Deliverable Report

Project Title:

Solar-Biomass Reversible energy system for covering a large share of energy needs in buildings

Project Acronym:

SolBio-Rev

Work Package 6: Social acceptance, potential for uptake and engagement

Deliverable 6.1

"Survey's outcome report "

Responsible for Deliverable:

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Executive summary

Aims and objectives

The SolBio-Rev is a flexible renewable energy system designed to cover a large share of building energy demand (heating/cooling/electricity); it is based on solar, ambient and bioenergy; and is suitable for various building types and geographies. This 'Surveys Outcome Report' (Deliverable D6.1) outlines initial findings in Work Package 6 (WP6) on social acceptance of the SolBio-Rev system, based on new empirical data collected with key user groups. This included 40 semi structured interviews across three countries: the UK, Finland, and Greece between October 2020 – June 2021, and a household survey (March 2021), with 3,478 respondents across the United Kingdom (N=1231), Greece (N=1065), and Finland (N=1182). D6.1 addresses the following key aims: (1) to examine the views of existing users and installers of renewable energy technologies that form part of the SolBio-Rev concept (e.g., heat pumps, solar thermal, and biomass), and (2) to examine the views of its prospective users, e.g., households, building managers, building designers, and installers.

Background on energy demand and national variability

Energy consumption in buildings is influenced by a range of physical and social factors. Social and demographic factors may include household composition, family size, socio-economic status, heating and sanitation practices, cultural norms and traditions etc. Higher energy users may consume 2-4X more energy within similar households in similar properties [1,2] - with the highest consumers sometimes using 9X more energy than the lowest [3]. Indeed, studies have observed a 300% variance in identical apartments [4] with others attributing 37% to occupant behaviour alone [5]. Therefore, based on our literature review we can expect significant variability in household energy demand, behaviour, and social practices both within and between countries.

Greece's household energy demand[1] is only 66% of the EU average, while the UK's is 104% of the EU average, despite having highly similar (56% and 55%) share of degree days[2] (i.e., equivalent heating/cooling needs). Equally, while Finland's degree days are 318% of the EU average, household energy demand is only 187% of this average – suggesting Finnish homes/households are more efficient than UK.

Single family households tend to use significantly less energy than larger family units. Eurostat data[3] indicates Finland has a higher share of single-family households (44%), due to an increased number of under 65's living alone, whereas Greece has only 25.2% (UK 29%). The UK and Finland have a similar mix of co-habiting couples (52.9% and 51.9% of households respectively). Greece has the highest share of co-habiting adults and due to a much higher share of households with three or more adults (20% of households), suggesting a trend for multiple family generations to co-habit in Greece. Single parent households are more likely to be at risk of energy poverty than co-habiting couples [6]. While the UK has a higher share of single parent households (10%) than Finland, (7%), both have a much higher share than Greece (1%).

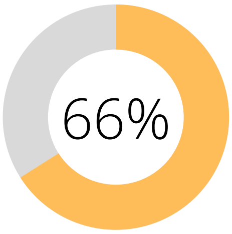
[1] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20190620-1

[2] https://ec.europa.eu/eurostat/web/products-datasets/product?code=nrg_chdd_a

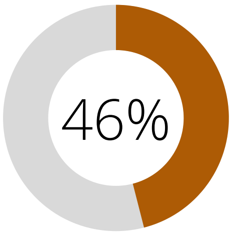
[3] https://ec.europa.eu/eurostat/web/products-datasets/-/hbs_car_t313

Survey Findings

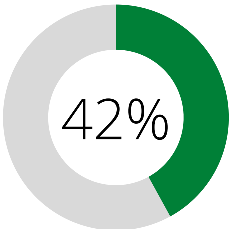
Current energy system characteristics



Natural gas boilers heating dominant in the UK



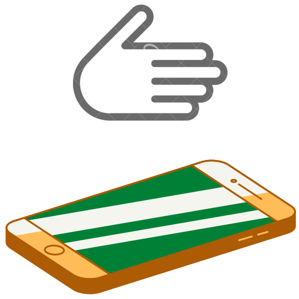
Heat network dominant in Finland



Oil heating dominant in Greece

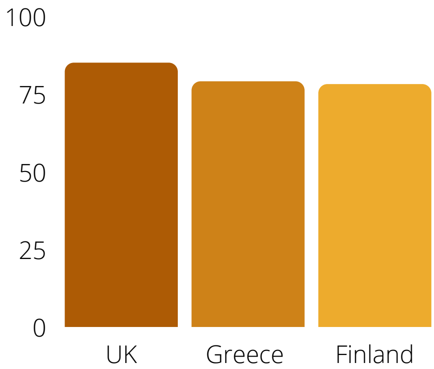
The most common cooling method was opening windows in all three countries (>60% of respondents). However, in Greece air conditioning was prevalent (68.1%), while in Finland shutters/ blinds were also common (44.2%).

Greece had more basic heating controls with 48% of respondents having only a simple "on/off" control, while the UK (40.6%) and Finland (34.4%) often had multiple room thermostats or smart controls

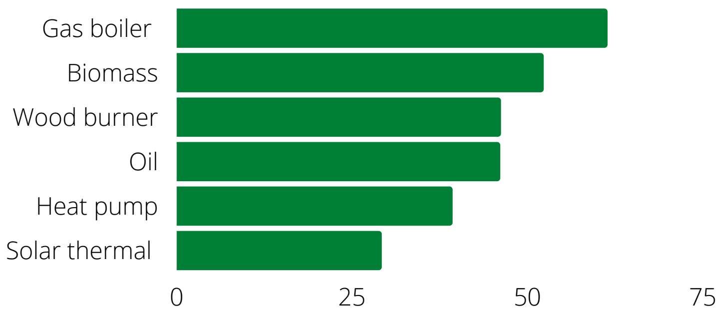


Users with advanced controls had higher satisfaction with 49.6% "smart thermostat and controls (smartphone app)" and 36% "multiple room thermostats/ thermostatic radiator valves and programmer" being "very satisfied" compared to 33.3% of those with "no controls" were either "very" or "somewhat" unsatisfied.

Reliability & Affordability



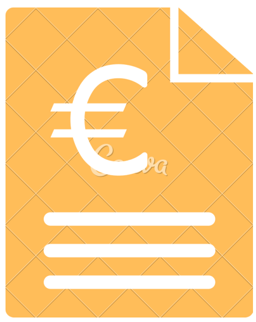
81% of users described their energy systems are either "very" or "somewhat" reliable



% who described their energy systems are either "very" or "somewhat" reliable

Mean energy bills were €96.22 for the UK, €119.56 for Finland and €117.56 for Greece

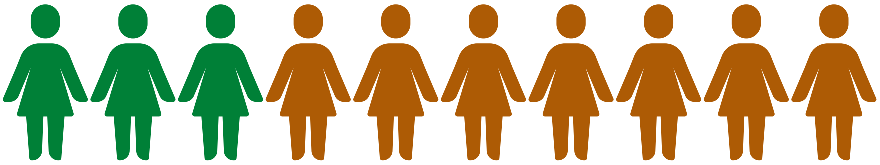
bills by heating system were: Natural Gas boiler €96; Biomass Boiler €164; Woodburner/ fireplace €142; GSHP €133; ASHP €159; District heating/ heat network €78; Fuel cell €295; Oil/ fuel oil / LPG €129; Solar Thermal/ PV €181; Resistive/ electric heating €125; Other €141; Don't know €55.



Comfort & Environmental concern

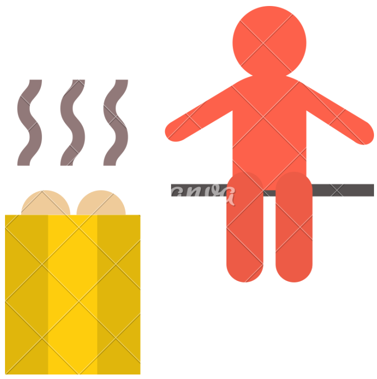
30.2% of Greek participants either "agreed" or "strongly agreed" with "I find it difficult to afford my energy bills"

59.1% of people in Finland either "disagreed" or "strongly disagreed" with "I find it difficult to afford my energy bills"



36.8% of Greek participants were "sometimes" or "never" able to remain warm in winter, compared to only 12.3% in the UK and 9% in Finland.

38.1% of Greek participants were only "often" or "always" unable to remain cool in summer, compared to only 16.8% in the UK and 28.2% in Finland. Heat pumps and GSHPs had the highest share of people "always" able to remain warm at 53.6% and 47.9% respectively, with Oil/ fuel oil/ LPG users having the lowest share at 20.5%.

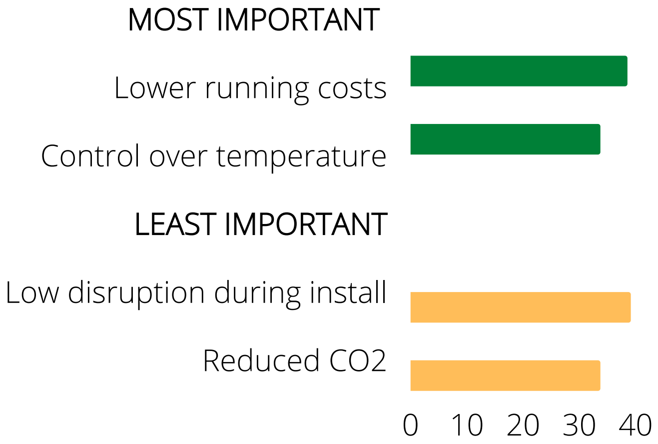


Greek respondents expressed greater concern for the climate impact of HVAC, with 67.1% describing it as "somewhat" or "very" important, compared to only 53.6% in the UK and 53.6% in Finland

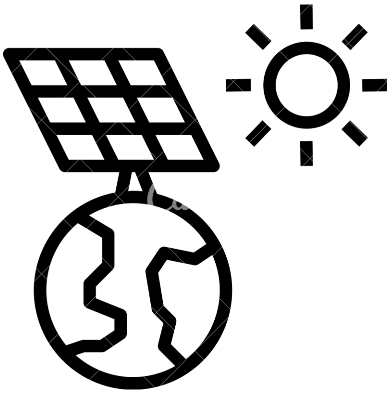
21.7% of Greek participants willing to pay 30% or more for carbon free energy, compared to only 10.1% in the UK and 6.5% in Finland. 39.8% of Finnish respondents and 31.3% in the UK were not willing to accept any increase in their energy bills

User expectations for SolBio-Rev

"I believe that this type of installation [SolBio-Rev] is perfect for Greece...perfect because you have this ability to make let's say, stand alone for each apartment without destroying anything, so it's something that you plug and play, let's say, you change the heater, you add a storage tank, you have this solar thermal collector changed, I think it would do a great, great job in Greece."- Greek building designer (GD1)



MOST and LEAST important features of HVAC systems (%)

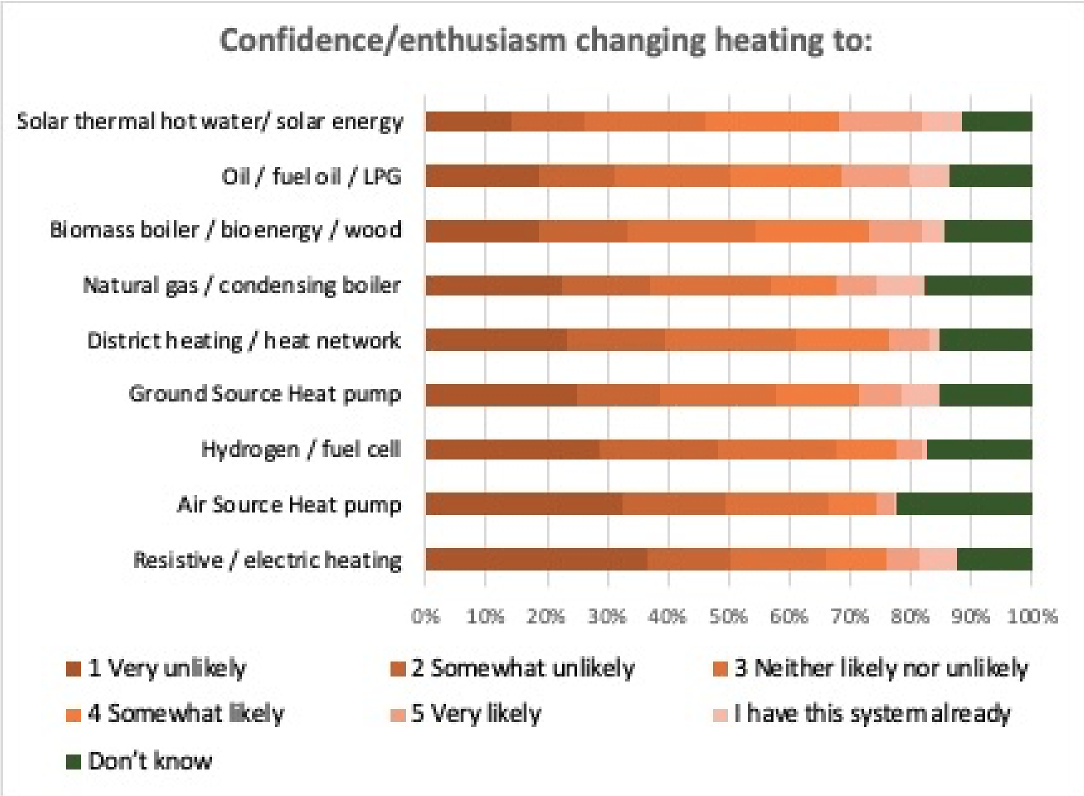


56.5% of Greek respondents were "very familiar" with solar thermal, compared to only 8.4% in the UK and 6% in Finland. 42.7% of UK respondents and 43.5% of those in Finland were "not familiar" or had "never heard of" the technology.

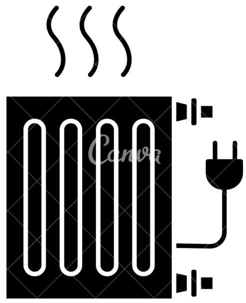
60.9% of Finnish respondents were "very familiar" or "quite familiar" with ASHP compared to only 20.7% in the UK and 22.5% in Greece. 57.4% of UK respondents and 53.6% of Greek respondents were "not familiar" or had "never heard" of ASHP.

Familiarity with biomass was low with 19.1% of UK respondents "very familiar" or "quite familiar" with the technology, compared to only 10% in Greece and 9.3% in Finland. 58.3% of UK respondents, 73.9% of those in Greece and 76.8% of those in Finland were "not familiar" or had "never heard" of the technology.

Willingness to adopt renewable HVAC



Resistive/ electric heating was the least popular new heating/hot water system with 50.1% "somewhat" or "very" unlikely to adopt these systems. Solar thermal was the most popular with 35.7% of people either "somewhat" or "very" likely to adopt



Greece were the most enthusiastic about solar thermal with 46.2% who were "somewhat" or "very likely" to adopt compared to only 18.1% who were either "unlikely" or "very unlikely" to adopt

Finland was the most enthusiastic about ASHP with 41.3% "somewhat" or "very likely" to adopt ASHP compared to only 19.6% who were either "unlikely" or "very unlikely" to adopt

UK participants were the most enthusiastic about biomass with 19.2% who were "somewhat" or "very likely" to adopt and 39.8% "unlikely" or "very unlikely" to adopt , 17.3% of responses "don't know"

Education, Income & Age

Higher educated respondents were slightly more likely to adopt SolBio-Rev's core technologies.

9.5% of postgraduate degree educated respondents were "very likely" to adopt biomass systems compared to only 3.5% of those with no education and 2.9% who have only graduated high school. 14.9% of postgraduate degree educated respondents were "very likely" to adopt ASHP compared to only 7% of those with no education and 8% of those who have only graduated high school. 19% of postgraduate degree educated respondents "very likely" to adopt solar thermal compared to only 3.5% of those with no education and 12.1% of those who have only graduated high school.

Higher income respondents were also slightly more likely to adopt SolBio-Rev's core technologies

7.9% of >£100,000/year and 8.4% of £80,000-£99,000/year households were "very likely" to adopt biomass compared an average of only 3.9%. 15.8% of >£100,000/year households were "very likely" to adopt ASHP compared an average of only 8.8%. Income level was not shown to be a strong predictor of the willingness to adopt solar thermal.

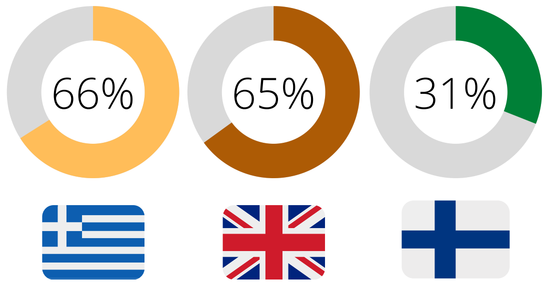
Respondents aged 25-34 were most likely to adopt to adopt SolBio-Rev's core technologies

34.8% of 18-24s and 38.4% of 25-34s we either "very likely" or "somewhat likely" to adopt biomass, only 17.6% of over 65s were. 43.7% of over 65s were "very unlikely" to adopt these systems. While 27.7% of 18-24s and 43.8% of 25-34 we either very likely or somewhat likely to adopt ASHP, only 23.5% of over 65s were. While 44.6% of 25-34s we either very likely or somewhat likely to adopt these solar thermal, only 28.4% of over 65s were.

