as follows:

(i) 18.8^{0}C

(ii) 19.4^{0}C, which corresponds to a consumption increase of 0.030 kWh (3%) relatively to scenario (i)

(iii) 22.0^{0}C, which corresponds to a consumption increase of 0.160 kWh (14%) relatively to scenario (i)

Table A V-1– Relation between the temperature from **(WeatherUnderground, 2011)** and the room temperature concerning the simulation in the refrigerator INDESIT.

	September 1st to 7th [^{0}C]	**September 8th to 12th [^{0}C]**	**ΔT [^{0}C]**
(WeatherUnderground, 2011)	22.75	25.0	2.25
Measured	24.0	25.1	1.1

As for the registered temperatures in the station of Amadora (the closest one to the author's house), one presents only the chart and the daily average temperatures, being the temperature variation in the author's kitchen only half of the measured in this weather station.

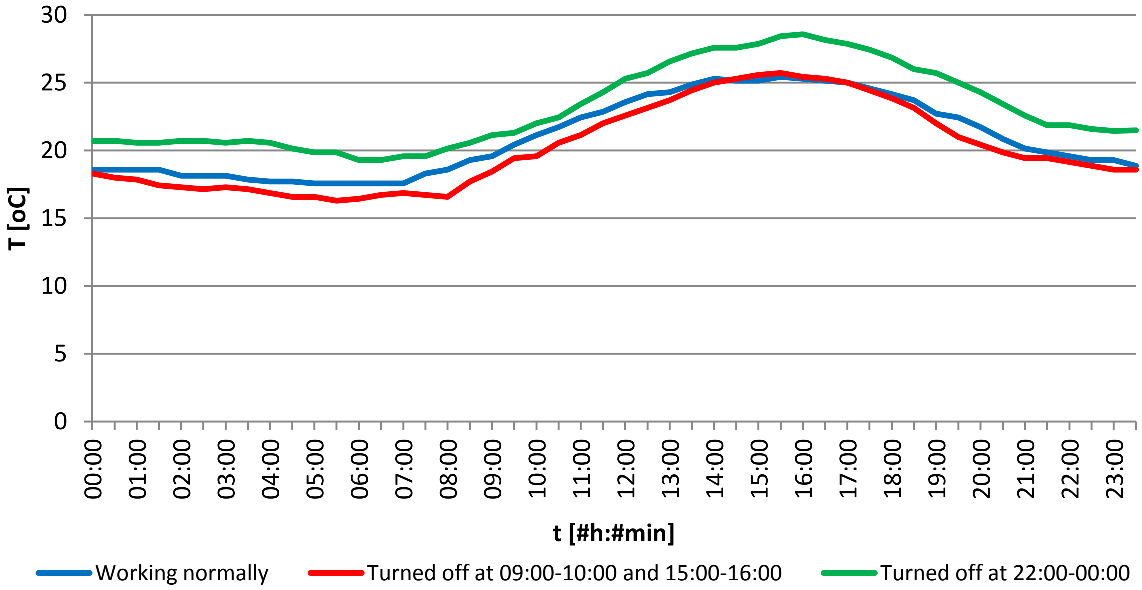


Chart A V-2 – Average temperatures measured in **(WeatherUnderground, 2011)** during the tested periods in the refrigerator BOSCH KGN46A03

The average temperatures, which are those represented in subchapter 3.2A, are downloaded from (WeatherUnderground, 2011) and, as it can be concluded with Table A V-2, the room temperature varies at half the rate of the outside temperature. Therefore, the air temperature registered in (WeatherUnderground, 2011) is related to the room temperature as follows:

(i) 20.9^{0}C

(ii) 23.1^{0}C, which corresponds to a temperature increase of 1.1^{0}C and a consumption rise of 0.055 kWh (5%) relatively to scenario (i)

(iii) 20.2^{0}C, which corresponds to a temperature decrease of 0.4^{0}C and a consumption lowering of 0.020 kWh (2%) relatively to scenario (i)

Table A V-2 – Relation between the temperature from **(WeatherUnderground, 2011)** and the room temperature concern the simulation in the refrigerator BOSCH.

	September 1st to 7th [^{0}C]	**September 8th to 14th [^{0}C]**	**ΔT [^{0}C]**
(WeatherUnderground, 2011)	24.1	26.9	2.8
Measured	23.8	25.1	1.3

These consumption variations in both refrigerators are taken in account, in order the results can be discussed.

