UNIVERSIDADE DE LISBOA
FACULDADE DE CIÊNCIAS
DEPARTAMENTO DE CIÊNCIAS DA TERRA E ENERGIA

Assessing Energy Sufficiency Measures: User Perception and Experimental Validation

Leonor Maria Marques David

Mestrado em Engenharia da Energia e Ambiente

Dissertação orientada por:
Professora Doutora Marta João Nunes Oliveira Panão

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Resumo

Segundo a *International Energy Agency* (IEA), em 2022 os edifícios representaram cerca de 30% do consumo final de energia, dos quais 21% correspondem aos edifícios residenciais. Em termos de emissões globais de dióxido de carbono (CO_2), o setor residencial foi responsável por 17% das emissões, das quais 6% correspondem a emissões diretas e 11% a emissões indiretas. Em Portugal, de acordo com o Instituto Nacional de Estatística (INE) e a Direção-Geral de Energia e Geologia (DGEG), os edifícios residenciais foram responsáveis por 19,5% do consumo final de energia em 2020. Estes valores reforçam a importância de promover mudanças nos padrões de consumo energético, essenciais para a transição energética.

Em 2023, um trabalho colaborativo entre vários países europeus, propôs a integração da suficiência, eficiência e renováveis como estratégia para a segurança energética, sustentabilidade e alterações climáticas, uma vez que apenas a eficiência energética não é suficiente. A aplicação desta estratégia pode reduzir o consumo final de energia nos edifícios, entre 13% e 25%, em países como França, Alemanha e Reino Unido.

O termo suficiência pode ser definido pela quantidade de algo que é suficiente para um determinado objetivo. Suficiência energética refere-se apenas ao uso da energia necessária para assegurar o bem-estar, respeitando os limites ambientais. Contudo, por não apresentar uma definição concreta, pode ser interpretada como um nível de consumo adequado ou uma redução do consumo. As medidas de suficiência energética são práticas que visam reduzir o consumo energético por alteração do serviço prestado sem comprometer as necessidades básicas.

Este trabalho procura identificar as medidas de suficiência energética mais frequentemente referidas nos guias de boas práticas nacionais, analisar a perceção dos residentes portugueses face a este conceito e às suas ações. E, por fim, quantificar o potencial de aplicação de algumas medidas em contexto real.

A noção de suficiência foi introduzida na política de sustentabilidade por Sachs em 1993, como um complemento à eficiência, notando a necessidade de reduzir o consumo e redefinir prioridades para garantir o bem-estar humano sem ultrapassar os limites ecológicos. Em 2003, Princen aprofundou o conceito no meio académico, enquadrando a suficiência como estratégia para reduzir o consumo dentro da capacidade ecológica do planeta. O conceito de suficiência energética tem ganho importância nas últimas décadas, contudo ainda não existe uma definição consensual. Na literatura são apresentadas diversas abordagens, como o foco nas necessidades básicas, nos limites ambientais, no incentivo a mudanças comportamentais e em transformações estruturais.

A literatura destaca um conjunto vasto de práticas associadas à suficiência energética, distribuídas pelas áreas dos edifícios, mobilidade, alimentação e bens de consumo. Exemplos recorrentes incluem opções como, secar a roupa ao ar livre, a adoção de dietas à base de vegetais, e a substituição do uso do automóvel por caminhadas ou deslocações em bicicletas. No âmbito do setor residencial algumas das medidas de suficiência energética apresentadas são ajustar a temperatura do ar condicionado, desligar as luzes e equipamentos quando não estão a ser utilizados, preferir equipamentos com capacidade adequada às necessidades, aproveitar a iluminação e ventilação natural, e adaptar as configurações dos equipamentos. Apesar de menos mencionadas, surgem medidas como usar roupa adequada à temperatura interior, preferir duches a banhos, e reduzir o tempo de duches e de uso de equipamentos. Segundo a literatura estas medidas podem ser classificadas em várias tipologias, geralmente não divergindo muito entre si. Para efeitos de análise, considerou-se os tipos de medidas mais adotados, sendo medidas de redução, substituição e adaptação.

Para atingir os objetivos deste trabalho foram consideradas três fases. Numa primeira fase foi feita uma análise aos guias de boas práticas nacionais, para identificar as medidas de suficiência energética referidas no contexto do setor residencial. As práticas foram consideradas como medidas de suficiência energética se delas resultassem a redução do consumo de energia pela mudança do serviço prestado sem comprometer as necessidades básicas. Após a identificação das medidas, estas foram analisadas quanto à sua frequência de ocorrência nos guias. A fase seguinte centrou-se na aplicação de um inquérito, com o objetivo de recolher informação sobre práticas de consumo energético dos consumidores, bem como a sua perceção e aceitação quanto a medidas de suficiência energética. Adicionalmente, foram estudados dois fatores sociodemográficos, que pudessem condicionar os comportamentos, a idade e a pertença à comunidade da FCUL.

Na última fase realizou-se uma avaliação prática da aplicação de algumas medidas, através da monitorização do consumo de equipamentos com recurso a tomadas inteligentes, nomeadamente de máquinas de lavar a roupa e loiça, e termoacumuladores. Foram testadas medidas que envolvessem a variação da temperatura de lavagem, de programas, da velocidade de centrifugação, e do setpoint para o termoacumulador. Com base nos consumos registados, estimou-se a poupança energética associada a cada medida, bem como a correspondente poupança monetária e emissões evitadas, assumindo os seguintes fatores 0.245 €/kWh e 0.112 $kgCO_2eq/kWh$.

Entre os 18 guias consultados, foram identificadas 27 medidas. As mais referidas são desligar as luzes quando não são necessárias e a eliminação do consumo no modo standby. Em oposição, as menos mencionadas estão associadas ao uso da capacidade máxima do micro-ondas e à redução da iluminação decorativa interior. No que respeita à entidade produtora dos guias, observou-se que estes foram, em geral, elaborados por agências de energia ou por autoridades locais (câmaras municipais e juntas de freguesia). Verificou-se que os guias produzidos por agências de energia tendem a apresentar uma gama mais diversificada de medidas, incluindo recomendações com maior conhecimento técnico. Por outro lado, os guias elaborados por entidades locais incluem, de forma consistente, menos medidas e privilegiam ações com fácil implementação e com menos exigência técnica. Com a classificação das medidas, verificou-se que a maioria das medidas encontradas enquadram-se na categoria adaptação, estas referem-se ao ajuste da oferta e procura de energia de forma a melhor corresponder às necessidades sem implicar consumo excessivo. Seguindo as de redução, visam a diminuição da quantidade, intensidade e/ou duração do uso de energia. E as de substituição, à troca de práticas intensivas por alternativas menos exigentes.

Da aplicação do inquérito resultaram 316 respostas válidas, com 47% dos participantes entre os 18 e os 27 anos e os restantes com mais de 28 anos, o que permite uma análise comparativa representativa do fator idade. Apenas 24% dos inquiridos pertencem à comunidade da FCUL, sendo os restantes externos, conferindo a representativa da amostra para efeitos de comparação. Os resultados do inquérito indicam que muitas das medidas já são aplicadas pelos participantes, embora algumas revelem margem para melhoria, como a eliminação do consumo em standby. A principal motivação na adoção destas práticas deve-se às poupanças monetárias, surgindo as preocupações ambientais em terceiro lugar. A maioria dos participantes afirma familiaridade com o conceito de suficiência energética e atribui elevada importância às suas medidas. O estudo da possível influência destes dois fatores revelou que não se observam diferenças significativas nas práticas ou perceções entre faixas etárias distintas, nem entre participantes da comunidade FCUL e da população externa.

As medidas experimentais em contexto real permitiram quantificar o impacto energético, monetário e ambiental das medidas aplicadas. Para a máquina de lavar a roupa, verificou-se que reduzir a temperatura de lavagem leva à redução do consumo de energia. A substituição de ciclos a 60ºC por ciclos a 20ºC ou 30ºC permite reduções significativas no consumo, de 82.4% e 62% por ciclo. Que em 100 ciclos se traduz em poupanças na ordem dos 56 kWh, 13.6 € e 6.3 $kgCO_2eq$. Mesmo a mudança de 40ºC para 30ºC resulta numa redução relevante (48.9% por ciclo) e poupanças consideráveis (27.8 kWh, 6.8 € e 3.1 $kgCO_2eq$).

Na máquina da loiça, o impacto das medidas foi avaliado pela escolha de programas de lavagem. Observou-se a seguinte ordem crescente de consumo: rápido, ECO, normal e intensivo. A escolha do programa rápido revelou-se a mais vantajosa, por exemplo, passar do normal para o rápido pode levar a uma redução de 30.5% no consumo de energia por ciclo, resultando numa poupança de 34 kWh em 100 ciclos (8.3€ e 3.8 $kgCO_2eq$). Optar pelo programa ECO é amplamente recomendado e uma boa alternativa, no entanto, os resultados mostram que o programa rápido também deveria ser recomendado.

Para o termoacumulador, foram testadas três temperaturas de setpoint (60ºC, 55ºC e 50ºC) para avaliar o seu impacto no consumo de energia. Conforme previsto, as temperaturas mais altas resultam em consumos e perdas térmicas superiores. A redução de 60ºC para 50ºC revelou-se a mais eficaz, resultando numa poupança anual de 724.9 kWh, correspondendo a 177.6 € e 81.2 $kgCO_2eq$, assumindo 5 utilizações diárias de água quente. Contudo, este valor deve ser interpretado com alguma reserva, uma vez que resulta da análise de apenas um termoacumulador. As restantes alterações também apresentaram poupanças consideráveis, ainda que menos expressivas. Embora a alteração da temperatura exterior não configure uma medida de suficiência energética, influencia grandemente o consumo do termoacumulador, em março as perdas térmicas foram elevadas enquanto em junho foram praticamente inexistentes. Estabelecendo um setpoint de 50ºC observou-se uma diferença média de 10.5ºC na temperatura exterior, resultando numa redução de 0.814 kWh/dia no consumo de junho face a março.

Apesar de uma ligeira limitação de representatividade, este estudo oferece contributos relevantes sobre comportamentos e perceções, bem como quanto ao impacto da aplicação de certas medidas de suficiência energética no setor residencial.

Palavras-chave: Suficiência energética; Consumo de Eletricidade Residencial; Comportamentos energéticos; Ciclos de lavagem; Temperatura de setpoint

Abstract

Residential buildings account for a significant share of final energy consumption and associated emissions. Therefore, it is essential to rethink current practices to achieve energy transition. This study explores energy sufficiency (ES) in the residential sector, combining an analysis of good practice guides with a survey and experimental monitoring.

The research begins with an analysis of national guides promoting good consumption practices, namely ES measures, identifying typical recommendations. This analysis was followed by a survey aimed to understand consumers' habits, perceptions, and awareness regarding ES measures. Based on this, an experimental component was carried out to assess how the implementation of ES measures influences energy consumption. The measurements focused on quantifying the impact of changes in washing cycles in washing machines and dishwashers and on the temperature setpoint of water heaters.

From the guides analysis, it was found that the measures presented in them tend to converge around the same set of measures and are repeated in most documents. The survey responses showed that many of these measures are already being adopted by users, indicating a general awareness, and acceptance of ES measures. However, certain practices still allow for improvement.

Regarding the experimental phase, washing machines consistently consumed less energy at lower washing temperatures. For dishwashing, the short program proved to be the least energy consuming, even surpassing the ECO program usually recommended, implying the need to review and update the guides. In the case of the water heater, it was observed that reducing the temperature settings led to significant reductions in energy consumption, impacting both active consumption and thermal losses. Overall, these findings demonstrate that making even minor adjustments in appliance usage can lead to meaningful energy savings.

Keywords: Energy sufficiency; Residential Electricity Consumption; Energy behaviors; Washing cycles; Setpoint temperature

Nomenclature

Abbreviations and Acronyms

CLEVER	Collaborative Low Energy Vision for the European Region
CO_2eq	Carbon dioxide equivalent
DGEG	Direção-Geral de Energia e Geologia
EC	Energy conservation
EE	Energy efficiency
ES	Energy sufficiency
GHG	Greenhouse gases
INE	Instituto Nacional de Estatística
IPMA	Instituto Português do Mar e da Atmosfera
SDGs	Sustainable Development Goals

Index

List of Figures

List of Tables

1 Introduction

1.1 Contextualization

Despite the concerns and efforts regarding energy use, it is expected that energy demand continues to increase, due to population growth and their demand for better living conditions. Energy consumption in the building sector is mainly derived from the various energy services available and the frequency of use, with users playing a significant role in energy consumption. The building sector is an energy-intensive consumer, based on the International Energy Agency [1], building operations accounted for 30% of total final energy consumption in 2022, with 21% of this consumption related to residential buildings. This accounted for 17% of carbon dioxide (CO_2) emissions, with 6% relating to direct emissions and 11% to indirect emissions. According to Statistics Portugal (INE) and Directorate-General for Energy and Geology (DGEG), the Portuguese residential sector was responsible for 19.5% of the final energy consumption [2] in 2020. Considering these values is imperative for changing consumption patterns.

In 2023, the CLEVER report, resulting in a collaborative work between several European countries, highlighted a particular combination of sufficiency, efficiency and renewable to face energy security, sustainability and climate change [3]. Energy efficiency (EE) as a principle has yet to be fully implemented. Despite the increase on EE, rebound effects and growing consumption trends [4], [5], [6], highlight the fact that EE alone is not enough. However, combined with energy sufficiency (ES) is possible to achieve the desired goals. The report estimates that the final energy consumption in buildings, residential and non-residential, in France, Germany and United Kingdom, could decrease by 13% to 25% through energy sufficiency. The CLEVER scenario is based on SER framework, standing for sufficiency, efficiency, and renewables, which is an integrated approach to the energy system. The SER framework prioritizes the demand side by aligning energy needs to a level of services (sufficiency). Having established this level, energy intensity is further reduced through technological innovation (efficiency). The remain demand is expected to be supplied by renewable sources [7].

In simplistic terminology and considering Oxford Dictionary definition, sufficiency is defined as a quantity of something that is enough for a certain purpose [8]. When applied to energy, ES does not have an unanimous definition. For some authors it is an outcome, characterized by a level of energy service consumption that aligns with human well-being and environmental limits. Others, however, see it as a guide aiming to reduce energy service consumption in order to minimize environmental impacts [4]. ES measures are a set of actions, everyday practices and routines intended to reduce energy demand by promoting a sustainable change in energy service's quality and quantity while meeting people's basic needs [9], [10].

The concept of ES shares significant similarities with the earlier notion of energy conservation (EC) from the 1970s, developed as a response to the oil crisis [11]. During this period, the need to reduce energy demand was recognized. As a result the idea of EC was introduced to describe a wide range of actions, in particular limiting electricity supply, rationing petrol, promoting building insulation, and adjusting thermostats and turning off unnecessary lights [12], to reduce the demand as a response to resources scarcity and rising prices. These actions might have been the first step to managing energy use in a more sustainable way. EC refers to a decrease in energy demand by changing consumers' habits and behaviors, which were short-term measures and difficult to maintain. To tackle this issue, during the 1980s the emphasis changed to EE, which aims to maximize output while minimizing energy input through technological improvements. However, EE did not reduce energy demand as fast and as expected. Which led to the idea of ES, a complementary measure to efficiency and conservation.

In 2015, the United Nations Member States established the Sustainable Development Goals. The 17 SDGs provide a comprehensive framework for addressing global challenges, including poverty, inequality, climate change, and environmental degradation. Among these, several goals directly target energy sustainability and climate action, underscoring the global consensus on the urgent need to mitigate climate changes. Side by side with SDGs, the Paris Agreement has set targets to limit global temperature rise below 2°C [13].

Within the scope of this research, SDGs like number 7: Affordable and Clean Energy, 12: Responsible Consumption and Production, and 13: Climate Action, become particularly relevant to the matter of energy sufficiency, as its measures result in reduced consumption of energy, and therefore lower resources consumption.

SDG 7 focuses on ensuring access to affordable, reliable, sustainable, and modern energy for all [14], which aligns with the idea from ES concept to meet people's basic needs. Additionally, SDG 12 promotes sustainable consumption and production patterns [15], and SDG 13 takes urgent action to combat climate change and its impacts [16]. Motivating behavioral changes, such as turning off the lights and appliances when not needed, using equipment's full capacity, preferring line-drying laundry, avoiding oversized equipment's, lowering temperature settings for dishwasher and washing machine [17],[18], are example of ES measures that directly align with the purpose of SDG 12, with intention of a responsible consumption, and with SDG 13, taking part of climate action and proactivity.

SDGs can be seen as the inner circle of the Doughnut Economics theory [19], representing the basic human needs that must be met for people to live dignified and healthy, named 'social foundation'. Surrounding the inner ring is an outer circle which encompasses the ecological limits, 'environmental ceiling'. The concept of ES is connected to the idea of the Doughnut Diagram Theory, as they both emphasize the idea of fulfilling people´s essential needs within planet's limits.

The Doughnut Diagram, presented in figure 1.1.1, was developed by Kate Raworth for Oxfam in 2012 [20], which brought a new insight into sustainable development. This approach considers a 'safe and just space for humanity' that is placed between an 'environmental ceiling' and a 'social foundation', respecting both people's needs and ecological limits. It can be seen as the framework within which energy sufficiency fits.

The 'Environmental ceiling' is the outer circle of the doughnut, it includes nine planetary boundaries that define the ecological limits the planet can sustain without damage, proposed by Rockström et al. [21] in 2009. It was acknowledged that overstepping certain thresholds could lead to tragic consequences, these nine boundaries are: climate change, freshwater use, nitrogen and phosphorous cycles, ocean acidification, chemical pollution, atmospheric aerosol loading, ozone depletion, biodiversity loss and land use change [22].

The inner circle of the doughnut, known as the 'Social foundation', is a minimum limit where all individuals can satisfy their needs and thrive. Which includes access to food, water, health care, and education. Staying within the 'safe and just space for humanity' requires that human activities do not exceed these planetary limits while ensuring that everyone has access to the resources needed for a decent life.

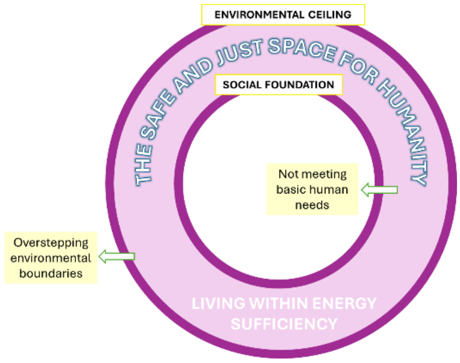


Figure 1.1.1: Raworth/ Oxfam Doughnut Diagram. Adapted from [20].

A question that may arise when presenting and discussing the concept of energy sufficiency is whether it makes sense to promote reduction in energy consumption through simple actions when several households still face energy poverty.

In the Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency [23], energy poverty is defined as the lack of access of a household to essential energy services, which provide basic and decent standards of living and health, such as adequate heating, hot water, cooling, and lighting, and the energy for household appliances. Mainly driven by a combination of factors, such as high energy cost, insufficient household income, high energy expenditure and poor energy efficiency of homes. However, each country has specific characteristics that influence its level of energy poverty, depending on national circumstances, cultural and social contexts, and existing energy and social policies.

According to data from the Eurostat data [24], considering all 27 European Union countries, the share of households unable to keep their home warm has shown a general reduction trend over the last decade, from 9.6% in 2015 to 6.9% in 2019. In subsequent years, this percentage fluctuated slightly among EU-27 households, but without major deviations, remaining between 6.9% and 7.5%. However, this decreasing trend was interrupted by the most recent energy crisis, largely triggered by geopolitical tensions following the invasion of Ukraine by Russia in 2022, which led to sharp increases and volatility in electricity and energy prices. This resulted in an increase in the energy poverty rate to 9.3% in 2022, and rising further to 10.6% in 2023, before decreasing to 9.2% in 2024.

In 2024, the highest percentage of people facing energy poverty were reported in Bulgaria (19%), and Greece (19%), followed by Lithuania (18%), Spain (17.5%) and Portugal (15.7%).On the contrary, the lowest levels were reported in Norway (2.2%), Finland (2.7%), Slovenia and Poland (3.3% both), and Luxembourg and Estonia (3.6%) [24].

Focusing on Portugal in particular, Eurostat [24] reports that the situation is consistently more severe than in the EU-27. In 2015, nearly one in four people (23.8%) reported an inability to keep their homes adequately warm. Despite the improvement noticed over the subsequent years, it reduced to 16.4% in 2021. The energy crisis interrupted this trend, in 2022 the number of households facing energy poverty rose to 17.5%, and in 2023 reached 20.8%, before decreasing slightly to 15.7% in 2024. Even though this decline, Portugal remains among the countries with higher levels of energy poverty in the European Union, reflecting low household incomes, inadequate building insulation, and inefficient heating systems. Furthermore, the relative burden of electricity and energy costs on households remains higher than before the crisis, indicating the lasting effects of price increases.

Leading to the fact that, nowadays, in Portugal, approximately 15% of the population is supposably living in energy poverty conditions, reflecting the need of policies that ensure minimum levels of comfort and well-being, the so-called 'the safe and just space for humanity'. Simultaneously, this means that the remaining 85% of Portuguese households do not face energy poverty and therefore have a greater possibility to adjust their energy practices without jeopardizing their basic needs.

For this last group, ES measures can play a significant role in reducing energy consumption by encouraging behavioral changes and adjustments in daily practices, while ensuring that ecological boundaries are not overstepped. Thus, ES is not about imposing restrictions on those households that already lack adequate access to energy, but rather about promoting reductions among those who can consume less without compromising their well-being. These realities demonstrate that ES and energy poverty should not be seen as contradictory or exclusive, but rather as complementary to each other. While households in energy poverty need support to ensure that their basic needs are met, those adopting ES measures are able to reduce their excessive energy consumption.

1.2 Objectives and Research Questions

The goals of this study are to determine the ES measures most frequently promoted by the Portuguese best practice guides, to understand how they are perceived by the consumer and their willingness to adopt ES measures, and also to explore whether the age and belonging to an academic community, namely FCUL, with a greater exposure to energy-related knowledge influence consumers' practices. And finally, to assess the actual impacts of implementing selected measures.

In this context, the research questions to be addressed are:

RQ 1: Which energy sufficiency measures are most frequently highlighted in Portuguese best practice guides?

This research question will be answered through a systematic content analysis of Portuguese best practice guides on residential energy consumption, with the objective of identifying the most frequently mentioned ES measures.

RQ 2: How do Portuguese residents perceive the identified energy sufficiency measures?

This research question will be answered through a survey, aiming to capture Portuguese user's perceptions, practices, and willingness to adopt the ES measures identified in RQ1.

RQ 3: What potential energy savings, cost reductions, and GHG emissions mitigations can result from implementing a set of energy sufficiency measures in residential buildings?

This research question will be answered through a quantitative analysis, using experimental data to estimate the impacts of implementing certain measures in residential buildings, considering energy consumption, monetary savings, and GHG emissions reduction.

1.3 Document structure

This document is organized into seven chapters, following a clear and logical progression to ensure a coherent and straightforward presentation of the work. The first chapter presents an overview of the topic, its framing into SDG, the study goals and its research questions.

The second chapter presents the theoretical background of the study. It traces the origins of energy sufficiency, presents the definition of ES from the point of view of several authors, and explores related terminology. Additionally, it presents a range of ES measures, followed by an overview of similar studies that serve as references.

Third chapter describes the methodology used to complete this work, detailing the steps taken to compile the Portuguese best practice guides and identify the measures promoted. It presents an overview of the survey structure and further considerations, and explains the approach adopted for the experimental validation of the selected measures.

The fourth chapter presents the results obtained from each stage of the research. And the fifth chapter summarizes the main conclusions of the study and points out considerations for future research.

Sixth chapter lists the references consulted during the work. And the seventh chapter presents a set of appendixes with supporting documents and additional materials.

2 Literature Review

The review will start by exploring the roots of sufficiency, tracing its historical context. This is followed by definitions and core ideas of ES. Afterwards, key terminology, such as energy services, energy needs, service demand, and energy demand, are going to be presented to set up an understanding. The review will then explore various ES measures, especially the ones related to the residential sector. Ultimately, similar studies in the field will be highlighted, providing perspectives on existing research.

2.1 Energy sufficiency definition

Often related to a contemporary strategy and a modern response to overconsumption, the concept of sufficiency is, in fact, a timeless idea whose roots trace back to earlier reflections on limits, balance, and the responsible use of resources. The concept of sufficiency was introduced into sustainability policy by Sachs in 1993 [25], as a complementary action to efficiency. Sachs highlighted the urge to reduce consumption and redefine priorities to achieve human well-being without overstepping ecological limits. In subsequent years, Sachs stated "While efficiency is about doing things right, sufficiency is about doing the right things." [26]. This statement emphasizes that efficiency focuses on improving the output/input relation, whereas sufficiency focuses on differentiating essential needs from overconsumption. Years later Princen brought the concept to academia, in 2003 [27], framing sufficiency as a strategy to consume less in absolute terms within planet's ecological boundaries.

Over the last decades, the concept of sufficiency has gained importance and recognition across diversified fields, especially in the context of energy sufficiency. Although, there is no universally agreed definition for ES, as different authors point distinct aspects, such as prioritizing individual basic needs [28], not overstepping environmental limits [4], encouraging behavioral changes [29], [30] and promoting structural transformation [31]. The following definitions of ES, drawn from the literature, illustrate how the concept has been contextualized and applied from several perspectives.

In his book [32], Princen explores the idea of sufficiency through common examples while presenting it as a notion of "enoughness" and "too muchness", a balance between having/using enough or excess. Likewise, Okushima [33] describes ES as an optimal balance, avoiding both energy poverty (insufficient consumption) and energy extravagance (overconsumption). Equilibrium in energy consumption is the major factor to avoid both insufficient and overconsumption. Insufficient consumption, or energy insufficiency, occurs when the energy consumption falls below that threshold of "enough" to meet human basic needs, resulting in energy poverty and limited access to essential services. On the other hand, energy extravagance reflects the excessive use of energy services, resulting in waste and environmental degradation. Following the same line of thought, Zell-Ziegler et al. [34] present the concept of ES as a way to decrease energy services use, by encouraging low-energy activities, in order to reach a level of "enoughness" compatible with sustainability.

Having presented an idea for ES definition, that balances between insufficiency and excess, is important to point different ideas regarding ES. In accordance with what was proposed by Muller [35], an energy sufficient life means using only the energy truly needed, understanding the essential for a good life while considering the environmental impacts caused by consumption choices. For Sorrell et al. [4], ES is defined as a reduced consumption of energy services, with the intention to minimize energy use and the associated environmental impacts. In the same way, Samadi et al. [36] associated sufficiency to limiting the demand for energy intensive goods and services to a level able to support a good life. From the point of view of Vadovics and Živčič [37], ES refers to a level of consumption that guarantees everyone has enough energy to satisfy their needs while respecting planet's ecological limits. Likewise, Burke's [38] definition for ES focuses on maximum amount of energy use that improves well-being, measured across society, while supporting renewable energy and EE efforts for fairness. These ideas underscore the concept of ES as a consumption level that guarantees both basic needs and environmental boundaries.