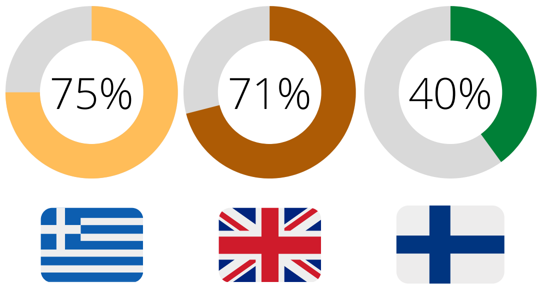
Current Business Model

Finnish respondents often had a different business model for heat supply & system maintenance than UK and Greek respondents

24.2% of Finnish respondents indicated that they "pay a fixed amount based on the size of my apartment/home" & 31.3% of Finnish respondents indicated that it was their "Building cooperative/ freehold company" who had responsibility for maintaining or changing their HVAC system

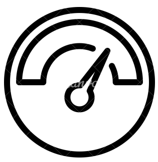


"I pay for the amount of energy/fuel I use for my heating"



"Myself/my family is/are responsible for maintaining or changing the HVAC system"

Alternative business & finance models



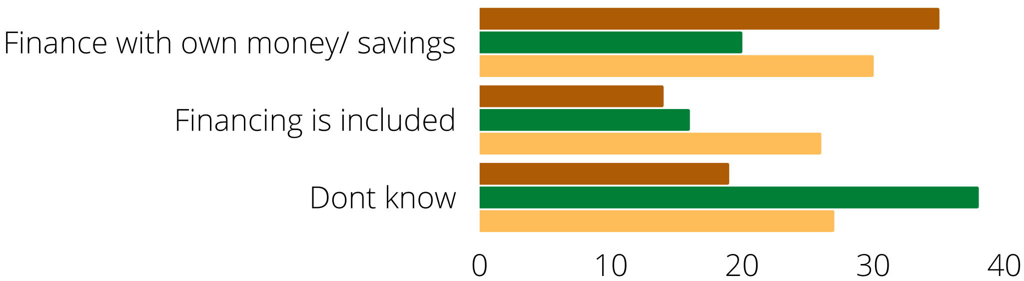
Generally, respondents wished to maintain current heat supply model

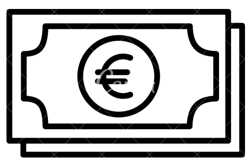
Most respondents would prefer to "pay for the amount of energy/fuel I use for my heating" in a future HVAC system, with 48.5% of UK and 40.8% of Greek respondents providing this answer, with 12.8% and 12.1% stating "no change" respectively. 17.5% of those in Finland indicated that they would prefer to "pay for the amount of useful hot water / heat/ cooling I use", with 22.5% requesting no change.

Generally, respondents thought it was their own responsibility to make their HVAC system carbon neutral

Most respondents stated that "myself/my family" should have responsibility for making their HVAC system carbon neutral with 53.3% of UK and 47.4% of Greek respondents providing this answer, compared to only 25.6% in Finland. Instead, 21.2% of Finnish respondents indicated that it should be their "Building cooperative/ freehold company" with 15.2% arguing it should be an ESCO.

Many respondents did not know how they would pay for these new systems





How respondents would prefer to finance a new HVAC system UK (Brown), Finland (Green), Greece (Yellow)

1 Introduction

1.1 Aims and objectives

This ‘Survey’s Outcome Report’ Deliverable D6.1 outlines initial findings from Task 6.1 of SolBio-Rev WP6 on ‘Social acceptance, potential for uptake and engagement’ led by the University of Sussex, UK (UOS). It specifies the three following key aims: (1) to examine the views of existing users and installers of renewable energy technologies that form part of the SolBio-Rev concept (e.g., heat pumps, solar thermal, and biomass), and (2) to examine the views of its prospective users, e.g., households, building managers, building designers, and installers. This report also uses feedback from the project’s internal discussions that sought the views of the developers of the SolBio-Rev concept, which will be used further in aim (3) providing input into the design process in forthcoming D6.2.

During Task 6.1 UOS has undertaken an extensive literature review of the drivers of variability in residential energy demand. This has included a review of national statistical data on energy consumption and demographic differences between the three focus countries Greece, UK and Finland. Subsequently, we interviewed various groups (e.g., users and installers, and concept developers) to analyse the extent to which the SolBio-Rev concept is different or improves upon current energy systems regarding user, designer and installer experience (e.g., features, limitations, delivered energy services, costs etc.).

Following the interviews, UOS conducted an online survey examining further perceptions of SolBio-Rev. This was followed by a survey conducted amongst households in a mix of countries from south/central/north Europe (Greece, UK and Finland), using a randomised sample. Questions focused on aspects such as user expectations and practices of SolBio-Rev system, heat/cold/electricity as an energy service, business models and policy implications/ changes. The relationships observed in the survey were then tested for their statistical significance, before considering these findings in the context of existing knowledge and literature.

Consequently, this report analyses the social aspects of SolBio-Rev and its potential positive and negative impacts using interview and survey data (though we will use parts of the interview data in later deliverables). These focus on user interface, delivered energy services, business models, estimated energy efficiency/cost savings, indoor climate comfort, environmental impact and policy implications. These findings will provide input into Task 6.2 for the integration of users and installers’ needs and views at the design stage.

The interviews and surveys were developed in cooperation with the whole SolBio-Rev team, who were given an opportunity to feed into the design process of the survey and interview questions. In addition, WP6 feeds into WP3 on behavioural models (providing input to Task 3.1)., WP6 on policy implications (Task 6.3) and WP8 in relation to different business models (Task 8.4). However, the data generated in WP6 is useful for the whole SolBio-Rev project team in understanding the user acceptance and future applications of the SolBio-Rev system.

1.2 Contributions of partners

UOS has developed this deliverable with input from NTUA, DBC, UDL, TECH as the respective Task Leaders across the SolBio-Rev WPs. In particular NTUA provided invaluable support in securing and interpreting the Greek interviews. Techlink were also very supportive in securing interviews with key policy actors and installer bodies – the results of which will be presented in D6.2.

1.3 Report structure

The report began by introducing WP6 and its main purpose. Section 2 outlines background on the impact of occupant behaviour on building energy demand, before exploring the national demographic variability on occupancy and energy demand in our main case countries of Finland, Greece and the UK, as well as the EU average. Section 3 outlines our research methodology, including the research design, data collection and data analysis methods. Section 4 presents the empirical findings from our user survey and semi-structured interviews. Section 5 discusses these findings in the context of existing literature, before providing conclusions in Section 6.

2 Background on occupant behaviour and variability in household energy demand

2.1 Energy in buildings, models, and their assumptions

Energy consumption in buildings is influenced by a range of physical and social factors. Physical factors include the properties of the building fabric, heating ventilation and cooling systems (HVAC), the control and optimization of these elements and climatic and weather conditions. Since the late 20th century, there has been increasing interest in energy conservation and the climate change impacts of buildings. Recognizing this, the EU Energy Performance in Buildings Directives (EPBD) 2002/2010 and its successors have sought to ensure increasing energy conservation and climate change mitigation in new buildings. Accompanying, and in some cases predating these directives, have been a range of national policy initiatives and assessment methodologies, delivered through national building regulations and planning policies. In the EU, these initiatives have typically taken the form of standardized metrics for energy and carbon performance, utilising standard building energy models to produce Energy Performance Certificates (EPCs) benchmarked against the performance of a notional building of that type and construction. These models such as the UK's 'Standard Assessment Procedure' (SAP) include a range of assumptions in terms of the physical and thermal properties of buildings and are continually updated, usually through revisions of national building regulations.

However, there is increasing concern that in many cases, buildings do not perform in the manner modelled; with studies indicating as much as a 300% 'energy performance gap' between modelled and actual performance [7]. Much literature has been focused on the reasons for this performance gap - with a large body devoted to the inaccuracy of the standard energy models [8–10], a significant focus on poor quality workmanship in the installation of energy saving measures and HVAC [11–14], and the lack of enforcement of building regulations [15,16]. However, a significant source of this variability in the performance of buildings is due to 'social and behavioural factors' arising from variations in occupancy and behaviour.

2.2 Factors influencing variability in demand

Standard energy models apply universal assumptions regarding occupant behaviour, heating and cooling practices and often omit the use of non-building integral electrical appliances altogether [10]. Typically, this involves a standard heating/cooling set temperature (usually 21-25°C in residential buildings), standard occupancy patterns based on number of habitable rooms, and other assumptions surrounding sanitation, clothes washing, lighting, working and leisure practices. Variability in these factors and the relationship between them, may however, be extremely significant and has subsequently been the subject of much academic research. Multiple studies show a large variance in post occupancy evaluation of energy demand between otherwise identical buildings [17–20]. Therefore, much of the variability in energy consumption within buildings is not accounted for by standard energy models [7].

In a review article Delzendeh et al. [7] attempt to categorise these factors as follows (see Figure 1), although these categories are just one way of describing these variables.

- **Climatic parameters**—such as outdoor temperature, relative humidity, solar radiation, wind, and rain—influence occupants' interactions with building systems and clothing to acquire thermal comfort.
- **The building type and function** determines the type of activity, clothing, and production of metabolic heat, together with the occupants' needs and expectations and their degree of interactions with building systems. With studies disproportionally focusing on residential buildings, behaviour in other building types is much less well understood.
- **Social and personal parameters**—such as cultural, psychological, and physiological factors—play a substantial role in occupants' comfort and energy attitudes. Whole fields of research, study how these elements interact with energy demand within and across different social and cultural contexts [21].
- The relationship between **energy regulations and economic** factors is also seen to be of critical importance, with a multitude of studies centred on the relationships between household income, socio-economic status and energy demand [22–24].
- Further studies link the **demographics of occupants** in terms of their age, family status and employment relating to working patterns and social schedules have been shown to have a major impact on energy demand behaviour.
- Finally, **architecture and interior design features** can influence occupant behaviour including: visual quality of windows and doors, movement through spaces and how colours, material and compositions may change occupants' thermal perception. However, the effects of interior design of space on occupants' energy attitudes have not been studied extensively [7].

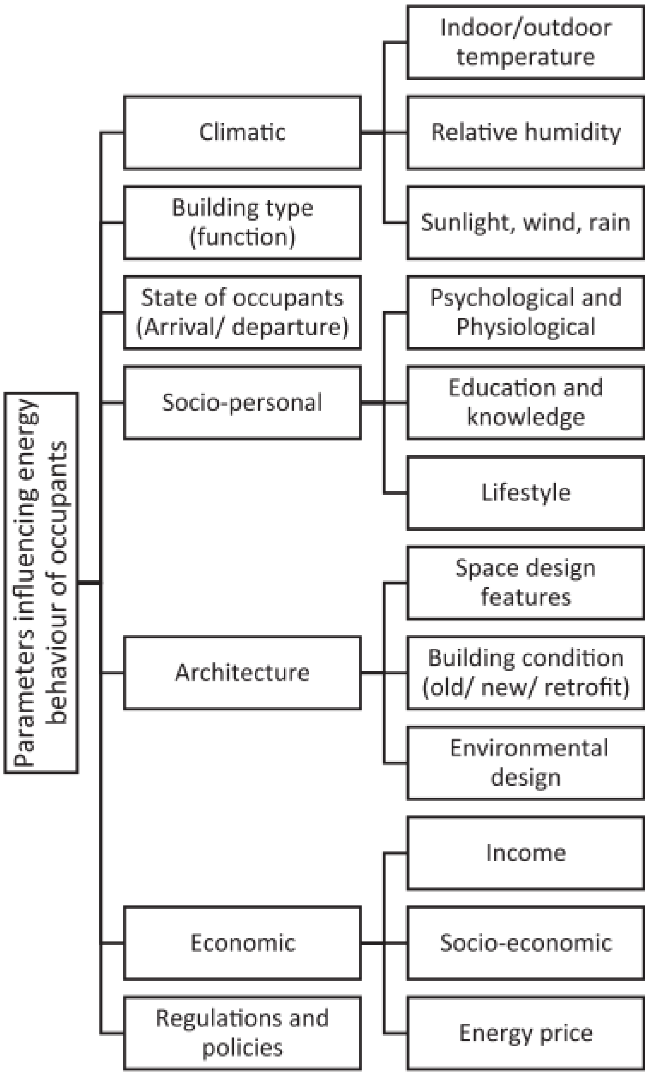


Figure 1 Factors and sub-factors influencing energy behaviour of occupants [1]

A large body of literature provides evidence of significant variation in all forms of household energy demand [25]. Higher energy users have been shown to consume between two and four times more energy - even between demographically similar households in similar properties [1,2] - with the highest electricity consuming households using nine times more than their most frugal counterparts [3]. Indeed a 300% variance was observed in identical apartments in California [4] with a 37% variance in 26 identical UK dwellings attributed to occupant behaviour alone [5]. Below we provide a short and non-exhaustive review of this vast and complex literature which has sought to identify sources of this 'behavioural variability' [7,19,26].

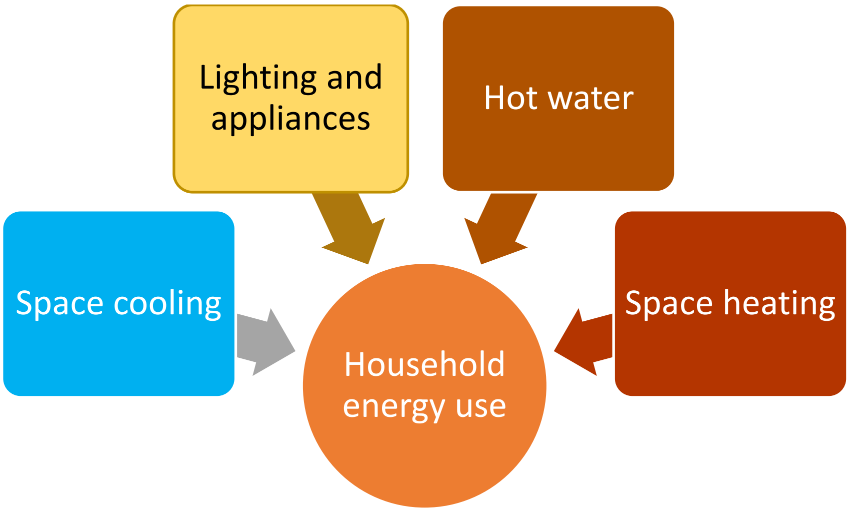


Figure 2 Key components of household energy use

Demographic differences in *household size* has been shown to account for 22–35% of the variance in electricity consumption in buildings of the same size and type [1]. A large study in the Netherlands [27] for example, showed significant variance in heating behaviours, due to demographic factors. Relative to households without children, single households were shown to consume double the amount of natural gas per capita, whereas elderly households consume about 31% more. Single elderly households consume approximately 23% less than married seniors and per capita heating usage decreases by about 23% per additional child. Female-dominated households were seen to consume ~2% more natural gas and significantly less electricity, even when controlling for income. Although no further explanation as to why these differences were present was provided.

Household *income* has also been shown to be a significant determinant of energy consuming behaviour. Brounen et al, [27] show that income in the Netherlands has a stronger impact on electricity consumption than for gas, with a 1% increase in disposable income associated with an 11% increase in household electricity usage. Various studies also show that those on low incomes, or in 'energy poverty'—i.e. those who do not have adequate access to energy services due to a host of factors—may consume substantially less energy than required to maintain a healthy indoor temperature [6,22,28]. These 'underheating' practices may mean that retrofitted measures may actually lead to an increase in energy demand or 'comfort taking' in these homes [29]. Further, Druckman and Jackson [30] showed that the poorest 10% of UK households use on average, only 43% of the energy used by the richest 10% of households.

However, these easier to measure socio-economic variables explain perhaps only a third of variability in electricity consumption [1]. Further, variability in energy demand is therefore related to complex and interrelated cultural and interpersonal factors that are difficult to predict and account for in standardised modelling approaches [25]. One factor that has been commonly studied is the impact of *information and user education* on energy consuming behaviour. Indeed, meta studies indicate these impacts can be in the region of 20% of total energy consumption. Fischer p79 [31] describes how successful energy saving advice can reduce demand when *"it is given frequently and over a long time, provides an appliance-*

specific breakdown, is presented in a clear and appealing way, and uses computerized and interactive tools". In a review of 26 information projects, electricity savings were between 1.1% - 20% and commonly ranged between 5% and 12% [31].

Even where households have no form of energy saving advice, socio-cultural dimensions can influence energy consuming behaviour. Dutch foreign-born households were shown to use slightly less gas and significantly less electricity than their native born counterparts [27]. In a US-wide study, non-Latino white ethnicity groups spent relatively more on electricity, despite a larger share of the black population living in the south where air conditioning is used [32]. These differences are often observed between countries – with residents in a Spanish city switching off unused devices 6% more often, and 30% more active in adjusting household-appliances-use habits than their Dutch counterparts [33].

However, many of these dimensions cannot be easily delineated along demographic, gender, economic or ethic lines. Chen et al., [34] demonstrated that residents from colder climates had lower energy-saving intentions than participants from warmer climate zones, reflecting that the desire for 'warmness' may override economic or environmental concerns in colder countries. Further, differing rates of adoption of air conditioning and cooling systems, may be influenced by expectations surrounding thermal comfort that bear little relationship to summer peak temperatures [35,36]. Various studies on social practices have shown that energy consuming behaviour may be intimately linked to family traditions, complex cultural norms, and perceived social status. For example, a study on Swiss households showed that hedonistic attitudes towards showering and egoistic value orientation (high self-confidence) were both positively associated with increased showering and the use of a tumble dryer [37]. Further, home heating practices are typically linked to differing perceptions of 'thermal comfort', as anyone who has battled a partner or family member on the preferred set temperature on a thermostat can attest.

Consequently, the complex interaction between this multitude of influences and their location - often beyond the 'behavioural' actions of the individual – has in recent years instead led to a focus on broader 'social practices' which influence energy consuming behaviour [38]. Thus, energy consuming practices - such as preferences for certain heating or control systems, the frequency and intensity to which we used them - are influenced by a multitude of interrelated issues including our age, gender, economic status, occupation and lifestyle, the type and design of the buildings we use and our cultural perceptions and expectations of energy use in buildings.

Of particular relevance to the SolBio-Rev project is the difference in practices between key demographic groups in the behavioural model (WP3) and between different national contexts. In the following section we investigate some of the energy consumption and demographic differences between the core case study nations of Greece, the UK and Finland - highlighting how different occupancy patterns may in turn influence energy consuming behaviour and thus the suitability of the SolBio-Rev system to these different contexts.