VI.Electricity consumption of the refrigerator INDESIT R 18

After processing the consumption data recorded by the PlugMeter® into the program developed by the author, the resulting average consumptions for each hour during the day, and for each simulated scenario, are presented in Table A VI-1.

Table A VI-1 – Electricity consumption concerning the simulated scenarios for the refrigerator INDESIT R 28.

	Scenario (i)		Scenario (ii)		Scenario (iii)	
t [h]	Accumulated consumption [kWh]	Consumption [kWh/h]	Accumulated consumption [kWh]	Consumption [kWh/h]	Accumulated consumption [kWh]	Consumption [kWh/h]
1	0.049	0.049	0.093	0.093	0.043	0.043
2	0.096	0.048	0.141	0.048	0.098	0.055
3	0.141	0.044	0.186	0.044	0.154	0.055
4	0.179	0.038	0.249	0.063	0.206	0.053
5	0.219	0.041	0.315	0.066	0.246	0.040
6	0.264	0.044	0.373	0.058	0.287	0.041
7	0.312	0.049	0.417	0.043	0.334	0.048
8	0.360	0.047	0.455	0.038	0.386	0.051
9	0.401	0.041	0.511	0.056	0.386	0.000
10	0.442	0.041	0.569	0.058	0.445	0.008
11	0.482	0.040	0.635	0.065	0.530	0.085
12	0.529	0.047	0.679	0.044	0.581	0.051
13	0.584	0.055	0.722	0.043	0.633	0.052
14	0.639	0.055	0.779	0.057	0.673	0.040
15	0.688	0.048	0.847	0.067	0.673	0.000
16	0.736	0.049	0.908	0.061	0.745	0.003
17	0.782	0.046	0.958	0.050	0.841	0.096
18	0.832	0.050	1.007	0.049	0.885	0.044
19	0.884	0.052	1.073	0.066	0.926	0.041
20	0.935	0.051	1.141	0.067	0.985	0.059
21	0.980	0.045	1.198	0.057	1.052	0.067
22	1.027	0.047	1.244	0.046	1.107	0.055
23	1.071	0.044	1.268	0.000	1.155	0.048
24	1.115	0.044	1.268	0.000	1.192	0.037

VII. Electricity consumption of the refrigerator BOSCH KGN46A03

After processing the consumption data recorded by the PlugMeter® into the program developed by the author, the resulting average consumptions for each hour during the day, and for each simulated scenario, are presented in Table A VII-1.

Table A VII-1 – Electricity consumption concerning the simulated scenarios in the refrigerator BOSCH KGN46A03.

t [h]	Scenario (i)		Scenario (ii)		Scenario (iii)	
	Accumulated consumption [kWh]	Consumption [kWh/h]	Accumulated consumption [kWh]	Consumption [kWh/h]	Accumulated consumption [kWh]	Consumption [kWh/h]
1	0.052	0.052	0.038	0.038	0.065	0.065
2	0.109	0.056	0.082	0.044	0.133	0.068
3	0.146	0.037	0.129	0.046	0.195	0.062
4	0.180	0.035	0.188	0.060	0.250	0.056
5	0.211	0.031	0.218	0.030	0.284	0.034
6	0.251	0.039	0.264	0.046	0.332	0.048
7	0.280	0.029	0.295	0.031	0.375	0.043
8	0.307	0.028	0.350	0.055	0.422	0.047
9	0.358	0.050	0.394	0.044	0.456	0.034
10	0.408	0.050	0.394	0.000	0.494	0.037
11	0.461	0.053	0.467	0.065	0.545	0.051
12	0.500	0.040	0.508	0.041	0.595	0.050
13	0.538	0.037	0.553	0.046	0.652	0.057
14	0.570	0.032	0.605	0.051	0.703	0.051
15	0.623	0.053	0.660	0.055	0.751	0.048
16	0.674	0.051	0.660	0.000	0.799	0.048
17	0.728	0.054	0.736	0.062	0.843	0.044
18	0.779	0.051	0.785	0.050	0.892	0.050
19	0.821	0.042	0.833	0.047	0.940	0.048
20	0.869	0.049	0.871	0.038	0.978	0.037
21	0.915	0.046	0.924	0.054	1.053	0.075
22	0.954	0.039	0.973	0.049	1.120	0.067
23	0.988	0.034	1.042	0.069	1.120	0.000
24	1.028	0.039	1.095	0.052	1.120	0.000

VIII. Data for the three selected programs in subchapter 3.2.2

The analyzed data had a time interval of 1 min. To simplify, the presented consumption values in Table A VIII-1are given at a time interval of 10 min.