Another definition for ES presented in the literature involves changing the quality and quantity of the service provided due to reducing energy consumption. Thomas et al. [31] characterized ES as a reduction in energy consumption, accompanied by changes in quantity and/or quality of provided utility and technical services. Similarly, in [39] is described as a strategy to reduce energy input to a sustainable level. Bertoldi [40] proposed that in an ES situation, the amount of used energy decrease, while quantity and/or quality of utility and technical services change, as long as the energy services remain adequate to meet an individual's basic needs. Reflecting these insights, the present study adopts a working definition of ES as a reduction in energy consumption through changes in the service output, as long as basic needs are not compromised.

2.2 Related terminology

ES is often confused with EE, although the two concepts have distinct focuses. EE refers to using fewer inputs or less energy to produce the same amount of services or useful output [41]. While ES considers a reduction in energy input as the output service changes in quantity or quality.

Most definitions of ES emphasize meeting people's basic needs, setting a difference between needs and wants (enough and overconsumption). Needs are the essential requirements for survival and well-being, whereas wants are the non-essential desires beyond basic needs [42]. While needs are fundamental, wants are influenced by external factors. Similarly, energy needs refer to the essential energy requirements that enable people to perform necessary tasks for their well-being [42]. Energy needs drive the demand for specific energy services, which represent the means to satisfy those needs.

Several authors, when presenting their definitions of ES, often emphasize the idea of reducing energy services. In this context, [23] refers to energy service as the utility or obtained product from combining energy with energy-efficient technology to deliver the service. The concept of energy services is about meeting people's needs, including things like lighting, heating and cooling spaces, cooking and refrigeration [43].

Service demand quantifies how much of those energy services are required to meet the needs. Energy demand is the actual amount of energy consumed to fulfill the service demand.

For example, staying warm indoors is the energy need, while the energy service will be space heating, the service demand is the amount of heating needed, and the energy demand the amount of energy consumed.

2.3 Energy sufficiency measures

ES measures are essential for reducing energy consumption and promoting sustainable living. These actions involve changes in daily routines and lifestyle that reduce energy consumption. Despite the focus of this study on residential sector, it is fundamental to recognize that ES measures are being explored in other fields. The literature highlights a wide range of actions across various domains, including buildings, mobility, food, and goods [44], which illustrate the different strategies used to enhance ES.

Several of these measures are clearly identified as ES measures, although sometimes they appear categorized as energy saving measures [45], or as conservation behaviors [46],[47].

Some examples of ES actions reported in the literature, include preferring line-drying laundry rather than using a tumble dryer, plant-based diets over meat based ones, and walking or cycling instead of relying on private cars [30].

Of the various studies exploring energy sufficiency and its actions across the referred sectors, [29] and [44] provide a structured and comprehensive overviews of key actions. Drawing on these sources, the following examples illustrate some of the proposed strategies.

In the mobility field, it is common to recommend ES measures focusing on the reduction of private car use and air travel, by promoting walking or cycling for short distances and preferring traveling by train, and encouraging the idea of shared mobility, whether by carpooling or public transportation. As for the food sector, it is considered measures such as reducing food waste and adopting plant-based diets or reducing meat consumption. When it comes to buildings, both residential and tertiary, it includes reducing floor space, shifting in building type and reducing heating and cooling needs. The domain of goods, which includes materials and products, is less mentioned in the literature, however, it is typically recommended to reduce the overall product consumption, extend product lifespans, and also sharing goods, such as using community facilities. Nevertheless, within the scope of this research, only measures related to the residential sector will be considered from this point on, as the others fall outside the study's focus.

Although sufficiency is being increasingly recognized as playing a major role in reducing energy demand and environmental impacts, the barriers of sufficiency are multidimensional and transcend to consumer behavior and practices. In 2021, Sandberg [29] compiled a total of 36 publications, the most relevant to the sufficiency transition, to identify the main barriers to sufficiency explored in each of the articles. A total of five barriers were identified, including consumer attitudes and behaviors, culture, economic system, political system, and the physical environment.

In a recent review, Oliveira Panão [42], emphasized the importance of expanding the range of ES measures available to consumers. The main idea behind expanding ES actions is that the greater the dissemination of information, the greater the understanding and adoption by users. Based on this, this section pretends to present several ES measures related to the residential sector.

Thomas et al. [39] identify various ES actions related to hygiene and cleaning, particularly for clothing. These include wearing clothes for a longer period, reducing washing frequency, using washing machine at full capacity, reducing temperature settings, lowering spinning speed when not using a clothes dryer, and using shared facilities, such as community facilities and laundry shops.

Seyedrezaei et al. [47], analyzed the frequency of several ES measures related to comfort, lighting, and appliances. These measures included adjusting indoor temperatures, using portable heating or cooling equipment, dressing adequately for indoor temperatures, opening windows for fresh air and ventilation, closing windows to minimize solar gains, turning off lights when leaving a room, utilizing natural daylight, and turning off or unplugging unused devices.

Other commonly referenced ES measures in the literature focus on living space, as building size significantly impacts the environment due to their high energy consumption. The larger the buildings, the greater their energy needs tend to be, particularly for lighting, heating, cooling, and equipment.

Besides the land needed for construction, it is also necessary infrastructure to supply energy, water, and communication technology. These measures include reducing dwelling size and sharing living spaces or facilities [18], [29].

To illustrate the wide diversity of ES measures presented in the literature, a compilation of several actions for residential sector is presented in the following table, in descending order of occurrence. Although the intention is for the table not to be extensive, but rather to summarize representative examples of measures frequently emphasized in scientific debate.

Table 2.3.1: ES measures examples in residential sector.

ES measures	References
Adjusting indoor temperature settings	[9], [36], [39], [45], [47], [48], [49], [50], [51], [52], [53], [54]
Turning off lights when not in use	[30], [33], [45], [47], [51], [52], [53], [54], [55], [56], [57]
Avoiding oversized appliances/right-sizing appliances	[9], [36], [39], [48], [49], [52], [55], [56], [58], [59]
Switching off appliances when not in use	[30], [33], [39], [45], [47], [50], [51], [52], [57]
Using natural ventilation	[18], [30], [47], [48], [50], [54], [60]
Turning off appliances completely (avoid standby consume)	[9], [33], [39], [45], [47], [51], [57]
Line drying laundry instead of tumble drying	[18], [49], [51], [52], [55], [59]
Loading appliances at maximum capacity (e.g.: washing machine, dishwasher, oven)	[30], [39], [49], [50], [51], [59]
Using natural light	[47], [48], [49], [56], [58], [60]
Washing at lower temperatures	[39], [49], [50], [52], [55]
Reduce frequency of washing cycles	[39], [45], [51], [54], [58]
Adjusting appliances settings (e.g.: brightness of TV and computer)	[9], [33], [45], [49], [52]
Reducing living and heating/cooling space	[18], [36], [51], [52], [56]
Reducing number of appliances	[9], [36], [55], [56], [58]
Using community/shared facilities	[36], [39], [52], [56]
Reducing shower time	[45], [49], [53], [54]
Adequate clothing to indoor temperature	[47], [50], [51]
Avoiding keep-warm functions (rice cooker, etc.)	[33], [45], [50]
Reducing electrical devices' use time	[9], [48], [52]
Reduce hot water use	[18], [45], [58]
Adjusting refrigerator temperature	[33], [39], [49]
Limiting the use of air conditioning	[18], [45], [58]
Adjusting washing program	[39], [52], [57]
Closing blinds/windows to retain heat or reduce solar gains	[50], [53]
Preferring fresh food over frozen	[48], [49]
Reducing spinning speed	[39]
Delaying heating activation	[50]
Using a power strip and turning it off	[50]
Adjusting water heater temperature	[49]
Closing refrigerator door when not needed	[45]
Replace baths with showers	[50]
Adjust the flame to the bottom of the pan	[33]

2.4 Classifying ES measures

After presenting a range of different measures, it is useful to consider how these can be grouped into categories. This classification helps to better understand their scope and purpose. Different authors have suggested different types of ES actions, ranging from direct and simple two-category classifications to more detailed ones, up to five categories. A brief overview of these frameworks is presented in the following table.

Table 2.4.1: Overview of ES measures typologies in literature.

Literature	Type of ES measures suggested
Sandberg [29]	Absolute reductions; modal shifts; product longevity; sharing practices
Sorrell et al. [55]	Reduction; substitution
Thomas et al. [39]	Reduction; substitution; adjustment
Toulouse et al. [61]	Reduction; substituting; better sizing; sharing; lifestyle changes
Zell-Ziegler et al. [34]	Reduction; substitution; general

As presented in Table 2.4.1, despite the differences, some categories emerge consistently across the literature, namely reduction and substitution measures. This suggests a common ground in how ES measures are viewed and contextualized. Some authors broaden the classification to include other categories such as product longevity, sharing practices, adjustment, better sizzing, lifestyle changes and general measures.

Reduction measures are actions that lead to lower energy demand by limiting the quantity or intensity of consumption, such as reducing air conditioning use and the number of electrical devices. They cover different perspectives in the literature, like reducing the amount of consumption, decreasing the ownership and use of energy-intensive goods and services, and reducing the demand for energy services. In a broader sense, they represent a quantitative reduction in utility, reflecting an intentional transition to lower levels of consumption.

Substitution measures involve shifting from more energy-intensive modes of consumption to less demanding alternatives, like line-drying laundry instead of using the tumble dryer and using natural light when possible. They can take the form of switching from one mode of consumption to another that requires less resources, replacing high-consumption services with less energy-based ones, or adopting different practices that enable a transition to lower energy consumption. In the literature, this type of measure is often referred to as shifting measures.

Product longevity measures focus on extending the useful life of products, by repairing them and delaying their replacement and reducing overall demand for new goods and associated energy consumption.

Sharing measures refer to practices that promote the joint use of products and services by multiple individuals, like shared laundry facilities, thereby optimizing the utilization rate of energy-based services and simultaneously reducing the need for additional ownership.

Adjustment measures are tailored-fit solutions that ensure the provision of an adequate level of technological service, avoiding unnecessary overuse. Such as adjusting refrigerator and room temperature settings.

Better sizing measures are actions that promote the use of appropriate services and appliances that match the actual demand, avoiding energy waste resulting from oversized equipment or services.

Lifestyle changing measures involve shifts in daily routines and social practices, directed to low energy lifestyles.

General measures encompass actions that alter the regulatory or incentive framework to promote a reduction of greenhouse gas emissions more broadly, rather than targeting specific consumption practices.

2.5 State of art

In recent years, a growing number of studies in the field of energy sufficiency have emerged. In this regard, to complete the theoretical framework and reinforce the link between the research questions of this work and the existing literature, this section explores a set of case studies that illustrate how energy sufficiency has been addressed in different contexts regarding the residential sector.

The studies selected represent a variety of approaches, from future oriented scenarios, through interventions aimed at reducing consumption and quantifying those reductions, to surveys exploring users' perceptions and practices. Altogether, they facilitate a broader understanding of how sufficiency measures have been conceptualized and tested in practice.

2.5.1 Case study: Consumption and conservation behaviors in low-income housing (California)

In this case study [47], the researchers employed an online questionnaire over a two-month period (May to June 2023) across four affordable housing properties in Southern California, with a total of 120 responses accounted. The survey was specifically designed to capture the perspectives of low-income households living in affordable housing, a population that often experiences significant utility burdens and is critical to understanding conservation potential.

The questionnaire encompassed four main sections, consumption and conservation behaviors, related to energy and water practices; satisfaction and experience with building services, assessing comfort levels and the adequacy of household facilities; energy burden, analyzing the percentage of household income spent on utilities; and conservation drivers, identifying factors that encourage or discourage residents' engagement. This approach provided a comprehensive view of how residents of affordable housing engage with energy and water services, while highlighting the social and economic constraints that shape their behaviors. Although the study addresses the mentioned aspects, the present analysis focuses primarily on residents' everyday practices and behavioral patterns.

The results highlighted several everyday behaviors adopted by residents to manage energy consumption. Some of the most common measures include turning off the lights when not used, eliminating standby consumption and unplugging unused appliances. Most respondents report that they turn off appliances and electronic devices rather than leaving them on standby. And almost half of the residents said always or most of the time unplugging unused electronic devices. 60% reported always turning off the lights when leaving a room or the house, although a large number admitted that they sometimes left lights on unnecessarily.

Other relatively common strategies included using natural light whenever possible, leaving windows open for ventilation, adjusting clothing to indoor temperature, and modifying thermostat settings. In terms of kitchen practices, it was reported the frequent use of microwaves, ovens, and coffee makers, however more energy-intensive appliances such as dishwashers and washing machines were used less often.

It is worth noting that the study also explored residents' environmental concerns as a major factor in these practices. Most of the respondents expressed at least some level of concern and awareness for the environment and energy. Similarly, 56% of respondents reported adjusting their behaviors to save more on utility bills, while the other 44% said they did not adjust their behaviors due to economic savings.

Generally, the results revealed that while financial constraints remain an important factor, many residents also demonstrate an underlying environmental awareness that is shaping their daily practices. This suggests that affordable housing communities have great potential for energy conservation behaviors, provided that structural barriers are addressed and supportive policies are in place.

2.5.2 Case study: Occupant behavior and energy-saving potential (China)

This study assessed the impact of behavioral improvements on energy consumption improvements in urban residential sector of Hangzhou, China [62]. The objective was to compare households' energy consumption in July across two consecutive years. A total of 124 households in three typical residential buildings were selected for the study and then categorized into groups based on a type of building, floor area, and whether they are part of the educated group (behavioral improved) or the reference group.

Prior to the measurement in the second year, 62 of the 124 households participated in energy education workshops intended to encourage behavioral changes that could reduce their energy use. The recommendations emphasized adjustments on behavior, within a balance between an acceptable comfortable life and energy savings.

The suggested measures were mainly related to household appliances, namely air-conditioning, refrigerator, TV, computer, electric cooker, lighting, water heater, washing machine, microwave, fanner, and all the other equipment. And included practices such as adjusting setpoint temperatures, cleaning filter dust, reducing usage time, turning off appliances a few minutes ahead, using equipment's full capacity, eliminating unnecessary lighting, adjusting brightness, unplugging unused equipment, among others. Most of these energy-saving measures are ES measures, as there is a reduction in energy consumption within a service change, although some are EE measures.

According to the results, behavioral improvements can indeed reduce energy consumption. Comparing July 2007 and July 2008, more than 90% of those 62 educated households reduced their energy consumption, on average, above 10%. The influence of the household income was also studied, among other variables. The results showed that households without energy-saving education tended to increase their energy consumption, driven by improved living standards and the greater reliance on electrical equipment. While the households with energy-saving education would rethink their choices.

2.5.3 Case study: Energy sufficiency in the French debate (France)

In this article Toulouse et al. [63] investigate how sufficiency has been approached and modelled by comparing four scenarios for energy transition in France by 2050. For over two decades, the French négaWatt Association has been promoting the idea of ES in national discussion, especially through publication of energy scenarios focusing on ES.

The study compares four energy transition scenarios for France: the "2050 négaWatt scenario" (nW) by négaWatt Association, the "Transition(s) 2050: Frugal generation (Ad1) and Regional cooperation (Ad2)" by the French Energy Agency and the "Futures Energétiques 2050" (RTEs) by the French electricity grid authority. Although all recognize sufficiency, they differ significantly in methodology and level of quantification.

Regarding the sufficiency potential, the nW scenario and the RTEs were structured in a way that can isolate sufficiency assumptions. This approach allowed an assessment of potential energy savings from sufficiency, compared to a scenario that does not consider sufficiency, as illustrated in the following figure. In summary, nW and RTEs stand out as mixed qualitative and quantitative scenarios with numerical assumptions, while Ad1 and Ad2 remain more qualitative, with less solid quantifications derived from narratives.

In the building sector, the nW scenario highlighted measures like higher cohabitation, moderate tertiary space growth, higher share of collective housing, renovation instead of new construction, better sizing of building equipment and shorter use of appliances, achieving 10% of energy savings by 2050. On the other hand, the RTEs scenario include measures like shared spaces and higher cohabitation, reduced shop surfaces, work from home, fewer advertisements and displays, moderation on heating and cooling, and on appliance use, leading to 15% of energy savings by 2050.

For the mobility sector, both scenarios include similar measures, such as carpooling, lighter vehicles, lower speeds, home office, shorter travel and modal shifts. The nW scenario places additional emphasis on reducing freight transport and achieves 28% energy savings by 2050. Meanwhile, the RTEs scenario focuses on a more centralized urban planning, resulting in 22% of energy savings.

Lastly, in the industry sector, the nW scenario proposes changes like more sustainable food production, reduced inputs in agriculture, longer product lifetime, fewer sales of vehicles, high material recycling rates and reducing packaging, leading to 21% of energy savings. In contrast, the RTEs scenario focuses on less industrialized food, fewer chemical inputs in agriculture, longer product lifetime, fewer sales of individual vehicles, renovation instead of new construction, increased use of biobased materials, circular economy and reduced packaging, achieving 13% of energy savings by 2050.

3 Methodology

This chapter outlines the methodology adopted to address the research questions of this study, which aim to explore, understand and validate ES measures in residential sector in Portugal. The methodology is structured in three complementary phases, each corresponding to a research question.

3.1 Portuguese best practice guides

The first step of this research involved identifying relevant best practice guides related to ES in the residential sector in Portugal. The aim was to collect publicly available documents that could be accessed and consulted by anyone interested in the subject.

In order to find the guides, an internet search was conducted using keywords in Portuguese, such as "suficiência energética", "guias de suficiência energética". These terms were considered to identify documents written in Portuguese and important to the Portuguese residential context.

As no specific ES guides for the residential sector were found, the scope of the research was broadened to include more general documents promoting responsible energy use and energy efficiency. This decision was made based on insights from the literature review, which highlighted the common confusion between ES and EE, and therefore in its measures. Thus, guides and manuals focused on energy efficiency were also considered for analysis.

Once a set of relevant guides was compiled, each guide was reviewed to identify the measures that align with energy sufficiency principles and regarding the residential sector. In this study, ES measures are defined as changes in individual actions intended to reduce energy consumption, resulting in modifications in the service provided without compromising basic human needs.

After compiling all the ES measures presented in each guide, the measures were then standardized through a simplification, this step aimed to ensure consistency and to facilitate the following analysis. The simplification consisted in summarizing and rephrasing the measures presented in the guides, which were often presented in a long and descriptive form, outlining the intention behind each measure. To streamline the analysis and allow for easier comparison across guides, a shorter and more direct label was assigned to each measure, capturing its core idea. A table presenting the simplified designation alongside a corresponding description was created to illustrate this simplification, in Appendix A. Subsequent to this patronization process, a frequency analysis was conducted to determine how often each measure appeared across the guides.

3.2 Online survey

For the second phase of the research, an online survey was conducted to gain insights into user behavior regarding energy consumption and to assess the perception and awareness of energy sufficiency among consumers. The questionnaire, presented in Appendix B, was available online using the Google Forms platform and open for a period of two months. The survey was reviewed and approved by the Ethics Committee of the Faculty of Sciences of the University of Lisbon (FCUL), ensuring compliance with ethical standards for research involving human participants.

The first section starts with five questions about the socio-demographic characteristics of each participant, such as age group, level of education, residence region, type of residence, and whether the participant is a member of the Faculty of Sciences of the University of Lisbon community (as a student, researcher, professor, staff member, etc.) or not.

The following sections focused on participants' habits and practices regarding energy consumption in their houses, particularly related to lighting, domestic appliances, and heating and cooling systems.

Additionally, a few questions were raised to assess participants' understanding and perception of the concept of ES, if respondents were familiar with the term and the level of importance they attribute to it. But also, to understand the motivations behind the adoption of ES measures, including whether these practices are consciously implemented, driven by environmental concern, financial considerations, or other factors.

While the survey was open to the public in general, it was also particularly directed at the FCUL community. As the survey simultaneously aimed to explore potential differences in behaviors and perceptions between members of the FCUL community and participants outside this community. In addition to being distributed through personal networks and social media platforms, the questionnaire was also distributed via institutional mailing lists and in the FCUL newsletter *CIÊNCIAS PROMOVE*.

To ensure the reliability of the results from the survey to compare potential differences in practices regarding energy use between FCUL members community and individuals outside this community, it is important to have a minimum number of answers from FCUL members that is a representative sample of the population. As a representative sample is a smaller group that has the same characteristics as the population [64].

Additionally, to the FCUL community, responses from individuals outside this community were also collected. Despite this sample being relatively small compared to the Portuguese population, it will still be relevant for the purposes of this research, as it will allow a meaningful comparison between FCUL and non-FCUL respondents.

To calculate the required sample size, considering the total population, the desired confidence level and margin of error, and population proportion of 0.5, which yields the most conservative sample size when the exact population proportion is unknown.

$$n = \frac{\frac{z^2 \times p(1-p)}{e^2}}{1 + \left(\frac{z^2 \times p(1-p)}{e^2 N}\right)} \tag{3.1}$$

Where:

n = sample size

z = z-value associated with the desired confidence level

p = estimated population proportion

e = margin of error

N = total population size

According to [65], a total of 5513 students were enrolled in 2024/2025 at FCUL and the staff, in 2024, was composed by 717 people, making a total of 6230 people belonging to FCUL's community.

The following table presents the resulting sample sizes required for a representative sample from the FCUL community, for different combinations of confidence levels and margins of error, assuming a population proportion of 0.5 and a total population of 6230 individuals. These values were calculated using the equation above. The confidence level associated to a certain confidence interval presents the confidence of the results reflecting the population, and the margin of error represents the difference expected between the sample and the population in maximum terms [66], [67].

Table 3.2.1: Required sample sizes for different combinations of confidence levels and margins of error.

Confidence level	z-value	Margin of error (e)	Required sample size (n)
95%	1.960	5%	362
90%	1.645	5%	259
95%	1.960	10%	95
90%	1.645	10%	67
95%	1.960	20%	24
90%	1.645	20%	17

3.3 Experimental validation

The final part of this study focuses on the experimental application of a range of ES measures, with the aim to quantify their impact on household energy consumption. Measurements were carried out in the homes of volunteers.

To monitor energy consumption, the smart plug TP-Link Tapo P110 was used. It allows real-time tracking of energy use of a connected device. The smart plug connects to an app, named *Tapo*, which enables users to monitor energy consumption in real time and to export the data, in a CSV format for more detailed analysis. This device records energy use on an hourly basis, storing this data for up to 7 days, and simultaneously records power every 5 minutes, stored for a period of 24 hours.

The ES measures tested were the following. For washing machines, the tests focused on the impact of lowering the washing temperature (e.g.: 30ºC, 40ºC and 60ºC), and, in a few cases, comparing the energy consumption of ECO program, as well as the influence of adjusting the spin speeds. As for the dishwasher, it was compared the energy consumption of the different programs, namely the ECO, short, normal, and intensive program.

For the storage water heaters, it was tested the influence of adjusting the setpoint temperatures on energy consumption. The duration of hot water use, although not directly measured, was acknowledged as an important factor affecting energy consumption. Additionally, the influence of outdoor temperature on energy consumption was also observed, as it directly affects heat loss from the tank and, consequently, the energy required to maintain water at the desired temperature.

These measures were chosen due to the fact of the referred appliances representing a significant share of household energy use. Adding to it, they are commonly mentioned in energy sufficiency guides and considered particularly relevant, even though there are several other measures that could be applied. Lastly, the measures are easy for the volunteers to apply independently, without any additional support, after explaining the purpose of this step for the study.

This experimental phase included a total of 7 washing machines, 5 dishwashers, and 2 storage water heaters. These numbers were determined by the availability of the appliances in each of the volunteered households.

Measurements duration varied depending on the daily routines of the households. For the washing machines and dishwashers, the monitoring period lasted at least for two weeks, but in some cases, extended over a month, to ensure a representative sample of energy consumption across multiple programs and temperature settings.

In the case of the water heaters, one was monitored for two weeks, in March and June. And the other one was monitored for a little more than three weeks, during which time three setpoint temperatures (50ºC, 55ºC and 60º) were tested. It should be noted that storing water at low temperatures can promote the growth of Legionella bacteria. However, the risk is relatively low at these temperatures, especially since some modern water heaters include periodic temperature peaks (thermal shocks) to mitigate this risk and ensure safe water storage.

During this period, volunteers were asked to keep a simple record sheet, a blank version of this sheet is presented in appendix C, where they noted the program, temperature, date and a few more details about the cycle used every time the appliance was used. This information represents a significant and essential part of the dataset, to accurately match the recorded energy consumption data with the correspondent usage patterns.

Although the tested appliances have different intrinsic and extrinsic characteristics, such as capacity, age, washing programs, spin speeds, detergents used, and water hardness, the analysis focuses on the variations in energy consumption associated with the changes in washing cycles temperature, setpoint temperature, and the use of eco and short programs. These variables are common features in the appliances under analysis.

Therefore, it is important to emphasize that the purpose of this comparison is to identify general trends in the impact of temperature and program type on energy consumption, rather than to evaluate the performance of each appliance, regardless of other influencing factors.

To analyze the results, the first step involved matching the energy consumption data recorded by the smart plug with the corresponding usage details recorded by the volunteers. Once all the data was compiled, it was carried out an individual analysis for each appliance.

For each temperature and program, average energy consumption was calculated, alongside the percentual increase or/and decrease in consumption when passing from the lowest temperature cycle tested to the highest temperature and vice versa, as well as for the programs tested. After this separate analysis, a comparative assessment was conducted across all case studies for each appliance, in order to identify trends and insights on the impact of the tested ES measures.

Due to some inconsistencies in the water use records provided by the volunteers during the monitoring of the water heaters, certain assumptions and corrections were made to enable a more reliable analysis. This included the classification of different hot water uses and the adoption of a fixed value for the cold tap water temperature.

According to Jordan et al [68], hot water uses are categorized into four different types, short, medium, shower and bath. Each category has an associated flow rate, duration, volume per use, and daily frequencies. The authors considered a hot water temperature of 45ºC and a mean consumption of 200 L per household as input parameters. Short and medium uses typically correspond to hand washing, dishwashing and other similar uses. These uses have the lowest flow rate as well as lower duration, resulting in a volume of 1 and 6 L per use. In contrast, showers and baths have higher flow rate and duration, resulting in an average hot water volume per use of 40 L and 140 L, respectively.

For the purpose of this analysis, only two categories were considered: dishwashing and other small uses, and baths and showers. This division aligns with the range between medium and shower uses, providing a distinction between lower and higher water consumption uses. However, the difference between these two categories is quite significant, 6 L for medium uses and 40 L for showers.

And, when compared to the collected data, most values fall between these two categories, which makes the classification ambiguous. So, a volume threshold was established to distinguish between different types of use. As a result, estimated hot water use above 8L are classified as showers or baths, and those below are classified as hand or dishwashing.