2.3 National variability in occupancy and energy demand

As discussed, social/behavioural factors may lead to differences in energy consuming behaviour which may occur between different cultural and national contexts. Figure 3 compares household energy demand with heating and cooling degree days in Greece, UK and Finland. The figure shows that household energy demand is highest in Finland, followed by the UK and then Greece. The combined heating and cooling degree days describe the energy requirements to ensure thermal comfort in homes, with Finland requiring the most energy to overcome its cold winters. Degree day figures combine heating and cooling load; therefore, the UK's colder winters are roughly equivalent to Greece's warmer summers and need for cooling. Interestingly, while Greece's household energy demand is only 66% of the EU average, the UK's is 104% of the EU average, despite having highly similar (56% and 55%) share of degree days. This highlights that the UK's household energy consumption is much higher than Greece's despite having equivalent heating/cooling needs. Equally, while Finland's degree days are 318% of the EU average, household energy demand is only 187% of this average – suggesting Finnish homes/households are more efficient than their UK counterparts.

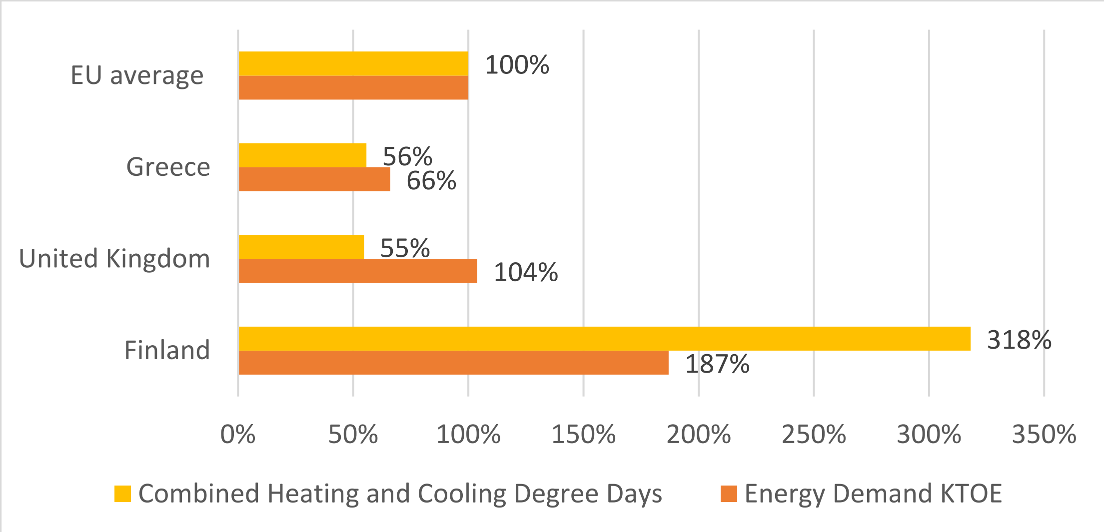


Figure 3 Household energy demand (Kilotons of Oil Equivalent (KTOE4)) vs. heating and cooling degree days5 as a % of EU average in Greece, UK and Finland. (Data from Eurostat)

National demographic differences are also likely to have a significant impact on energy demand. As shown in Figure 4, Finland has a higher share of single-family households, largely due to an increased number of under 65's living alone when compared to the UK. Single family households tend to use significantly less energy than larger family units, although older people have been shown to prefer higher internal temperatures and may also live-in larger properties which may be harder and more expensive to heat. In contrast to Finland, Greece has many fewer people living alone and significantly fewer than the UK.

[4] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20190620-1

[5] https://ec.europa.eu/eurostat/web/products-datasets/product?code=nrg_chdd_a

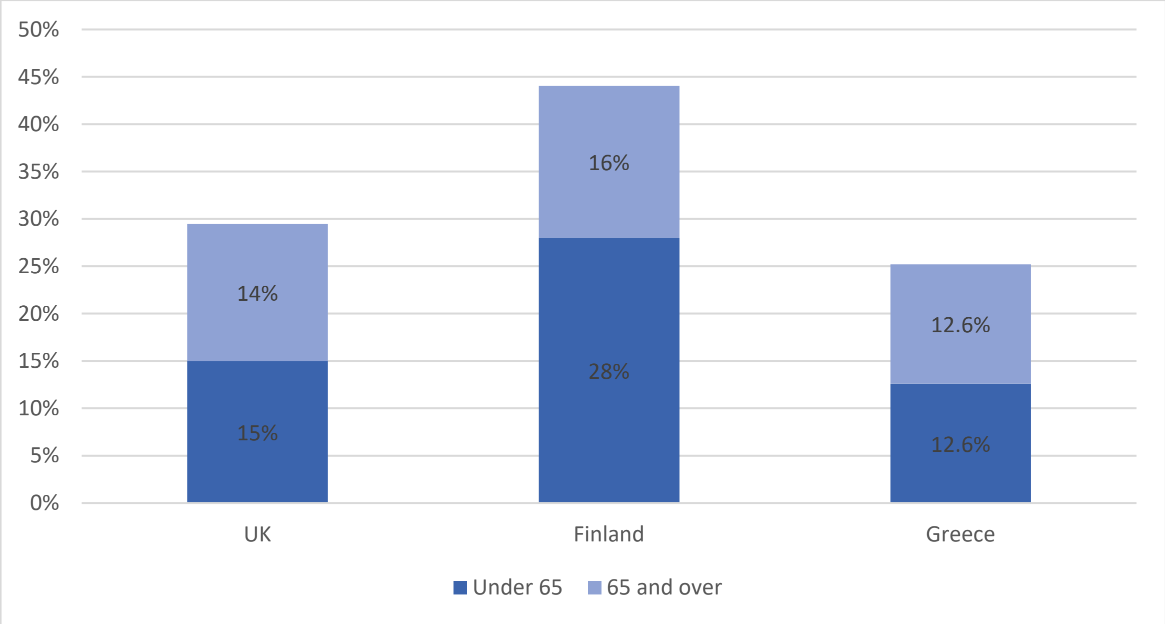


Figure 4 Percentage of single-family households and share above and below 656 (Demographic Data from Eurostat)7

Figure 3 shows that the UK and Finland have a similar mix of family sizes for co-habiting couples, although the UK has a higher total share - reflecting the higher number of co-habiting adults. Both countries have a similarly high share of co-habiting couples without children. Greece has the highest share of co-habiting adults and interestingly has a much higher share of households with three or more adults co-habiting. Although not evident from the data, we can infer that this higher share of 3 or more co-habiting adults reflects a trend for multiple family generations to co-habit in Greece.

[6] The data for single inhabitants Greece from Greece was not disaggregated by age so an even split was assumed.

[7] https://ec.europa.eu/eurostat/web/products-datasets/-/hbs_car_t313

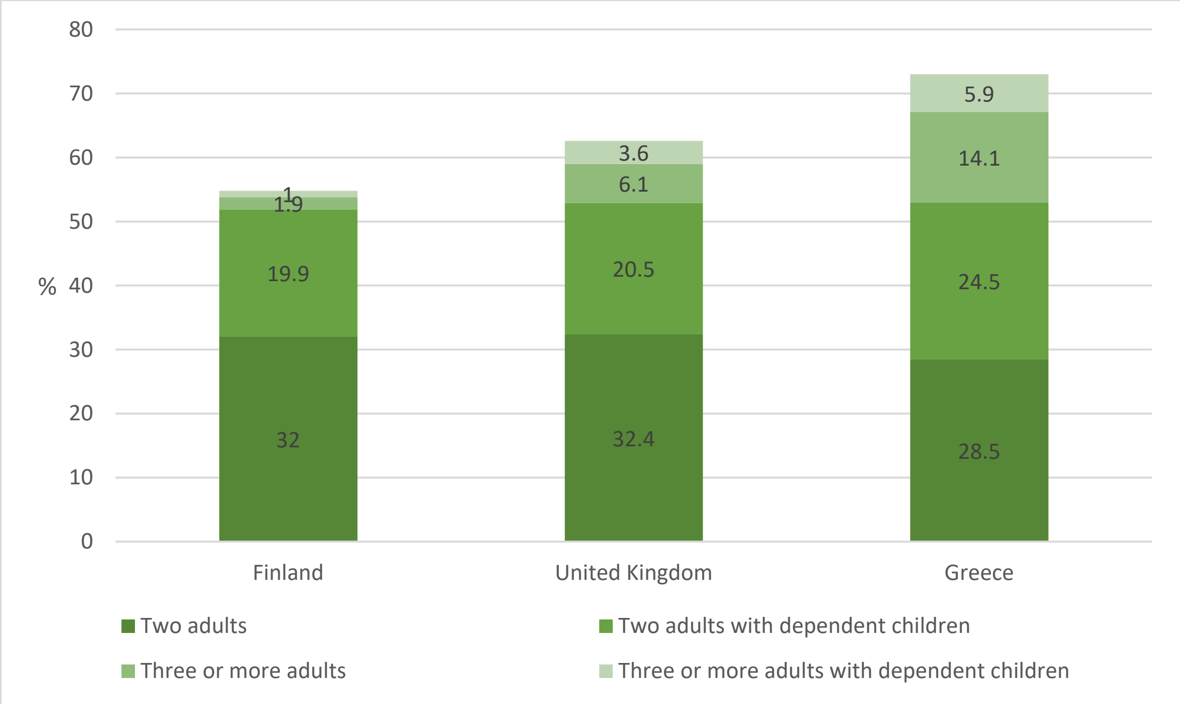


Figure 5 Share of households comprising co-habiting couples, broken down by numbers of children (Demographic Data from Eurostat)

Further, the UK has a higher share of single parent households than Finland, (10% compared to 7%), with both having a much higher share than Greece (Figure 5). Single parent households are more likely to be at risk of fuel poverty than co-habiting couples and therefore may underutilize heating or cooling, or ration electricity [6]. These differences may result from cultural perceptions surrounding single parent families or divorce, although the reasons for this are beyond the focus of this report.

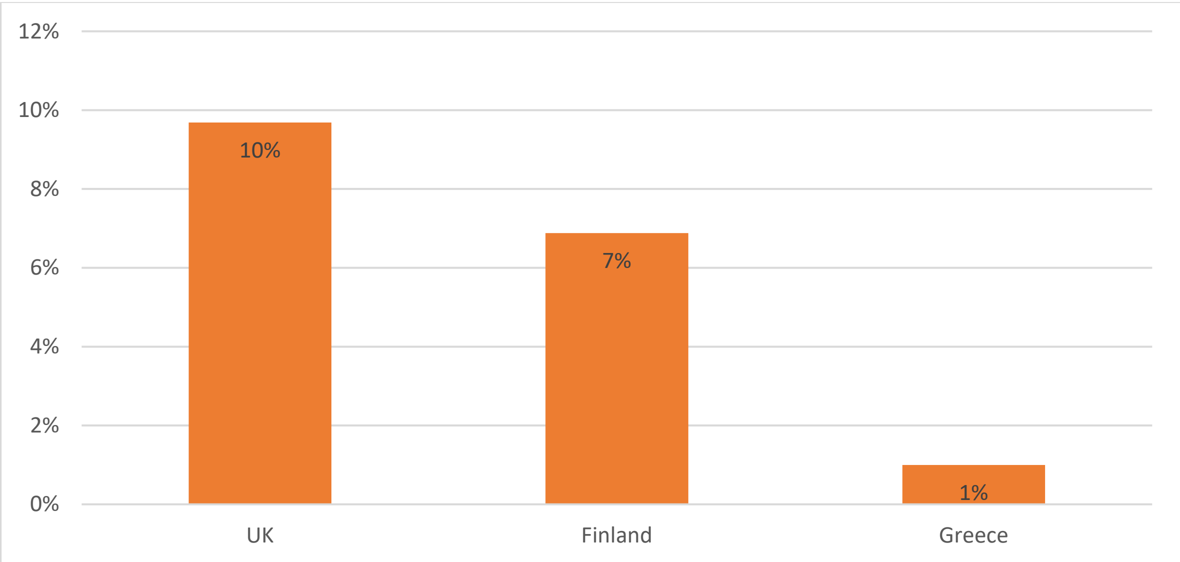


Figure 6 Share of single parent households in UK, Finland, and Greece (Demographic Data from Eurostat)

2.4 Literature summary

This short review of the literature on energy behaviour in buildings and household demographics of the three case study countries: the UK, Finland and Greece has highlighted some important social, demographic and cultural factors that should be considered alongside assumed behaviour patterns for the SolBio-Rev project. These data suggest that there is likely to be significant variability in the demographics, occupancy patterns, energy consuming behaviour and energy demand between countries - regardless of the physical characteristics of the building energy models and climate conditions of the study countries. A summary of some important between country difference is provided in Table 1 below.

Table 1 Summary of national differences Finland, Greece, UK

Indicator	Finland	Greece	UK
Population[a]	5.5 million	10.7 million	67 million
Number of households[a]	2.7 million	4.2 million	28.1 million
Energy use per capita Household energy demand[b] **(% EU average)**	187%	66%	104%
Degree days[c] **(% EU average)**	318%	56%	55%
Share of final energy consumption in the residential sector by type of end-use in 2019[b]	Space heating: 66.1% Space cooling: 0.2% Water heating: 15.3% Cooking: 1.0% Lights and appliances: 12% Other: 5.5%	Space heating: 56.3% Space cooling: 4.9% Water heating: 13.3% Cooking: 6.2% Lights and appliances: 19.2% Other: 0%	Space heating: 62.2% Space cooling: 0.1% Water heating: 17.6% Cooking: 2.8% Lights and appliances: 17.4% Other: 0.0%
Share of fuels in the final energy consumption in the residential sector in 2019[b]	Electricity: 34.4% Derived heat: 28.3% Gas: 0.5% Solid fuels: 0.1% Oil & petroleum: 5.3% Renewables & waste: 31.4%	Electricity: 36.3% Derived heat: 1.3% Gas: 9.3% Solid fuels: 0.1% Oil & petroleum: 28% Renewables & waste: 24.9%	Electricity: 23.4% Derived heat: 0.7% Gas: 62.9% Solid fuels: 1.2% Oil & petroleum: 6.3% Renewables & waste: 5.5%
Average electricity price per kWh in 2020[d, e]	0.17 Euro / kWh	0.16 Euro / kWh	0.22 Euro / kWh
Median equivalised disposable income per inhabitant in 2019 [f, g]	24,879 Euros	8,195 Euros	33,790 Euros* (£29,600)
Single person households (% of total)	44%	25.2%	29%
Single parent households (% of total)	7%	1%	10%

Sources:

[a] Euromonitor International, Country Reports: https://www.euromonitor.com/countries [accessed 20.07.2021]

[b] Eurostat, Energy consumption in households: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Share_of_final_energy_consumption_in_the_residential_sector_by_type_of_end-use,_2019_(%25)_T3.png [accessed 20.07.2021]

[c] Eurostat, Cooling and heating degree days by country - annual data https://ec.europa.eu/eurostat/web/products-datasets/product?code=nrg_chdd_a [accessed March 2020]

[d] Eurostat, electricity price statistics: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics [accessed 20.07.2021]
[e] Statista, Electricity prices for households in the United Kingdom (UK) from 2010 to 2020, semi-annually: https://www.statista.com/statistics/418126/electricity-prices-for-households-in-the-uk/ [accessed 20.07.2021]
[f] Eurostat, Living conditions in Europe - income distribution and income inequality: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Living_conditions_in_Europe_-_income_distribution_and_income_inequality#Income_distribution [accessed 20.07.2021]
[g] Office of National Statistics, Average household income, UK: financial year ending 2019: https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/bulletins/householddisposableincomeandinequality/financialyearending2019 [accessed 20.07.2021]
[h] Eurostat, Household characteristics by type of household https://ec.europa.eu/eurostat/web/products-datasets/-/hbs_car_t313 [accessed March 2020]
* Rate converted from £29,600 to Euros using average exchange rate for 2019: https://www.poundsterlinglive.com/best-exchange-rates/best-british-pound-to-euro-history-2019 [accessed 20.07.2021]

3 Methods

3.1 Research design

The following section sets out the research design of Task 6.1 Social acceptance of SolBio-Rev. The core objectives of Task 6.1 are to examine the views of:

(1) Existing users and installers of other renewable [& non-renewable] energy technologies
(2) The developers of the SolBio-Rev concept
(3) Its prospective users and installers.

To meet these objectives, the research design consisted of several phases of qualitative and quantitative research. While most of these objectives are dealt with in Deliverable 6.1 "Surveys Outcome Report" (this document), Objective 2 will be presented in the subsequent Deliverable 6.2 "Definition of user and installer needs and their introduction in the design process", as these findings would be of more relevance when integrated into the design process for SolBbio-Rev. The relationship between the objectives for Task 6.1, the core deliverables and these data are shown in the table below.

Table 2 Research design overview for Task 6.1

Objective	To examine the views of…	Quantitative data	Qualitative data	Deliverable
1	*Existing users and installers of renewable [& non-renewable] energy technologies*	3 country householder user survey (March 2021)	Semi-structured interviews (3 countries) (October 2020 – June 2021)	6.1 & 6.2
2	*The developers of the SolBio-Rev concept*	Internal project partners survey (June/July 2020)	Workshop with Internal project partners (September 2020)	6.2
3	*[SolBio-Rev] prospective users and installers*	3 country householder user survey (March 2021)	Semi-structured interviews (3 countries) (October 2020 – June 2021)	6.1 & 6.2

To better understand SolBio-Rev's features we first ran a small internal survey[8] and workshop with the SolBio-Rev project participants. These findings informed the design of 40 semi structured interviews with 44 individuals (October 2020 – June 2021) conducted across three countries: the UK, Finland, and Greece. The aim was to interview not only household users but also building managers, designers/installers. We also aimed to interview users from different building types with case studies of two multifamily buildings (apartments) and an office building. Where possible we also sought contrasting cases between new buildings or those with renewable energy systems and older ones without. This qualitative research design is summarised in Figure 7.