Table A VIII-1 – Electricity and gas consumption for scenarios (i) and (ii) concerning the three tested programs.

t [min]	Accumulated electricity consumption		Electricity consumption in each minute		Gas consumption in (ii)	
	(i) [kWh]	(ii) [kWh/h]	(i) [kWh]	(ii) [kWh/h]	[min]	[m^3/h]
	Dishwashing machine, working in program at 70°C					
10	0.181	0.034	0.181	0.034	0.542	0.021
20	0.279	0.133	0.099	0.099	0.000	0.000
30	0.443	0.250	0.164	0.116	0.000	0.000
40	0.491	0.260	0.048	0.010	0.000	0.000
50	0.710	0.555	0.219	0.295	0.000	0.000
60	0.759	0.568	0.049	0.014	0.250	0.010
70	0.768	0.578	0.009	0.009	0.000	0.000
80	0.776	0.586	0.008	0.008	0.000	0.000
90	0.784	0.593	0.008	0.007	0.208	0.008
	Dishwashing machine, working in program auto at 45-65°					
10	0.097	0.124	0.097	0.124	0.083	0.001
20	0.187	0.131	0.090	0.007	0.083	0.001
30	0.193	0.137	0.006	0.006	0.000	0.000
40	0.199	0.142	0.006	0.006	1.667	0.018
50	0.213	0.147	0.014	0.005	1.000	0.011
60	0.465	0.414	0.252	0.268	0.000	0.000
70	0.636	0.503	0.171	0.089	1.042	0.011
80	0.639	0.504	0.003	0.001	0.000	0.000
90	0.640	0.50455	0.001	0.001	0.458	0.005
100	0.641	0.124	0.001	0.124	0.083	0.001
	Washing machine, working in program at 40°C					
10	0.025	0.006	0.025	0.006	3.825	0.005
20	0.369	0.040	0.344	0.033	0.175	0.016
30	0.444	0.057	0.075	0.018	3.125	0.018
40	0.463	0.075	0.019	0.018	2.875	0.017
50	0.483	0.093	0.019	0.018	2.417	0.017
60	0.502	0.108	0.019	0.015	0.250	0.016
70	0.520	0.116	0.018	0.008	0.433	0.006
80	0.532	0.006	0.008	0.006	3.825	0.005

Concerning the water temperature at the entrance of the machines, the time interval of the presented values in Table A VIII-2 and is 1 min, so that one can notice the detailed temperature variation of the water at the entrance of the machine. The values for *T* are determined with the calculation of ΔT (Eq. (2)) and subtracting this value after a gas consumption period finishes.

Table A VIII-2 and Table A VIII-3presents the values concerning Chart 3.2-9.

Table A VIII-2 – Water temperature and water consumption concerning the dishwashing machine working in program auto at 45-65°C.