Firstly, the energy consumption data recorded by the smart plugs were converted to the equivalent amount of water heated, expressed in liters, using the following formula.

$$V = \frac{Q}{\rho \cdot c_p \cdot \Delta T} \tag{3.2}$$

Where:

V = volume of hot water used (m³)

Q = energy consumed (J)

ρ = density of water (1 kg/m³)

c_p = specific heat capacity of water (4.18 kJ/kg.K)

ΔT = difference between the water heater setpoint temperature and the cold tap water temperature (K)

To estimate the water consumption, it was necessary to assume a value for the temperature of the cold water entering the water heater. For that purpose, the formulas presented in [69] were used, equation 3.3.This article compiles several models developed by different authors to estimate tap water temperature, in degrees Celsius, based on air temperature data. It is important to point out that the following values are for Lisbon, which is appropriate given that the experimental measurements of water heaters also took place in Lisbon.

$$T_m = \overline{T_a} + \Delta T_{of} - \alpha \cdot \Delta T_{amp} \cos(\phi) \tag{3.3}$$

Where:

T_m = temperature of the mains water (ºC)

$\overline{T_a}$ = annual mean temperature of ambient air (16.8 ºC)

ΔT_{of} = offset temperature difference (-2 ºC)

α = reduction factor, defined by:

$$\alpha = 0.326 + 0.021\overline{T_a}$$

ΔT_{amp} = annual ambient air temperature (5.3 ºC)

ϕ = phase angle, defined by:

$$\phi = \frac{2\pi}{365}(d - d_{min})$$

d = Julian day

d_{min} = Julian day corresponding to the minimum point of the mains water temperature (45.75)

In order to simplify the model and focus on the seasonal extremes of cold tap water temperature, only the maximum and minimum values of cosine function were considered, so the $\cos(\phi)$ is either 1 or -1.

For $\cos(\phi) = 1$, $T_m = 11.2$ ºC.

And for $\cos(\phi) = -1$, $T_m = 18.4$ ºC.

These values represent the expected range of cold tap water temperatures entering the water heater during the year. As the goal is not to analyze cold tap water temperature variations, the average value between the minimum and maximum estimated temperature of mains water was used. Therefore, a constant cold water temperature of 15 ºC will be considered throughout the study.

Additionally, another study [70] conducted in Lisbon reported that the measured mains water temperatures at four points, varies between 10 ºC and 25 ºC over a year. This range supports the use of 15 ºC as a representative value in this research.

By observing the data collected from the water heaters, it became evident that energy consumption occurred even when hot water was not used. Although this consumption did not occur ongoing, they tended to follow a recurring pattern, which corresponds to thermal losses.

To accurately compare the influence of different setpoint temperatures on energy consumption, it was necessary to apply a correction to all recorded values. This consisted of identifying the maximum loss value observed in the thermal loss band for each setpoint temperature. These values were therefore applied as an hourly correction across the dataset to isolate active-use energy consumption from standby consumption. It is important noting that different correction values were identified for each setpoint temperature, as thermal losses increase with the temperature difference between the water in the tank and the surrounding environment.

However, for the analysis of the influence of outdoor temperature, such correction was not applied, as thermal losses in June were negligible. And applying such correction in March, where significant thermal losses were observed, would have unfeasible the comparison between both periods.

On the final stage of the analysis, the trends identified for each appliance regarding energy consumption, expressed in average savings or increases in kWh, will be transposed into monetary terms (€) and global warming impact ($kgCO_2eq$).

This conversion implies selecting conversion parameters, such as the average electricity price (€/kWh) in Portugal for residential purposes and the emission factor associated to electricity generation ($kgCO_2eq/kWh$). According to [71], the average carbon intensity of electricity generation in Portugal, in 2024, was 0.112 $kgCO_2eq/kWh$. And based on [72], the electricity price on average for residential use in Portugal over the last three semesters, namely 2023 S2, 2024 S1 and 2024 S2, was approximately 0.245 €/kWh.

4 Results and Discussion

This chapter presents the main findings of the research, organized in three sections. First, a review of the best practice guides in Portugal identifies the most frequently recommended ES measures, which are then classified according to the most common classifications found in the literature (section 4.1). Second, the survey results are presented, providing insights on users' awareness, perceptions, and daily practices regarding energy consumption (Section 4.2). Finally, a selection of ES measures is tested experimentally in real-life situations to quantify their impact on energy use (section 4.3).

4.1 Identification and classification of ES measures in Portuguese guides

To identify the most common and recommended ES measures for the residential sector in Portuguese best practice guides, a total of 18 documents were analyzed, selected according to the search criteria described in the methodology. To facilitate identification and referencing throughout the analysis, each guide was assigned a simplified designation, numbered from 1 to 18, as detailed in appendix section (appendix D).

Despite the limited range of best practice guides reviewed, thus may not encompass all those related to the topic, the recommended measures and suggestions identified are consistently similar and rooted in the same principles. Therefore, any additional guide that may exist for Portuguese residential buildings is unlikely to deviate significantly from the observed pattern. Furthermore, the measures found in these guides not only vary little among themselves, but also closely resemble those presented in the literature.

Across the 18 guides reviewed [73 - 90], 27 ES measures were identified. Most of the guides analyzed are presented as energy efficiency guides or general good practice guides for responsible energy use. However, most of the measures included considered to be EE measures are, in fact, more accurately described as ES measures. Rather than aiming to maximize the output/input ratio, ES measures seek to promote behavioral changes that lead to a reduction in energy consumption without affecting individuals' fundamental needs. Which is clear evidence of the lack of documents available on ES and its measures for user's general knowledge, resulting on the current confusion made around ES and EE concepts, particularly on Portuguese residential sector.

An overview of the matrix presented in appendix E highlights notable differences in how each guide addresses practices aligned with energy sufficiency. Among the 18 guides, documents 1, 2, 15 and 18 are the ones presenting the highest number of measures, precisely with twenty ES measures. Particularly, these guides were developed by entities such as energy agencies, which might reflect greater technical expertise or a more structured approach. On the contrary, documents 7, 14 and 17 include a reduced number of measures, only five measures. These guides are namely authored by parish councils or other local entities, suggesting a more simplified approach regarding ES, in detail further on.

While some ES measures appear frequently across most of the analyzed documents, reflecting broad consensus about their relevance, others are referenced only once or twice. This variation is further detailed in the following figure. Figure 4.1.1 summarizes the number of times each ES measure was cited across the guides.

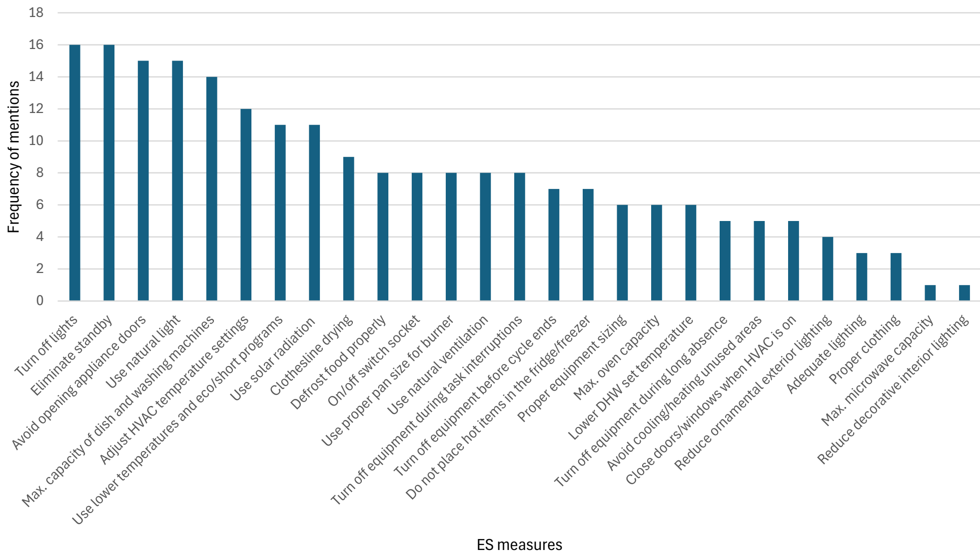


Figure 4.1.1: Frequency of ES measures in best practice guides.

The most frequently mentioned measures, with 16 mentions each, are turn off lights and eliminate standby power consumption. These are simple behavioral measures that require no financial investment and are widely acknowledged as effective ways to reduce energy use. Close behind, with 15 mentions each, are avoid opening appliances doors and using natural light, suggesting a strong awareness of how small changes in daily habits can contribute to energy savings.

Several suggested measures focus on the efficient use of appliances, for example, maximizing the capacity of dishwashers and washing machines, mentioned 14 times, and using lower temperatures and ECO or short programs, appeared 11 times. These actions reflect an increasing understanding of how user choices affect energy performance of appliances.

Others commonly recommend ES measures focus on thermal comfort and indoor climate. Such as adjust HVAC (heating, ventilation and air conditioning) temperature setting, mentioned 12 times. Several guides suggest adjusting temperature setpoints a few degrees below or above the outdoor temperature, with recommendations being around 25ºC in summer and 19-20ºC during the winter. It is also recommended taking advantage of solar radiation (or solar gains) (11 mentions) and natural ventilation (8 mentions), passive strategies to reduce heating and cooling needs, as natural ventilation can be used to cool down spaces naturally during the summer and solar radiation to naturally heat spaces during the winter.

Among the less frequently mentioned actions, other noteworthy measures include, prefer using clothesline to dry clothes instead of dryers, with 9 mentions. Measures such as defrosting food properly and in advance, using sockets with on/off switch, using a proper pan size for burner, and turning off equipment during task interruptions, were mentioned 8 times.

A few other measures mentioned less often but still relevant, include turning off equipment before task is complete if adequate and not placing hot items in the fridge or the freezer (both 7 mentions). It is also mentioned proper sizing equipment to match household needs (6 mentions), maximizing oven and microwave capacity (6 and 1 mentions respectively), and lowering domestic hot water (DHW) set temperature, mentioned 6 times.

With fewer mentions it was recommended to turn off equipment during long absences, avoiding cooling and heating of unused spaces, and keeping doors and windows closed when HVAC systems or other forms of climate control are being used, cited 5 times each. Reducing ornamental exterior lighting, 4 mentions, while minimizing decorative indoor lighting was mentioned once. Adjusting clothing to suit indoor temperatures and tailoring lighting to the specific task were each mentioned twice.

A review of the ES measures presented in the guides revealed notable differences in focus and content between the guides developed by energy agencies and those produced by local entities. Despite the aim of both groups promoting better practices of energy use, the depth of recommendations diverges slightly. Table 4.1.1 presents a cross-comparison of ES measures according to the type of guide producer, simultaneously providing a simplified visual analysis of overlaps and divergences.

Guides issued by energy agencies, in light blue, tend to have a more systematic and technical approach, including broader and more technical measures. Measures such as adjusting indoor temperature settings, lowering the DHW temperature setpoint, turning off equipment slightly before finishing, and avoiding heating or cooling unused spaces are frequently mentioned across energy agencies guides, these recommendations tend to require some level of technical knowledge.

On the other hand, the guides developed by parish councils or other local entities, shown in light orange, tend to focus on simpler behavioral practices and easier to implement. Like turning off lights when not needed, eliminating standby energy consumption, avoiding opening appliances doors frequently or prolongedly, and using natural light, are measures that appear more consistently in these guides. These recommendations are generally straightforward, easily applicable, and do not require significant technical understanding.

This divergence may be related to differences in technical expertise, target audience, or intended purpose of the documents. With energy agencies producing more specialized and technical content, whereas local councils prioritize general awareness and practical advice for the population.

Table 4.1.1: Cross-comparison of ES measures by entity type.

		Energy Agencies												Parish Council & Local Entities					
	Document Designation	**1**	**2**	**3**	**4**	**5**	**8**	**9**	**10**	**11**	**12**	**15**	**18**	**6**	**7**	**13**	**14**	**16**	**17**
ES Measures	Turn off lights	■	■	■	■	■	■	■	■	■		■	■	■		■	■	■	■
	Eliminate standby	■	■	■	■	■	■	■	■		■	■		■	■	■	■	■	■
	Avoid opening appliance doors	■	■	■	■	■	■		■	■	■	■	■	■	■	■		■	
	Use natural light	■	■	■	■	■	■	■	■	■		■	■	■	■			■	■
	Max. capacity of dish and washing machines	■	■	■	■	■	■		■	■	■	■	■		■			■	■
	Adjust HVAC temperature settings	■	■		■	■		■	■	■	■	■	■			■		■	
	Use lower temperatures and eco/short programs	■	■		■	■	■			■	■	■	■					■	■
	Use solar radiation			■	■	■			■	■	■	■	■			■	■	■	
	Clothesline drying	■	■				■		■	■	■	■	■				■		
	Defrost food properly	■	■		■	■	■			■		■	■						
	On/off switch socket	■	■	■	■		■				■	■	■						
	Use proper pan size for burner	■	■		■	■	■			■		■	■						
	Use natural ventilation	■	■		■		■			■	■	■		■					
	Turn off equipment during task interruptions	■	■				■					■	■			■	■	■	
	Turn off equipment before cycle ends	■	■			■	■			■		■	■						
	Do not place hot items in the fridge/freezer	■	■			■	■		■			■				■			
	Proper equipment sizing	■	■		■	■				■			■						
	Max. oven capacity	■	■		■	■				■			■						
	Lower DHW set temperature	■	■		■	■				■			■						
	Turn off equipment during long absence				■	■	■			■			■						
	Avoid cooling/heating unused areas						■	■	■			■	■						
	Close doors/windows when HVAC is on						■	■	■				■			■			
	Reduce ornamental exterior lighting	■	■									■	■						
	Adequate lighting	■	■									■							
	Proper clothing											■		■	■				
	Max. microwave capacity					■													
	Reduce decorative interior lighting					■													

Considering the differences shown, regarding the type of entity responsible for developing practice guides on more appropriate energy use, it is essential to have a stronger collaboration between energy agencies and local entities to ensure that the guidance provided to the consumer is both technically robust and ease of implementation.

Although the comparison across entities highlighted differences in the scope and emphasis of the recommendations, it does not fully capture the nature of the measures themselves. To this end, the measures identified were categorized by type, according to the literature presented in section 2.4, namely reduction, adjustment, and substitution measures. This step allows for a better understanding of the logic underlying the proposed practices and provides a complementary perspective to the comparison based on entities.

The following table presents a brief definition of the mentioned types of measures. Building on this, table 4.1.3 presents the classification of the identified measures according to the three categories.

Table 4.1.2: Types of ES measures and definitions.

Category	Definition
Reduction measures	Actions aiming to decrease the quantity, size, or duration of energy services, leading to a lower overall demand.
Substitution measures	Actions intended to replace energy-intensive practices or technologies with less demanding alternatives.
Adjustment measures	Actions aiming to adapt how energy services are supplied or requested to better match actual needs and preferences.

The classification between reduction and adjustment measures may be unclear in some situations, since both involve changes in how the service is provided. Reduction measures refer to quantitative changes in utility, focusing on quantitative reductions in the sizes, features, or usage time to reduce energy demand. Some examples include reducing shower time or turning off appliances before the task is completed. On the other hand, adjustment measures aim to adapt the way energy services are provided or requested to match needs and preferences, without reducing the perceived level of service. It can be viewed as an intention to optimize the use of existing devices, ensuring adequate service without unnecessary overconsumption. For example, lowering setpoint temperature of a water heater or lowering washing temperature are considered adjustment measures, as the service (hot water and clean clothes) continues to be provided, but in a way that avoids excessive energy consumption. To address this uncertainty, two guiding questions can be applied: does the measure reduce the amount of service provided (reduction)? Or does it optimize how the service is delivered without lowering the service level (adjustment)?

For example, the measure turning off the lights was classified as an adjustment measure rather than a reduction, because it refers to turning them off when it is not needed, thus avoiding unnecessary use without reducing the level of service. Likewise, avoiding opening appliances' doors was also considered an adjustment measure, as it prevents losses in the equipment operation without implying a reduction in the service itself. In contrast, avoiding heating or cooling unused areas was categorized as a reduction measure, as it intentionally reduces the space air-conditioned by active systems, and thus reduces the energy consumption. In the same way, wearing proper clothing to indoor temperatures was classified as a reduction measure, as it reduces the dependence on heating and cooling systems

Table 4.1.3: Classification of ES measures identified.

Classification	ES measures
Adjustment	Turn off the lights
	Eliminate standby
	Max. capacity of dish and washing machines
	Adjust HVAC temperature settings
	Use lower temperatures and eco/short programs
	On/off switch socket
	Use proper pan size for burner
	Do not place hot items in the fridge/freezer
	Proper equipment sizing
	Max. oven capacity
	Lower DHW set temperature
	Close doors/windows when HVAC is on
	Adequate lighting
	Max. microwave capacity
	Avoid opening appliance doors
Reduction	Turn off equipment during task interruptions
	Turn off equipment before cycle/task ends
	Turn off equipment during long absence
	Avoid cooling/heating unused areas
	Reduce ornamental exterior lighting
	Proper clothing
	Reduce decorative interior lighting
Substitution	Use natural light
	Use solar radiation
	Clothesline drying
	Defrost food properly
	Use natural ventilation

The distribution reveals that most measures belong to the adjustment measures category (15), followed by reduction (7), while substitution measures are less mentioned (5). In relative terms, it corresponds to almost 56% of the identified measures being categorized as adjustment measures, 26% as reduction, and 19% as substitutions measures. This suggests that the reviewed guides tend to focus on optimizing existing appliances, technologies and practices rather than directly reducing energy use or replacing energy-intensive services with alternative solutions.

Although this distribution by general categorization of ES measures provides valuable insight into the focus of the reviewed guides, it is possible to gain a more detailed understanding by simultaneously considering the type of producing entity. The figure below gives an overview of how the distribution of adjustment, reduction, and substitution measures depends on the entity producing the guides.

As shown in figure 4.1.2, the frequency of adjustment, reduction and substitution measures is relatively similar between energy agencies and local entities. In both entities, adjustment measures represent slightly more than half of the total identified measures, 61.1% in energy agencies and 63.2% in local entities. This reflects the trend of a stronger emphasis on improving the use of existing devices and practices. Reduction measures represent 15.6% for energy agencies and 13.2% for local entities of the total suggestions presented, similarly substitution measures accounted for 23.3% in energy agencies and 23.7% in local entities.

Interestingly, local entities show a slightly higher share of reduction and substitution measures in comparison to energy agencies, indicating a more openness to shift for less energy-intensive services and directly reduce energy demand. Overall, the results suggest that despite the local entities tend to present fewer measures and with less technical expertise the balance between the three categories of measures is aligned with the measures presented in energy agencies guides. This indicates the prioritization of adjustment measures over reduction and substitution is consistent, independently of the entity producing the guides.

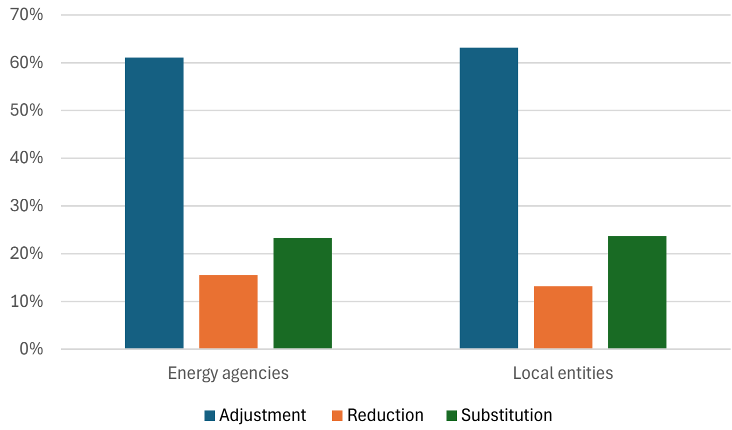


Figure 4.1.2: Distribution of ES measures type by producing entity.

4.2 User perceptions and practices: survey results

In this section the key findings from the survey conducted are presented, starting with a general characterization of the sample. Following this, the analysis will focus on respondents' practices and perceptions regarding ES and its measures. Additionally, comparisons will also be made between adult and younger respondents, as well as between FCUL community members and participants outside this community.

The survey was available online from April 1st to May 31st, 2025. A total of 323 responses were collected. After excluding responses from participants who did not provide written informed consent, 321 responses were accounted. Furthermore, respondents under the age of 18 were excluded from the study, totaling 316 valid responses, used for further analysis.

The 316 responses obtained are not a representative sample of the national population. Therefore, it is not possible to draw general conclusions about the Portuguese population from the results. Nevertheless, it is possible to understand the behaviors and perceptions of a small part of the population, which is relevant considering the exploratory nature of this work.

4.2.1 Sample characterization

This subsection aims to provide an overview of the participants who answered the survey. Socio-demographic characteristics will be considered, such as age group, level of education, region, and type of housing where they reside, and whether they are part of the FCUL community or not.

The figure below shows the distribution of the population by age groups. Nearly half of the participants are between 18 and 27 years old, representing 47% of the total population, indicating a predominantly young sample. The age groups 28 to 37 and 48 to 57 years each represent 13%, while the age group 38 to 47 accounts for 16% of the total population. Only a small part of the population is over 67 years old, 1%. These remaining groups represent 53% of the population.

Considering this distribution and that age might be a key factor on awareness, behaviors and perceptions regarding the topic, a comparison between young population and the adult population will be made, to assess if age is indeed a major factor.

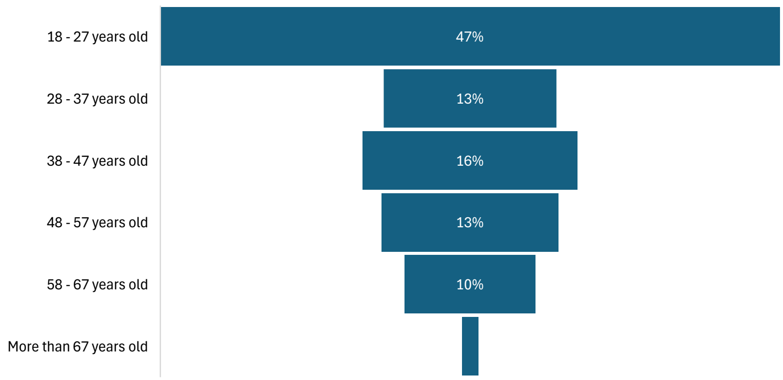


Figure 4.2.1: Age distribution of the participants.

In figure 4.2.2 is presented the distribution of participants according to their level of education. 42% of the participants hold a bachelor's degree, followed by 22% with a master's degree. Secondary education accounts for 18% of the total population, and 5% of participants have a doctorate degree. Basic education and higher technical professional courses represent a small percentage of the sample. The data reflects a well-educated population.

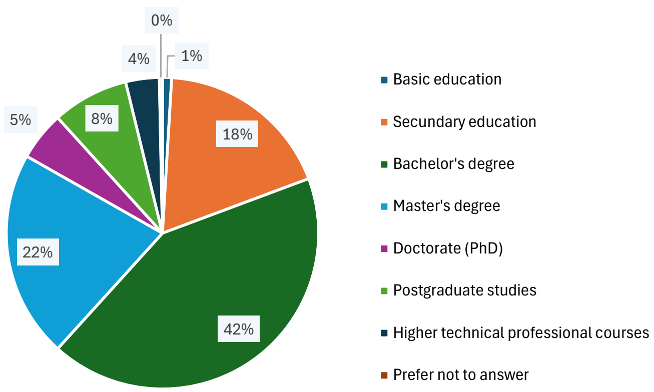


Figure 4.2.2: Level of education of the participants.

Figure 4.2.3 shows participants' distribution according to their region of residence. The majority live in Greater Lisbon, 180 responses. Followed by Center region, Setúbal Peninsula, and West and Tagus Valley, with 55, 38 and 22 responses respectively. Ten and five respondents live in the North and Algarve regions, respectively. Regions like Alentejo and Autonomous Regions of Madeira and of Azores, were reported by only 1 participant each. Additionally, three participants preferred not to answer. These results highlight a geographic concentration of respondents in Greater Lisbon.

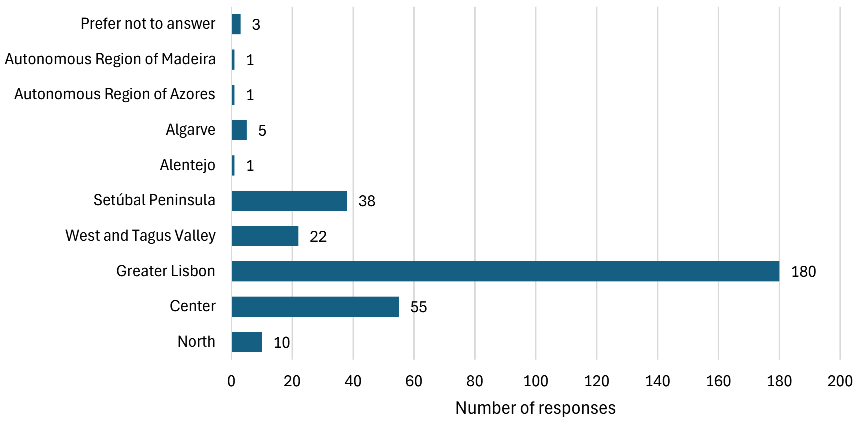


Figure 4.2.3: Region of residence of the participants.

The figure below shows the distribution of participants by dwelling type. Most of the participants (66%) reported living in apartments, followed by 28% living in detached or semi-detached houses. Only 5% of respondents live in terraced houses, and 1% in student residence. This data indicates that apartments are the predominant house type among the respondents.

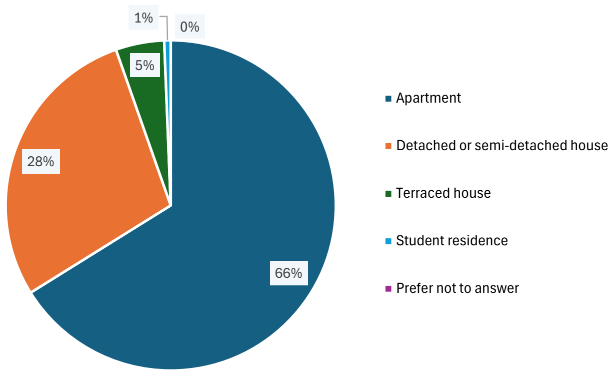


Figure 4.2.4: Participants' type of house.

To finish this first analysis, figure 4.2.5 presents whether the participants are a member of the FCUL community. 76% respondents indicated that they do not belong to the FCUL community, while the remaining 24% reported that they belong. This indicates that the survey reached both members of the FCUL community and participants outside the community.

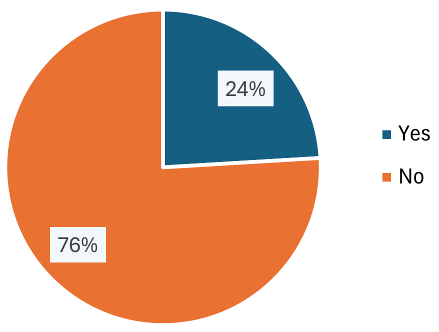


Figure 4.2.5: Participants belonging to FCUL community.

This initial characterization provides an overview of the participants' profile, offering a foundation for the following stages of analysis. It can be concluded that approximately half of the respondents belong to the young population, while the remaining participants represent the adult population. The overall population is generally well educated, with more than half of the population living in the Greater Lisbon area and residing in apartments. Additionally, only about one-quarter of the respondents are members of the FCUL community.

4.2.2 General results

This subsection presents the overall results of the survey, the objective is to provide an overview of participants' practices and perceptions regarding ES and ES measures. This analysis enables the identification of the most common behaviors and attitudes among participants.

With respect to behavioral patterns regarding lighting practices, figure 4.2.6 illustrates the overall results. Practices such as using natural lighting and turning off lights when not needed are very common among respondents, with more than 60% reporting always doing so. As for measures related to decorative lighting, a significant number of respondents reported reducing indoor decorative lighting frequently or always. In contrast, a larger share of respondents considered that reducing outdoor ornamental lighting did not apply, however among those it applies many reported always doing it.