[8] The results of this survey will be presented in D6.2

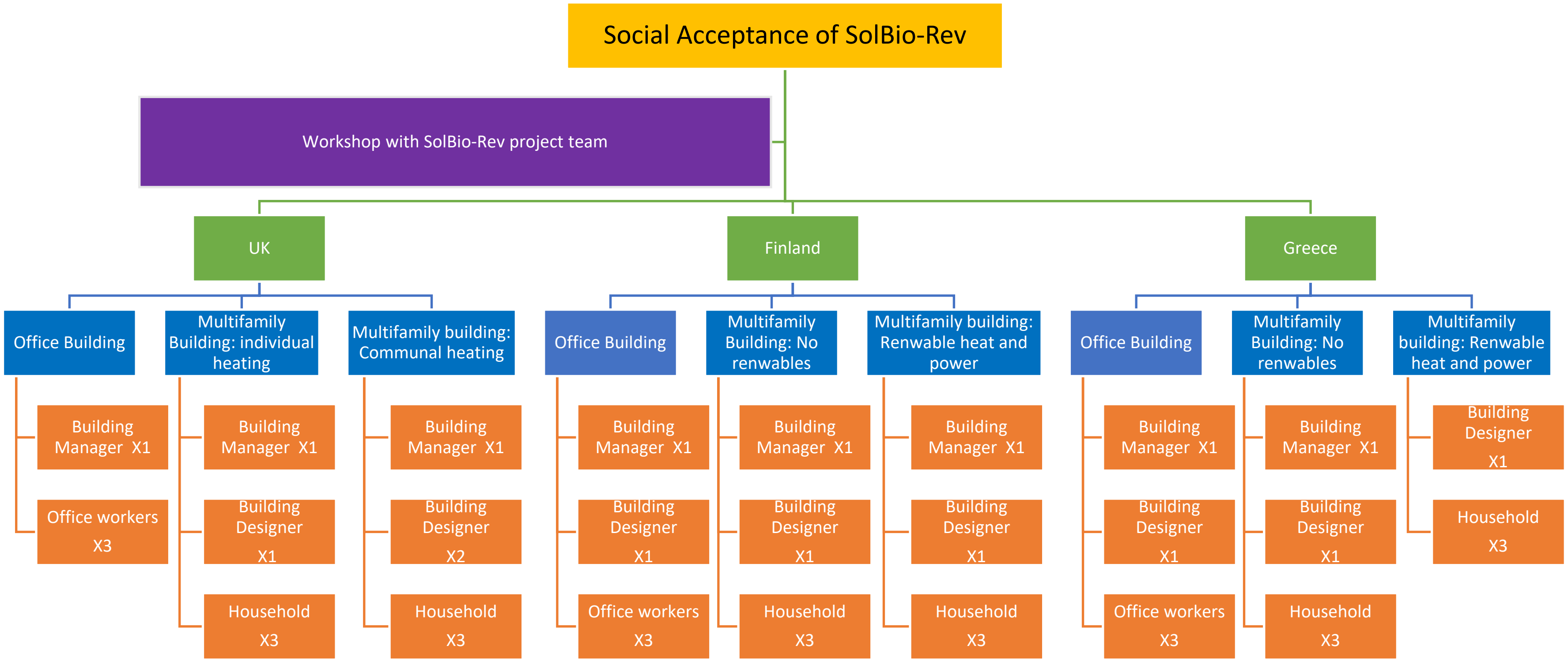


Figure 7 Qualitative research design

Following the qualitative research, we developed a quantitative survey instrument which sought to gather quantitative data on user perceptions of energy systems and the potential social acceptance of the SolBio-Rev system. Again, this survey was conducted across the three countries of the UK, Finland, and Greece – selected due to their contrasting climatological and cultural characteristics. Due to the desire to gather a representative sample, for the survey we focussed only on household users rather than building managers or designers.

3.2 Data collection

3.2.1 Semi-structured interviews

40 semi-structured interviews were conducted between October 2020 and June 2021. The interviews were divided by country with the aim of securing three case study buildings for each country (15 interviews in Finland, 12 in Greece, and 13 in the UK). For the UK, a partnership with the Royal Borough of Kensington and Chelsea (RBKC) Council in London, yielded the two residential case studies. Both were from the same Lancaster West estate in West London, one having an old district heating system, the other having individual gas boilers. The office case study was a multi-use workspace – converted from a former car park – in Peckham Southeast London. For the Greek case study, the two buildings were multifamily blocks, one with solar thermal hot water in a more suburban location, the other solely oil heated and closer to the city centre. The office building was the office of the Laboratory of Steam Boilers and Thermal Plants in the School of Mechanical Engineering at the National Technical University of Athens (NTUA). For the Finnish case studies, the two apartment buildings were in two different suburbs of Helsinki. Both buildings had switched from city district heating networks to having their own, building-specific ground source heat pumps systems. The office building is also in Helsinki, and it is a large, multi-use building housing different organisations including a local transport provider, a theatre, church-provided nursery and a restaurant. The building is connected to the city district heating network. Further detail on these interviews and case studies will be provided in D6.2.

For each case study at least three household/ office users were sought, with the aim of also speaking to the buildings manager or a person involved in building and/or heating maintenance. In addition, a designer or engineer was interviewed for each case. In the UK, these individuals were linked to a planned renovation of the case study building, while the Greek designers were professionals working in Athens. For the Finnish cases these included buildings managers, building maintenance officers and a heating system designer.

Household interview questions (Appendix 1) first sought to understand the buildings' characteristics as well as the nature of the heating and cooling systems. Subsequently participants were asked about their perceptions and preferences for the energy control systems, followed by questions surrounding their knowledge and potential willingness to adopt renewable heating and cooling systems. Finally, interviewees were asked to reflect on their preference for different business and delivery models as well as their views on the policy challenges surrounding decarbonisation. Building managers were interviewed with a similar protocol (Appendix 1) although with a focus on their management role, while designers (Appendix 1) were asked to provide their professional perspective and experience on these issues.

Interviews were primarily conducted using video conferencing software, with some on the telephone. While the UK and Finnish interviews were conducted in their native language, for several of the Greek interviews an interpreter was used, with others conducted in English. Interviews were recorded and subsequently transcribed through a professional transcriber. Each interviewee was provided with an information sheet explaining the project and a consent form which provided them with options for their preferred level of anonymity and disclosure. Before interviews commenced, ethical approval was sought and approved from the UOS Cross Schools Research Ethics Committee - C-REC.

3.2.2 Three country household survey

Following the initial phase of interviews, a household survey was launched in March 2021. The survey instrument, (Appendix 2), was designed to take 10-15 minutes to complete, and consisted of 46 questions across several theme areas. The first section explored the socioeconomic and demographic attributes of respondents. Subsequently it investigated the attributes of the buildings heating and cooling system, followed by a focus on thermal comfort and controls. The questions then focussed on the important features of these system and who has responsibility for them. A series of questions then explored the respondent's familiarity with different energy systems and willingness to adopt new systems. Questions were then centred on perceived energy poverty before a final focus on preferences for different finance and business models of a new HVAC system.

Most questions used a 5-point Likert Scale (1 = strongly disagree, 5 = strongly agree) or similar, with the survey implemented online by a market research company, Dynata, using a respondent panel representative of the three European countries (UK, Greece, Finland). Dynata scripted an online version of the survey instrument using their proprietary software. Once checked by the research team, Dynata sent unique person-specific links to the survey to individuals in their respondent panel who have agreed previously to take part in survey. The sampling frame consisted of adults in each of the three countries who had to be over the age of at least 18 years old. The final sample comprised 3,478 respondents spread across the United Kingdom (N=1231), Greece (N=1065), and Finland (N=1182).

3.3 Data analysis

3.3.1 Qualitative analysis

Interviews were analysed with the NVivo 12 qualitative analysis software, using common themes to code the data and structure the analysis. Each interview has unique signifier (#X) which are referred to in (Appendix 1).

3.3.2 Quantitative analysis

To analyse the survey results we used the SPSS statistical analysis package. The survey results were first analysed descriptively and with the help of frequency tables and bar charts. For a large number for the responses, we focussed on differences between the three case study countries. In addition, we also sought to understand variations based on the existing heating system of the user as well as their current control system. Certain questions were also disaggregated by income, education level and age. While we also examined if there were significant differences between variables such as housing and tenure type, this yielded no notable relationships and so is excluded from this report's findings.

To evaluate possible significant associations among the variables in our study, we then undertook a series of statistical tests. Where both variables are categorical or ordinal, we adopted the Chi square test for goodness of fit - with most of the relationships studied having this characteristic. To determine the strength of this relationship we adopted the Phi and Cramer's V test. In all the cases in this study, both variables have n=>2 categories, and we therefore adopt the Cramer's V test. To interpret Cramer's V, the following approach was used:

- $V \in [0.1, 0.3]$: weak association

- $V \in [0.4, 0.5]$: moderate association
- $V > 0.5$: strong association

In addition to the Chi squared test, two relationships involved an ordinal/categorical variable and a continuous one. Here we would commonly adopt an ANOVA based test. However, due to the non-normal distribution an Independent-Samples Kruskal-Wallis Test was used to compare the means in these cases. Further details of these tests are provided in Section 4.

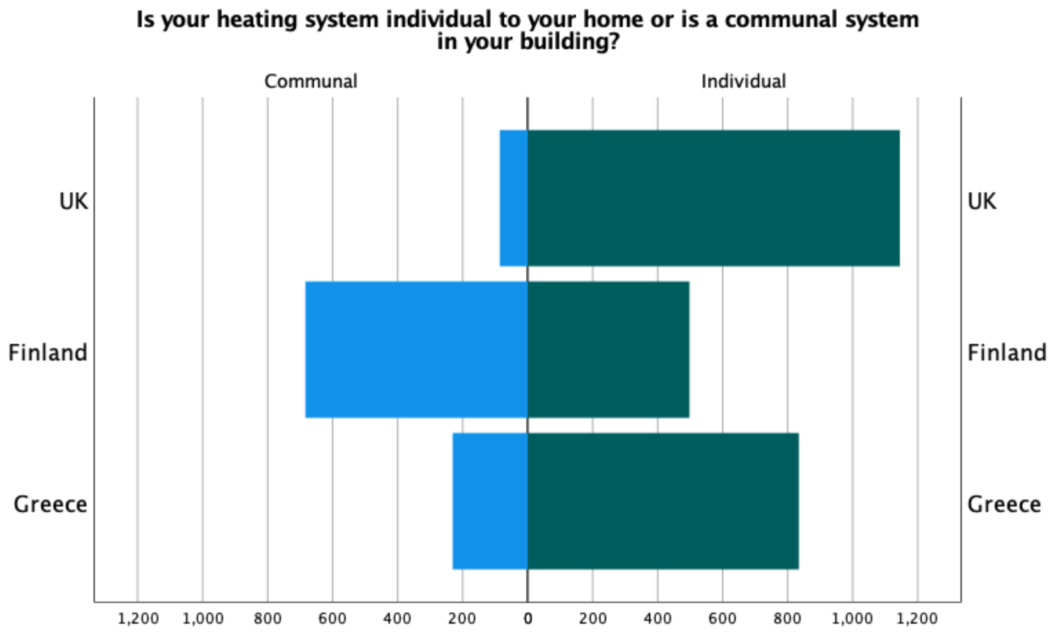
4 Survey of Finland, Greece, and the United Kingdom

4.1 National differences in energy services and perceptions

We first investigated the relationship between the three surveyed countries in terms of households' reported energy system characteristics and subsequently their perceptions of reliability, affordability, comfort, and environment concern.

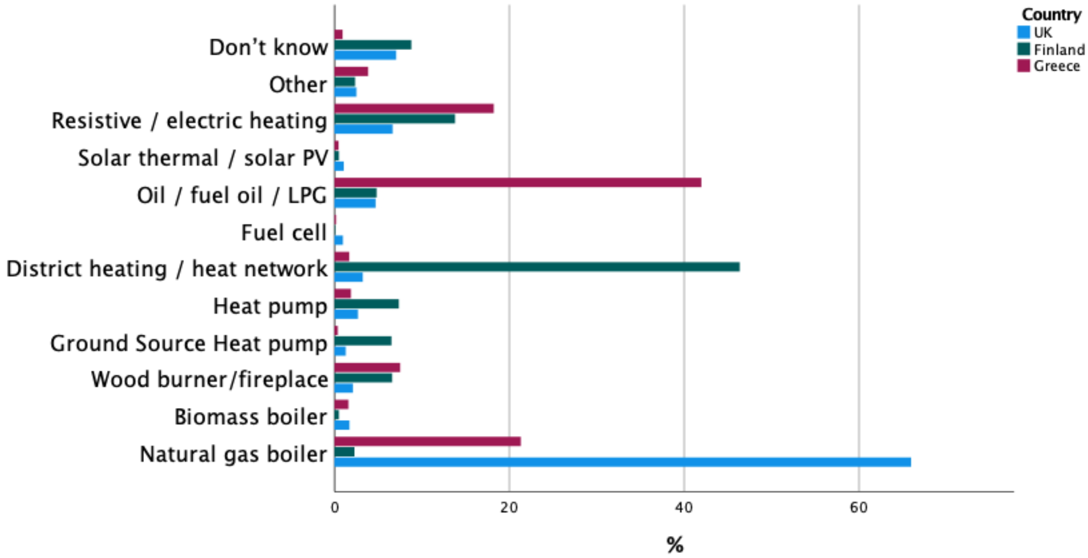
4.1.1 Energy system characteristics

The figure below indicates the relative split between communal and individual heating systems between the three countries, showing a much higher share of communal systems in Finland vs the UK, or Greece.



We then disaggregated the primary heating system by country as shown in the figure below. The dominant heating regime was shown to vary significantly between the three countries: with natural gas boilers dominant in the UK (66%), district heating/ heat networks in Finland (46.4%), and oil/ fuel oil/ LPG in Greece (42%). Heat pumps and biomass boilers comprised a relatively small share of the primary heating systems across the three countries at <8% and <2% respectively. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(22df) = 2672.139$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **strong relationship of 0.62 between primary heating method and the country.**

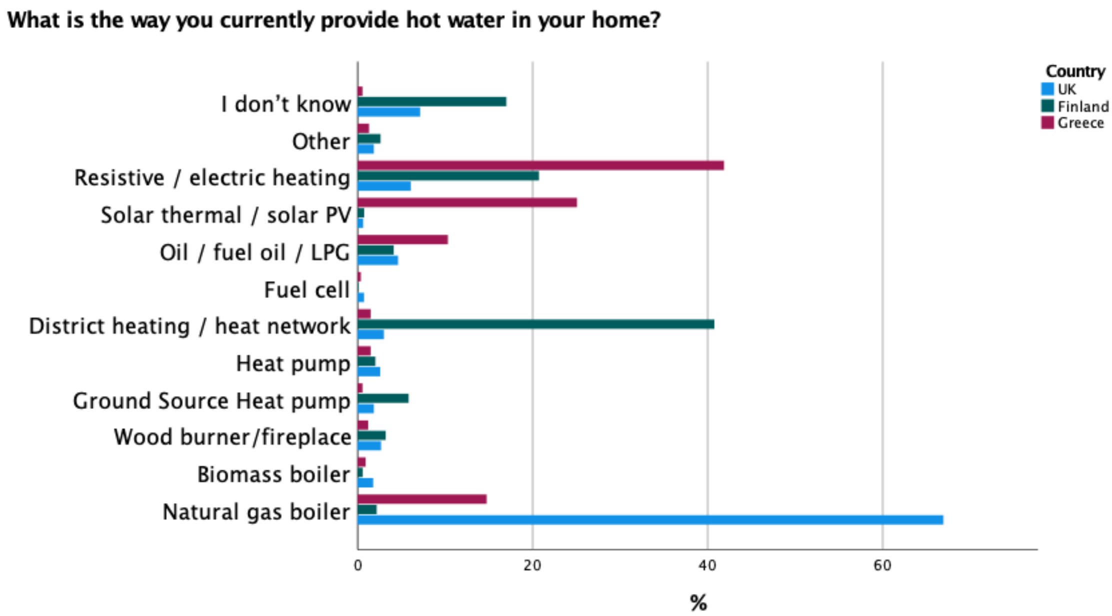
What is the primary way you currently provide heat in your home?