t [min]	t of gas consumption [min]	ΔT [°C]	T water [°C]	V water [L]	t [min]	t of gas consumption [min]	ΔT [°C]	T water [°C]	V water [L]
0	0.00	2.85	70.00	0.00	**34**	0.29	2.02	25.00	1.25
1	0.00	2.85	67.15	0.00	**35**	0.15	2.43	70.00	0.63
2	0.00	2.85	64.31	0.00	**36**	0.27	2.08	70.00	1.16
3	0.00	2.85	61.46	0.00	**37**	0.31	1.96	70.00	1.34
4	0.00	2.85	58.61	0.00	**38**	0.48	1.48	70.00	2.06
5	0.00	2.85	55.77	0.00	**39**	0.02	2.79	67.21	0.09
6	0.00	2.85	52.92	0.00	**40**	0.00	2.85	64.37	0.00
7	0.00	2.85	50.07	0.00	**41**	0.96	0.12	64.25	4.12
8	0.00	2.85	47.22	0.00	**42**	0.00	2.85	61.40	0.00
9	0.00	2.85	44.38	0.00	**43**	0.00	2.85	58.55	0.00
10	0.00	2.85	41.53	0.00	**44**	0.00	2.85	55.71	0.00
11	0.00	2.85	38.68	0.00	**45**	0.00	2.85	52.86	0.00
12	0.00	2.85	35.84	0.00	**46**	0.00	2.85	50.01	0.00
13	0.06	2.67	33.17	0.27	**47**	0.00	2.85	47.17	0.00
14	0.00	2.85	30.32	0.00	**48**	0.00	2.85	44.32	0.00
15	0.00	2.85	27.47	0.00	**49**	0.00	2.85	41.47	0.00
16	0.00	2.85	25.00	0.00	**50**	0.00	2.85	38.62	0.00
17	0.00	2.85	25.00	0.00	**51**	0.00	2.85	35.78	0.00
18	0.00	2.85	25.00	0.00	**52**	0.00	2.85	32.93	0.00
19	0.00	2.85	25.00	0.00	**53**	0.00	2.85	30.08	0.00
20	0.00	2.85	25.00	0.00	**54**	0.00	2.85	27.24	0.00
21	0.00	2.85	25.00	0.00	**55**	0.00	2.85	25.00	0.00
22	0.00	2.85	25.00	0.00	**56**	0.00	2.85	25.00	0.00
23	0.00	2.85	25.00	0.00	**57**	0.00	2.85	25.00	0.00
24	0.00	2.85	25.00	0.00	**58**	0.00	2.85	25.00	0.00
25	0.00	2.85	25.00	0.00	**59**	0.00	2.85	25.00	0.00
26	0.00	2.85	25.00	0.00	**60**	0.00	2.85	25.00	0.00
27	0.00	2.85	25.00	0.00	**61**	0.00	2.85	25.00	0.00
28	0.00	2.85	25.00	0.00	**62**	0.00	2.85	25.00	0.00
29	0.00	2.85	25.00	0.00	**63**	0.00	2.85	25.00	0.00
30	0.00	2.85	25.00	0.00	**64**	0.00	2.85	25.00	0.00
31	0.00	2.85	25.00	0.00	**65**	0.48	1.48	25.00	2.06
32	0.00	2.85	25.00	0.00	**66**	0.48	1.48	70.00	2.06
33	0.00	2.85	70.00	0.00	**67**	0.29	2.02	25.00	1.25

Table A VIII-3 (cont.) – Water temperature and water consumption concerning the dishwashing machine working in program auto at 45-65^{o}C.

t [min]	t gas consumption [min]	ΔT [^{o}C]	T water [^{o}C]	V water [L]	t [min]	t gas consumption [min]	ΔT [^{o}C]	T water [^{o}C]	V water [L]
68	0.02	2.79	70.00	2.06	**81**	0.02	2.85	35.90	0.00
69	0.00	2.85	67.21	0.09	**82**	0.02	2.85	33.05	0.00
70	0.00	2.85	64.37	0.00	**83**	0.00	2.85	30.20	0.00
71	0.00	2.85	61.52	0.00	**84**	0.00	2.85	27.36	0.00
72	0.00	2.85	58.67	0.00	**85**	0.00	2.85	25.00	0.00
73	0.00	2.85	55.82	0.00	**86**	0.00	2.31	25.00	0.81
74	0.00	2.85	52.98	0.00	**87**	0.19	2.85	25.00	0.00
75	0.00	2.85	50.13	0.00	**88**	0.00	2.19	25.00	0.99
76	0.00	2.85	47.28	0.00	**89**	0.23	2.85	25.00	0.00
77	0.00	2.85	44.44	0.00	**90**	0.00	2.85	25.00	0.00
78	0.00	2.85	41.59	0.00	**91**	0.00	2.85	25.00	0.00
79	0.00	2.85	38.74	0.00					

The water temperature at the entrance of the dishwashing machine is, in average, 39.7^{o}C, which means that, in average, the dishwashing machine had to heat the water by 21.3^{0}C (once the considered temperature for this program is 61^{0}C).

Table A **I-1** presents the values concerning Chart 3.2-12. The values for T water are obtained through Eq. (2), subtracting ΔT to T_1, after the water heater deactivates.