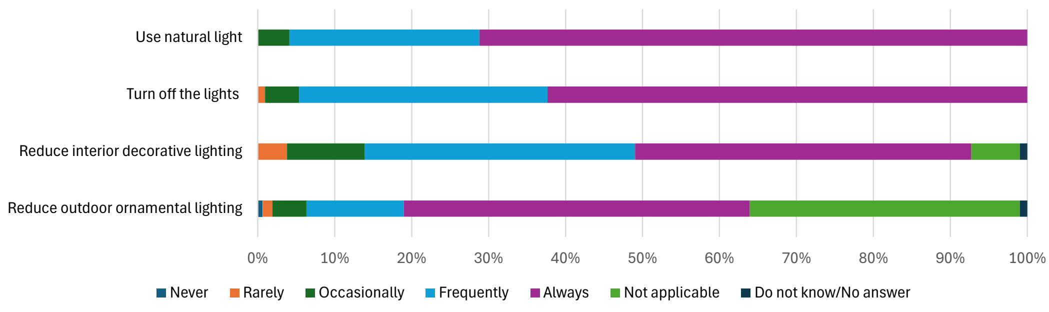


Figure 4.2.6: Frequency of respondents' lighting-related user behavior.

Regarding appliance-related user behaviors (figure 4.2.7), responses show that behaviors such as using machines' eco program, adjusting washing temperatures, using full capacity of appliances, and turning off equipment before finishing, when interrupting the task or during long absence are measures highly applied among respondents. It was also reported being done frequently the use of well-sized equipment and the use of a proper container to match the burner. Behaviors like leaving fridge/freezer door open for long periods, opening oven door too often during it use, and placing hot food into refrigeration equipment were reported rarely or never being done by most of participants, which reveals a clear concern on avoiding wasting useful energy. On the other hand, practices like eliminating standby energy consumption and using sockets with an on/off switch show a wide distribution of responses, from frequent and occasional use to low adoption or never adopting these measures. Which suggests that there is room for improvement in applying these practices across the sample.

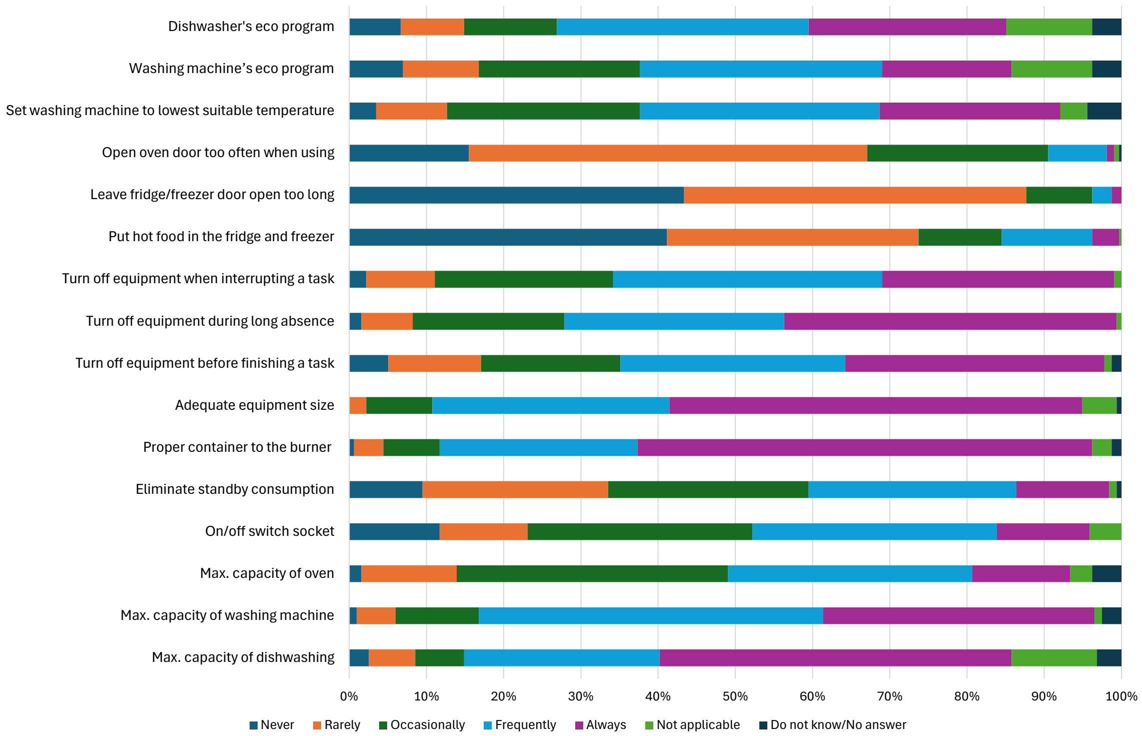


Figure 4.2.7: Frequency of respondents' appliance-related user behavior.

Figure 4.2.8 illustrates measures related to heating, cooling and thermal comfort, in general shows a high level of adoption of these practices among responses. Measures such as adequate clothing to indoor temperature, using solar radiation and natural ventilation are widely practiced, with most participants reporting always or frequently doing it. Whereas for active HVAC-related measures, a high percentage of respondents selected "Not applicable", indicating they might not have air conditioning systems in their household, a common situation in Portugal. However, among the participants who have, there is a tendency to close doors and windows when using and to avoid heating or cooling unoccupied spaces. In contrast, adjusting the temperature settings based on the seasonal temperature appears to be a measure less adopted.

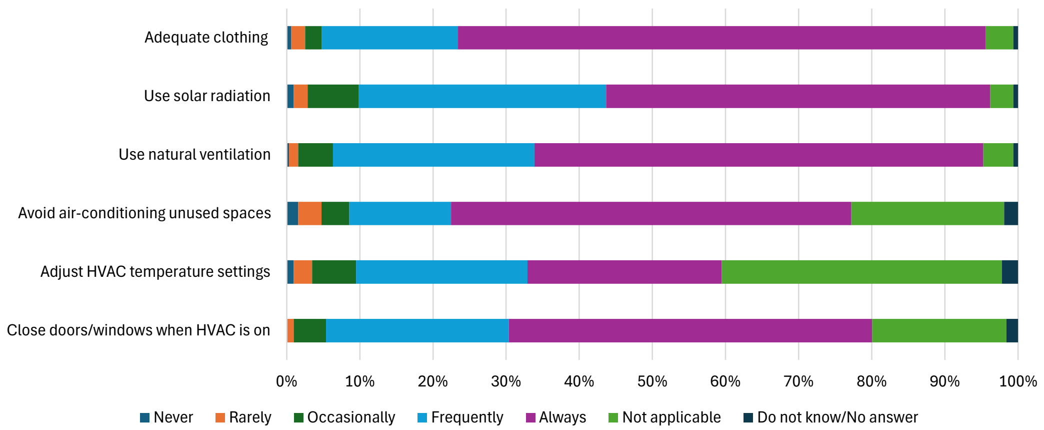
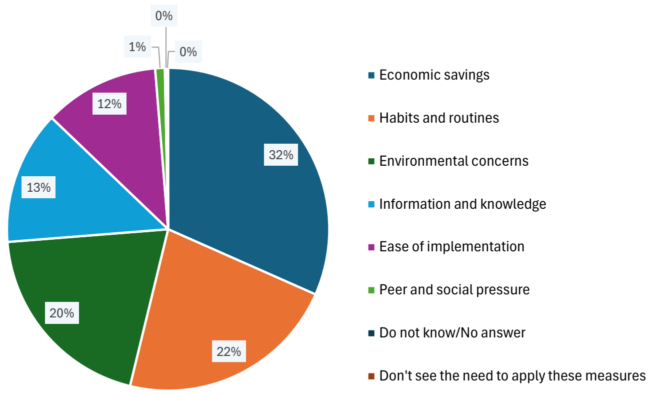


Figure 4.2.8: Frequency of respondents' heating, cooling, and ventilation-related user behavior.

When questioned about the main factors behind their adoption of ES measures (fig. 4.2.9.a), respondents most frequently pointed out economic savings, followed by habits and routines, and environmental concerns. Other factors like information and knowledge, and ease of implementation were selected less frequently. A small number of participants stated not seeing the need to apply these measures, which suggests that ES is seen as a relevant and beneficial strategy.

Regarding the familiarity with the concept of ES (fig. 4.2.9.b), a large majority reported being familiar with it, approximately 71%, while about 29% were not. Only 0.6% of the participants preferred not to answer. These results point to a good level of knowledge among respondents, although there is still room for improvement on dissemination of the concept.

a)



(b)

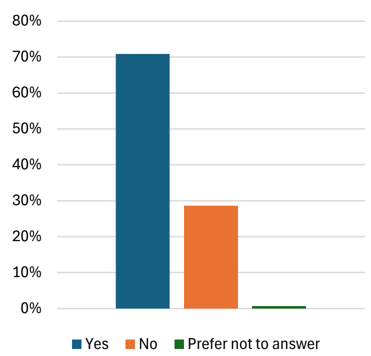


Figure 4.2.9: a) Main factors influencing the adoption of ES measures; b) Respondents' familiarity with the concept of ES.

The figure below illustrates the importance respondents attribute to ES measures. The majority of respondents consider ES measures to be relevant, with more than half of the sample rating it to be very important, and when combining it with the respondents who considered it to be fairly important and important, the total exceeds 90%. A small share of the respondents expressed no opinion, and no participant viewed these measures as not important at all.

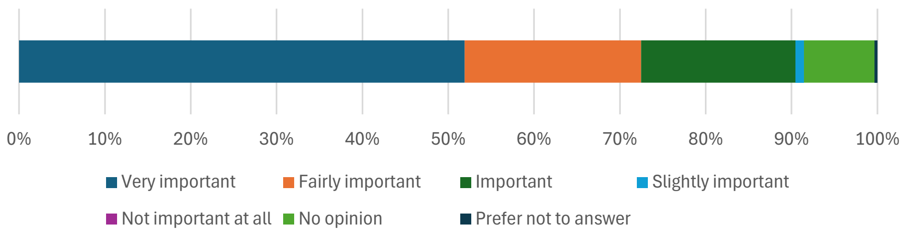


Figure 4.2.10: Perceived importance of ES measures among respondents.

Lastly, the participants were asked about their willingness to adopt ES measures. Figure 4.2.11 shows that almost 45% of respondents reported already applying these practices, and about 41% indicated their willingness to adopt more in the near future. Interestingly, nearly 14% expressed interest in adopting additional measures but stated that they would like to have more information about the actual impact of these actions before implementing them. This highlights the importance of providing consumers with accurate information about the benefits and effectiveness of ES measures, as this could help consumers make informed decisions and increase adoption rates. Remarkably, only one participant showed no interest in adopting ES measures. When questioned about the reasons behind this lack of interest, the participant simply replied, “I don’t care”.

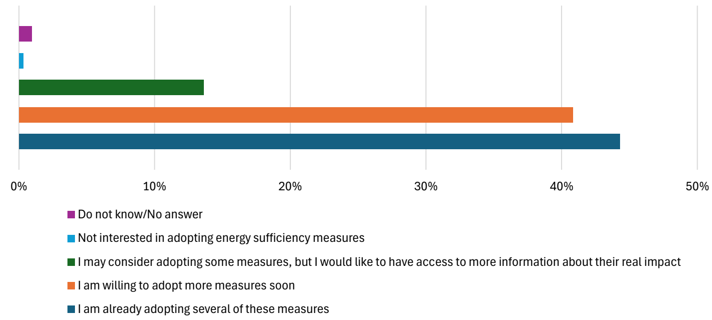


Figure 4.2.11: Respondents' willingness to adopt ES measures.

To sum up the main findings from general results, many participants already apply several ES practices in their daily lives, indicating a positive basis. However, there is still room for improvement, for example in areas such as eliminating standby energy consumption and adjusting indoor temperature settings. Financial savings emerged as the key factor in adopting these measures, showing that cost considerations often outweigh environmental concerns.

Most respondents reported being familiar with the concept of ES and most consider it to be between “very important” to “important”, reflecting a strong awareness of the topic. Regarding future action, more than half of the sample expressed willingness to adopt more ES measures soon. Notably, a significant percentage showed interest in receiving information about the real impact of these practices.

4.2.3 Age-based comparison

The following subsection explores whether there exists any major difference in behavioral practices and perceptions regarding ES, between different age groups, namely young people (18 to 27 years old) and adults (up to 27 years old). To support this comparative analysis, a total of 147 young people and 169 adults participated in the survey. The young participants represent 47% of the whole population, what ensures a balanced and meaningful comparison between age groups. This comparison allows for the identification of potential differences in behaviors, awareness, and motivations related to ES across generations, while maintaining a relatively proportional sample size for both groups.

In general, the analysis from the comparison between young people and adults showed that age is not a determining factor in being familiar with the concept of ES or in the adoption of its measures. However, adults appear to be slightly more consistent in applying several measures (Appendix G.1).

In terms of lighting-related measures, no major differences were observed between the two groups. Regarding equipment-related practices, adults reported that they more frequently set washing machines to a lower suitable temperature. When it comes to turning off equipment when interrupting a task, younger respondents showed a higher tendency to never or rarely turn off equipment, compared to adults. A notable difference was also identified in relation to the use of outlets with on/off switch, with younger respondents reporting a much lower adoption rate. Similarly, when considering the use of the oven at full capacity, younger participants showed less adoption than adults.

With respect to heating, cooling, and ventilation practices, younger respondents tend to demonstrate greater resistance to the adoption of passive measures, although both groups report frequent use of these practices in their daily lives. Regarding active measures, such differences between both groups were not observed, however the younger group was more likely to select “not applicable” when compared to adults.

Both groups ranked the factors influencing the adoption of ES measures in the same order, although economic savings weighed more heavily among adults than younger participants. Whereas, habits and routines, and environmental concerns were more important to the younger group.

Regarding the familiarity with the concept of energy sufficiency, younger respondents reported being more familiar with it, however the difference between the groups is minimal. The majority of both groups rated ES measures between “very important” to “important” for reducing energy consumption.

Ultimately, their willingness to adopt more measures in the future was similar, but a significant percentage of young people expressed interest in having access to information about the real impacts of these measures (19.7%), compared to 8.3% of adults.

4.2.4 Comparison between FCUL respondents and external participants

This part of the section focuses on the comparative analysis between another two groups, participants belonging to FCUL community and external participants. This comparison aims to understand if being part of an academic scientific environment influences people’s energy-related behaviors, specifically towards ES. And, to verify if this knowledge is already widespread among the population, or whether other factors have a greater influence on such behavior.

Based on the number of responses obtained from participants belonging to the FCUL community, (76 responses) representing 24% of the surveyed population. A sample size of 67 responses were deemed adequate for this study based on a 90% confidence level with a 10% margin of error as shown in Table 3.1. This reflects a balance between statistical rigor and the practical constraints of collecting survey data. Despite the level of confidence and margin of error representing a slightly higher margin of uncertainty compared to the typical 95% confidence level and 5% margin of error, it is still appropriate given the exploratory goals of the research and the intention to identify potential differences between groups.

The comparison between participants being part of the FCUL community (students, teachers, researchers, staff, and others) and those outside this community does not reveal any major differences. This suggests that being part of this community does not affect the adoption of ES measures (Appendix G.2).

Regarding lighting-related practices, the observed patterns among both groups were very similar. In terms of equipment-related practices, despite the identical behavior on putting hot food in the fridge or freezer, a small percentage of external participants of FCUL reported always doing this, while none of the FCUL participants did so.

With regard to heating, cooling, and ventilation, both groups reported frequent adoption of these practices, however some minor differences appeared. Regarding the use of natural ventilation and solar radiation, members of the FCUL community showed a stronger tendency to apply these measures compared to external participants, which might be related to a higher understanding of passive mechanisms. As for avoiding heating and cooling unused spaces, the results were very similar, however FCUL members reported the situation as not applicable more often. Similarly, when considering the adjustment of HVAC temperature settings, FCUL has a higher percentage of "not applicable," a 10% difference with non-FCUL members. Nevertheless, the trends tend to be similar, although non-FCUL participants reported adjusting HVAC operating conditions more often.

In terms of the drivers influencing the adoption of ES measures, the results were very similar, both in ranking order and in the weight of each factor. Some differences were observed regarding the familiarity with. While 84.2% of respondents of the FCUL community reported being familiar with the concept, compared to 66.7% of external respondents. This result suggests that being regularly exposed to discussions about scientific and energy-related topics may lead to a higher level of awareness and understanding.

Interestingly, when asked to rate the importance of ES measures, external participants were more certain in its importance and expressed stronger agreement, with 55.8% rating them as "very important", compared to 39.5% of the FCUL respondents. In contrast, FCUL community members expressed a more diverse range of opinions, which may reflect a more comprehensive understanding of the concept, a greater awareness of its potential issues and limitations, or a more cautious approach. On the other hand, external participants may have provided more socially desirable responses than detailed conceptual knowledge.

To conclude the comparison between the FCUL community and external participants, the willingness to adopt more measures in the future was quite similar in both groups. The main difference was that FCUL participants expressed more interest in having access to information and evidence of the actual impacts of these measures. Such difference may suggest that those in scientific environments rely more on evidence, while external participants tend to rely more on general perceptions.

4.3 Experimental data on the impact of ES measures

In this section, the data collected during experimental campaign of a range of ES measures is presented, based on monitoring household appliances under different operating conditions. The goal is not to establish absolute consumption values, since these are influenced by multiple factors, but rather to identify and discuss relative trends in the increase or decrease in energy use resulting from the application of sufficiency-oriented practices. In general, this practical assessment illustrates the potential impact of energy sufficiency measures on household energy demand.

Additionally, to the direct comparison of consumption trends, the reductions identified are simultaneously converted into monetary savings and equivalent CO_2 emissions avoided. This step offers a clearer picture of the potential environmental and economic impact of ES measures.

The results are organized by appliance, starting with the washing machine, followed by dishwasher, and storage water heater.

4.3.1 Washing machine

The experimental measurements of washing machine energy consumption were conducted by seven volunteers performed and as described in the previous chapter. The results presented in this subsection refer to the different temperatures, programs and spin speeds tested for each washing machine. Each tested washing machine is identified by a code, WM1 to WM7, where WM stands for washing machine.

The following figures are a great starting point for the influence of temperature and different programs. The first figure represents the average energy consumption of all cycles tested for each washing machine. And, the second figure aggregates these results, presenting the average energy consumption for each cycle across all washing machines. Based on this, it shows a clear trend of washing cycles performed at lower temperatures (20ºC and 30ºC) resulting in lower energy consumption. In contrast, washing cycles at higher temperatures (60ºC) lead to significantly higher energy consumption.

Furthermore, ECO programs also demonstrate potential for energy savings. This program reduces and optimizes consumption through lower washing temperatures and longer duration [91]. In this way, ECO program achieves a balance between performance and efficiency, making them a good option for regular use. The operating temperature of this program in the washing machines, where it was tested, was reported as cold, probably at tap water temperature.

It is worth to note the unique characteristics of the delicate or wool/silk program, as this program is intended for clothes made of delicate fabrics, such as wool and silk. These programs usually operate at very low temperatures, with short cycles, often using water at tap temperature, and for a partial load, significantly below the machine's full capacity. Therefore, its energy consumption is the lowest observed. However, given the limited load and the specific type of use, this program is not representative of typical washing practices.

The minimum program shows low energy consumption, however it is not clear if it is due to lower washing temperatures or a specific setting designed to reduce energy consumption. Regardless, it will be considered a program that uses the lowest possible temperature. This program was exclusively tested on WM6, which limits its representativeness.

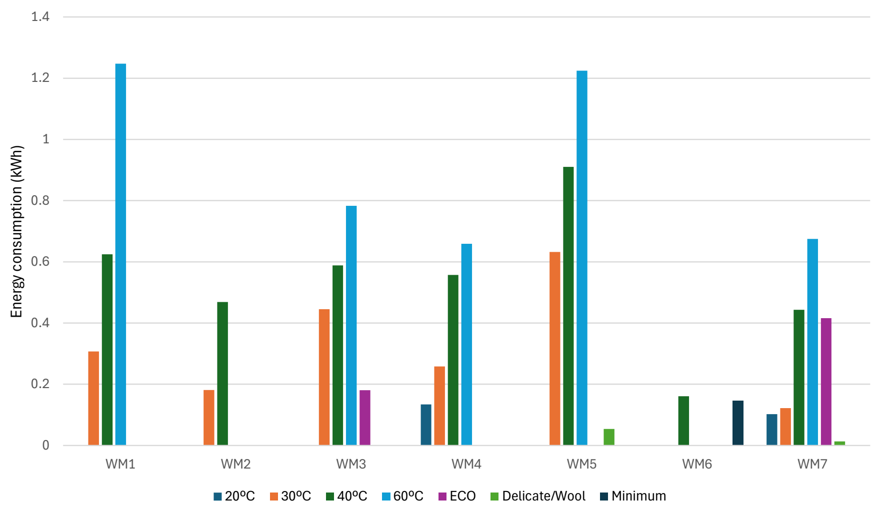


Figure 4.3.1: Average energy consumption (in kWh) of different washing temperatures and programs of each tested washing machine.

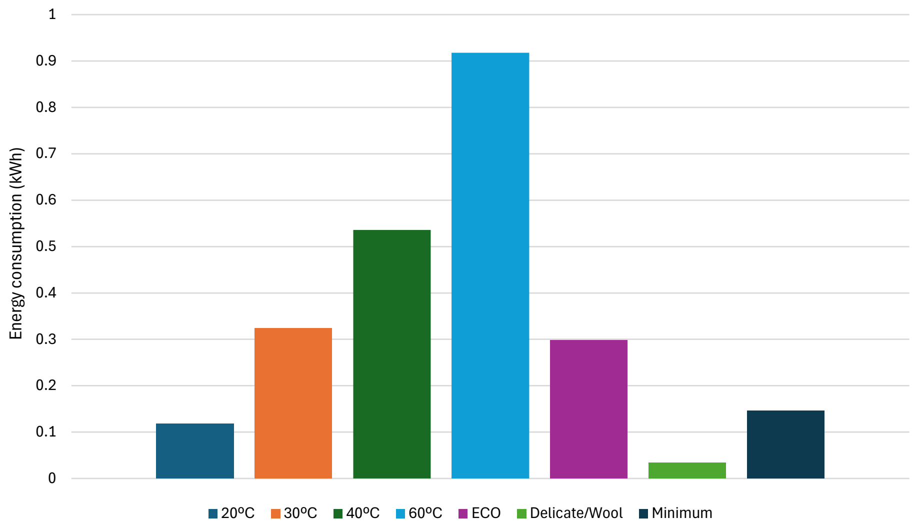


Figure 4.3.2: Average energy consumption (in kWh) per washing cycle tested.

The figure clearly illustrates that energy consumption increases with higher washing temperatures. The delicate or wool program presents the lowest energy consumption, mainly due to its operating settings. ECO program's energy consumption is between the 20ºC and 30ºC programs' energy consumption. Minimum program has slightly higher consumption than the cycles performed at washing temperatures of 20ºC.

To identify the potential impact of applying ES measures, namely the ones involving the use of washing machines, the figure below presents the relative change in energy consumption (y-axis) across switches in washing temperature and programs. Each bar represents the average change in energy consumption for a certain transition, positive values indicate a reduction, while negative values represent an increase in energy consumption. The maximum reduction observed is represented by the orange points, while the minimum reduction is represented by the green points, in one situation this point indicates an increase in energy consumption.

On average, lowering the washing temperature from 60ºC to 20ºC resulted in a reduction in energy consumption of 82.4%, corresponding to an average saving of 0.550 kWh. With a maximum observed of 85% and a minimum of 79.7%. Switching from a program at 60ºC to the ECO program resulted in an average reduction of 57.7% (0.431 kWh), the maximum reduction was 77% and the minimum was 38.4%.

A temperature shift from 60ºC to 40ºC leads to a reduction of 30.1% (0.293 kWh), with a maximum reduction of 49.9% and a minimum of 15.5%. And reducing the washing temperature from 60ºC to 30ºC was associated with a reduction in energy consumption of 62% ranging between 82% and 43.2%, on average corresponding to 0.565 kWh.

When the temperature is reduced from 40ºC to 20ºC, a 76.5% reduction in energy consumption was observed, resulting in an average reduction of 0.382 kWh, ranging from 77.1% and 75.9%. Using a 30ºC program instead of a 40ºC program can result in a reduction of 48.9% (0.278 kWh), with a maximum observed of 72.6% and a minimum of 24.4%. And choosing the ECO program over a 40ºC program leads to a reduction in energy consumption of 37.7% (0.218 kWh), with reductions observed between 69.4% and 6%.

The transition from 40ºC to the minimum program resulted in a reduction of 9.2%, corresponding to a 0.015 kWh decrease in energy consumption. As just one machine includes this program, there are no ranging values.

Lowering the temperature from 30ºC to 20ºC resulted in a reduction of 32.3% (0.072 kWh) in energy consumption, fluctuating between 48.1% and 16.5%. As for the transition from 30ºC to the ECO program, the results depend on the washing machine tested. Usually, ECO programs are expected to consume less energy, but in this case, the two machines that had this program as an option showed different results, in one the energy consumption increases and the other decreased. This shows how the design of this program can vary among models, load, or even due to the age and condition of the appliance.

In order to better illustrate this difference, two scenarios were considered, one including the data from the machine in which energy consumption increased (WM7), and another excluding it. In the scenario including the data from WM7, the change from 30ºC to ECO program resulted in an average increase in energy consumption of 91.6%, with values varying between a reduction of 59.5% and an increase of 242.4%. Contrarily, when WM7 values are excluded, the transition leads to a 59.5% reduction in energy consumption, corresponding to a saving of 0.265 kWh.

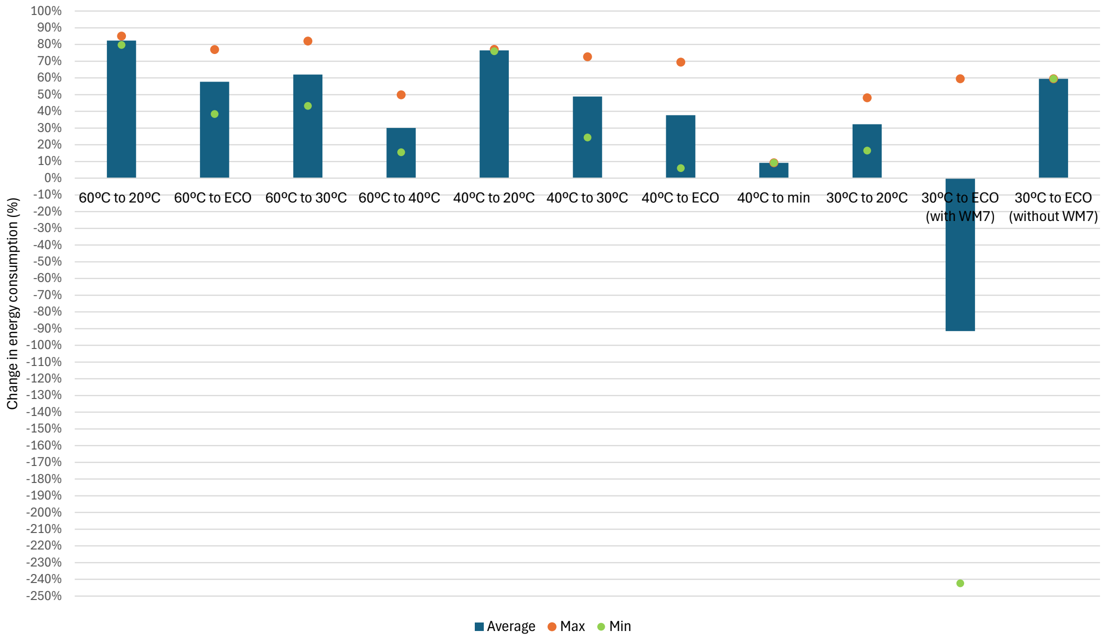


Figure 4.3.3: Change in energy consumption by temperature and program transition.
Note: Positive values represent a reduction in energy consumption, while negative values indicate an increase.