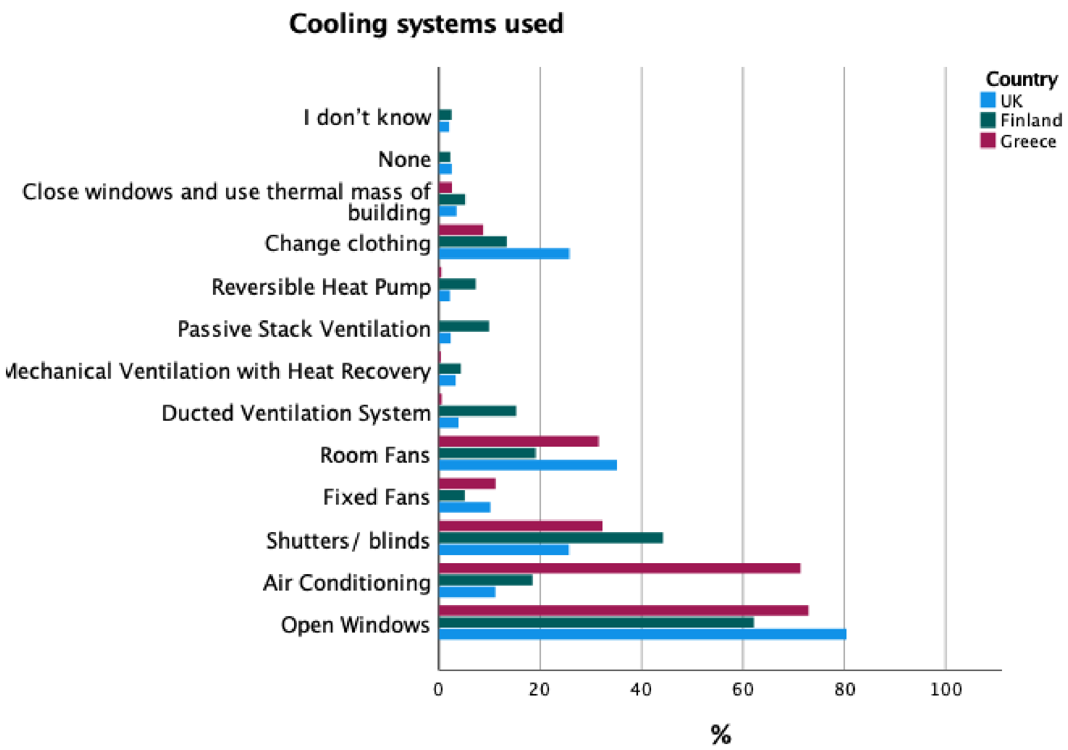
It was noted by interviewees that different systems had advantages and disadvantages, with people living in in Finland describing how with district heating occasionally kept their home warm inadvertently:

> *"It's not only a problem in our housing company but I just talked with somebody about how the heating in your apartment is affected by how others in the building live. So, for example if you live on the bottom floor and your heating is on maximum level and the person in the second floor also has their heating on maximum level, the people on the upper floors have to be sweating. That's something that is annoying."* - Finnish household user (FHU4)

The dominant hot water regime was shown to vary significantly between the three countries: with natural gas boilers dominant in the UK (66.9%), district heating/ heat network in Finland (40.8%). However, in Greece this regime was split between resistive/ electric heating (41.9%) and solar thermal/ solar PV (25.1%). Heat pumps and biomass boilers were shown to comprise a relatively small share of the water heating systems across the three countries at <3% and <2% respectively.



Using a Chi Square test, these between country differences were shown to be statistically significant, χ2(22df) = 2920.692, p < .001. The effect size using the Cramer's V test, was a **strong relationship of 0.648 between water heating method and the country.**



Survey participants could provide more than one answer for the systems the use to cool their homes. The most common cooling regime was opening windows in all three countries (>60% of respondents). However, in Greece air conditioning was prevalent (68.1%), while in Finland shutters/ blinds were also commonly used (44.2%). Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi 2(26df) = 2087.579$, $p < 0.001$. The effect size using the Cramer's V test was modelled between the country and each cooling method – showing the strength of the difference between the countries (Table 3).

Table 3 Between country differences in cooling method prevalence using Cramer's V test

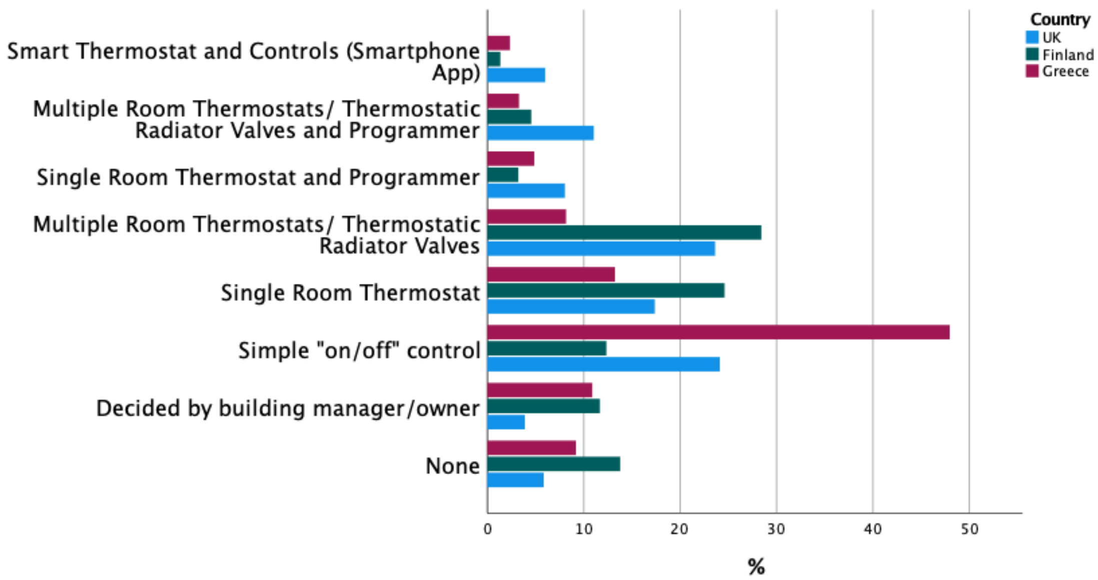
Method	Cramer's V	Approximate significance	Strength of difference
Opening Windows	0.170	.000	Weak
Air Conditioning	0.563	.000	Strong
Shutters/ blinds	0.165	.000	Weak
Fixed Fans	0.093	.000	Weak/none
Room Fans	0.154	.000	Weak
Ducted Ventilation System	0.249	.000	Weak
MVHR	0.100	.000	Weak
Passive Stack Ventilation	0.203	.000	Weak
Reversible Heat Pump	0.159	.000	Weak
Change Clothing	0.195	.000	Weak
Close windows and use thermal mass of building	0.056	.004	Weak/none
None	0.088	.000	Weak/none
I don't know	0.086	000	Weak/ none

Indeed, the use of multiple cooling methods was often observed in the interviews, with AC units also paired with room fans on the hottest Greek days:

> *"for example, in periods of much warmth, many times with the air-conditioner I turn on also the fan. Because ok you are in your place but maybe it doesn't come the cool in the face. It is absolutely subjective the way that each one sees the situation. What he wants given the moment."*- Greek household user (GU1H1)

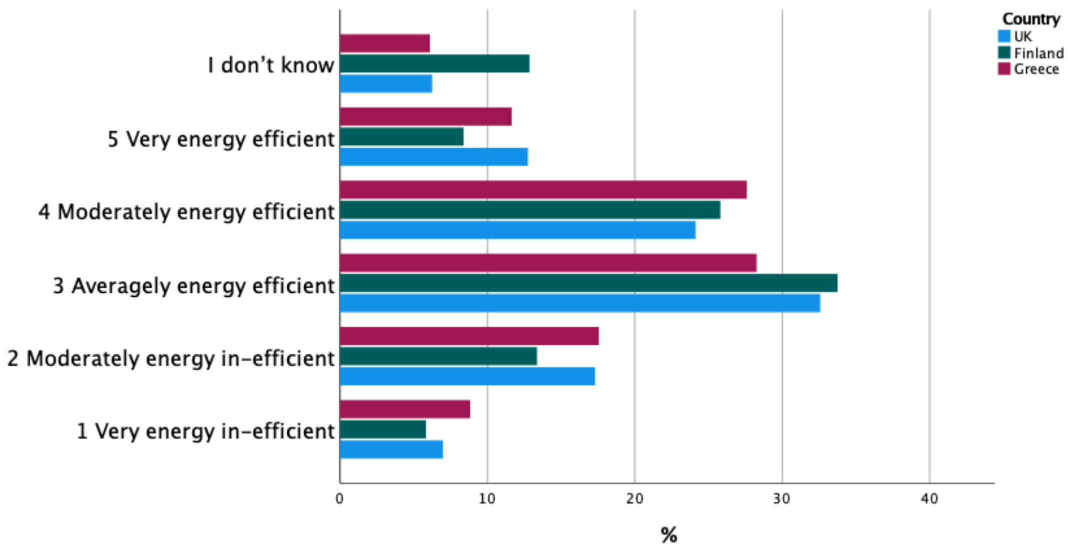
The type of control system was shown to vary moderately between the three countries. In general people in Greece had more basic controls with 48% of respondents having only a simple "on/off" control, while people in the UK (40.6%) and Finland (34.4%) often had more sophisticated multiple room thermostats or smart controls. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi 2(14df) = 652.606$, $p < .001$. The effect size using the Cramer's V test, was a **moderate relationship of 0.306 between the control method and the country.**

What type of control do you have over your current heating, hot water and cooling system?



The self-reported level of energy efficiency was shown to vary only slightly between countries. However, using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(10df) = 76.006$, $p < .001$. The effect size using the Cramer's V test, **was a weak relationship of 0.105 between the level of energy efficiency and the country.**

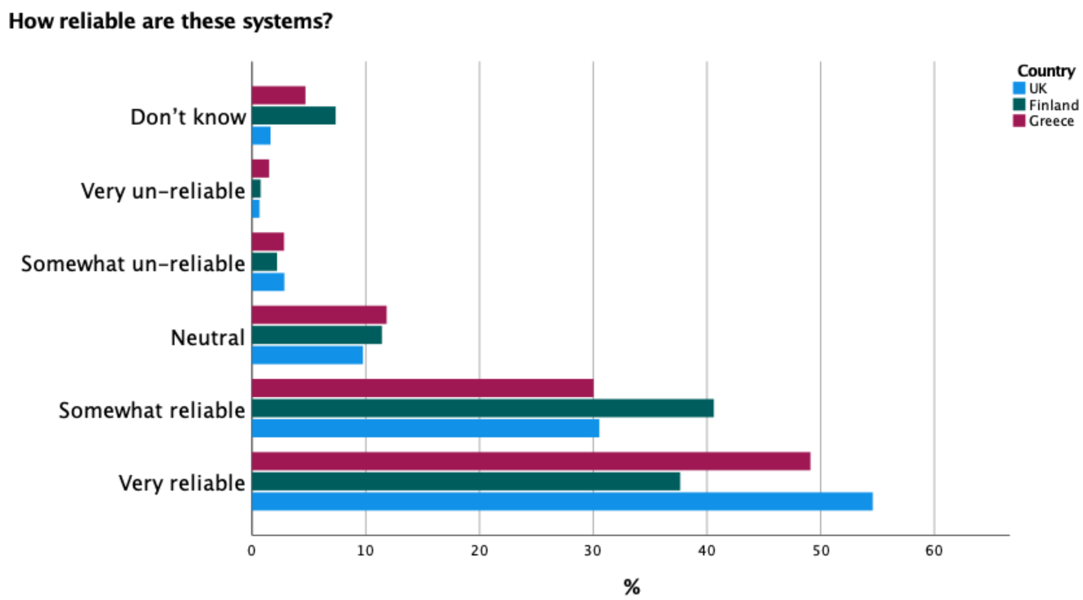
How well insulated/ energy efficient is your home?



While household users generally felt that their homes were moderately or averagely energy efficient, experts we interviewed discussed how most homes required major energy efficiency improvements:

> *"But we have so many heat loses, from experience I will tell you that when in the beginning I went to convince a client about a house that he had bought and was either to continue as a typical and either to make it a passive house... so I actually measured the kilowatt hours that the heating demand. And it was something around 360 [kWh/m2/year]. And then we went to passive house design, and it was 12 [kWh/m2/year]"* – Greek building designer

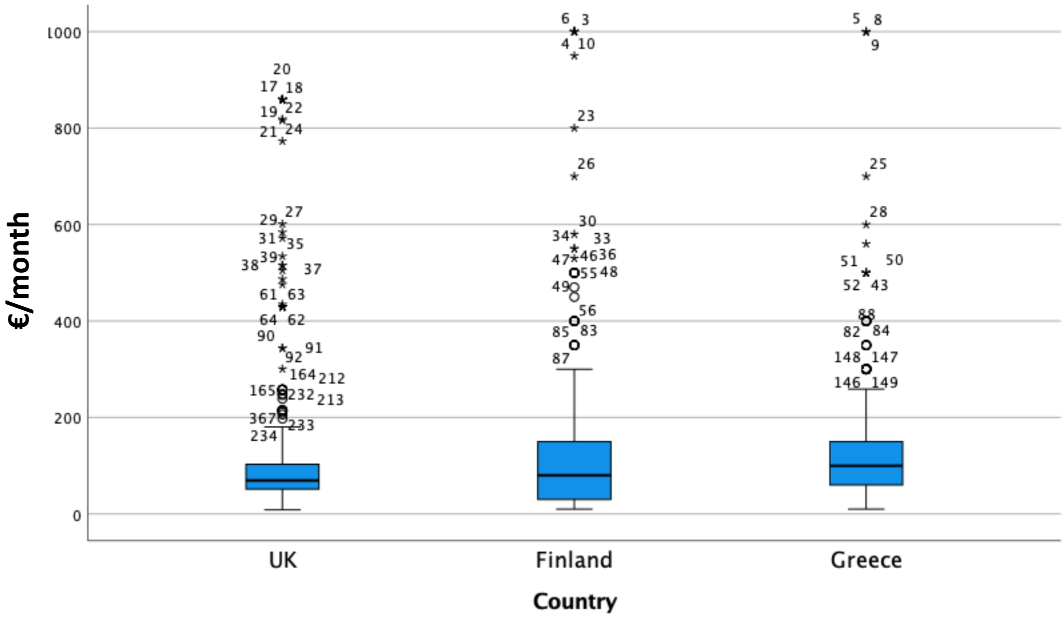
4.1.2 Reliability, affordability, comfort, and environment concern



The self-reported level of energy system reliability was shown to vary only slightly between countries, with the vast majority of UK (85.1%), Greek (79.1%) Finland (78.2%) stating that their system was either very or somewhat reliable. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(10df) = 115.352$, $p < .001$. The effect size using the Cramer's V test, **was a weak relationship of 0.129 between the level of energy reliability and the country.**

The monthly energy spend data by country was converted to euros (€) and then plotted as boxplots to investigate the presence of outliers[9]. As shown in the boxplots below there was significant evidence of extreme high values.

Monthly energy bill spend by country



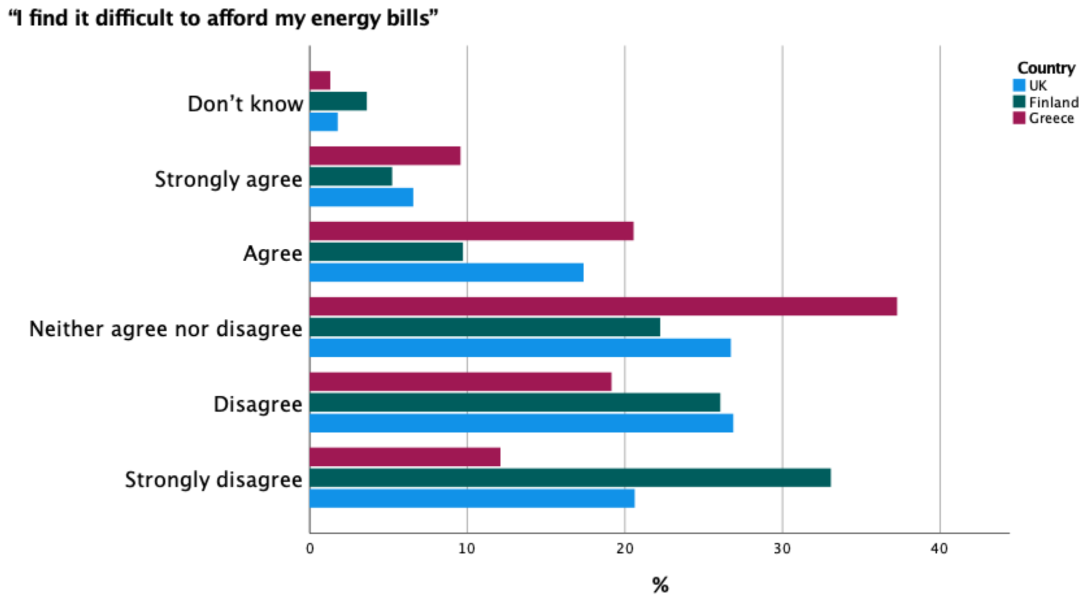
Subsequently we ran a z-score test to eliminate 55 extreme values (z=>3) from the analysis, with the threshold at €470/month and above. With the extreme values removed the revised mean values for energy bills were €96.22 for the UK, €119.56 for Finland and €117.56 for Greece.

A Shapiro-Wilk test indicated that none of the countries' energy bills follow a normal distribution: UK (Df 863) = 0.747, p = <0.001; Finland (Df 748) = 0.858, p = <0.001; and Greece (Df 828) = 0.872, p = <0.001, with the data positively skewed for all three cases. Subsequently, a Lg10 transformation was undertaken. Despite this transformation a Shapiro-Wilk test indicated that none of the countries' a Lg10 energy bills follow a normal distribution: UK (Df 863) = 0.983, p = <0.001; Finland (Df 748) = 0.968, p = <0.001; and Greece (Df 828) = 0.980, p = <0.001. Due to the non-normal distribution an Independent-Samples Kruskal-Wallis Test was used to show that there was a **statistically significant difference between the UK and Greece** energy bills, $\chi2(2)$) = -282.623, p = <0.001 **and Finland and Greece's energy bills**, $\chi2(2)$ = -240.72, p = <0.001.