Table A VIII-3 – Water temperature and water consumption concern the washing machine working in program at 40°C.

t [min]	t gas consumption [min]	ΔT [°C]	T water [°C]	V water [L]	t [min]	t gas consumption [min]	ΔT [°C]	T water [°C]	V water [L]
0	0.95	0.08	45	4.09	**34**	0.62	0.60	45	2.65
1	0.7	0.47	45	3.01	**35**	0.49	0.79	45	2.11
2	0.95	0.08	45	4.09	**36**	0.12	1.37	45	0.50
3	0.7	0.47	45	3.01	**37**	0.20	1.24	45	0.86
4	0.12	1.37	45	0.50	**38**	0	1.55	43.45	0
5	0	1.55	43.44	0	**39**	0	1.55	41.89	0
6	0	1.55	41.89	0	**40**	0	1.55	40.34	0
7	0.08	1.44	40.46	0.32	**41**	0	1.55	38.79	0
8	0	1.55	38.90	0	**42**	0	1.55	37.23	0
9	0	1.55	37.35	0	**43**	0	1.55	35.68	0
10	0.09	1.41	35.94	0.39	**44**	0.20	1.2	34.44	0
11	0	1.55	34.39	0	**45**	0.45	0.85	45	0.86
12	0	1.55	32.83	0	**46**	0.49	0.79	45	1.94
13	0	1.55	31.28	0	**47**	0.91	0.14	45	2.11
14	0	1.55	29.73	0	**48**	0.12	1.37	45	3.91
15	0	1.55	28.17	0	**49**	0.20	1.24	45	0.50
16	0	1.55	26.62	0	**50**	0	1.55	43.45	0.86
17	0	1.55	25.07	0	**51**	0	1.55	41.89	0
18	0	1.55	23.52	0	**52**	0	1.55	40.34	0
19	0	1.55	25	0	**53**	0	1.55	38.79	0
20	0.45	0.85	25	1.94	**54**	0	1.55	37.23	0
21	0.95	0.08	45	4.09	**55**	0	1.55	35.68	0
22	0.78	0.34	45	3.37	**56**	0	1.55	34.13	0
23	0.41	0.92	45	1.76	**57**	0	1.55	32.58	0
24	0.12	1.37	45	0.50	**58**	0	1.55	31.02	0
25	0.12	1.37	43.63	0.50	**59**	0.18	1.28	29.74	0
26	0	1.55	42.07	0	**60**	0.03	1.50	28.24	0.75
27	0	1.55	40.52	0	**61**	0.08	1.44	26.80	0.14
28	0	1.55	38.97	0	**62**	0	1.55	25.25	0.32
29	0	1.55	37.42	0	**63**	0	1.55	25	0
30	0	1.55	35.86	0	**64**	0	1.55	25	0
31	0	1.55	34.31	0	**65**	0	1.55	25	0
32	0.45	0.85	33.46	1.94	**66**	0	1.55	25	0
33	0.7	0.47	45	3.01	**67**	0	1.55	25	0

The water temperature at the entrance of the washing machine is, in average, 37.1°C, which means that, in average, the washing machine had to heat the water by 2.9°C (once the considered temperature for this program is 40°C).

IX. Data concerning the residential electricity consumption in the four analyzed families

Table A IX-1 – Average daily electricity consumption concerning "House 1" during the working and vacation periods in the summer (measured) and concerning the whole year (determined)[a].

t [h]	Accumulated consumption [kWh]				Consumption [kWh/h]			
	Working period	Vacation period	Whole year(1)	Whole year(2)	Working period	Vacation period	Whole year(1)	Whole year(2)
1	0.298	0.211	0.306	1.072	0.298	0.211	0.306	1.072
2	0.566	0.394	0.581	1.326	0.268	0.182	0.275	0.254
3	0.816	0.611	0.842	1.567	0.250	0.217	0.261	0.241
4	1.080	0.794	1.112	1.817	0.264	0.183	0.271	0.250
5	1.334	1.008	1.376	2.062	0.254	0.214	0.264	0.244
6	1.580	1.208	1.631	2.297	0.246	0.200	0.255	0.236
7	1.825	1.401	1.884	2.532	0.245	0.193	0.253	0.234
8	2.144	1.616	2.211	2.834	0.319	0.216	0.327	0.302
9	2.469	1.790	2.541	3.138	0.325	0.174	0.329	0.304
10	2.846	2.021	2.924	3.493	0.377	0.230	0.384	0.355
11	3.271	2.234	3.354	3.889	0.425	0.214	0.429	0.397
12	3.768	2.434	3.851	4.348	0.497	0.199	0.498	0.459
13	4.355	2.637	4.437	4.888	0.587	0.203	0.586	0.540
14	4.855	2.865	4.940	5.353	0.500	0.228	0.503	0.464
15	5.384	3.120	5.473	5.845	0.529	0.255	0.533	0.492
16	5.865	3.322	5.956	6.291	0.481	0.202	0.483	0.446
17	6.265	3.561	6.363	6.667	0.400	0.239	0.407	0.376
18	6.729	3.786	6.831	7.099	0.464	0.225	0.468	0.432
19	7.249	3.992	7.351	7.579	0.520	0.206	0.520	0.480
20	7.969	4.209	8.066	8.238	0.720	0.217	0.715	0.659
21	8.616	4.432	8.711	8.833	0.647	0.222	0.645	0.595
22	9.487	4.653	9.572	9.627	0.871	0.221	0.861	0.794
23	10.189	4.851	10.269	10.269	0.703	0.198	0.697	0.642
24	10.656	5.066	10.739	10.702	0.467	0.215	0.470	0.434