Due to the atypical behavior observed when changing from a washing temperature of 30ºC to the ECO program, particularly in the WM7 data, a second graph (Figure 4.3.4) was created to prevent the extreme result from dominating the visual scale and potentially hiding the remaining changes, thereby providing a clearer view of the results.

This second figure excludes three transitions: from 30ºC to ECO with WM7 data, mainly due to the scale; from 30ºC to ECO without WM7 data, because in this situation the ECO program would only be represented by the other machine where it was tested; and from 40ºC to minimum program (Min), because this program was only available on one of the machines, makes this result less reliable and not widely representative. Such exclusions were made to allow for a more direct comparison between transitions with more consistent and representative results.

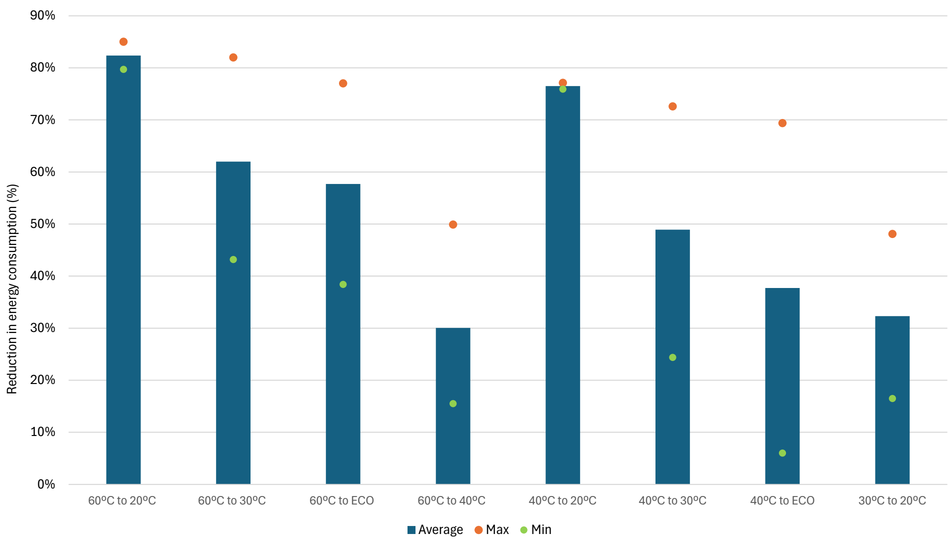


Figure 4.3.4: Reduction in energy consumption, excluding extreme cases.

Table 4.3.1 presents a comparative analysis of the relative changes in energy consumption when changing from one washing temperature to a different one, comparing the experimental results from this study with results from the literature. Three changes were compared, lowering the washing temperature from 60°C to 20°C and raising the temperature from 30°C to 40°C and 60°C.

Table 4.3.1: Comparative analysis of relative energy consumption changes across washing machines temperature.

Temperature change	Literature (Δ consumption)	Experimental results
60ºC to 20ºC	-70% [92]	-82.7%
30ºC to 40ºC	+30% to +100% [93]	+119.8%
30ºC to 60ºC		+217.3%

According to [92], changing the temperature from 60°C to 20°C energy consumption could reduce in 70%. In this study the results reached a reduction of 82.7%, suggesting that greater energy savings are possible.

As summarized in [93], using washing machines at temperatures higher than 30ºC or with fast programs can result in 30% to 100% increase in energy consumption. So, for comparison purposes, transitions from 30°C to 40°C and to 60°C were taken into account. With the experimental results obtained, for the transition from 30°C to 40°C was recorded an increase of 119.8%, and a 217.3% increase for 30°C to 60°C, values notably higher than the ones reported in the literature. This difference can be related to several factors, such as different test conditions and program characteristics, and therefore these results should be interpreted with some caution. No comparison was made for fast programs because there was no data for such program in this study.

To complement the information provided in Fig.4.3.3, the following tables illustrate the impact of changes in temperature and programs on washing cycles. These impacts are presented in terms of average energy consumption reduction (kWh), and the corresponding financial savings (€) and environmental impact (kgCO_2eq). In Table 4.3.2, these values are presented by per-cycle change. Because they tend to be meaningless to consumers, the values are also presented for 100 cycles, Table 4.3.3. The 100 cycles were chosen because it reflects a reasonable usage scenario, if considered a one-year timeline there are about two washing cycles per week, and this reference is commonly included on energy labels and in marketing materials. It is important to note that the negative values in the tables represent increases in energy consumption for a certain washing change, and therefore the financial savings and environmental impact will be negative.

Table 4.3.2: Average per-cycle change by washing temperature and program change.

Washing cycle change	Average reduction (kWh)	Monetary savings (€)	Environmental impact ($kgCO_2eq$)
60ºC to 20ºC	0.550	0.135	0.062
60ºC to ECO	0.431	0.106	0.048
60ºC to 30ºC	0.565	0.138	0.063
60ºC to 40ºC	0.293	0.072	0.033
40ºC to 20ºC	0.382	0.094	0.043
40ºC to 30ºC	0.278	0.068	0.031
40ºC to ECO	0.218	0.053	0.024
40ºC to min	0.015	0.004	0.002
30ºC to 20ºC	0.072	0.018	0.008
30ºC to ECO (with WM7)	-0.015	-0.004	-0.002
30ºC to ECO (without WM7)	0.265	0.065	0.030

Table 4.3.3: Estimated impact over 100 washing cycles due to temperature and program transitions.

Washing cycle change	Average reduction (kWh)	Monetary savings (€)	Environmental impact ($kgCO_2eq$)
60ºC to 20ºC	55.0	13.5	6.2
60ºC to ECO	43.1	10.6	4.8
60ºC to 30ºC	56.5	13.8	6.3
60ºC to 40ºC	29.3	7.2	3.3
40ºC to 20ºC	38.2	9.4	4.3
40ºC to 30ºC	27.8	6.8	3.1
40ºC to ECO	21.8	5.3	2.4
40ºC to min	1.5	0.4	0.2
30ºC to 20ºC	7.2	1.8	0.8
30ºC to ECO (with WM7)	-1.5	-0.4	-0.2
30ºC to ECO (without WM7)	26.5	6.5	3.0

The transitions impacting the most are the washing temperature changes from 60ºC to 30ºC and to 20ºC, respectively, with reductions in energy consumption of 56.5 kWh and 55 kWh. Corresponding to 13.8 € and 13.5 € of monetary savings, and emissions avoided between 6.2 and 6.3 $kgCO_2eq$. Close behind, switching from a program at 60ºC to the ECO program, leads to a reduction of 43.1 kWh in 100 cycles, 10.6 € and 4.8 $kgCO_2eq$.

Reducing the washing temperature from 60ºC to 40ºC, results in an energy reduction of 29.3 kWh, which corresponds to 7.2 € and 3.3 $kgCO_2eq$. Preferring a washing temperature of 20ºC instead of 40ºC can lead to an average reduction of 38.2 kWh, and cost savings of 9.4 € and avoid the emissions of 4.3 $kgCO_2eq$.

A 10ºC reduction in washing temperature, from 40ºC to 30ºC, also leads to significant impacts, 27.8 kWh, 6.8 € and 3.1 $kgCO_2eq$. Similarly, the change from 40ºC to ECO results in an average reduction in energy consumption of 21.8 kWh, corresponding to a monetary saving of 5.3 € and a 2.4 $kgCO_2eq$ of avoided emission. On the other hand, a minimal impact was observed when switching from a 40ºC program to a minimum program, only a 1.5 kWh reduction in energy consumption, 0.4 € and 0.2 $kgCO_2eq$.

Changing the washing temperature from 30ºC to 20ºC results in an average reduction of 7.2 kWh, which corresponds to a decrease in energy-related costs of 1.8 € and 0.8 $kgCO_2eq$ of avoided emitted emissions.

As for the preference of ECO program over a program at 30ºC, results show two different scenarios, one where consumption decreases with this change, and another where this change leads to an increase in energy consumption. Considering the WM7 data, it leads to an increase in consumption of around 1.5 kWh (0.4 € and 0.2 $kgCO_2eq$). On the contrary, not considering the data from this machine has considerable impacts, an average reducing in energy consumption of 26.5 kWh, which corresponds to 6.5 € and 3 $kgCO_2eq$ of emissions that were not emitted. However, these values must be interpreted within the context of its limitations.

Overall, the results showed that lowering washing temperature can lead to significant savings in consumption. This indicates that the application of ES measures regarding washing machines has high savings potential.

Additionally, an analysis was conducted to evaluate the influence of spin speed on energy consumption, in two washing machines. The measurements performed in WM1 were at 600 and 800 rpm for 30ºC, 40ºC, and 60ºC. And the other was WM5, a program at 30ºC was tested at 800, 1200 and 1400 rpm. However, the results did not reveal a pattern. For some temperatures, reducing the spin speed led to lower energy consumption, while on others, an increase in energy consumption was observed.

In WM1, it was observed that reducing the spin speed from 800 to 600 rpm at 30ºC resulted in a 9.1% reduction in energy consumption. Similarly, at 60ºC, the same change led to an 18.5% reduction. In contrast, reducing spin speed from 800 to 600 rpm at 40ºC resulted in a 4.1% increase in energy consumption.

As for WM5, using the cotton program at 30ºC, reducing the spin speed from 1400 rpm to 800 rpm resulted in a reduction of 21.3% in energy consumption. Whereas reducing from 1200 rpm to 800 rpm led to an energy reduction of 48.3%.

Despite some variability in the results, a trend toward reducing energy consumption with lower spin speeds was observed in most of the cases tested. For instance, significant reductions were observed in WM5, reducing the spin speed from 1200 to 800 rpm. However, not all results followed this pattern, in WM1 at 40ºC reducing from 800 to 600 rpm led to an energy increase. Due to this inconsistency, it is not possible to draw conclusions regarding the influence of spin speed on energy consumption. Detailed data is presented in appendix H (table H.1.3 and H.1.4) for reference.

4.3.2 Dishwasher

As presented in the methodology chapter, the study also included the analysis of dishwashing programs. Each tested dishwasher is identified by a code, DW1 to DW5, where DW stands for dishwasher. The programs tested were ECO, quick/short, intensive and normal. Each program differs in terms of temperature and duration. Follows a brief description of each program for a clearer understanding of the tested conditions.

ECO programs were tested on all dishwasher, operated at a temperature range between 40ºC to 50ºC. These types of programs are designed to be energy and water efficient, generally compensating for the lower temperatures with longer duration. The duration ranged from 2h45min up to 4h40min, with DW3 having the longest ECO cycle. As well as for ECO programs, quick programs were tested in all 5 machines, operating at lower temperatures, between 35ºC and 45ºC, and with significant shorter durations, around 30 to 35 minutes.

Intensive programs were tested in three of the five dishwashers, operated consistently at 70ºC, the highest temperature tested. Program's duration varied from 1h55min to 3h15min, the operating temperature and the long duration are suitable for heavily soiled dishes or cookware requiring a more meticulous wash. Similarly, the normal program was tested in three machines. Although, with lower washing temperatures, ranging from 45ºC to 60ºC and shorter durations, between 2h05min and 2h40min.

Figure 4.3.5 represents the average energy consumption of all programs tested for each dishwasher. And, Figure 4.3.6 compiles these results, presenting the average energy consumption per program across all washing machines. This analysis shows that the selection of washing program plays a significant role in energy consumption.

The following figures clearly illustrate the consumption trends depending on the type of program used. Programs such as ECO and short were generally designed to reduce energy and water consumption, and as shown they tend to result in lower energy consumption. In contrast, programs such as normal and intensive tend to be associated with higher consumption.

These differences among other factors are directly related to the operating temperature of each program [94]. Programs with lower temperatures require less energy to heat the water, whereas cycles with higher washing temperatures naturally require more energy, which explains the contrast observed between the short and ECO, and the normal and intensive programs.

Despite these tendencies, it is important noting that in one of the dishwashers tested (DW3), the ECO program had a higher energy consumption than the normal program. This might be due to the configuration of each program on this dishwasher, but it could also be related to other factors, such as the age and state of the appliance, which were not assessed.

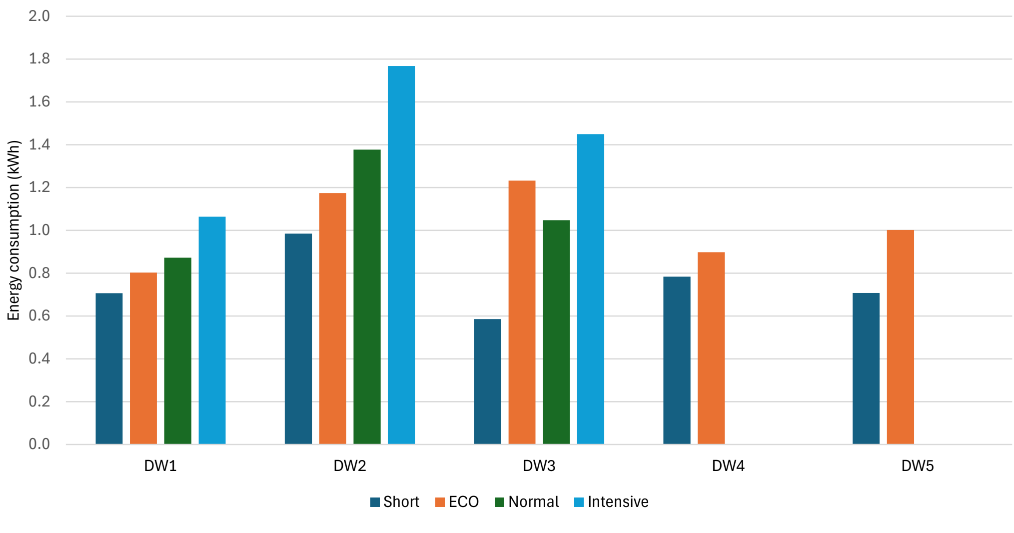


Figure 4.3.5: Average energy consumption (in kWh) of different programs of each tested dishwasher.

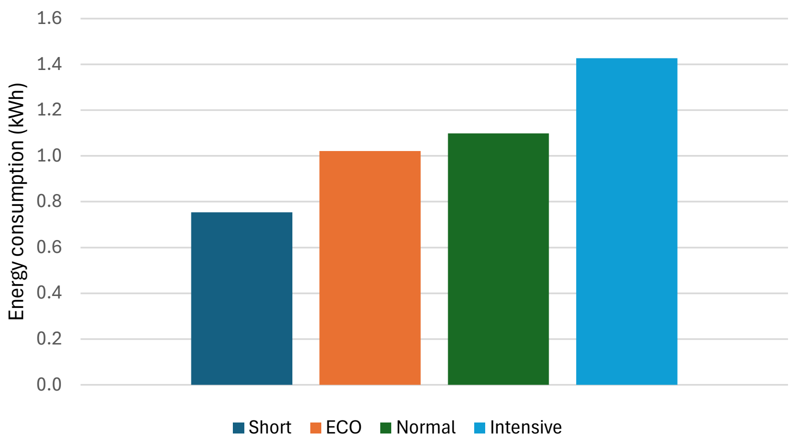


Figure 4.3.6: Average energy consumption (in kWh) for program tested.

As indicated, there is an obvious progression in the energy consumption of the tested programs. The intensive program has the highest consumption, followed by the normal, with the ECO program in third place, and finally the short program. This reinforces the importance of program selection for household energy savings.

In order to illustrate the potential impact of ES measures, especially those involving the selection of dishwasher programs, the next figure shows the change in energy consumption in percentage when selecting one program over another.

The y-axis represents the change in energy consumption (%), where positive values indicate a reduction in energy use and negative values an increase. The bars represent the average variation in energy consumption resulting in changing from one program to another considering all dishwasher where the program was tested. The orange points show the maximum reduction observed, and the green points represent the minimum reduction, or in one case the increase.

As mentioned before, an unexpected situation was found for DW3, namely in the transition from the normal program to the ECO, which resulted in an increase in energy consumption. Contrary to what is normally expected as figures in Fig.4.3.6. Therefore, to prevent this difference from influencing the percentage change in energy consumption and to keep the data as transparent as possible, two situations were considered for this program transition, one that includes DW3 data and one that excludes it. So, in addition to presenting the results from all measurements, the expected results are also presented when switching from normal to ECO mode. To sum up, this double representation helps to illustrate the atypical behavior observed with DW3 as well as the expected behavior.

On average, switching from intensive to short program resulted in a reduction in energy consumption of 45.8%, corresponding to an average saving of 0.668 kWh per cycle. It was observed a maximum reduction of 59.6% and a minimum of 33.6%.

Changing from intensive to ECO program led to an average reduction of 24.4%, corresponding to 0.357 kWh, with results ranging from 14.9% to 33.6%. As for switching from intensive to normal, it showed an average reduction of 22.6% (0.328 kWh), with a maximum reduction of 27.7% and a minimum of 18%. The transition from normal to short led to reduction of 30.5% (0.340 kWh), on average, fluctuating between 44.1% and 19%.

The shift from normal to ECO program presents two results, if considering the data from DW3, the average reduction was just 1.6%, corresponding to 0.028 kWh. Due to the fact that DW3 showed an increase in energy consumption of 0.186 kWh, in this case the ECO mode consumed more than the normal program. However, if excluding DW3, the average reduction rose to 11.3% (0.136 kWh), with values ranging 14.7% (0.202 kWh) and 8% (0.069 kWh). Indicating a trend towards lower energy consumption when shifting to the ECO mode, as expected.

Finally, the transaction from ECO program to the short resulted on average in a reduction of 24.5% (0.268 kWh), with a maximum reduction of 52.5% (0.647 kWh) and a minimum of 12% (0.096 kWh) observed.

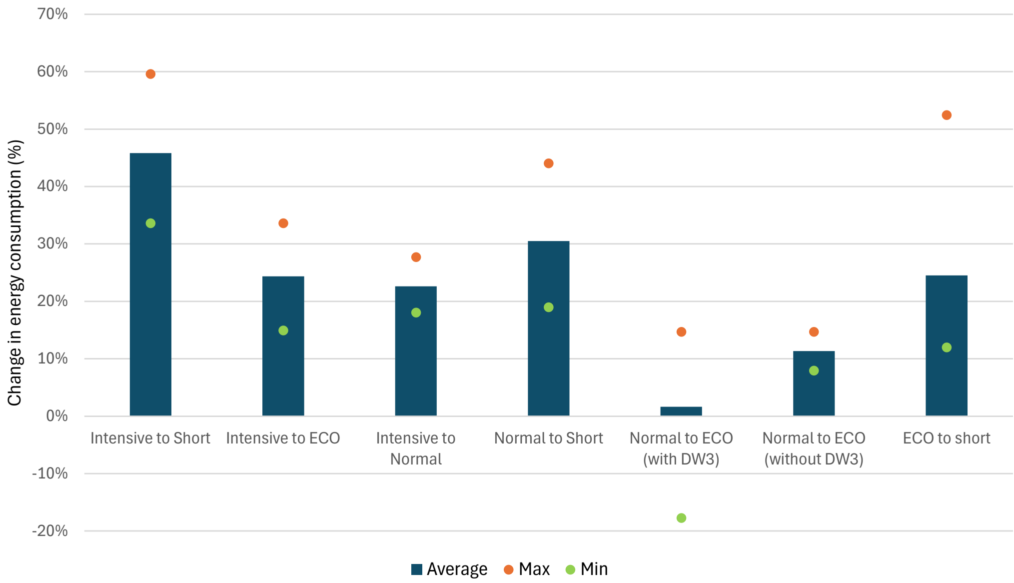


Figure 4.3.7: Energy consumption changes by program transition (average, maximum and minimum observed). Note: Positive values represent a reduction in energy consumption, while negative values indicate an increase.

The following table attempts to present a comparative analysis of the relative changes in energy consumption when switching from one program to another, between results found in the literature and those observed in this study. Three program changes were analyzed, from ECO to Short, to Intensive, and to Normal.

Table 4.3.4: Comparative analysis of relative energy consumption changes across dishwasher programs.

Program change	Literature (Δ consumption)	Experimental results
ECO to Short	≈ -20% [95]	-24.50%
ECO to Intensive	+49% to +73% [95]	+33.5%
ECO to Normal	+26% to +35% [95]	+3.6% (with DW3)
	+20% to +30% [93]	+12.9% (without DW3)

According to [95], among the models tested (from Bosch and Miele), switching from the ECO program to the short resulted in a reduction in energy consumption of about 20%, which is in line with the experimental results obtained in this study, where a 24.5% decrease was observed. On the other hand, changing from the ECO to the intensive program resulted in a considerable increase in energy consumption, with literature ranging from 49% to 73%. The data obtained reflects the same trend of increased consumption, however with a slightly lower increase (33.5%).

The results compiled in [93] indicates that switching from energy-saving to automatic programs (also referred as normal) may result in an increase of energy consumption ranging from 20% to 30%. Therefore, for comparison purposes the transition from ECO program (energy-saving) to normal program was considered. For this transition, [95] suggests an energy consumption increase between 26% and 35%. Two scenarios were considered for this change, with and without the data from DW3, since in this dishwasher, this change results in lower consumption. However, the increases observed were 3.6% and 12.9%, respectively, which is below the ranges reported in the literature.

In addition to the previous figure (Fig. 4.3.6), Table 4.3.5 presents the average results of switching the dishwasher program, in absolute terms per cycle. Namely the reduction in energy consumption (kWh), and the corresponding monetary savings (€) and environmental impact ($kgCO_2eq$). Nevertheless, these values per cycle are quite small and may seem insignificant to consumers. For that reason, Table 4.3.6 illustrates the same impact for 100 cycles, which gives a more comprehensive perspective.

Table 4.3.5: Average per-cycle reductions by dishwasher program change.

Program change	Average reduction (kWh)	Monetary savings (€)	Environmental impact ($kgCO_2eq$)
Intensive to Short	0.668	0.164	0.075
Intensive to ECO	0.357	0.087	0.040
Intensive to Normal	0.328	0.080	0.037
Normal to Short	0.340	0.083	0.038
Normal to ECO (with DW3)	0.028	0.007	0.003
Normal to ECO (without DW3)	0.136	0.033	0.015
ECO to short	0.268	0.066	0.030

Table 4.3.6: Estimated reductions over 100 dishwasher cycles by program change.

Program change	Average reduction (kWh)	Monetary savings (€)	Environmental impact ($kgCO_2eq$)
Intensive to Short	66.8	16.4	7.5
Intensive to ECO	35.7	8.7	4.0
Intensive to Normal	32.8	8.0	3.7
Normal to Short	34.0	8.3	3.8
Normal to ECO (with DW3)	2.8	0.7	0.3
Normal to ECO (without DW3)	13.6	3.3	1.5
ECO to short	26.8	6.6	3.0

The program changes that provide the most savings are those switching to short programs. The transition impacting the most is from intensive to short with an average reduction of 66.8 kWh in 100 cycles, corresponding to about 16.4 € in cost savings and 7.5 $kgCO_2eq$ of avoided emissions. Following this is the change from normal to short program, with reductions of 34 kWh, 8.3 € and 3.7 $kgCO_2eq$. Lastly, the change from ECO to short also leads to significant benefits of 26.8 kWh, 6.6 € and 3 $kgCO_2eq$.

Similarly, changes to ECO programs contribute to savings. The transition from intensive to ECO results in reductions of 35.7 kWh, corresponding to 8.7 € and 4 $kgCO_2eq$. The impact of the change from normal to ECO, as already seen, is dependent on dishwasher characteristics. If excluding the data of DW3, the optimistic and expected scenario, the average reduction is 13.6 kWh, meaning a financial saving of 3.3 € and 1.5 kgCO_2eq of avoided emissions. While with DW3, the impact is much lower, with only a reduction of 2.8 kWh, 0.7 € and 0.3 kgCO_2eq.

Lastly, choosing the normal program over the intensive, despite the per cycle difference seem minor. However, opting for the normal in 100 cycles instead of the intensive resulted in an average reduction of 32.8 kWh, corresponding to 8 € of monetary savings and 3.7 kgCO_2eq emissions avoided.

In general terms, the results show that using less intensive programs, such as short and ECO, consistently provides the highest energy, monetary, and environmental benefits. Even choosing normal program over the intensive program proved to be advantageous. However, this program choice is intrinsically related to consumer's perception of each program. Some consumers avoid choosing ECO program because of its long duration [94], others avoid the short because it is too short and often believe it does not wash or dry well. And many choose normal because it is a middle point, and frequently the machine's default program.

4.3.3 Water heater

The analysis focused on assessing the impact of different temperature setpoints (60ºC, 55ºC and 50ºC) on energy consumption. And additionally, the influence of seasonal outdoor temperatures on thermal losses was also investigated. Each water heater is identified by a code, where WH stands for water heater. These influences will also be studied for type of use, varying from showers and baths, consuming more than 8 liters of water (long/larger uses), and handwashing, dishwashing and other small uses consuming less than 8L (short/smaller uses).

To study the influence of water heater temperature setpoint on energy consumption, three different temperatures were studied, 60ºC, 55ºC, and 50ºC, for WH1 only. As described in the methodology, to separate energy consumption due to active hot water uses from the consumption to maintain the temperature settings, was estimated an approximate value for thermal losses for each of the temperature setpoints studied and then was subtracted from the total energy consumption. These losses represent the quantity of energy required to keep the water stored at the desired temperature, even without hot water use, mainly due to heat losses to the surrounding environment.

The estimated values were based on the ranges associated with thermal losses consumption for each temperature, Figure H.3.1 in the appendix H shows the total energy consumption measured by the smart plug for the three setpoints. When analyzing these ranges, it became clear that thermal losses are directly influenced by the temperature setpoint.

The associated hourly thermal losses values were 0.215 kWh for 60ºC, 0.197 kWh for 55ºC, and 0.183 kWh for 50ºC, Figure H.3.2 in appendix H illustrates the adjusted consumption of active hot water uses with the reduction of thermal losses. Assuming a one-day period, daily thermal losses in the range of 4.4 kWh to 5.2 kWh were initially obtained. However, these relatively high values result from the filtering method used to isolate the standby period, which considered the maximum value observed in the thermal losses band for each setpoint. This approach leads to an overestimation of daily thermal losses, and therefore these values were not considered representative. With a basic statistical analysis of the data corresponding to the thermal losses band shows that, in 95% of the hours, standby consumption was below 0.185 kWh/h for 60ºC, 0.172 kWh/h for 55ºC, and below 0.167 kWh/h for 50ºC, indicating that the correction factor represents the worst-case scenario for thermal losses consumption.

Considering that the maximum value observed in the thermal losses band is rarely reached, a more realistic approach is to consider the average values within this range. Therefore, the hourly values considered for thermal losses were 0.111 kWh for 60°C, 0.093 kWh for 55°C, and 0.085 kWh for 50°C, in Figure H.3.3 appendix H is illustrated the adjusted consumption of active hot water uses considering an average value for thermal losses.