While people in Finland had the highest energy bills of the three countries in the survey, our interviews indicated that some users were making significant savings with GSHP technology:

> *"We are comparing to what we would pay if we still heated the house with district heating which we did the first 15 years of the housing cooperative. With that energy saving, our investment pays itself back as soon as in five or six years. It's cheaper."* - Finnish household user (FHU3)

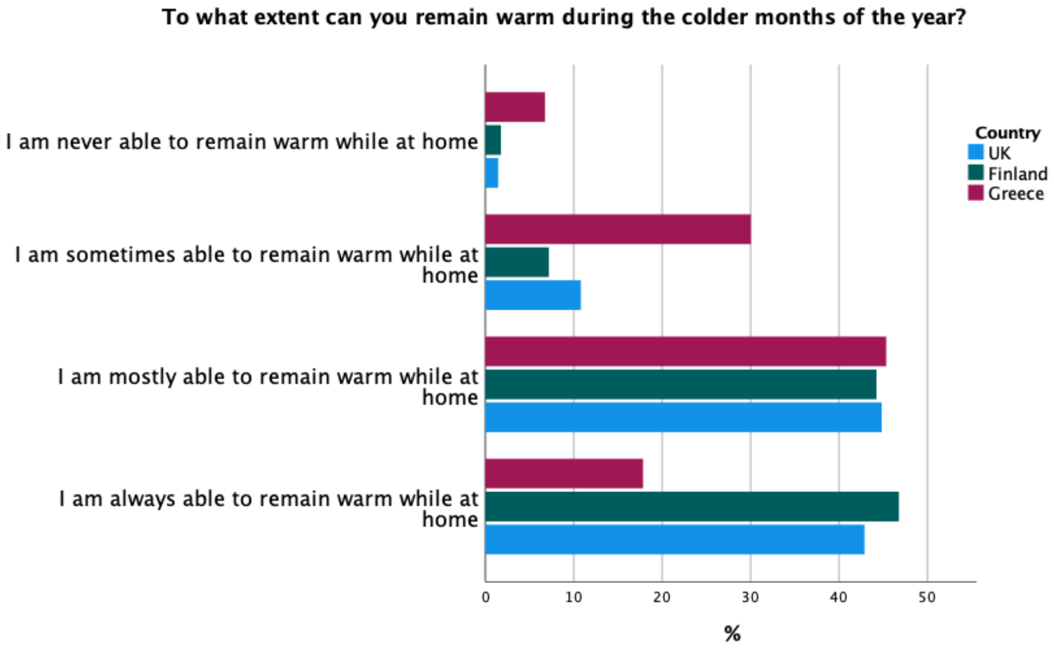
[9] Respondents who indicated "don't know" are excluded from this analysis



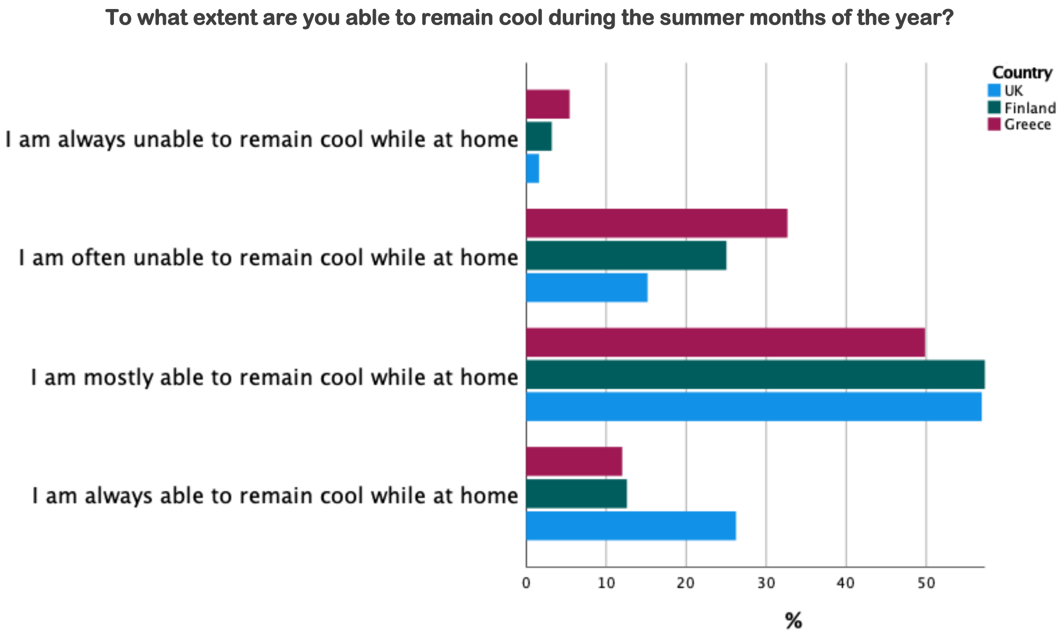
The statement "I find it difficult to afford my energy bills" was used as a proxy for energy poverty. In general people in Greece expressed higher levels of energy poverty with 30.2% of participants either "agreeing" or "strongly agreeing" with the statement. By contrast 59.1% of people in Finland either "disagreed" or "strongly disagreed" with the statement. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(10df) = 251.625$, $p < .001$. The effect size using the Cramer's V test, was a **weak relationship of 0.190 between the energy poverty level and the country.**

The survey's higher levels of self-reported energy poverty in Greece were also supported by some of the interviews, although government energy poverty programs were also mentioned:

> *"Greek Interpreter: So, it's a central heating system with an oil boiler and sometimes she personally uses her air-conditioner in her room as a supplementary supply of heating…Greek Local: (in Greek) Look, because the apartment building is old, we don't have such good insulation so slowly we will make it with "Save" program (called in Greek "Eksikonomo") to keep a little bit better the warmth."*- Greek household user (GU2H1)



There was shown to be a significant difference between winter thermal comfort and country. In general people in Greece expressed lower winter thermal comfort with 36.8% of participants either only "sometimes" or "never" able to remain warm whilst at home, compared to only 12.3% in the UK and 9% in Finland. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(6df) = 427.047$, $p < .001$. The effect size using the Cramer's V test, was a **weak relationship of 0.248 between winter thermal comfort and countr**y.

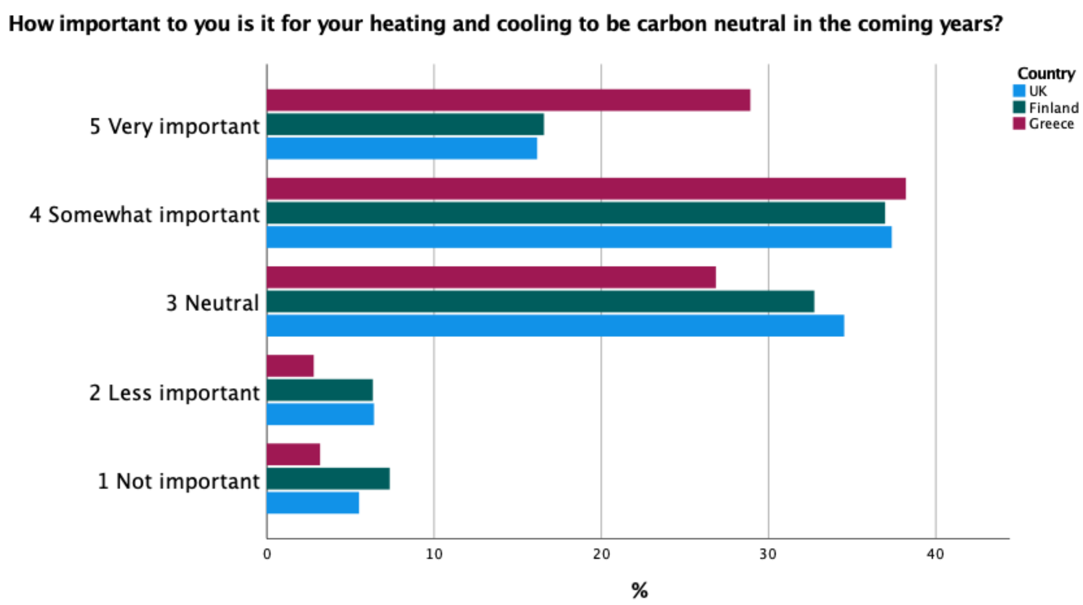


There was shown to be a significant difference between summer thermal comfort and country. In general people in Greece expressed lower summer thermal comfort with 38.1%

of participants either only "often" or "always" unable to remain cool whilst at home, compared to only 16.8% in the UK and 28.2% in Finland. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi 2(6df) = 197.842$, $p < .001$. The effect size using the Cramer's V test, was a **weak relationship of 0.169 between summer thermal comfort and countr**y.

While the UK and Finnish users had fewer issues with remaining cool, a UK building manager of a district heating system reported that sometimes the system inadvertently provides unwanted space heating:

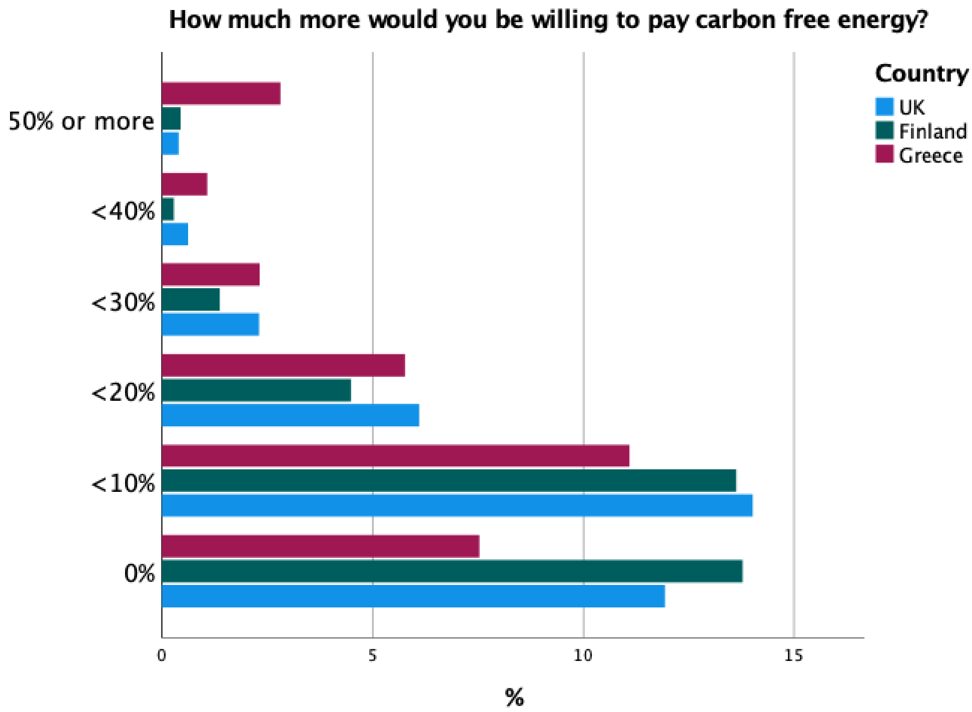
> *"Obviously the pipework runs under the floors, they're on suspended floors in there, so the pipework still stays hot because it has to feed the next radiator down the line if you've got it on. So, people sort of refer to it as their under-floor heating even though it's not actually classed as that, but even if you turn all the radiators off in the property, you still end up with that loop being hot."* - UK Building Manager (UMH2)



There was shown to be some difference between the respective importance given to HVAC carbon neutrality. In general, Greek respondents expressed greater concern for the climate impact of their HVAC systems, with 67.1% of participants describing it as "somewhat" or "very" important, compared to only 53.6% in the UK and 53.6% in Finland. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi 2(8df) = 104.986$, $p < .001$. The effect size using the Cramer's V test, was a **weak relationship of 0.123 between the importance given to carbon neutrality and country**.

Many of those viewed climate change as an important issue, however these were often framed in terms that suggested people had limited power to make the change or seen as more important by younger people:

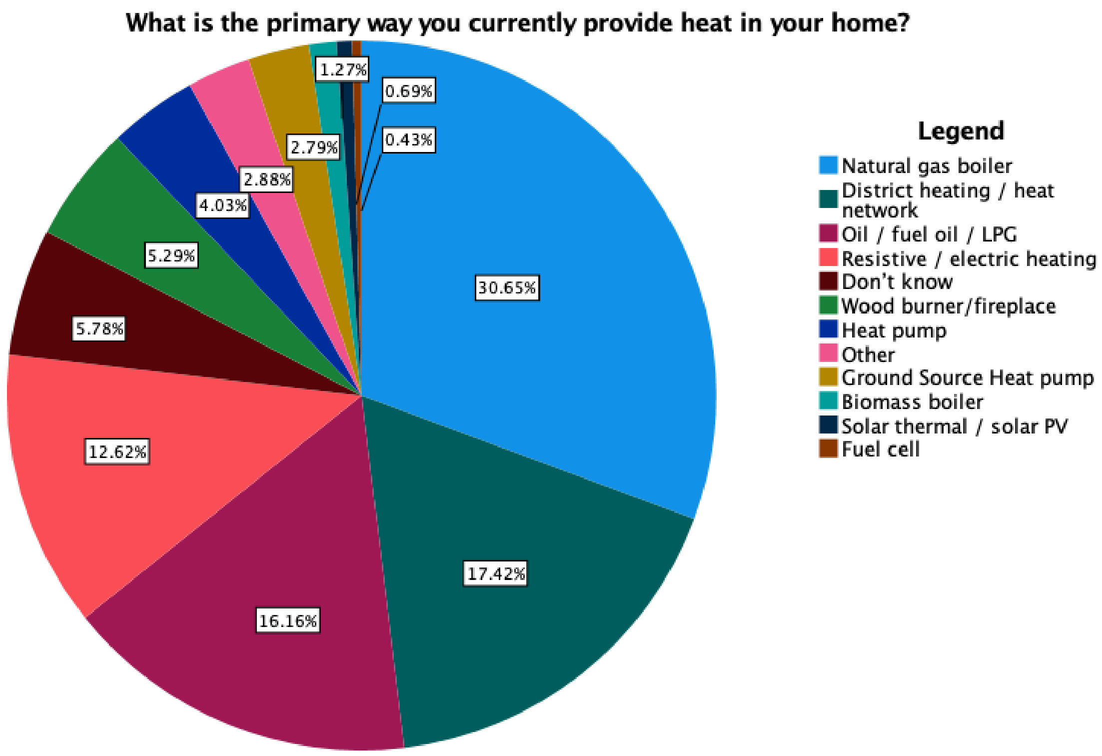
> *"in my previous job I managed 19-20 properties, and one of them, one board was environmentally conscious and was thinking about the source of electricity. But in the context of switching to geothermal from district heating for example, I have never encountered a discussion regarding whether electricity is renewable. I would say that renewable energy is on a certain generation's agenda."*- Finnish building manager (FM3)



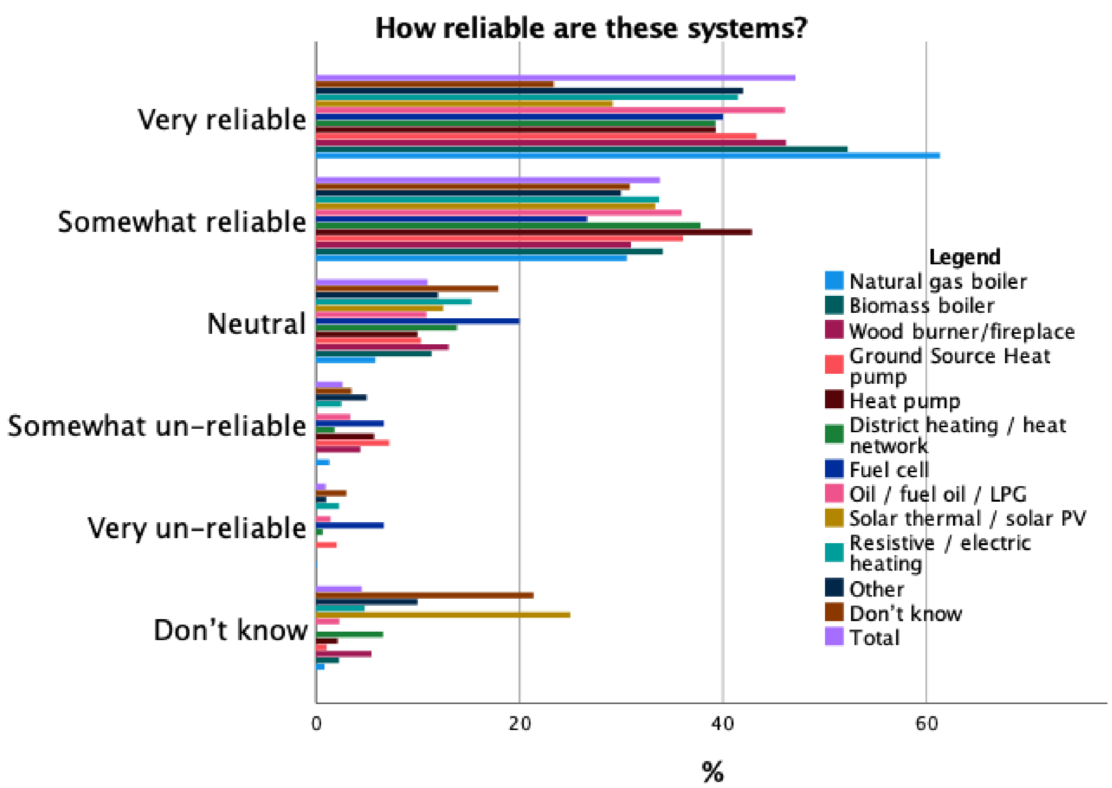
There was shown to be some difference between the willingness to pay for carbon free energy. In general people in Greece expressed greater willingness to pay for carbon free energy, with 21.7% of participants willing to pay 30% or more than they are currently paying, compared to only 10.1% in the UK and 6.5% in Finland. 39.8% of Finnish respondents and 31.3% in the UK were not willing to accept any increase in their energy bills for carbon neutrality. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(10df) = 228.676$, $p < .001$. The effect size using the Cramer's V test, was a **weak relationship of 0.181 between the willingness to pay for carbon free energy and country.**

4.2 *Views of users on existing energy technologies*

Following the review of the between country differences, we now explore the views and preferences surrounding respondents existing energy systems. As shown in the figure below, the dominant heating regime across the three countries was natural gas boilers (30.65%) followed by district heating/ heat networks (17.42%) and then oil/ fuel oil/ LPG.