[a] The refer indexes (1) and (2) refer, respectively, to the normal consumption habits and to the consumption of the dishwashing and washing machines during "off-peak" times.

Table A IX-2– Average daily electricity consumption concerning "House 2" during the working and vacation periods in the summer (measured) and concerning the whole year (determined) [a].

t [h]	Accumulated consumption [kWh]				Consumption [kWh/h]			
	Working period	Vacation period	Whole year(1)	Whole year(2)	Working period	Vacation period	Whole year(1)	Whole year(2)
1	0.474	0.361	0.489	1.356	0.474	0.361	0.489	1.356
2	0.955	0.735	0.987	1.816	0.481	0.374	0.497	0.460
3	1.420	1.102	1.468	2.262	0.465	0.366	0.481	0.445
4	1.852	1.454	1.916	2.676	0.432	0.352	0.448	0.415
5	2.260	1.824	2.342	3.070	0.407	0.370	0.425	0.394
6	2.656	2.186	2.755	3.453	0.396	0.362	0.414	0.383
7	3.043	2.543	3.160	3.828	0.387	0.357	0.405	0.375
8	3.431	2.927	3.568	4.205	0.388	0.384	0.407	0.377
9	3.857	3.298	4.011	4.616	0.426	0.371	0.444	0.411
10	4.354	3.701	4.526	5.093	0.497	0.403	0.515	0.477
11	4.899	4.144	5.091	5.615	0.545	0.443	0.565	0.523
12	5.455	4.575	5.665	6.146	0.556	0.430	0.574	0.531
13	6.017	4.994	6.245	6.683	0.563	0.419	0.580	0.536
14	6.584	5.395	6.827	7.221	0.567	0.401	0.582	0.538
15	7.118	5.768	7.376	7.728	0.534	0.373	0.549	0.507
16	7.731	6.186	8.005	8.310	0.613	0.418	0.629	0.582
17	8.317	6.570	8.604	8.864	0.586	0.384	0.599	0.554
18	8.897	6.996	9.202	9.417	0.580	0.425	0.598	0.553
19	9.471	7.410	9.793	9.963	0.574	0.414	0.590	0.546
20	9.976	7.904	10.320	10.451	0.504	0.494	0.527	0.488
21	10.565	8.271	10.921	11.007	0.589	0.367	0.601	0.556
22	11.164	8.617	11.531	11.570	0.599	0.346	0.610	0.563
23	11.669	8.969	12.049	12.050	0.504	0.352	0.519	0.480
24	12.156	9.308	12.550	12.513	0.487	0.338	0.501	0.463

[a] The upper indexes (1) and (2) refer, respectively, to the normal consumption habits and to the consumption of the dishwashing and washing machines during "off-peak" times.

Table A IX-3 – Average daily electricity consumption concerning "House 3" during the working period in the summer (measured) and concerning the whole year (determined) [a].