The following figure shows the average energy consumption for each of the temperatures tested, considering all active hot water uses. The results confirm that higher setpoint temperatures result in increased energy consumption.

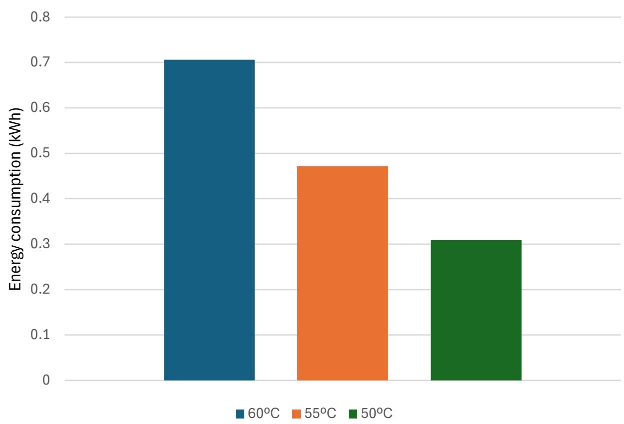


Figure 4.3.8: Average energy consumption for active hot water use per event for temperature setpoint.

Table 4.3.7 summarizes the reductions observed in thermal losses between different temperature setpoints. Results show that reducing the setpoint from 60ºC to 50ºC reduces thermal losses in 23.4%. While lowering the temperature from 60ºC to 55ºC leads to a reduction of 16.2%, and reducing from 55ºC to 50ºC results in a 8.6% reduction in thermal losses. These results highlight that the impact of reducing the temperature setpoint affects not only energy consumption during water use but also consumption associated with maintaining the desired temperature.

Table 4.3.7: Reduction in hourly thermal losses between temperature setpoints.

Temperature change	Absolute reduction (kWh)	Relative reduction (%)
60ºC to 50ºC	0.026	23.4
60ºC to 55ºC	0.018	16.2
55ºC to 50ºC	0.008	8.6

Since the values considered for thermal losses are very close to the typical energy consumption associated with small hot water usage (consumption below 8 L) and due to the lack of detailed usage events records, it is uncertain whether the consumption is from actual hot water uses or from thermal losses. For this reason, the analysis of the influence of changes in temperature setpoint on energy consumption will focus on longer uses (showers and baths), where the energy consumption can be clearly distinguished, and on an all uses scenario. Although consumptions from hand washing, dishwashing, and similar uses were not analyzed separately, some values were included in all uses assessment. As such, a filtering criteria was applied to distinguish between energy consumption due to thermal losses and water use. Consumption recorded outside of typical usage hours (between 1 a.m. and 7 a.m.), when hot water demand is generally minimal, was considered to correspond to thermal losses.

However, this assumption contains some margin of error, as it is not possible to completely rule out occasional misclassifications.

Figure 4.3.9 presents the average energy consumption for long uses and for all types of uses across the three temperature setpoint tested. It also includes the average energy consumption for both categories, regardless of the temperature setpoint. The results show that energy consumption related to long uses is considerably affected by temperature settings. In comparison, the variation in average energy consumption for all uses is less pronounced due to the presence of small usages.

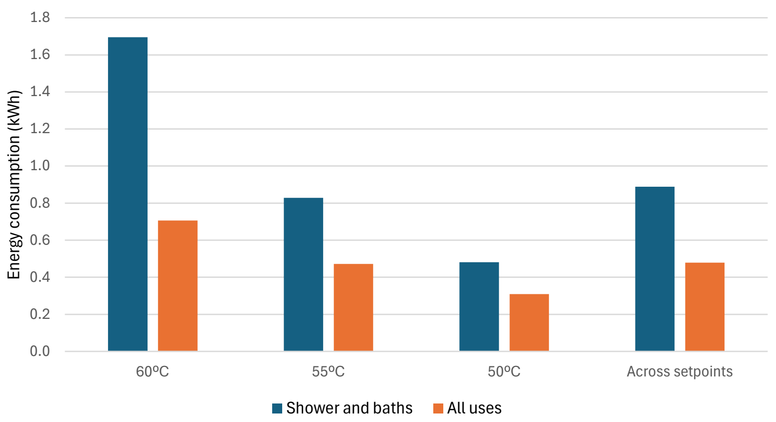


Figure 4.3.9: Energy consumption per hot water use event by temperature setpoint for different types of uses.

To illustrate the potential impact of adjusting the temperature settings of the water heater, the following figure presents the relative change in energy consumption when reducing temperature setpoint for long uses and for all uses.

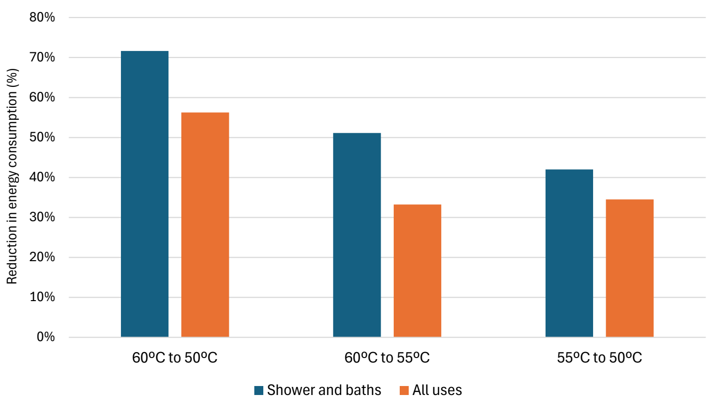


Figure 4.3.10: Reduction in energy consumption due to temperature setpoint change.

Reducing the temperature from 60ºC to 50ºC results in a 71.6% decrease in energy consumption for showers and baths, corresponding to a decrease of 1.214 kWh. Considering all types of use, this change led to a reduction in energy consumption of 56.3% (0.397 kWh). Switching from 60ºC to 55ºC reduces energy consumption by 51.1% (0.867 kWh) for long uses, and by 33.2% (0.235 kWh) for all uses. Lowering the temperature setpoint from 55ºC to 50ºC lead to a 42% reduction for long uses, and a reduction of 34.5% regardless of types of uses.

Table 4.3.8 presents a comparative analysis of the influence on energy consumption from increasing the temperature setpoint between the experimental results obtained and the literature.

Table 4.3.8: Comparative analysis of energy consumption due to temperature setpoint change.

Temperature change	Literature (Δ consumption)	Experimental results
50ºC to 60ºC	+6% to +11%	+128.6%

In accordance to what is summarized in [93], setting the water heater temperature at 60ºC instead of 50ºC can increase energy consumption from 6% up to 11%. However, the experimental results showed a much higher increase for this change, a rise of 128.6% in energy consumption. Particularly, the data was obtained from only one water heater, which reduces representativeness. Additionally, the conditions under which the measurements were taken may differ greatly, whether in terms of external and operational factors, such as where the water heater is installed, the tank insulation conditions, types of uses, for example. Therefore, although the observed increase in energy consumption is a strong indicator of the temperature setpoint increase, it should be considered with some reservation. Further testing with a higher number of devices would be essential to validate these findings.

Table 4.3.9 summarizes the average savings per event regardless of the type of use. Because these values are so small and difficult for consumers to understand, they have been translated into a one-year timeline (Table 4.3.10). To determine the estimated annual savings, it was necessary to assume a representative number of daily hot water uses, in this case 5 events per day.

Table 4.3.9: Average savings per hot water use event across all uses.

Temperature change	Average reduction (kWh)	Monetary savings (€)	Environmental impact ($kgCO_2eq$)
60ºC to 50ºC	0.397	0.097	0.044
60ºC to 55ºC	0.235	0.057	0.026
55ºC to 50ºC	0.163	0.040	0.018

Table 4.3.10: Annual savings due to temperature change by aggregated usage patterns.

Temperature change	Average reduction (kWh)	Monetary savings (€)	Environmental impact ($kgCO_2eq$)
60ºC to 50ºC	724.9	177.6	81.2
60ºC to 55ºC	428.2	104.9	48.0
55ºC to 50ºC	296.8	72.7	33.2

The findings show that the greatest savings in energy consumption, and corresponding monetary savings and avoided emissions, are reached by lowering the temperature setpoint from 60ºC to 50ºC. This 10ºC decrease resulted in a reduction of 724.9 kWh over a one-year period, meaning a monetary saving of 177.6 € and a 81.2 $kgCO_2eq$ of emissions avoided.

Reducing the temperature setpoint from 60ºC to 55ºC led to a 428.2 kWh reduction in energy consumption, corresponding to a saving of 104.9 € and 48 $kgCO_2eq$. In contrast, the reduction from 55°C to 50°C results in an annual reduction of 296.8 kWh, representing a monetary saving of 33.2 € and avoid the emission of 12.7 $kgCO_2eq$.

Although these results were also calculated for long uses separately, as they are included in the all uses scenario, only the aggregate uses are presented here. In fact, if only considering long uses the observed savings are substantially greater, as detailed in appendix H.3.

Similarly to what was done to investigate the influence of the setpoint temperature, the effect of outdoor temperature on energy consumption was also analyzed. For this situation, a constant setpoint temperature, of 50ºC, was maintained during the measurement periods.

The data were collected during the last week of March and June, allowing for a comparison between winter and summer conditions. This difference was assessed for WH2, which has a capacity of 80L and is installed on a closed balcony, making it particularly reactive to outdoor temperature fluctuations.

This approach attempts to assess how seasonal variations in outdoor temperatures may affect the energy required to maintain the water temperature at a fixed temperature. According to data from Portuguese Institute for Sea and Atmosphere (IPMA), the average daily outdoor temperature during the monitoring month was approximately 12.5ºC in March [96] and 20ºC in June [97]. This average outdoor temperature differs if only the average daily temperatures for those measurement days are considered, in which case it would be approximately 13.5ºC for the week in March and around 24ºC for June. These values represent a clear seasonal difference impacting directly the energy use of domestic hot water production. However, it is important to point out that the influence of outdoor temperature results from seasonal changes and not the implementation of any ES measure. Therefore, this analysis does not aim to quantify the potential savings due to the application of ES measures.

The most evident difference observed from the direct analysis of the graphs from the hourly profiles (Figure 4.3.11) is the presence of recurrent consumption peaks of approximately 0.3 kWh in March, which are mainly associated with standby heating to offset thermal losses. While in June such losses were practically negligible. Nevertheless, due to the similarity of these peaks with small hot water uses consumption, it becomes difficult to distinguish between standby heating events and actual hot water uses.

During winter periods, storage water heaters experience noticeable heat loss to the surrounding environment, due to the higher temperature difference between the water tank and outdoor air. This difference tends to increase on less insulated spaces, like a closed balcony. In contrast, during summer, the lower difference between the water tank temperature and the outdoor temperature reduces these losses, which results in lower energy consumption to maintain the same setpoint temperature.

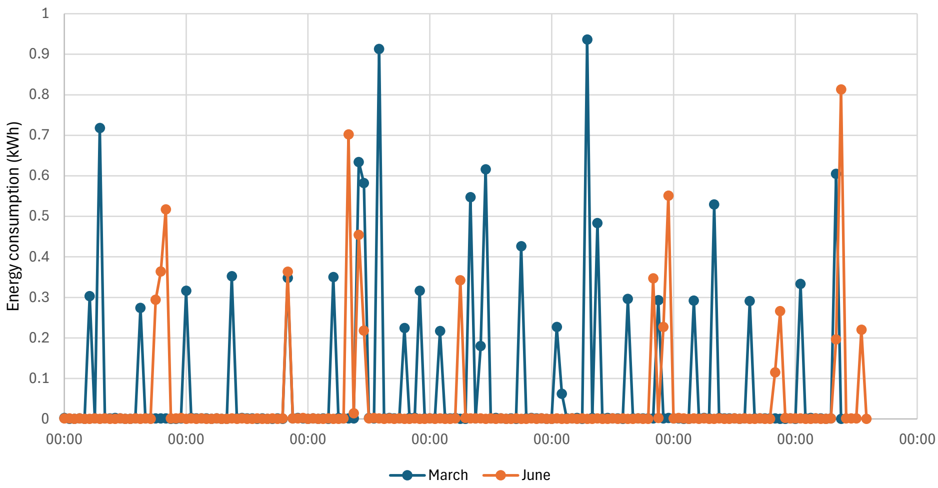


Figure 4.3.11: Energy consumption patterns of WH2 in March and June.

To complement the analysis of the impact of outdoor temperature variation on energy consumption, Table 4.3.14 summarizes the average daily consumption recorded during the monitoring period, along with the corresponding outdoor temperatures and the change in energy consumption from March to June. The results indicate a reduction in average energy consumption of 0.814 kWh, corresponding to 48.4%, associated with an increase of 10.5ºC in outdoor temperature. This difference can mainly be attributed to thermal losses, assuming all other factors remained unchanged.

In March, the greater difference between setpoint temperature of the water heater and the cooler outdoor temperature requires more frequent heating cycles to maintain the desired water temperature. In June, however, this difference is smaller, resulting in reduced or almost nonexistent thermal losses. Additionally, the cold water inlet is higher in June, leading to lower heating requirements to reach the desired setpoint.

Table 4.3.11: Effect of outdoor temperature on daily energy consumption.

Monitoring week	Average outdoor temperature (ºC)	Average daily consumption (kWh/day)	Δ consumption (kWh) (vs March)	Relative reduction (%)
March	13.5	1.682	-	-
June	24	0.868	0.814	48.4

5 Conclusions and Future Suggestions

This study aimed to investigate energy sufficiency (ES) measures in the residential sector, focusing on available information, consumer perspectives, and the quantification of their potential impacts. The study identified the ES measures most frequently promoted in Portuguese best practice guides, assessed both consumers' perceptions and their willingness to adopt such measures, and explored if sociodemographic factors (age or being part of an academic community like FCUL) shape these practices. In addition, the study assessed the actual impacts of implementing certain measures in real life context in terms of potential energy and monetary savings, and greenhouse gas emissions reduction.

The guides' analysis revealed that the most frequently promoted ES measures are turning off lights when not needed, avoiding standby consumption, avoiding frequent and prolonged opening of appliances doors, and using natural light whenever possible. This indicates that the current focus of these guides is on practical, low-effort measures. On the other hand, the least mentioned measures are using the microwave at maximum capacity, reducing decorative interior lighting, ensuring adequate lighting, and wearing appropriate clothes to indoor conditions. When compared the two main groups producing the guides, it was observed that energy agencies tend to propose measures with a higher technical level alongside simpler recommendations. Local entities, on the other hand, showed a tendency to present more direct and easy-to-use measures.

With regard to the classification of ES measures, three categories were considered (reduction, adjustment, and substitution). Most of the identified measures belong to the adjustment category, which focuses on optimizing the operation of existing equipment or the way services are provided, avoiding unnecessary consumption without reducing the level of service. And the least represented type of measures are substitution measures, replacing practices with less demanding alternatives.

Based on international literature, other recommendations could be added to the Portuguese guides, such as preferring showers over baths, encouraging shorter shower times, and adjusting refrigerator and freezer temperatures. These are just a few measures found that are not mentioned in the guides consulted. Furthermore, mentioning the use of short programs alongside ECO programs encourages energy savings, as in some cases the short programs consume less energy. Finally, a closer collaboration between energy agencies, who have technical expertise, and local authorities, who are proximate to consumers, is essential to increase the reach and impact of these guides.

The participants' responses suggest a very positive picture, with ES measures being broadly applied. The main motivations for adopting these measures were monetary savings, habits and routines, and environmental concerns. Slightly more than 70% of participants stated being familiar with the concept of energy sufficiency, and the majority of all respondents attributed great importance to such measures. Although encouraging, these responses may partly reflect a tendency to give socially expected answers, rather than actual beliefs. Despite the positive results, there is still room for improvement, namely in the adoption of ECO programs in washing machines and dishwashers, adjusting washing temperature and indoor temperature settings, eliminating standby consumption, and using power strips with on/off switches. However, due to the limited sample size and its consequent lack of representativeness of the total population, these results must be considered with caution. Comparisons made between age groups and affiliation with the FCUL community did not reveal major differences, suggesting that these factors do not play a decisive role in the adoption of ES measures.

For the washing machine, cycles at different temperatures and programs were experimentally tested. On average, cycles with a washing temperature of 20ºC had the lowest energy consumption, followed by the minimum program, the ECO, then the washing temperatures of 30ºC and 40ºC, respectively, and finally cycles at 60ºC had the highest consumption. When comparing the modifications between washing cycles, the most significant savings were observed reducing the temperature from 60ºC to 30ºC, which led to reductions of 56.5 kWh per 100 cycles (13.8 € and 6.3 $kgCO_2eq$). The change from 60ºC to 20ºC also showed considerable savings of 55 kWh. Switching from 60ºC to ECO and from 40ºC to 20ºC also revealed substantial savings, while the remaining changes were more moderate. Moreover, the results obtained for the effect of spin speed were drawn inconclusive, despite the trend to reduce energy consumption with lower spin speeds. Generally, the findings confirm that lowering washing temperatures offers the greatest potential for reducing energy consumption in washing machines.

The experimental analysis of dishwashing cycles revealed clear differences in energy consumption between programs. On average, the intensive program was the most energy consuming one, followed by the normal program, the ECO program, and lastly the short program. The short cycle showed the lowest consumption across all measurements. Replacing the intensive program with the short could save up to 66.8 kWh per 100 cycles, which is equivalent to 16.4 € and 7.5 $kgCO_2eq$ emissions avoided. Other significant savings were observed when switching from normal to short program, of 34 kWh, and of 26.8 kWh when using the short program instead of the ECO. Switching from the intensive program to the ECO program also resulted in substantial reductions of 35.7 kWh per 100 cycles. These findings highlight that the short program, even though barely mentioned in the practice guides, can play an important role in reducing energy consumption and household emissions.

For the water heaters, the results show that both energy consumption and thermal losses increased with higher temperatures, confirming the significant influence of the temperature setpoint. The most effective change for hot water use was reducing the setpoint from 60ºC to 50ºC, which, in a realistic scenario, could result in savings of 724.9 kWh per year, corresponding to 177.6 € and 81.2 $kgCO_2eq$. However, this result may be somewhat overestimated compared to other case studies, as it is based on a single water heater. Therefore, these results should be interpreted as indicative rather than absolute. As for outdoor conditions, it was found that thermal losses for the same temperature setpoint were affected by the season. In March, thermal losses were estimated at approximately 0.3 kWh, while in June were practically nonexistent. Considering the average temperature for the week when measurements were taken, the 10.5ºC observed difference between March and June resulted in 48.8% reduction in daily energy consumption, corresponding to 0.814 kWh. Despite highlighting the role of outdoor temperature in influencing standby consumption, this temperature variation does not correspond to ES practices but rather to seasonal variability.

In conclusion, improving the consistency of the results would make future work more representative. For the survey, this would mean ensuring that the sample is representative of the general population. In the experimental section, some conclusions were based on data from only one device, which limited the generalizability of the results. Therefore, collecting data from a wider range of devices would strengthen the analysis. Furthermore, attempting to quantify the impact of other measures to build a solid base on the effectiveness of ES measures would provide valuable insight into consumer behavior and usage patterns in the residential sector. It would also support a more informed discussion on the role of ES in reducing energy demand.

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7 Appendix

Appendix A – Simplified designation of ES measures used in analysis

Simplified designation	**Description**
Turn off lights	Turn off unnecessary lights in unoccupied spaces
Eliminate standby	Unplug devices or switch off power strips to avoid standby energy consumption
Avoid opening appliance doors	Avoid frequent or prolonged opening of fridge, freezer or oven doors to reduce energy waste
Use natural light	Maximize use of daylight instead of artificial lighting during the day
Max. capacity of dish and washing machines	Use dish and washing machines only when fully loaded
Lower HVAC temperature (when adjustable)	Adjust thermostat seasonally: lower in winter, higher in summer
Use lower temperatures and eco/short programs	Use low temperatures and select eco or short programs
Use solar radiation	Open blinds/shutters to allow passive solar heating during colder periods
Clothesline drying	Use a drying rack or outdoor clothesline instead of a tumble dryer
Defrost food properly	Defrost frozen food in advance to reduce cooking or microwave time
On/off switch socket	Use on/off buttons to fully disconnect equipment when not in use
Use proper pan size for burner	Use pots and pans that match the size of the burner or electric hob
Use natural ventilation	Open windows and doors to improve airflow instead of mechanical ventilation
Turn off equipment during task interruptions	Turn off equipment when pausing tasks (e.g.: during phone calls)
Turn off equipment before cycle ends	Turn off equipment a few minutes before finishing the task if adequate (e.g.: oven)
Do not place hot items in the fridge/freezer	Let hot food cool before storing to avoid increasing internal temperature
Proper equipment sizing	Choose appliances sized appropriately for your real needs

Max. oven capacity	Cook multiple dishes simultaneously to maximize oven use
Lower DHW set temperature	Set water heater to a lower but still comfortable temperature
Turn off equipment during long absence	Turn off or unplug appliances when away for extended periods
Avoid cooling/heating unused areas	Only heat or cool rooms that are occupied
Close doors/windows when HVAC is on	Close openings to avoid unnecessary energy loss in heated/cooled rooms
Reduce ornamental exterior lighting	Limit use of decorative outdoor lighting
Adequate lighting	Ensure lighting is appropriate for the activity
Proper clothing	Wear appropriate clothes to reduce reliance on heating/cooling
Max. microwave capacity	Use the microwave at or near full capacity
Reduce decorative interior lighting	Limit use of non-essential decorative lighting indoors

Appendix B – Survey applied

Aplicação de boas práticas no consumo de energia no setor residencial / Application of best practices in energy consumption in the residential sector

Solicito a vossa colaboração no preenchimento deste inquérito, para o desenvolvimento da minha tese de mestrado em Engenharia da Energia e Ambiente. O inquérito tem um tempo estimado de 5 a 10 minutos.
A sua participação é voluntária e os dados recolhidos serão tratados de forma anónima e confidencial, sendo utilizados exclusivamente para fins académicos e científicos.
Para mais informações sobre o estudo, pode consultar o folheto informativo através do seguinte link:
https://drive.google.com/file/d/1zV1-SosHM6KHhTi3Ottz-8L3zYohFxMj/view?usp=drive_link
Caso tenha alguma dúvida ou pretenda obter mais informações sobre o estudo, poderá contactar-nos através dos seguintes e-mails: fc62658@alunos.ciencias.ulisboa.pt ; mopanao@ciencias.ulisboa.pt.
Agradeço desde já o seu tempo e contributo para este estudo!

I kindly request your collaboration in completing this survey for the development of my master's thesis in Energy and Environment Engineering. The survey has an estimated time of 5 to 10 minutes.
Your participation is voluntary, and the data collected will be treated anonymously and confidentially, being used exclusively for academic and scientific purposes.
For more information about the study, you can consult the information leaflet at the following link:
https://drive.google.com/file/d/1zV1-SosHM6KHhTi3Ottz-8L3zYohFxMj/view?usp=drive_link
If you have any questions or would like more information about the study, please feel free to contact us at the following emails: fc62658@alunos.ciencias.ulisboa.pt ; mopanao@ciencias.ulisboa.pt.
Thank you in advance for your time and contribution to this study!

Nota: Todas as perguntas assinaladas com (*) são obrigatórias. / Note: All questions marked with (*) are mandatory.

Secção 1: Consentimento / Consent

1. Consente a participação neste estudo e o tratamento dos seus dados de forma anónima e confidencial? / Do you consent to participate in this study and to the anonymous and confidential processing of your data?

- ☐ Sim, consinto. / Yes, I consent. *(Avançar para a secção seguinte)*
- ☐ Não consinto / No, I do not consent. *(Enviar inquérito)*

Secção 2: Dados pessoais / Personal data

2. Indique a sua faixa etária. / Indicate your age group. *

- ☐ Menos de 18 / Less than 18 years old *(Enviar inquérito)*
- ☐ 18 - 27 anos / 18 - 27 years old *(Avançar para a secção seguinte)*
- ☐ 28 - 37 anos / 28 - 37 years old *(Avançar para a secção seguinte)*
- ☐ 38 - 47 anos / 38 - 47 years old *(Avançar para a secção seguinte)*
- ☐ 48 - 57 anos / 48 - 57 years old *(Avançar para a secção seguinte)*
- ☐ 58 - 67 anos / 58 - 67 years old *(Avançar para a secção seguinte)*
- ☐ Mais de 67 anos / More than 67 years old *(Avançar para a secção seguinte)*

Secção 3: Dados pessoais / Personal data

3. Qual é o seu nível de escolaridade? / What is your level of education? *

Considere a opção que melhor descreve a sua situação atual. / Consider the option that best describes your current situation.

- ☐ Ensino básico / Basic education
- ☐ Ensino secundário / Secundary education
- ☐ Licenciatura / Bachelor's degree
- ☐ Pós-graduação / Postgraduate studies
- ☐ Mestrado / Master's degree
- ☐ Doutoramento / Doctorate (PhD)
- ☐ Curso técnico superior profissional (CTESP) / Higher technical professional courses
- ☐ Prefiro não responder / Prefer not to answer
- ☐ Outra / Other: ____________

4. Em que região de Portugal reside? / In which region of Portugal do you live? *

Se possui mais do que uma residência, considere apenas a que reside durante mais tempo. / If you have more than one residence, consider only the one where you live the longest.

- ☐ Norte / North
- ☐ Centro / Center
- ☐ Grande Lisboa / Greater Lisbon
- ☐ Oeste e Vale do Tejo / West and Tagus Valley
- ☐ Península de Setúbal / Setúbal Peninsula
- ☐ Alentejo / Alentejo
- ☐ Algarve / Algarve
- ☐ Região Autónoma dos Açores / Autonomous Region of Azores
- ☐ Região Autónoma da Madeira / Autonomous Region of Madeira
- ☐ Prefiro não responder / Prefer not to answer

5. Em que tipo de habitação vive? / What type of home do you live in? *

Se possui mais do que uma residência, considere apenas a que reside durante mais tempo. / If you have more than one residence, consider only the one where you live the longest.

- ☐ Apartamento / Apartment
- ☐ Moradia isolada ou geminada / Detached or semi-detached house
- ☐ Moradia em banda / Terraced house
- ☐ Residência estudantil / Student residence
- ☐ Prefiro não responder / Prefer not to answer
- ☐ Outra / Other:

6. Faz parte da comunidade da Faculdade de Ciências (estudante, investigador, professor, etc.)? / Are you a member of the Faculty of Sciences community (student, researcher, professor, etc.)? *

- ☐ Sim / Yes
- ☐ Não / No
- ☐ Prefiro não responder / Prefer not to answer

Secção 4: Comportamentos e práticas atuais / Current behaviors and practices

7. Relativamente à iluminação, com que frequência aplica as seguintes medidas? / With regard to lighting, how often do you apply the following measures? *

Se a situação mencionada não se aplica ao seu caso, selecione "Não se aplica" /If the mentioned situation does not apply to you, select "Not applicable".