4.2.1 Heating system reliability

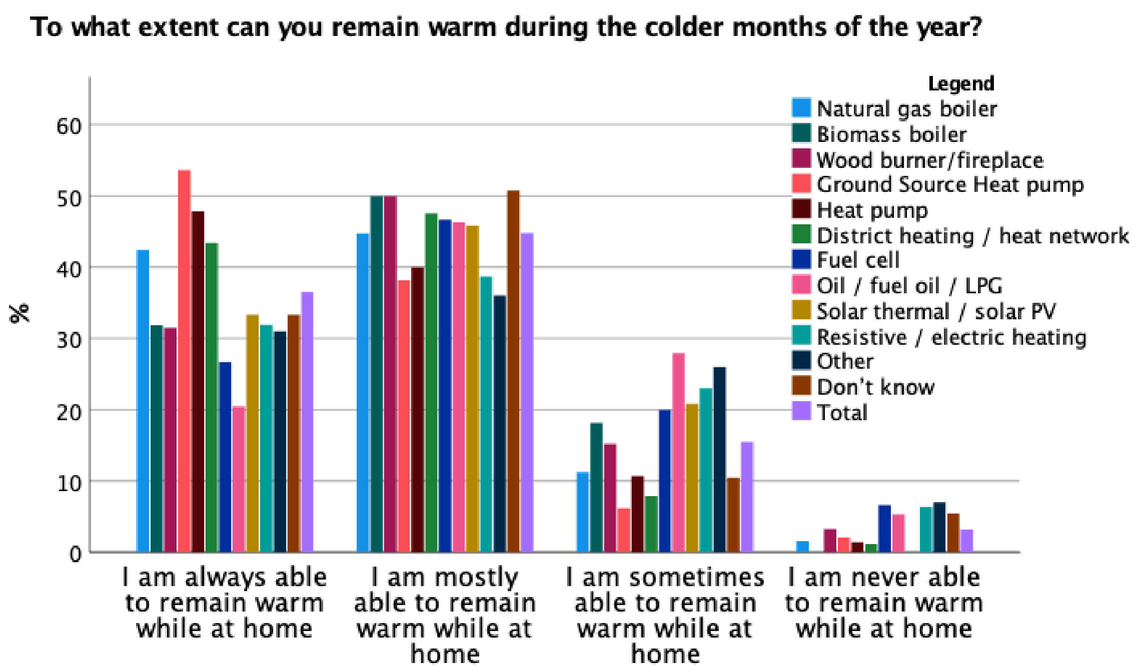


In general, 81% of users described their energy systems are either "very" or "somewhat" reliable. Natural gas boilers had the highest share of "very reliable" answers (61.4%) followed by biomass boilers (52.3%), wood burner/ fireplace (46.2%) and oil/ fuel oil / LPG (46.1%). Heat pumps and solar thermal/ solar PV had a much lower share of "very reliable" answers at 39.3% and 29.2% respectively. Interestingly solar thermal/ solar PV also had the highest share of "don't know" answers at 25%.

		Very reliable	Somewhat reliable	Neutral	Somewhat un-reliable	Very un-reliable	Don't know
	Natural gas boiler	61.4%	30.6%	5.8%	1.3%	0.1%	0.8%
	Biomass boiler	52.3%	34.1%	11.4%			2.3%
	Wood burner/fireplace	46.2%	31.0%	13.0%	4.3%		5.4%
	Ground Source Heat pump	43.3%	36.1%	10.3%	7.2%	2.1%	1.0%
	Heat pump	39.3%	42.9%	10.0%	5.7%		2.1%
	District heating / heat network	39.3%	37.8%	13.9%	1.8%	0.7%	6.6%
	Fuel cell	40.0%	26.7%	20.0%	6.7%	6.7%	
	Oil / fuel oil / LPG	46.1%	35.9%	10.9%	3.4%	1.4%	2.3%
	Solar thermal / solar PV	29.2%	33.3%	12.5%			25.0%
	Resistive / electric heating	41.5%	33.7%	15.3%	2.5%	2.3%	4.8%
	Other	42.0%	30.0%	12.0%	5.0%	1.0%	10.0%
	Don't know	23.4%	30.8%	17.9%	3.5%	3.0%	21.4%
Total		47.2%	33.8%	11.0%	2.6%	0.9%	4.5%

Using a Chi Square test, these differences between energy systems were shown to be statistically significant, χ2(55df) = 419.352, $p < .001$. The effect size using the Cramer's V test, was a **weak relationship of 0.155 between the energy system and its reliability.**

4.2.2 Heating system vs. thermal comfort - winter



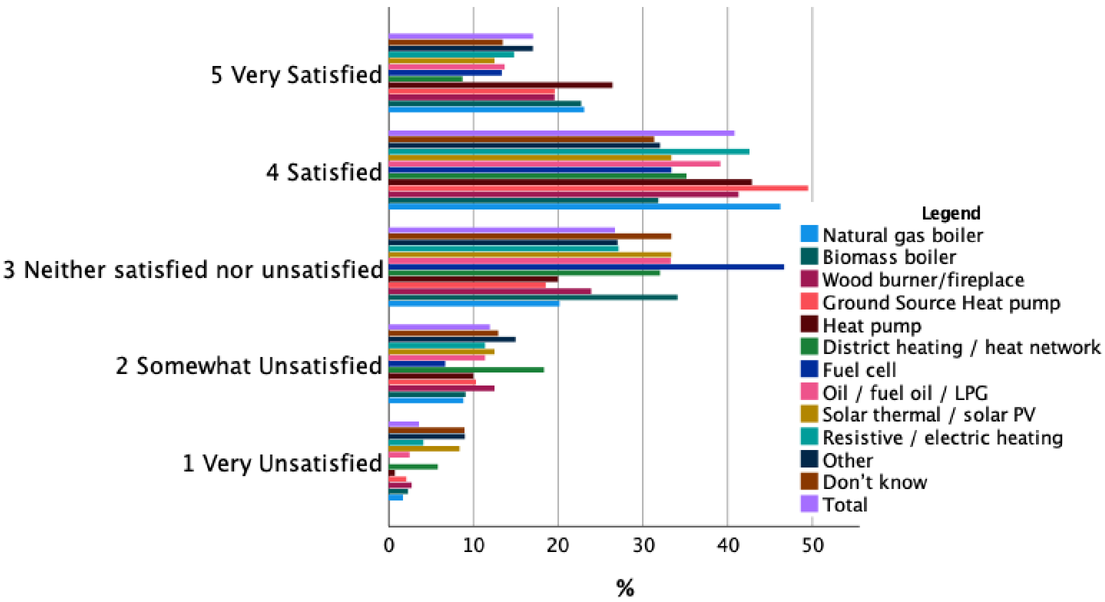
Generally, 81.3% of respondents were either "always" or "mostly" able to remain warm whilst at home in winter. Heat pumps and GSHPs were shown to have the highest share of people "always" able to remain warm at 53.6% and 47.9% respectively. Oil/ fuel oil/ LPG users had the lowest share of people "always" able to remain warm at 20.5%.

		I am always able to remain warm while at home	I am mostly able to remain warm while at home	I am sometimes able to remain warm while at home	I am never able to remain warm while at home
	Natural gas boiler	42.4%	44.7%	11.3%	1.6%
	Biomass boiler	31.8%	50.0%	18.2%	
	Wood burner/fireplace	31.5%	50.0%	15.2%	3.3%
	Ground Source Heat pump	53.6%	38.1%	6.2%	2.1%
	Heat pump	47.9%	40.0%	10.7%	1.4%
	District heating / heat network	43.4%	47.5%	7.9%	1.2%
	Fuel cell	26.7%	46.7%	20.0%	6.7%
	Oil / fuel oil / LPG	20.5%	46.3%	27.9%	5.3%
	Solar thermal / solar PV	33.3%	45.8%	20.8%	
	Resistive / electric heating	31.9%	38.7%	23.0%	6.4%
	Other	31.0%	36.0%	26.0%	7.0%
	Don't know	33.3%	50.7%	10.4%	5.5%
Total		36.5%	44.8%	15.5%	3.2%

Using a Chi Square test, these differences between energy systems were shown to be statistically significant, χ2(33df) = 264.185, p < .001. The effect size using the Cramer's V test, was a **weak relationship of 0.159 between the energy system and winter thermal comfort.**

4.2.3 Heating system vs control satisfaction

How satisfied are you with the level of control you have over your heating and cooling?

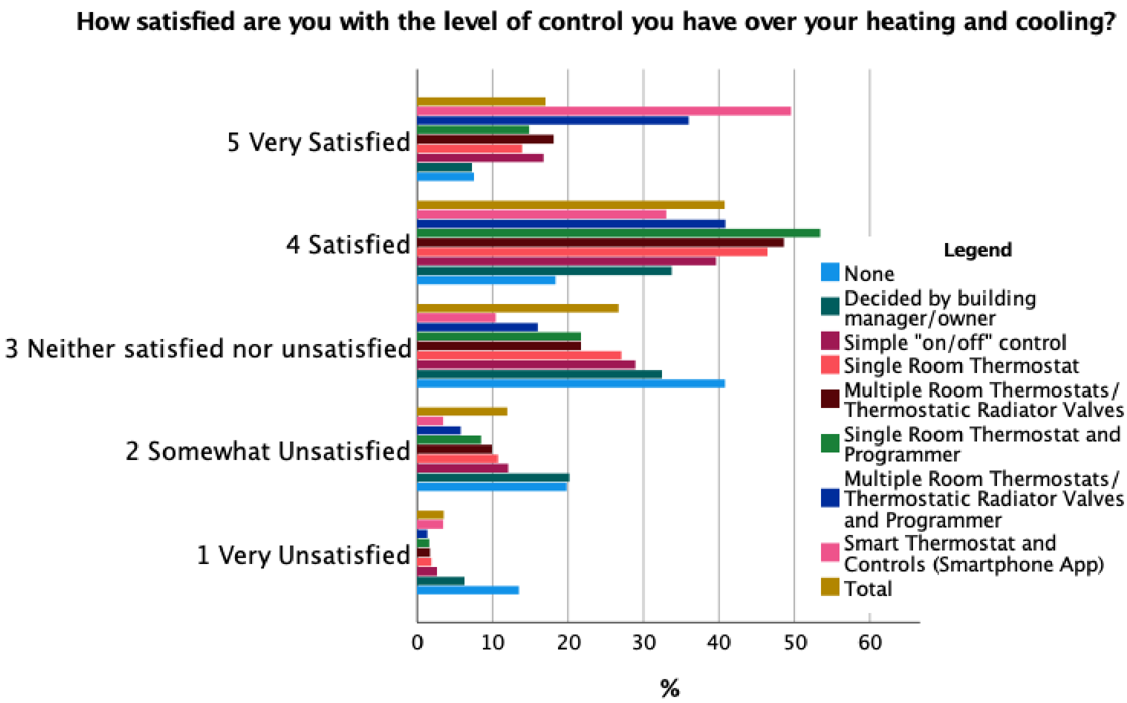


Generally, 57.8% of respondents were either "very" or "somewhat" satisfied with the level of control they had over their heating and cooling. Natural gas boilers, heat pumps and GSHPs were shown to have the highest share of people "very" or "somewhat" satisfied at 69.3%, 69.3% and 69.1% respectively. Only 8.7% of district heating users were "very" satisfied with the level of control they had, while 8.3% of solar thermal/ PV users were "very un-satisfied".

		1 Very Unsatisfied	2 Somewhat Unsatisfied	3 Neither satisfied nor unsatisfied	4 Satisfied	5 Very Satisfied
	Natural gas boiler	1.7%	8.8%	20.2%	46.2%	23.1%
	Biomass boiler	2.3%	9.1%	34.1%	31.8%	22.7%
	Wood burner/fireplace	2.7%	12.5%	23.9%	41.3%	19.6%
	Ground Source Heat pump	2.1%	10.3%	18.6%	49.5%	19.6%
	Heat pump	0.7%	10.0%	20.0%	42.9%	26.4%
	District heating / heat network	5.8%	18.3%	32.0%	35.1%	8.7%
	Fuel cell		6.7%	46.7%	33.3%	13.3%
	Oil / fuel oil / LPG	2.5%	11.4%	33.3%	39.1%	13.7%
	Solar thermal / solar PV	8.3%	12.5%	33.3%	33.3%	12.5%
	Resistive / electric heating	4.1%	11.4%	27.1%	42.6%	14.8%
	Other	9.0%	15.0%	27.0%	32.0%	17.0%
	Don't know	9.0%	12.9%	33.3%	31.3%	13.4%
Total		3.5%	11.9%	26.7%	40.8%	17.0%

Using a Chi Square test, these differences between energy systems were shown to be statistically significant, χ2(44df) = 215.410, p < .001. The effect size using the Cramer's V test, was a **weak relationship of 0.124 between the energy system and satisfaction over control.**

4.2.4 Control type vs control satisfaction



To further investigate the drivers of control satisfaction, we examined its relationship with the type of control. In general users with more advanced controls tended to be more satisfied with "smart thermostat and controls (smartphone app)" and "multiple room thermostats/

thermostatic radiator valves and programmer" being very satisfied in 49.6% and 36% of responses respectively. By contrast 33.3% of those with "none" of which were either "very" or "somewhat" unsatisfied.

		1 Very Unsatisfied	2 Somewhat Unsatisfied	3 Neither satisfied nor unsatisfied	4 Satisfied	5 Very Satisfied
	None	13.5%	19.8%	40.8%	18.3%	7.5%
	Decided by building manager/owner	6.3%	20.2%	32.5%	33.8%	7.3%
	Simple "on/off" control	2.6%	12.1%	28.9%	39.6%	16.8%
	Single Room Thermostat	1.9%	10.7%	27.1%	46.4%	13.9%
	Multiple Room Thermostats/ Thermostatic Radiator Valves	1.7%	9.9%	21.7%	48.6%	18.1%
	Single Room Thermostat and Programmer	1.6%	8.5%	21.7%	53.4%	14.8%
	Multiple Room Thermostats/ Thermostatic Radiator Valves and Programmer	1.3%	5.8%	16.0%	40.9%	36.0%
	Smart Thermostat and Controls (Smartphone App)	3.5%	3.5%	10.4%	33.0%	49.6%
Total		3.5%	11.9%	26.7%	40.8%	17.0%

Using a Chi Square test, these differences between control systems were shown to be statistically significant, $\chi 2(28df) = 461.821$, $p < .001$. The effect size using the Cramer's V test, was a **weak relationship of 0.182 between the energy system and satisfaction over control.**

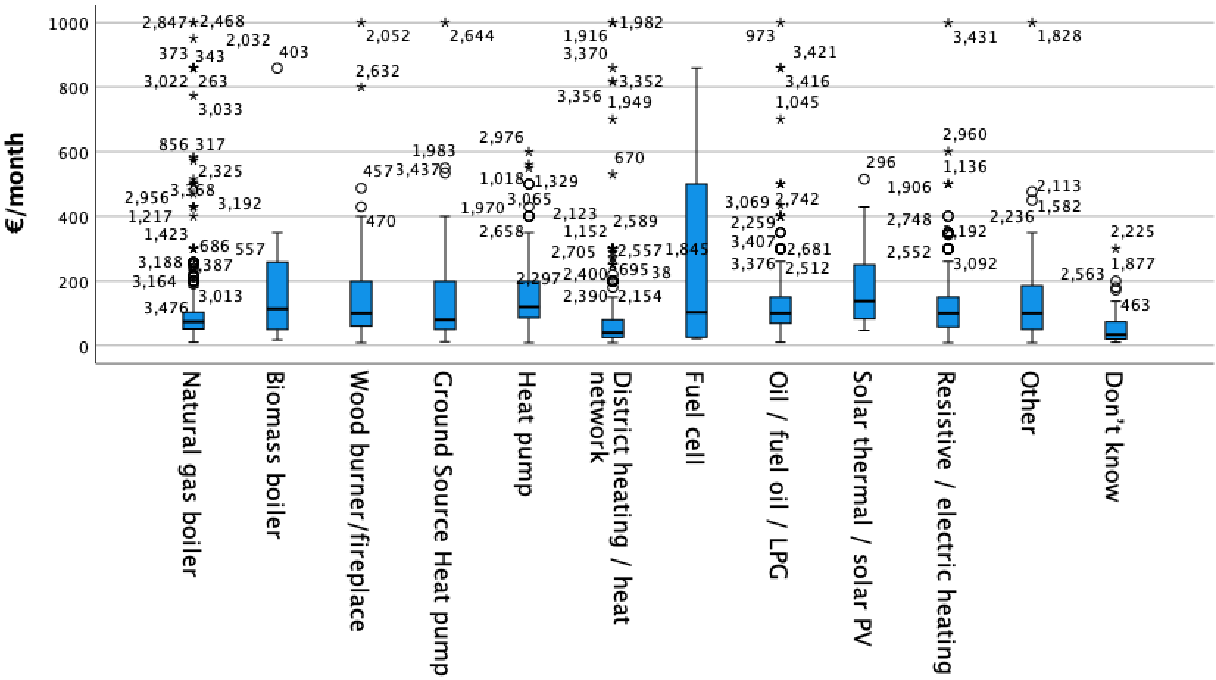
Indeed, Greek interviewees outlined how the level of control with their simple on/off systems was not ideal for thermal comfort:

> *"For sure, the [control] autonomy would be the ideal. Sure, because each house, depending on their economics could be heated more... Here, whatever we will do, if I am cold in the midday, I can't open the radiator. The radiator will be open certain hours, that the apartment building has already agree with. If I am cold in the morning or in the midday, or hours that the radiator is not on, I must have another heating way on my own, for example a stove/electric heater"* Greek building manager (GM1H1)

4.2.5 Heating type vs energy bills

The monthly energy spend data were converted to euros (€) and then plotted as boxplots to investigate the presence of outliers. As shown in the boxplots below there was significant evidence of extreme high values.

Monthly energy bill spend by heating system type



Subsequently we ran a z-score test to eliminate 55 extreme values (z=>3) from the analysis, with the threshold at €470/month and above. With the extreme values removed the revised mean values for energy bills by heating system are shown in the table adjacent. However, it is important not to over interpret these findings as many other significant factors such as house size, climate etc may be at play.