t [h]	Accumulated consumption [kWh]			Consumption [kWh/h]		
	Working period	Whole year(1)	Whole year(2)	Working period	Whole year(1)	Whole year(2)
1	0.283	0.283	1.193	0.283	0.283	1.193
2	0.462	0.464	1.363	0.179	0.181	0.170
3	0.603	0.610	1.499	0.141	0.145	0.136
4	0.736	0.746	1.628	0.132	0.137	0.129
5	0.856	0.872	1.746	0.121	0.126	0.118
6	0.969	0.989	1.857	0.112	0.117	0.111
7	1.094	1.119	1.979	0.125	0.130	0.122
8	1.376	1.401	2.241	0.282	0.282	0.262
9	1.984	1.997	2.792	0.607	0.596	0.551
10	2.944	2.935	3.658	0.961	0.938	0.866
11	3.925	3.893	4.542	0.981	0.958	0.884
12	4.744	4.694	5.281	0.819	0.801	0.740
13	5.363	5.301	5.842	0.618	0.607	0.561
14	5.988	5.914	6.409	0.625	0.613	0.567
15	6.548	6.465	6.919	0.561	0.551	0.510
16	6.976	6.888	7.311	0.428	0.423	0.392
17	7.323	7.231	7.629	0.346	0.344	0.319
18	7.710	7.615	7.985	0.387	0.383	0.355
19	8.230	8.126	8.458	0.520	0.512	0.474
20	8.992	8.872	9.147	0.762	0.746	0.689
21	9.756	9.620	9.838	0.764	0.748	0.691
22	10.637	10.481	10.633	0.881	0.861	0.795
23	11.569	11.391	11.472	0.931	0.910	0.840
24	12.213	12.023	12.057	0.645	0.632	0.584

[a] The upper indexes (1) and (2) refer, respectively, to the normal consumption habits and to the consumption of the dishwashing and washing machines during "off-peak" times.

Table A IX-4 – Average daily electricity consumption concerning "House 4" during the working period in the summer (measured) and concerning the whole year (determined) [a].

t [h]	Accumulated consumption [kWh]			Consumption [kWh/h]		
	Working period	Whole year(1)	Whole year(2)	Working period	Whole year(1)	Whole year(2)
1	0.596	0.595	1.287	0.596	0.595	1.287
2	1.023	1.026	1.685	0.427	0.431	0.398
3	1.344	1.354	1.988	0.321	0.328	0.303
4	1.595	1.615	2.230	0.251	0.261	0.241
5	1.830	1.860	2.457	0.235	0.246	0.227
6	2.059	2.100	2.679	0.229	0.240	0.222
7	2.269	2.320	2.883	0.209	0.220	0.204
8	2.476	2.539	3.085	0.207	0.219	0.202
9	2.683	2.757	3.288	0.207	0.218	0.202
10	2.904	2.989	3.502	0.221	0.232	0.215
11	3.159	3.253	3.747	0.255	0.264	0.245
12	3.569	3.667	4.130	0.410	0.414	0.383
13	4.303	4.395	4.801	0.734	0.728	0.671
14	5.000	5.088	5.440	0.698	0.693	0.639
15	5.577	5.664	5.971	0.576	0.575	0.531
16	5.984	6.076	6.351	0.407	0.412	0.381
17	6.336	6.434	6.682	0.352	0.358	0.331
18	6.692	6.796	7.017	0.356	0.362	0.334
19	7.100	7.209	7.398	0.409	0.413	0.382
20	7.582	7.693	7.845	0.481	0.484	0.446
21	8.139	8.250	8.359	0.558	0.557	0.514
22	8.853	8.959	9.012	0.713	0.708	0.653
23	9.512	9.615	9.617	0.660	0.656	0.605
24	10.163	10.262	10.214	0.651	0.647	0.597

[a] The upper indexes (1) and (2) refer, respectively, to the normal consumption habits and to the consumption of the dishwashing and washing machines during "off-peak" times.

Concerning the calculation of the dispensable standby consumption, it is only considered the period in which this consumption is easier to be eliminated, *i.e.*, the night time from 0 to 7h in which the families are sleeping.

According to (QUERCUS, 2004), the standby consumption in Portugal is around 5% of the total electricity consumption (11.39 kWh in this case, as determined for the normal consumption in subchapter 4.1; E), corresponding to a share in the overall consumption given by:

$$\frac{11.39\ \text{kWh}}{7\ \text{h}} \times 5\%$$

Thus, the value obtained in each hour is subtracted to the correspondent value in the normal consumption profile, regarding the period from 0 to 7h

Table A IX-5 – Average daily electricity consumption concerning the four presented houses, determined for the whole year[a].