Marcar apenas uma opção por linha

	Nunca/ Never	Raramente/ Rarely	Ocasionalmente/ Occasionally	Frequentemente/ Frequently	Sempre/ Always	Não se aplica / Not applicable	Não sabe, não responde / Do not know, no answer
Aproveita a luz natural / Take advantage of natural light	☐	☐	☐	☐	☐	☐	☐
Apaga as luzes quando estas não são necessárias / Turn off the lights when not needed	☐	☐	☐	☐	☐	☐	☐
Reduz a iluminação decorativa interior / Reduce interior decorative lighting	☐	☐	☐	☐	☐	☐	☐
Reduz a iluminação ornamental exterior / Reduce outdoor ornamental lighting	☐	☐	☐	☐	☐	☐	☐

8. Relativamente aos equipamentos, com que frequência aplica as seguintes medidas? / With regard to equipment, how often do you apply the following measures? *

Se a situação mencionada não se aplica ao seu caso, selecione "Não se aplica"/If the mentioned situation does not apply to you, select "Not applicable".

Marcar apenas uma opção por linha

	Nunca/ Never	Raramente/ Rarely	Ocasionalmente/ Occasionally	Frequentemente/ Frequently	Sempre/ Always	Não se aplica / Not applicable	Não sabe, não responde /Do not know, no answer
Utiliza a capacidade máxima da máquina de lavar loiça / Uses dishwasher's maximum capacity	☐	☐	☐	☐	☐	☐	☐

Utiliza a capacidade máxima da máquina de lavar roupa / Uses washing machine's maximum capacity	☐	☐	☐	☐	☐	☐	☐
Utiliza a capacidade máxima do forno / Uses oven's maximum capacity	☐	☐	☐	☐	☐	☐	☐
Utiliza tomadas com interruptor ON/OFF / Uses sockets with an ON/OFF switch	☐	☐	☐	☐	☐	☐	☐
Tenta eliminar os consumos por standby (modo de suspensão), desligando completamente os equipamentos / Try to eliminate standby consumption by completely switching off equipment	☐	☐	☐	☐	☐	☐	☐
Adequa o recipiente ao bico do fogão/placa elétrica / Match the container to the burner on the stove/electric hob	☐	☐	☐	☐	☐	☐	☐
Quando compra um equipamento novo, escolhe um modelo com capacidade adequada às suas necessidades / When buying a new equipment, you choose a model with the right capacity for your needs	☐	☐	☐	☐	☐	☐	☐
Desliga os equipamentos antes de terminar uma tarefa (ex.: ferro de engomar, forno) /	☐	☐	☐	☐	☐	☐	☐

Switch off equipment before finishing a task (e.g. iron, oven)							
Quando está ausente por um longo período de tempo, costuma desligar determinados equipamentos / When you are away for a long period of time, you usually turn off certain equipment	☐	☐	☐	☐	☐	☐	☐
Desliga os equipamentos ao interromper uma tarefa / Switch off equipment when interrupting a task	☐	☐	☐	☐	☐	☐	☐
Coloca alimentos quentes no frigorifico e congelador / Put hot food in the fridge and freezer	☐	☐	☐	☐	☐	☐	☐
Deixa a porta dos equipamentos de refrigeração aberta durante muito tempo / Leave the door of refrigeration equipment open for a long time	☐	☐	☐	☐	☐	☐	☐
Abre a porta do forno muitas vezes durante a sua utilização / Opens oven's door too many times during use	☐	☐	☐	☐	☐	☐	☐
Ajusta a temperatura de lavagem da máquina de lavar roupa ao mínimo adequado / Adjusts	☐	☐	☐	☐	☐	☐	☐

the washing temperature of the washing machine to the appropriate minimum							
Utiliza o programa eco da máquina de lavar roupa / Uses the washing machine's eco program	☐	☐	☐	☐	☐	☐	☐
Utiliza o programa eco da máquina de lavar loiça / Uses the dishwasher's eco program	☐	☐	☐	☐	☐	☐	☐

9. Relativamente aos sistemas de climatização, com que frequência aplica as seguintes medidas? / With regard to air conditioning systems, how often do you apply the following measures? *
Se não utiliza sistemas de climatização ou a situação mencionada não se aplica ao seu caso, selecione "Não se aplica"/ If you do not use climate control systems or the mentioned situation does not apply to you, select "Not applicable"

Marcar apenas uma opção por linha

	Nunca/ Never	Raramente/ Rarely	Ocasionalmente/ Occasionally	Frequentemente/ Frequently	Sempre/ Always	Não se aplica / Not applicable	Não sabe, não responde / Do not know, no answer
Durante a climatização fecha portas e janelas / Close doors and windows while using air conditioning	☒	☐	☐	☐	☐	☐	☐
Ajusta a temperatura de climatização do ar condicionado ao que considera razoável, mas não excessivo / Adjusts the air conditioning temperature setpoint to what you consider reasonable but not excessive	☐	☐	☐	☐	☐	☐	☐

Evita climatizar espaços não utilizados / Avoid air-conditioning unused spaces	☐	☐	☐	☐	☐	☐	☐
Aproveita a ventilação natural para arrefecer os espaços naturalmente / Take advantage of natural ventilation to cool spaces naturally	☐	☐	☐	☐	☐	☐	☐
Aproveita a radiação/luz solar para aquecer os espaços naturalmente / Take advantage of radiation/sunlight to heat rooms naturally	☐	☐	☐	☐	☐	☐	☐
Adequa o vestuário à temperatura interior / Adapt clothing to the indoor temperature	☐	☐	☐	☐	☐	☐	☐

10. Quais dos seguintes aspetos considera influenciarem mais na sua aplicação de medidas de suficiência energética, mesmo não sabendo que as está a aplicar? / Which of the following aspects do you consider having the greatest influence on your application of energy sufficiency measures, even if you are not aware you are applying them? *

Marcar tudo o que for aplicável

☐ Poupança económica / Economic savings

☐ Preocupações ambientais / Environmental concerns

☐ Informação e conhecimento / Information and knowledge

☐ Pressão social e dos pares / Peer and social pressure

☐ Hábitos e rotinas / Habits and routines

☐ Facilidade de implementação / Ease of implementation

☐ Não vejo necessidade de aplicar estas medidas / Don't see the need to apply these measures

☐ Não sabe, não responde / Do not know, no answer

Secção 5: Familiarização com o tema / Familiarization with the topic

11. Conhecia o conceito de "Suficiência Energética"? / Were you familiar with the concept of 'Energy Sufficiency'? *

Marcar apenas uma opção

☐ Sim / Yes

☐ Não / No

☐ Prefiro não responder / Prefer not to answer

12. Quão importante considera serem as medidas de suficiência energética para a redução do consumo de energia? / How important do you think energy sufficiency measures are in reducing energy consumption? *

Marcar apenas uma opção

☐ Nada importantes / Not at all important

☐ Pouco importantes / Slightly important

☐ Importantes / Important

☐ Bastante importantes / Fairly important

☐ Muito importantes / Very important

☐ Sem opinião / No opinion

☐ Prefiro não responder / Prefer not to answer

13. Qual é a sua dispoção para adotar medidas de suficiência energética? How likely are you to adopt energy sufficiency measures? *

Marcar apenas uma opção

☐ Já aplico várias destas medidas / I am already adopting several of these measures *(Avançar para a secção 7)*

☐ Estou disposto(a) a adotar mais medidas em breve / I am willing to adopt more measures soon *(Avançar para a secção 7)*

☐ Posso considerar adotar algumas medidas, mas gostava de ter acesso a mais informação sobre o seu impacto real/ I may consider adopting some measures, but I would like to have access to more information about their real impact *(Avançar para a secção 7)*

☐ Não estou interessado em adotar medidas de suficiência energética / Not interested in adopting energy sufficiency measures *(Avançar para a secção seguinte)*

☐ Não sabe, não responde / Do not know, no answer *(Avançar para a secção 7)*

Secção 6: Principais barreiras / Main barriers

14. Se não está interessado em adotar medidas de suficiência energética, quais considera serem as principais barreiras? / If you are not willing to adopt energy sufficiency measures, what are the main barriers?

Marcar apenas uma opção

☐ Falta de conhecimento ou informação/ Lack of awareness or information

☐ Falta de tempo ou esforço para implementar estas medidas / Lack of time or effort to implemente measures

☐ Considerar que a aplicação destas medidas não fará uma diferença significativa / Belief that these measures won’t make a significant difference

☐ Incerteza quanto aos benefícios ou à eficácia destas medidas / Uncertainty about the benefits or effectiveness

☐ Prefiro não responder / Prefer not to answer

☐ Outra / Other: ___________

Secção 7: Interesse nos resultados / Interest in results

Caso tenha interesse em receber os resultados deste estudo, por favor envie um email a solicitá-los para os endereços indicados abaixo. / If you are interested in receiving the results of this study, please send an email requesting them to the addresses listed below. fc62658@alunos.ciencias.ulisboa.pt; mopanao@ciencias.ulisboa.pt

Appendix C – Record sheets

C.1 – Record sheets for washing machines and dishwasher

Equipamento	**Data**	**Hora de início**	**Programa**	**Duração (h)**	**Temperatura (ºC)**	**Carga (≈ %)**

C.2 – Record sheets for water heater

Data	Hora	Temperatura setpoint	Utilização (ex.: banho, loiça, etc)	Duração	Nº de pessoas a usar a água quente

Appendix D – Referenced documents

Document designation (No.)	Document title	Entity	Reference
1	Guia da Eficiência Energética (May 2010)	ADENE – Agência para a Energia	[73]
2	Guia da Eficiência Energética (October 2013)	ADENE – Agência para a Energia	[74]
3	Estudo de mercado no âmbito das campanhas de sensibilização e de promoção da eficiência energética na Habitação Particular (July 2017)	ADENE – Agência para a Energia and Consulmark	[75]
4	Guia de Boas Práticas – Na Utilização de Energia e Água (2018)	AdEPORTO – Agência de Energia do Porto	[76]
5	Guia de Boas Práticas – Na Utilização de Energia (2022)	AdEPORTO – Agência de Energia do Porto (Porto Energy Hub)	[77]
6	Guia para o Munícipe – Eficiência Energética e Produção de Energia (September 2024)	Câmara Municipal de Azambuja and Get2C	[78]
7	Programa de Educação e Sensibilização Ambiental de Cascais - Guia de Educação Ambiental (2020)	Câmara Municipal de Cascais	[79]
8	Dicas de Eficiência Energética -Viva a sua casa com mais energia sustentável (June 2012)	EDP	[80]
9	Manual de eficiência energética – Formação e sensibilização para a eficiência energética (December 2019)	EDP, ERSE and Quercus	[81]

10	Guia de Boas Práticas – Eficiência Energética para a sua Casa (October 2023)	E-REDES	[82]
11	Manual do Cidadão para a Eficiência Energética (May 2024)	Câmara Municipal de Guimarães and RdA – Climate Solutions	[83]
12	Manual de Boas Práticas – Contadores Inteligentes para Decisões Eficientes	Lisboa E-Nova	[84]
13	Guia – Boas Práticas Ambientais	Câmara Municipal de Loures	[85]
14	Manual de Boas Práticas Ambientais (September 2018)	Câmara Municipal da Maia	[86]
15	Manual de Boas Práticas – Sustentabilidade Energética, Energia no Setor Doméstico	MédioTejo21 - Agência Regional de Energia e do Ambiente do Médio Tejo e Pinhal Sul	[87]
16	Guia de Boas Práticas Ambientais	Câmara Municipal de Penacova	[88]
17	Manual de Boas Práticas – Poupança Energética e Hídrica (November 2022)	Município de Póvoa de Lanhoso	[89]
18	Guia de Eficiência Energética – Setor Residencial	RNAE – Associação das Agências de Energia e Ambiente	[90]

Appendix E – Matrix of ES measures referenced across guides

Measures / Guides	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total of guides mentioning
Turn off lights	X	X	X	X	X	X		X	X	X	X		X	X	X	X	X	X	16
Eliminate standby	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		16
Avoid opening appliance doors	X	X	X	X	X	X	X	X		X	X	X	X		X	X		X	15
Use natural light	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	15
Max. capacity of dish and washing machines	X	X	X	X	X		X	X		X	X	X			X	X	X	X	14
Adjust HVAC temperature settings	X	X		X	X				X	X	X	X	X		X	X		X	12
Use lower temperatures and eco/short programs	X	X		X	X			X			X	X			X	X	X	X	11
Use solar radiation			X	X	X					X	X	X	X	X	X	X		X	11
Clothesline drying	X	X						X		X	X	X		X	X			X	9
Defrost food properly	X	X		X	X			X			X				X			X	8
On/off switch socket	X	X	X	X				X				X			X			X	8
Use proper pan size for burner	X	X		X	X			X			X				X			X	8
Use natural ventilation	X	X		X		X		X			X	X			X				8
Turn off equipment during task interruptions	X	X						X					X	X	X	X		X	8
Turn off equipment before cycle ends	X	X			X			X			X				X			X	7
Do not place hot items in the fridge/freezer	X	X			X			X		X			X		X				7
Proper equipment sizing	X	X		X	X						X							X	6
Max. oven capacity	X	X		X	X						X							X	6
Lower DHW set temperature	X	X		X	X						X							X	6
Turn off equipment during long absence				X	X			X			X							X	5
Avoid cooling/heating unused areas								X	X	X					X			X	5
Close doors/windows when HVAC is on								X	X	X			X					X	5
Reduce ornamental exterior lighting	X	X													X			X	4
Adequate lighting	X	X													X				3
Proper clothing						X	X								X				3
Max. microwave capacity					X														1
Reduce decorative interior lighting					X														1
Total measures per guide	20	20	7	16	18	6	5	17	6	11	16	9	8	5	20	9	5	20	

Appendix F – Frequency of ES measures by classification and entity type

Classification	ES measures	Energy agencies	Local entities
Adjustment	Turn off lights	11	5
	Eliminate standby	10	6
	Max. capacity of dish and washing machines	11	3
	Adjust HVAC temperature settings	10	2
	Use lower temperatures and eco/short programs	9	2
	On/off switch socket	8	0
	Use proper pan size for burner	8	0
	Do not place hot items in the fridge/freezer	6	1
	Proper equipment sizing	6	0
	Max. oven capacity	6	0
	Lower DHW set temperature	6	0
	Close doors/windows when HVAC is on	4	1
	Adequate lighting	3	0
	Max. microwave capacity	1	0
Reduction	Avoid opening appliance doors	11	4
	Turn off equipment during task interruptions	5	3
	Turn off equipment before cycle ends	7	0
	Turn off equipment during long absence	5	0
	Avoid cooling/heating unused areas	5	0
	Reduce ornamental exterior lighting	4	0
	Proper clothing	1	2
	Reduce decorative interior lighting	1	0
Substitution	Use natural light	11	4
	Use solar radiation	8	3
	Clothesline drying	8	1
	Defrost food properly	8	0
	Use natural ventilation	7	1

Appendix G – Comparative analysis of survey results

G.1 – Age-based comparison.

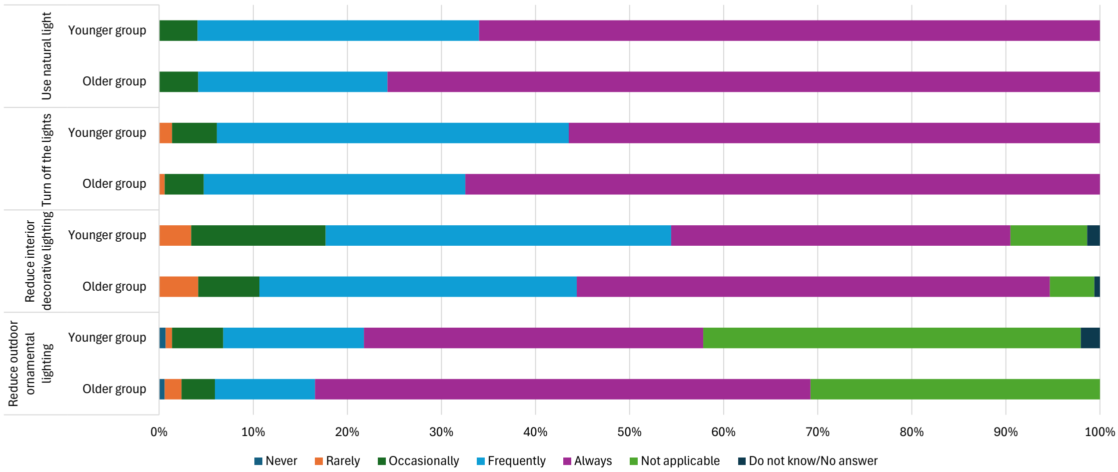


Figure G.1.1: Frequency of respondents' lighting-related user behaviors, by age group.

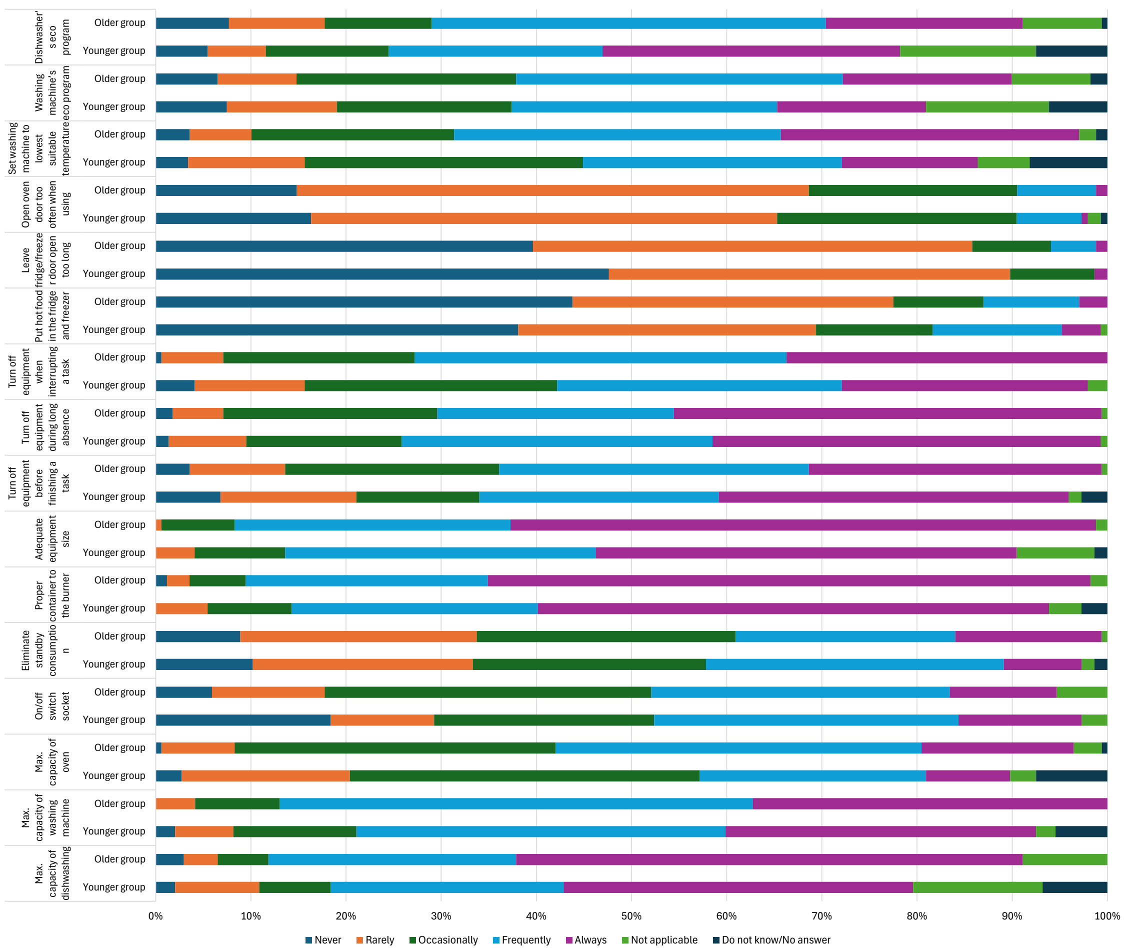


Figure G.1.2: Frequency of respondents' appliance-related user behaviors, by age group.

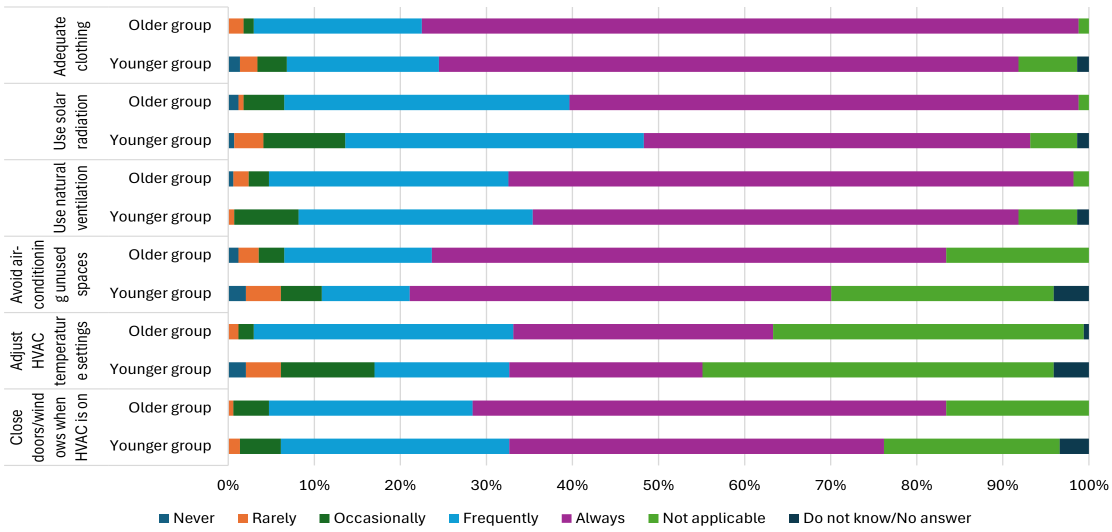
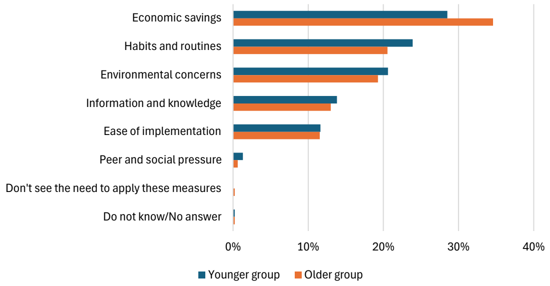
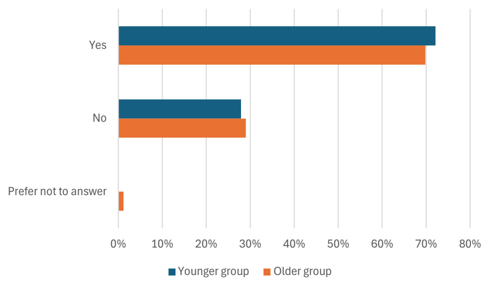


Figure G.1.3: Frequency of respondents’ heating, cooling, and ventilation-related user behavior -related user behaviors, by age group.

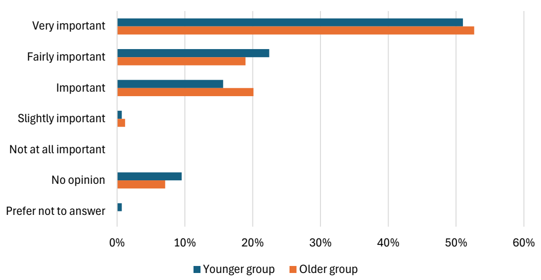
a)



b)



c)



d)

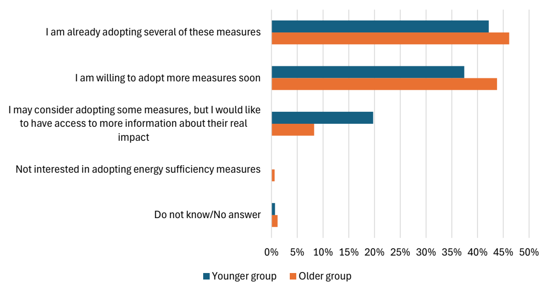


Figure G.1.4: a) Main factors influencing the adoption of ES measures; b) Respondents’ familiarity with the concept of ES; c) Perceived importance of ES measures among respondents; d) Respondents' willingness to adopt ES measures – age-based comparison.

G.2 – Comparison between FCUL respondents and external participants

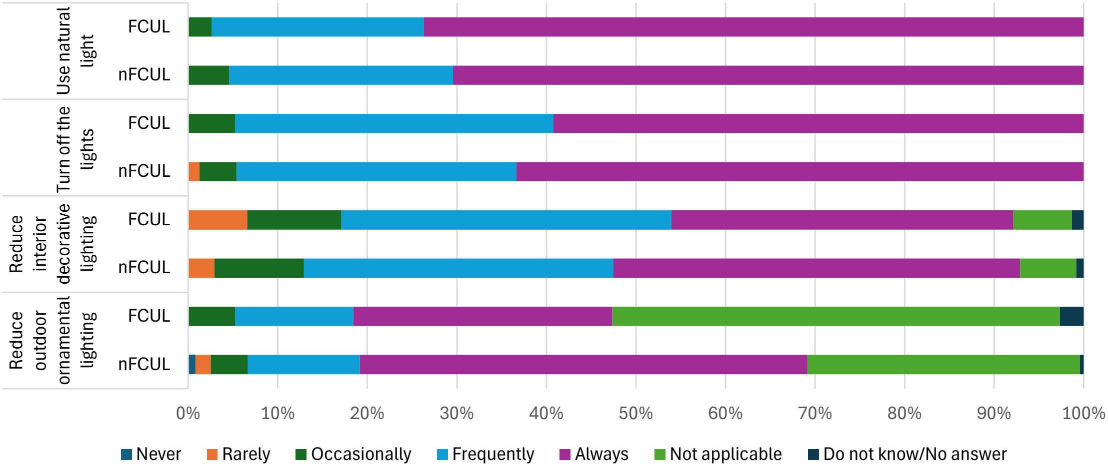


Figure G.2.1: Frequency of respondents' lighting-related user behaviors, by affiliation (FCUL community and external participants).

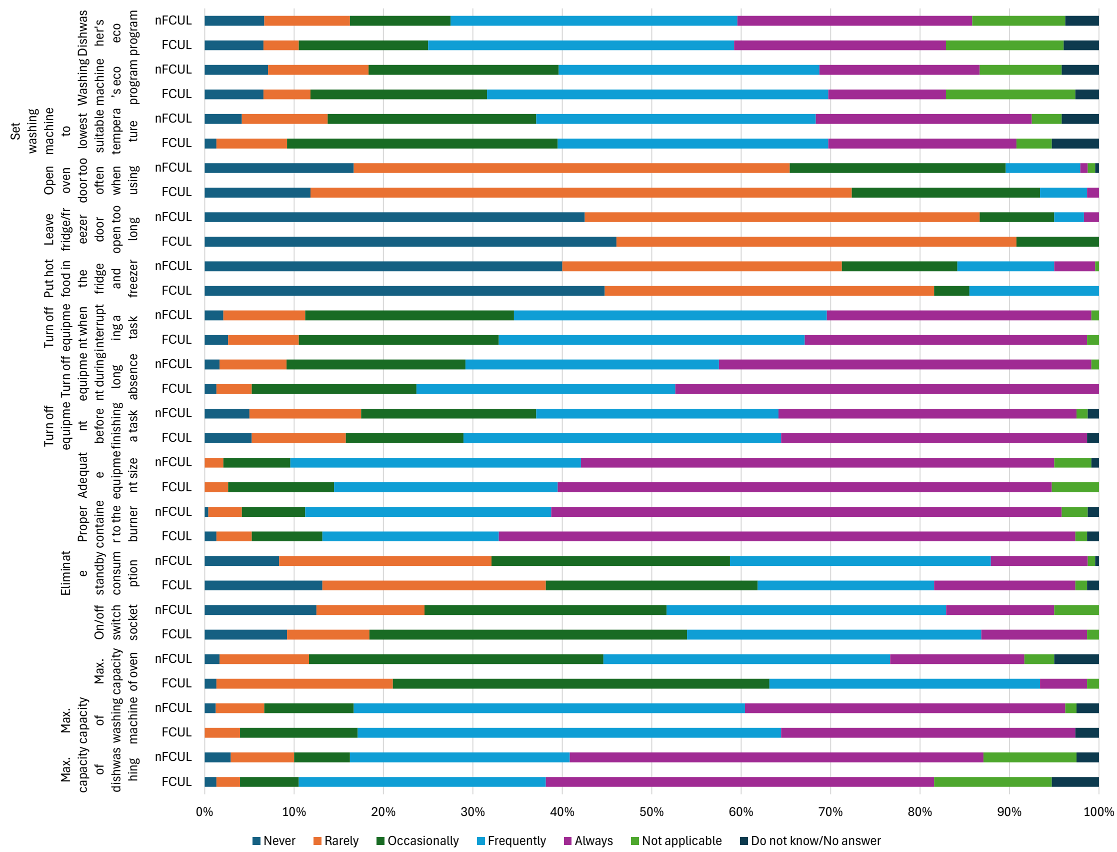


Figure G.2.2: Frequency of respondents' appliance-related user behaviors, by affiliation (FCUL community and external participants).

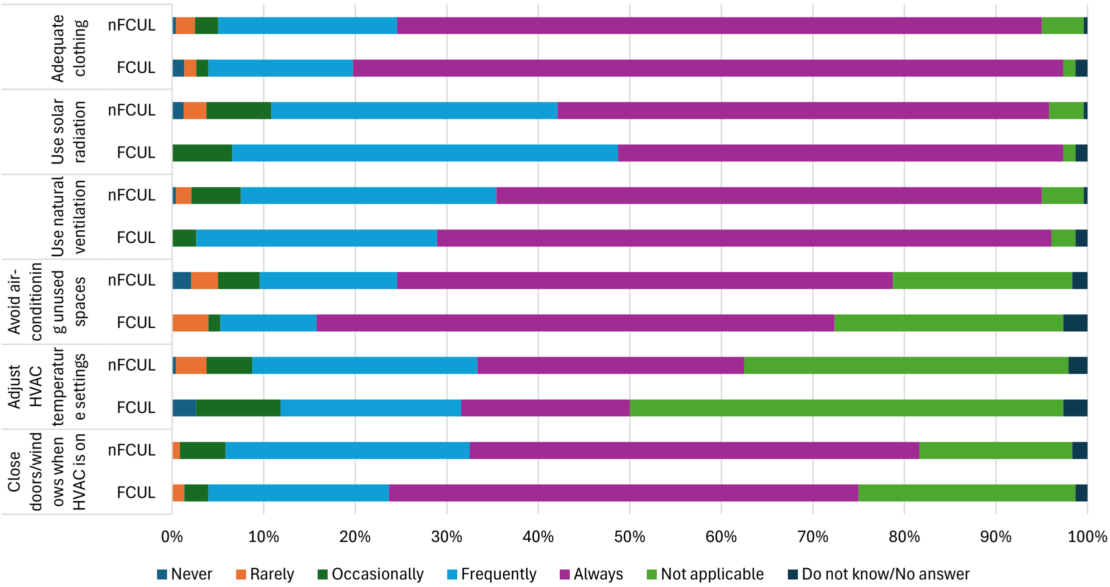
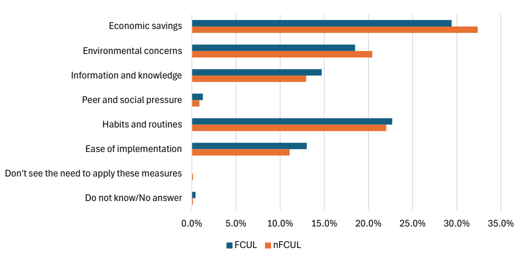
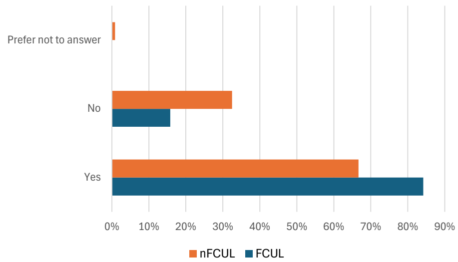


Figure G.2.3: Frequency of respondents’ heating, cooling, and ventilation-related user behavior -related user behaviors, by affiliation (FCUL community and external participants).

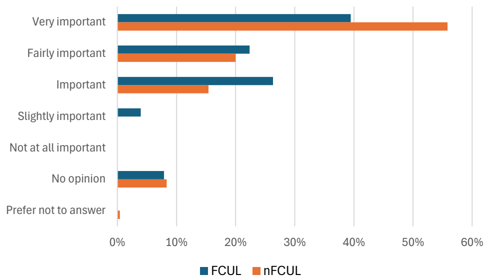
a)



b)



c)



d)

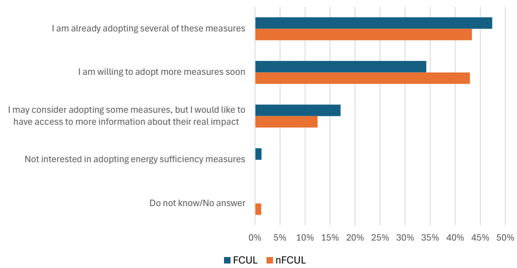


Figure G.2.4: a) Main factors influencing the adoption of ES measures; b) Respondents’ familiarity with the concept of ES; c) Perceived importance of ES measures among respondents; d) Respondents' willingness to adopt ES measures – Affiliation-based comparison.

Appendix H – Additional experimental data

H.1 – Washing machine

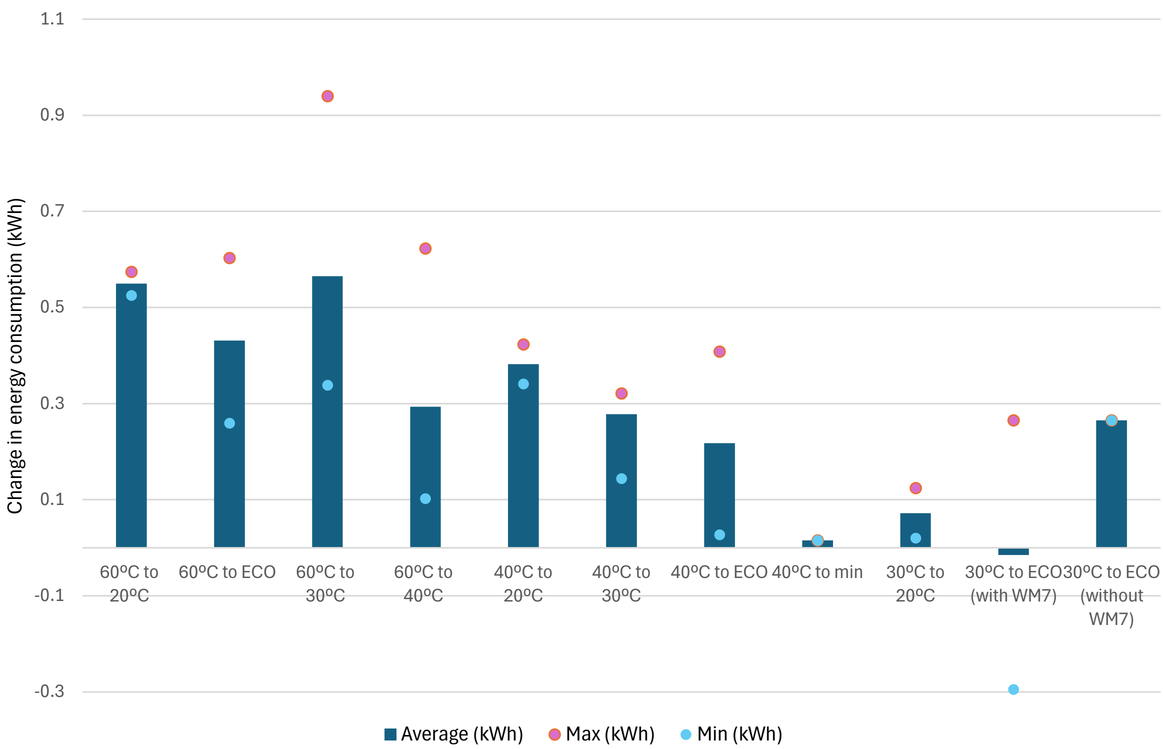


Figure H.1.1: Change in energy consumption (kWh) due to temperature and program transition.

Table H.1.1: Relative reduction in energy consumption due to washing cycle change (average reduction, maximum and minimum reduction observed).

Washing cycle change	Average	Max	Min
60ºC to 20ºC	82.4%	85.0%	79.7%
60ºC to ECO	57.7%	77.0%	38.4%
60ºC to 30ºC	62.0%	82.0%	43.2%
60ºC to 40ºC	30.1%	49.9%	15.5%
40ºC to 20ºC	76.5%	77.1%	75.9%
40ºC to 30ºC	48.9%	72.6%	24.4%
40ºC to ECO	37.7%	69.4%	6.0%
40ºC to min	9.2%	9.2%	9.2%
30ºC to 20ºC	32.3%	48.1%	16.5%
30ºC to ECO (with WM7)	-91.5%	59.5%	-242.4%
30ºC to ECO (without WM7)	59.5%	59.5%	59.5%

Table H.1.2: Absolute reduction in energy consumption due to washing cycle change (average reduction, maximum and minimum reduction observed).

Washing cycle change	Average (kWh)	Max (kWh)	Min (kWh)
60ºC to 20ºC	0.550	0.574	0.525
60ºC to ECO	0.431	0.603	0.259
60ºC to 30ºC	0.565	0.940	0.338
60ºC to 40ºC	0.293	0.623	0.102
40ºC to 20ºC	0.382	0.423	0.341
40ºC to 30ºC	0.278	0.321	0.144
40ºC to ECO	0.218	0.408	0.027
40ºC to min	0.015	0.015	0.015
30ºC to 20ºC	0.072	0.124	0.020
30ºC to ECO (with WM7)	-0.015	0.265	-0.295
30ºC to ECO (without WM7)	0.265	0.265	0.265

Table H.1.3: Detailed results for WM1 – Spin speed effects on energy consumption.

Temperature	Spin speed	Average energy consumption (kWh)	Absolute increase (kWh)	Percentual increase (%)	Absolute decrease (kWh)	Percentual decrease (%)
30ºC	600 rpm	0.292	///	///	-0.029	-9.1
30ºC	800 rpm	0.321	0.029	10.1	///	///
40ºC	600 rpm	0.629	0.025	4.1	///	///
40ºC	800 rpm	0.604	///	///	-0.025	-3.9
60ºC	600 rpm	1.120	///	///	-0.255	-18.5
60ºC	800 rpm	1.375	0.255	22.8	///	///

Table H.1.4: Detailed results for WM5 – Spin speed effects on energy consumption.

Program	Spin speed	Average energy consumption (kWh)	Absolute increase vs 800 (kWh)	Percentual increase vs 800 (%)	Absolute decrease vs 1400 (kWh)	Percentual decrease vs 1400 (%)	Absolute decrease vs 1200 (kWh)	Percentual decrease vs 1200 (%)
Cotton 30ºC	800	0.351	///	///	0.095	21.3	0.328	48.3
Cotton 30ºC	1200	0.679	0.328	93.4	///	///	///	///
Cotton 30ºC	1400	0.446	0.095	27.1	///	///	///	///

H.2 – Dishwasher

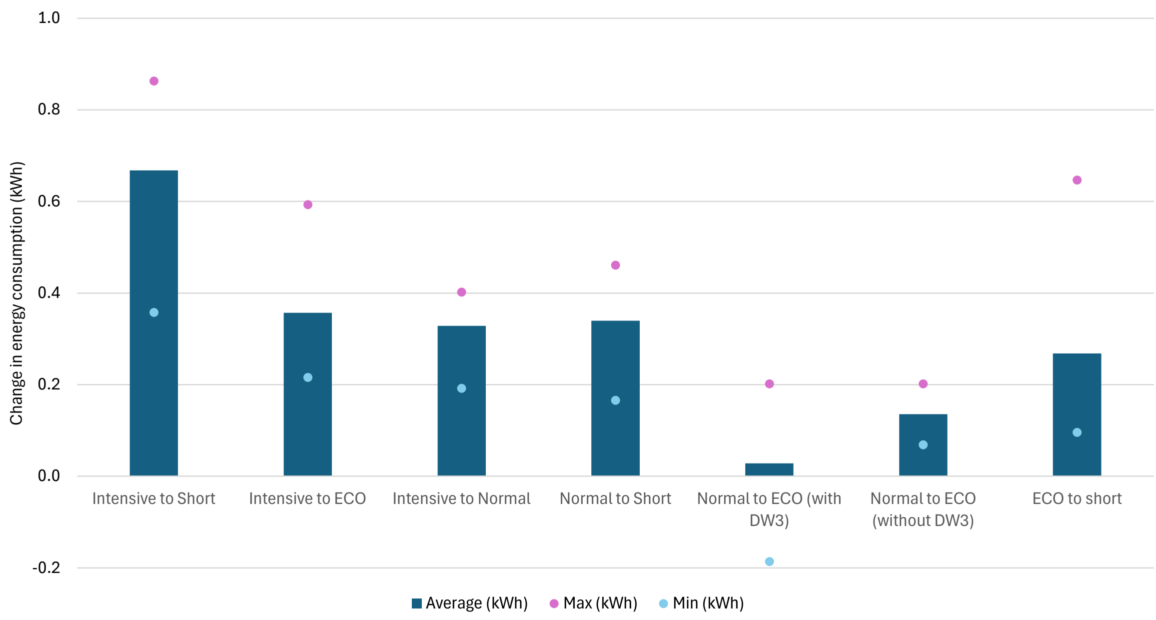


Figure H.2.1: Change in energy consumption (kWh) due to temperature and program transition.

Table H.2.1: Relative reduction in energy consumption due to program change (average reduction, maximum and minimum reduction observed).

Program change	Average	Max	Min
Intensive to Short	45.8%	59.6%	33.6%
Intensive to ECO	24.4%	33.6%	14.9%
Intensive to Normal	22.6%	27.7%	18.0%
Normal to Short	30.5%	44.1%	19.0%
Normal to ECO (with DW3)	1.6%	14.7%	-17.7%
Normal to ECO (without DW3)	11.3%	14.7%	8.0%
ECO to short	24.5%	52.5%	12.0%

Table H.2.2: Absolute reduction in energy consumption due to program change (average reduction, maximum and minimum reduction observed).

Program change	Average (kWh)	Max (kWh)	Min (kWh)
Intensive to Short	0.668	0.863	0.358
Intensive to ECO	0.357	0.593	0.216
Intensive to Normal	0.328	0.402	0.192
Normal to Short	0.340	0.461	0.166
Normal to ECO (with DW3)	0.028	0.202	-0.186
Normal to ECO (without DW3)	0.136	0.202	0.069
ECO to short	0.268	0.647	0.096

H.3 – Water heater

Figure H.3.1: Total energy consumption profiles at different setpoints.

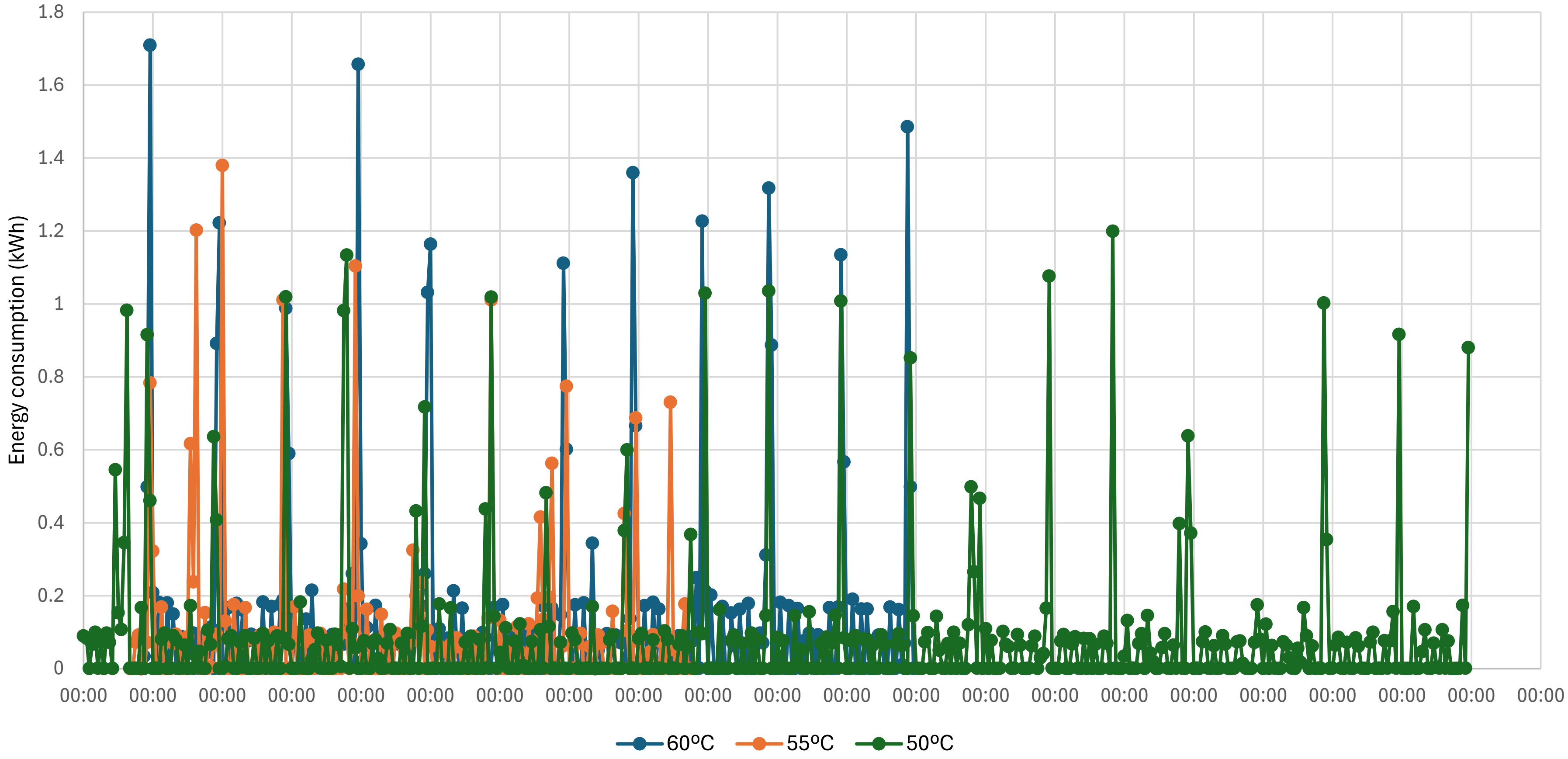


Figure H.3.2: Energy consumption excluding thermal losses (assuming the maximum value observed within the thermal losses range) at different setpoints.

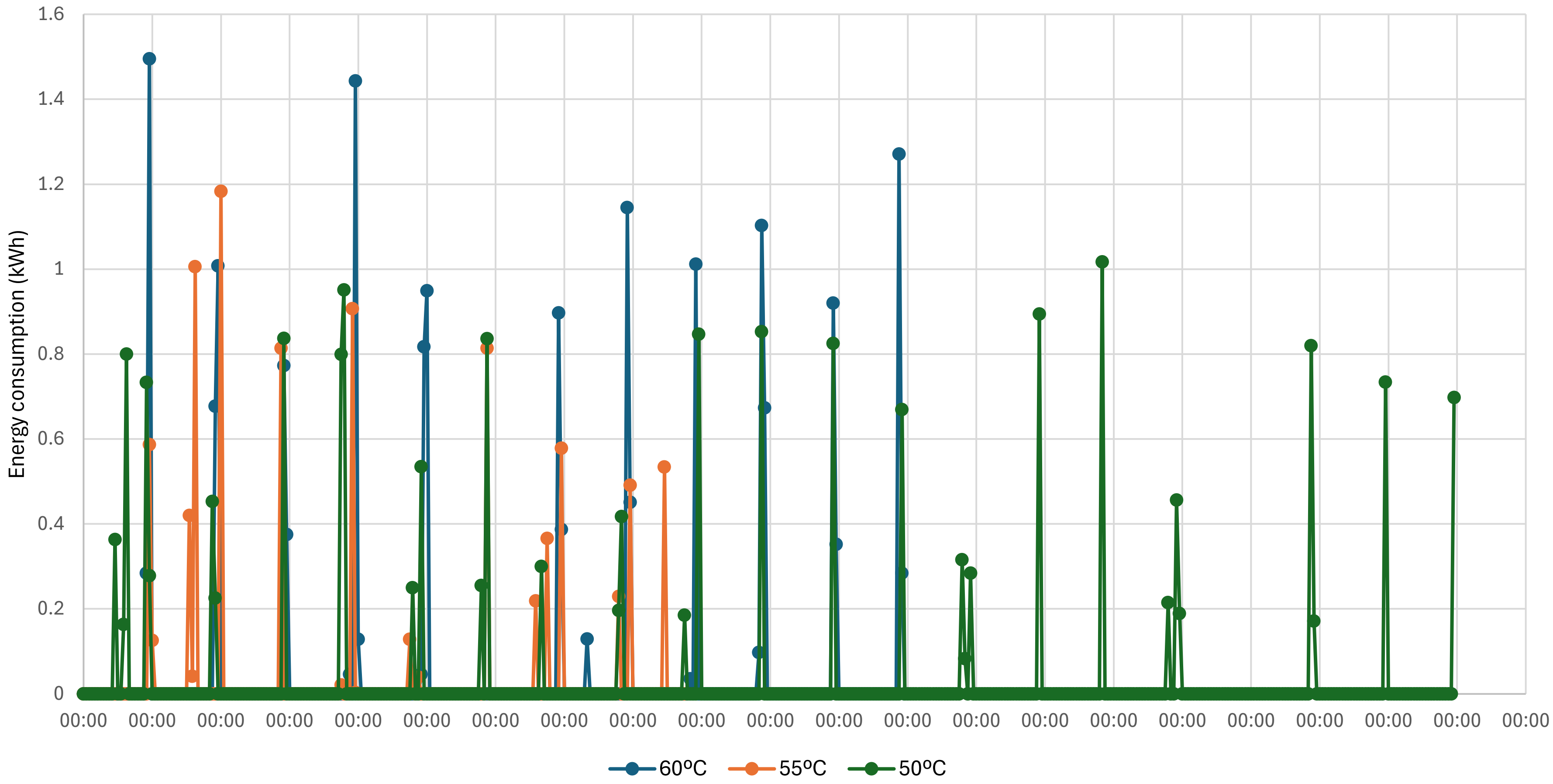


Figure H.3.3: Energy consumption excluding thermal losses (assuming the average value in the thermal losses range) at different setpoints.

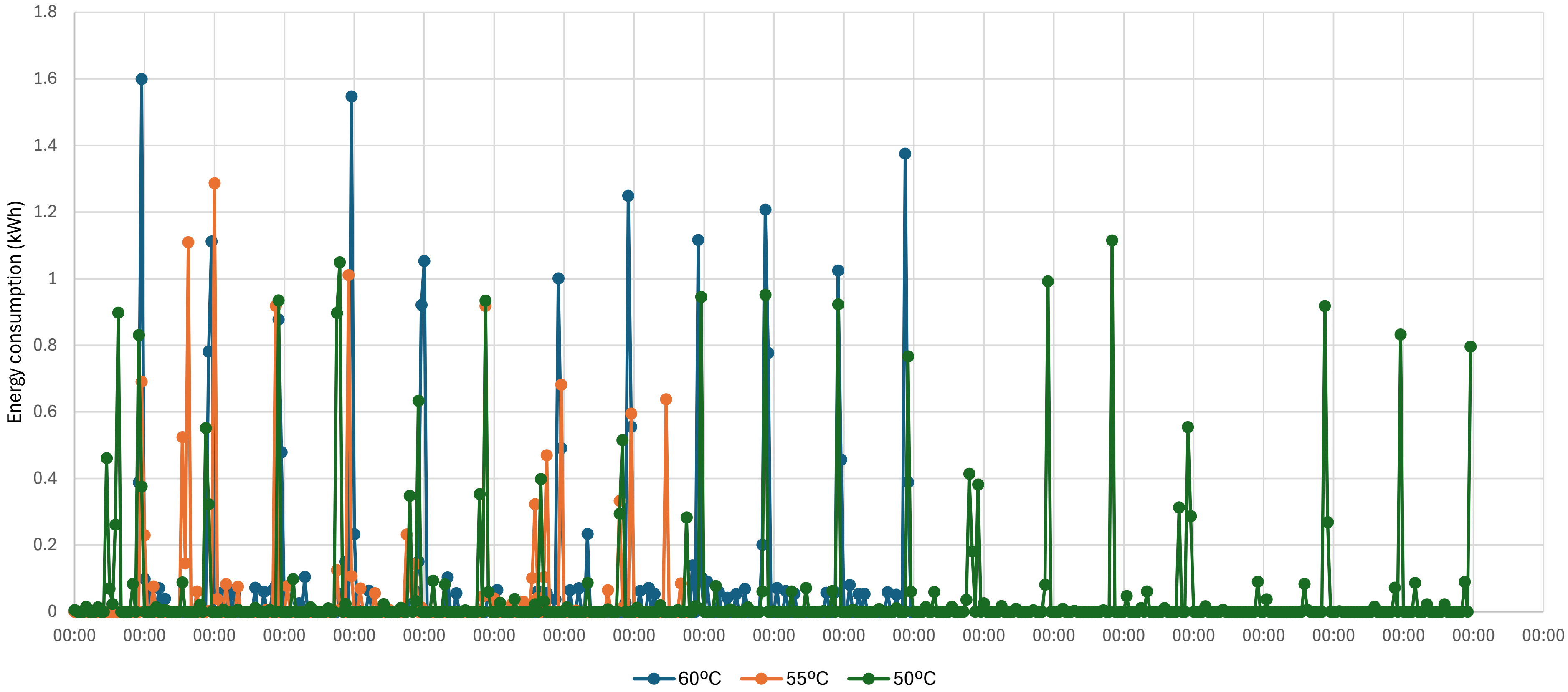


Table H.3.1: Average savings per long hot water use event

Temperature change	Average reduction (kWh)	Monetary savings (€)	Environmental impact ($kgCO_2eq$)
60ºC to 50ºC	1.214	0.298	0.136
60ºC to 55ºC	0.867	0.212	0.097
55ºC to 50ºC	0.348	0.085	0.039

Table H.3.2: Annual savings per long hot water use event

Temperature change	Average reduction (kWh)	Monetary savings (€)	Environmental impact ($kgCO_2eq$)
60ºC to 50ºC	886.6	217.2	99.3
60ºC to 55ºC	632.6	155.0	70.9
55ºC to 50ºC	254.0	62.2	28.4