t [h]	Accumulated consumption [kWh]		Consumption [kWh/h]	
	(1)	(2)	(1)	(2)
1	0.418	1.150	0.418	1.150
2	0.764	1.394	0.346	0.244
3	1.068	1.600	0.304	0.206
4	1.347	1.783	0.279	0.183
5	1.612	1.953	0.265	0.170
6	1.869	2.115	0.256	0.162
7	2.121	2.273	0.252	0.158
8	2.430	2.558	0.309	0.286
9	2.826	2.925	0.397	0.367
10	3.344	3.403	0.517	0.478
11	3.898	3.915	0.554	0.512
12	4.469	4.443	0.572	0.528
13	5.094	5.020	0.625	0.577
14	5.692	5.572	0.598	0.552
15	6.244	6.082	0.552	0.510
16	6.731	6.531	0.487	0.450
17	7.158	6.926	0.427	0.395
18	7.611	7.345	0.453	0.419
19	8.120	7.815	0.509	0.470
20	8.738	8.385	0.618	0.570
21	9.376	8.974	0.638	0.589
22	10.136	9.675	0.760	0.701
23	10.831	10.317	0.695	0.641
24	11.393	10.836	0.563	0.519

[a] The columns (1) and (2) refer, respectively, to the scenario with normal consumption habits and to the scenario using the washing machine and the dishwashing machines during “off-peak” time and eliminating the dispensable standby consumption from 0 to 7h and during the vacation period.

Concerning the overall potential scenario, the consumption at 0h, which corresponds to the time when the dishwashing and washing machines are being used. That scenario leads to a reduction of 52 and 88% (determined in subchapter 3.2.2), respectively to the dishwashing machine and the washing machine. That corresponds to a lowering in consumption during that period of:

$$11.39 \text{ kWh} \times (3\% \times 52\% + 5\% \times 88\%)$$

Table A IX-6 – Average daily electricity consumption concerning the four presented houses, determined for the whole year[a].

t [h]	Accumulated consumption [kWh]		Consumption [kWh]	
	(1)	(2)	(1)	(2)
1	0.418	0.646	0.418	0.646
2	0.764	0.883	0.346	0.238
3	1.068	1.082	0.304	0.199
4	1.347	1.258	0.279	0.176
5	1.612	1.421	0.265	0.163
6	1.869	1.577	0.256	0.155
7	2.121	1.728	0.252	0.151
8	2.430	2.014	0.309	0.286
9	2.826	2.381	0.397	0.367
10	3.344	2.858	0.517	0.478
11	3.898	3.370	0.554	0.512
12	4.469	3.898	0.572	0.528
13	5.094	4.475	0.625	0.577
14	5.692	5.027	0.598	0.552
15	6.244	5.537	0.552	0.510
16	6.731	5.987	0.487	0.450
17	7.158	6.381	0.427	0.395
18	7.611	6.800	0.453	0.419
19	8.120	7.270	0.509	0.470
20	8.738	7.841	0.618	0.570
21	9.376	8.429	0.638	0.589
22	10.136	9.130	0.760	0.701
23	10.831	9.772	0.695	0.641
24	11.393	10.291	0.563	0.519

[a] The columns (1) and (2) refer, respectively, to the scenario with normal consumption habits and to the scenario using the washing machine and the dishwashing machines during "off-peak" time, applying the potential consumption decrease in these machines (determined in subchapter 3.2.2; B; C and D) and eliminating the dispensable standby consumption from 0 to 7h – the overall potential scenario.

X. Potential impact in the national electricity consumption

Table A X-1 – National average daily electricity consumption impact of the potential consumption scenario in the national average daily electricity consumption, concerning three hypothesis: one with adhesion of 100% of the residential sector; one with the adhesion of 6 million (M) inhabitants; and another one with the adhesion of 3 M inhabitants (the total number of inhabitants is 10,555,853 **(INE, 2011)**).

t [h]	Total [GWh]	Total domestic [GWh]	6 M [GWh]	3 M [GWh]
1	5197	5822	5650	5423
2	4872	4570	4653	4763
3	4688	4390	4472	4580
4	4600	4303	4385	4493
5	4595	4298	4380	4488
6	4656	4358	4440	4548
7	4941	4638	4721	4831
8	5542	5441	5469	5506
9	6111	6000	6031	6071
10	6455	6338	6370	6413
11	6654	6533	6566	6610
12	6662	6540	6574	6618
13	6542	6423	6456	6499
14	6526	6407	6440	6483
15	6529	6410	6443	6486
16	6441	6324	6356	6399
17	6336	6221	6253	6294
18	6391	6275	6307	6349
19	6684	6562	6596	6640
20	6915	6789	6824	6870
21	6919	6794	6828	6874
22	6678	6557	6590	6634
23	6229	6116	6147	6188
24	5677	5574	5602	5639