	Monthly energy spend (€) (corrected for exchange rate) Mean	I don't know %
Natural gas boiler	96	30.6%
Biomass boiler	164	1.3%
Wood burner/fireplace	142	5.3%
Ground Source Heat pump	133	2.8%
Heat pump	159	4.0%
District heating / heat network	78	17.4%
Fuel cell	295	0.4%
Oil / fuel oil / LPG	129	16.2%
Solar thermal / solar PV	181	0.7%
Resistive / electric heating	125	12.6%
Other	141	2.9%
Don't know	55	5.8%

A Shapiro-Wilk test indicated that all the variables except for the fuel cell, are not normally distributed. with the data positively skewed for all these cases. Subsequently, a Lg10 transformation was undertaken. Despite this transformation a Shapiro-Wilk test indicated that although some cases did produce a normal distribution, it was not achieved for all heating system types.

Due to the non-normal distribution an Independent-Samples Kruskal-Wallis Test was adopted, which showed that there was a statistically significant difference between the heating system type and energy bills, $\chi2(df11)) = -330.467$, $p = <0.001$. The pairwise comparisons of mean energy bills vs. heating system are shown in Table 4, with only the significant differences shown.

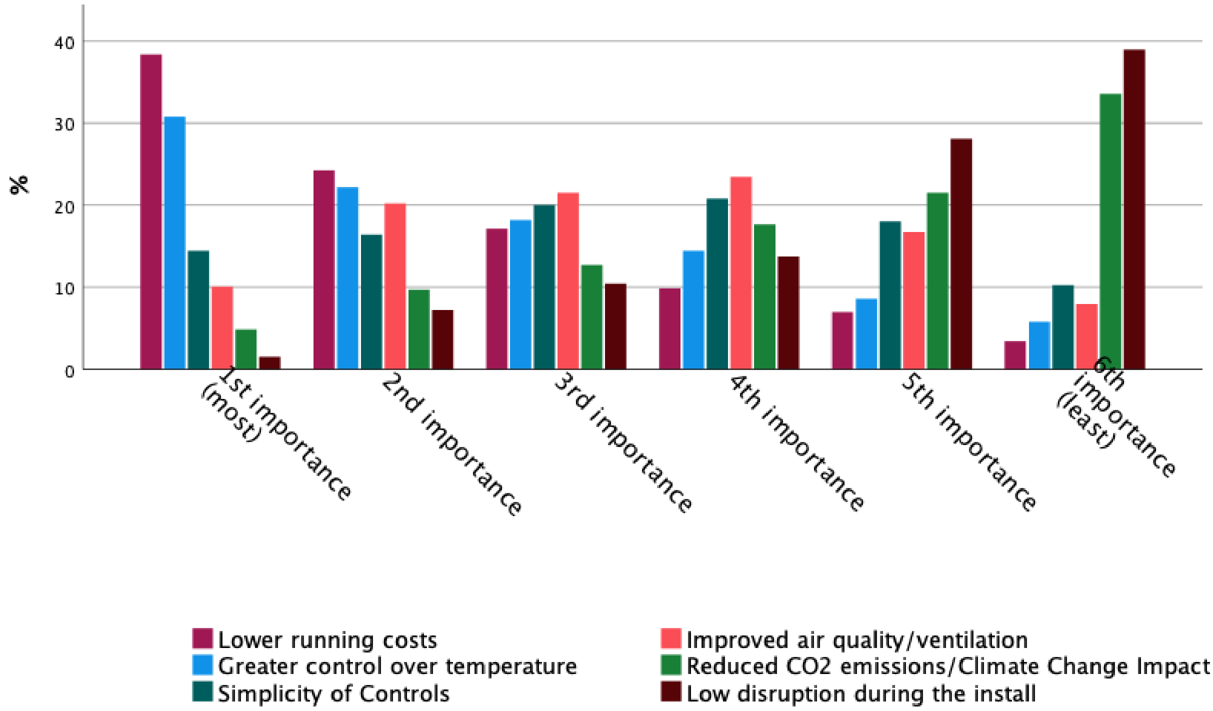
Table 4 Pairwise comparisons of mean bills vs. heating system (only significant differences shown).

	Monthly Energy Bill € (Mean)	Bills significantly higher than… (p=<0.05)	Bills significantly cheaper than… (p=<0.05)
Natural Gas boiler	€96	Don't know, District heating/ heat network	Resistive/ electric heating, Oil/ fuel oil / LPG, Woodburner/ fireplace, ASHP
Biomass Boiler	€164	Don't know, District heating/ heat network	
Woodburner/ fireplace	€142	Don't know, District heating/ heat network, Natural Gas boiler	
GSHP	€133	Don't know, District heating/ heat network	
ASHP	€159	Don't know, District heating/ heat network, Natural Gas boiler	
District heating/ heat network	€78	Don't know	Natural Gas boiler, GSHP, Other, Resistive/ electric heating, Oil/ fuel oil / LPG, Biomass Boiler, Wood burner/ fireplace, ASHP, Solar Thermal/ PV,
Fuel cell	€295		
Oil/ fuel oil / LPG	€129	Don't know, District heating/ heat network, Natural Gas boiler	
Solar Thermal/ PV	€181	Don't know, District heating/ heat network	
Resistive/ electric heating	€125	Don't know, District heating/ heat network, Natural Gas boiler	
Other	€141	Don't know, District heating/ heat network	
Don't know	€55		GSHP, Other, Resistive/ electric heating, Oil/ fuel oil / LPG, Biomass Boiler, Woodburner/ fireplace, ASHP, Solar Thermal/ PV

4.3 User expectations and preferences for SolBio-Rev

Following our analysis of user perceptions of existing energy systems, we investigated perceptions surrounding a new energy system. We first examined user's preferences for the features of these systems, before examining familiarity with the core SolBio-Rev technologies by country, then investigating user's willingness to change to different systems.

As shown in the table below participants ranked “lower running costs” as the most important feature of a new HVAC system, with 38.4% of respondents ranking this feature as of highest importance. Control over temperature was also ranked second highest - viewed as of most importance by 30.8% of the sample. By contrast 39% of respondents viewed “low disruption during the install” as the least important factor, with “reduced CO_2 emissions/ climate change impact” ranked second lowest - viewed as the least important factor by 33.6% of the sample.

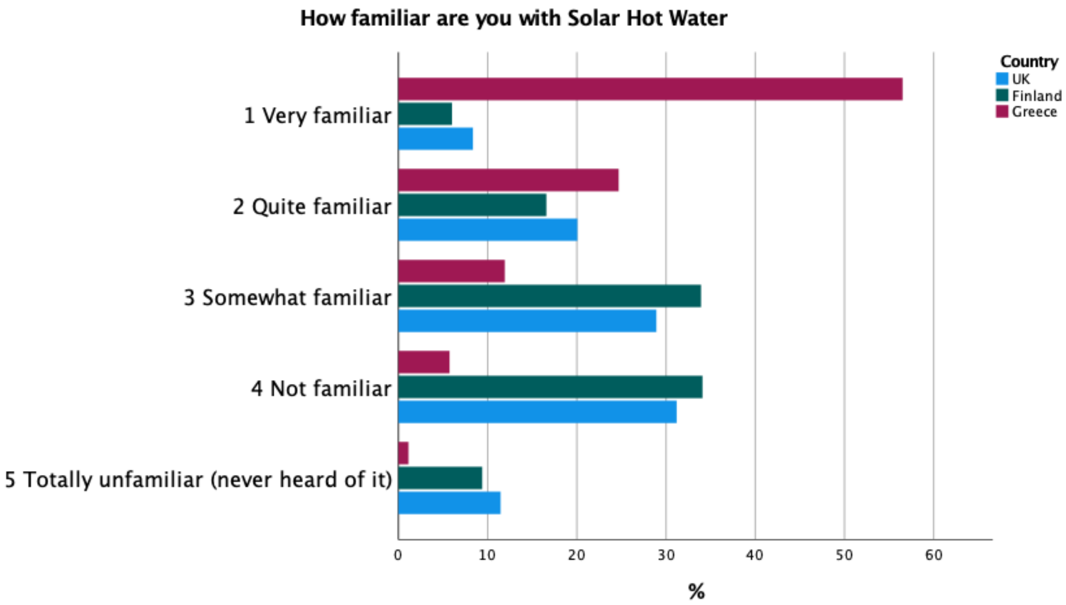


4.3.1 Familiarity with SolBio- Rev technologies

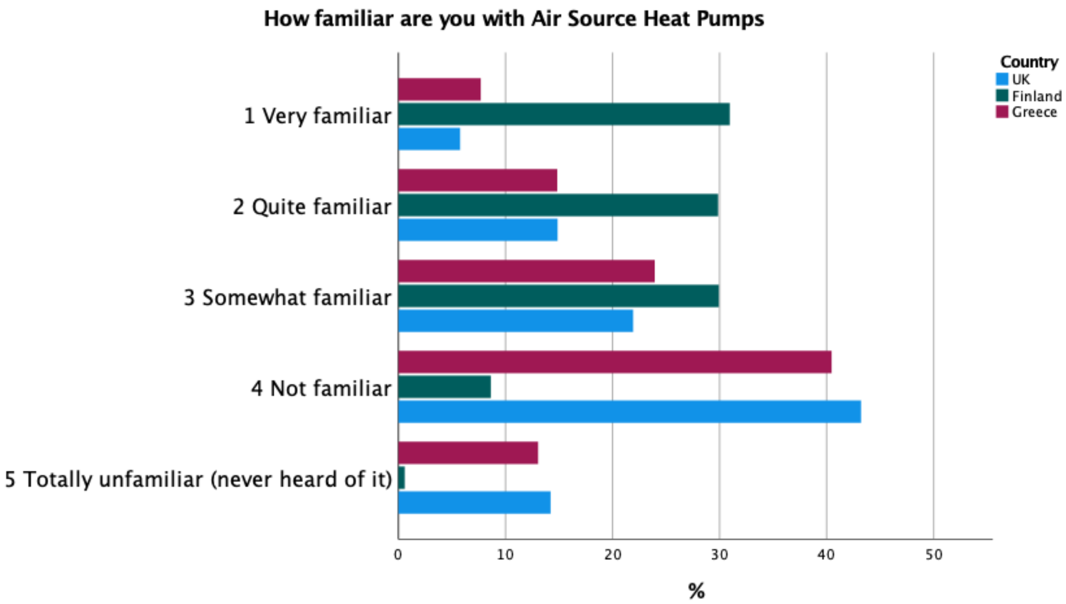
In general, building designers and engineers viewed the concept behind the SolBio-Rev system very favourably (they were shown a basic diagram).

> *“I believe that this type of installation is perfect for Greece...perfect because you have this ability to make let's say, stand alone for each apartment without destroy anything, so it's something that you plug in place, let's say, you change the heater, you add a storage tank, you have this solar thermal collector changed, I think it would do a great, great job in Greece.”*- Greek building designer (GD1)

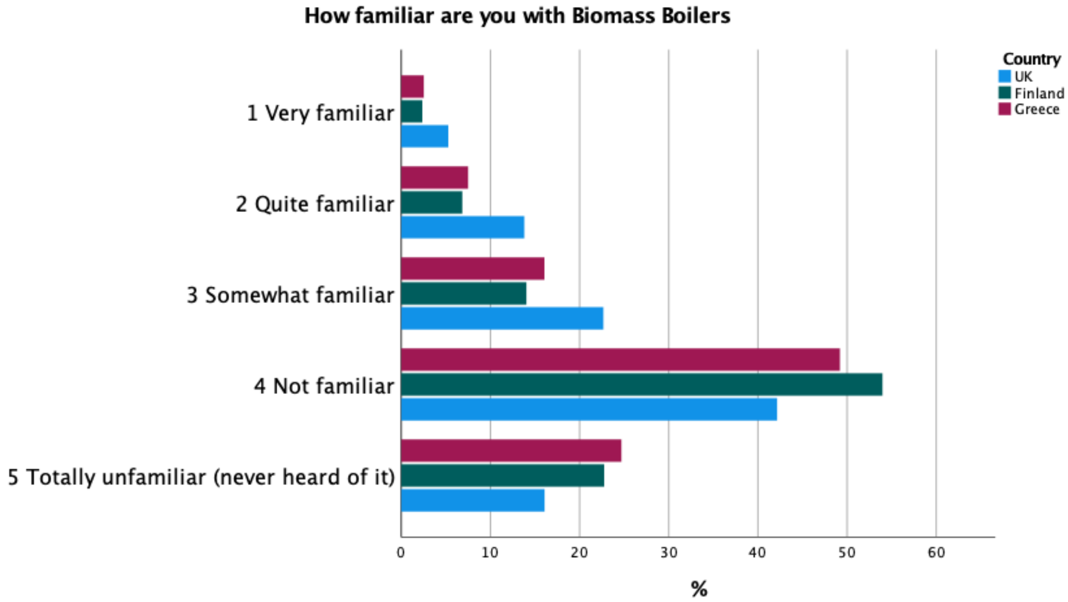
However, the household users in the survey in general had low familiarity with the core systems of SolBio-Rev, although this did vary by country to a degree.



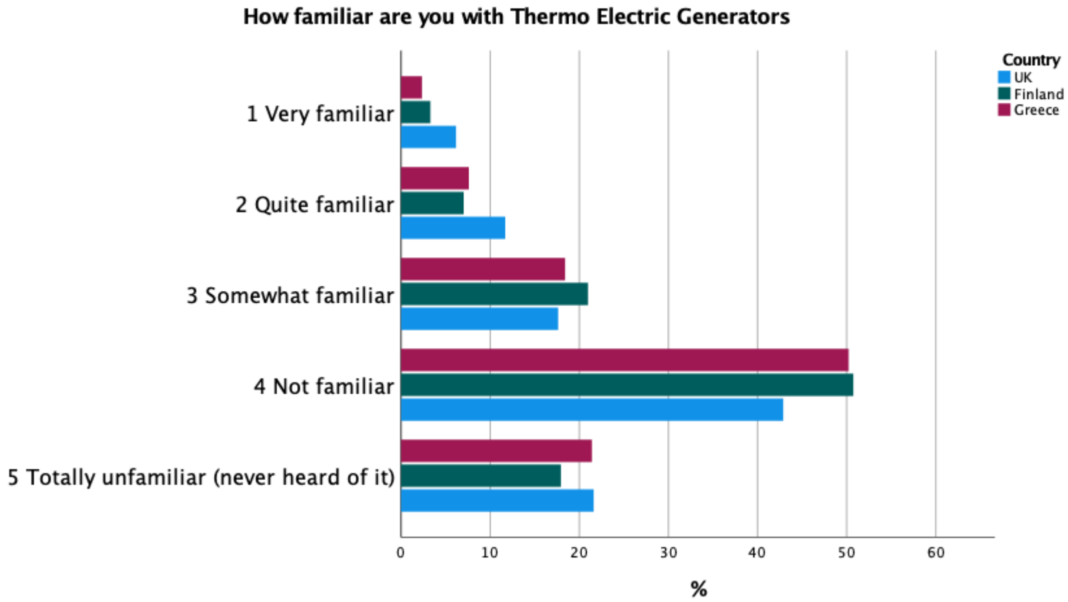
Familiarity with solar hot water was shown to vary significantly between the three countries: with 56.5% of respondents in Greece “very familiar” with the technology, compared to only 8.4% in the UK and 6% in Finland. Indeed 42.7% of UK respondents and 43.5% of those in Finland were not familiar or had never heard of the technology. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(8df) = 1250.025$, $p < .001$. The effect size for this finding, using the Cramer’s V, was a **moderate relationship of 0.424 between solar hot water familiarity and the country**.



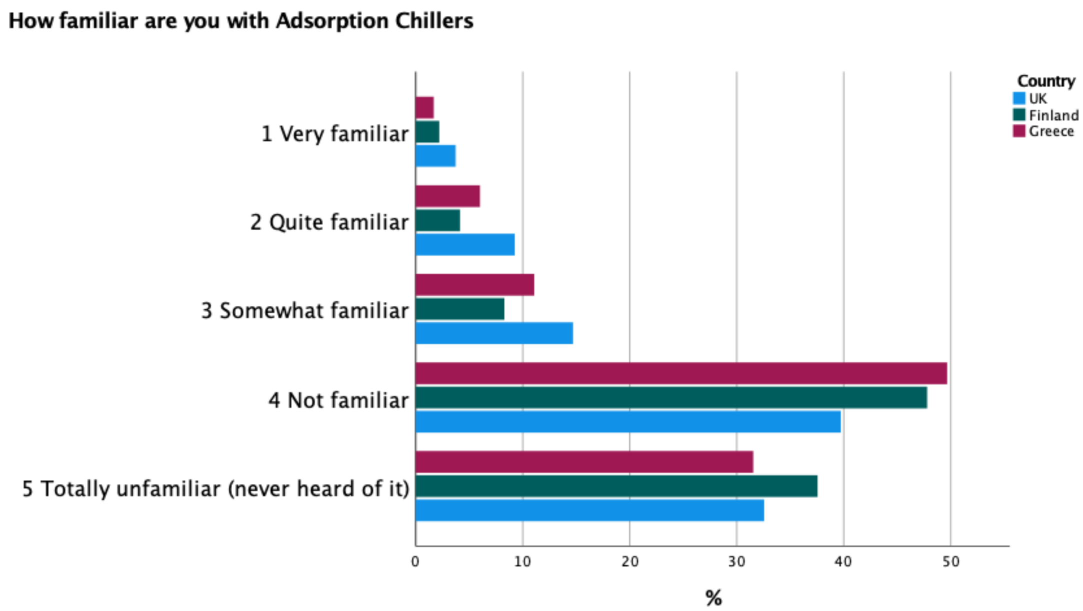
Familiarity with ASHP was generally lower than solar thermal and shown to vary significantly between the three countries: with 60.9% of Finnish respondents “very familiar” or “quite familiar” with the technology, compared to only 20.7% in the UK and 22.5% in Greece. Indeed 57.4% of UK respondents and 53.6% of Greek respondents were “not familiar” or had “never heard" of the technology. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(8df) = 844.521$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **moderate relationship of 0.348 between ASHP familiarity and the country**.



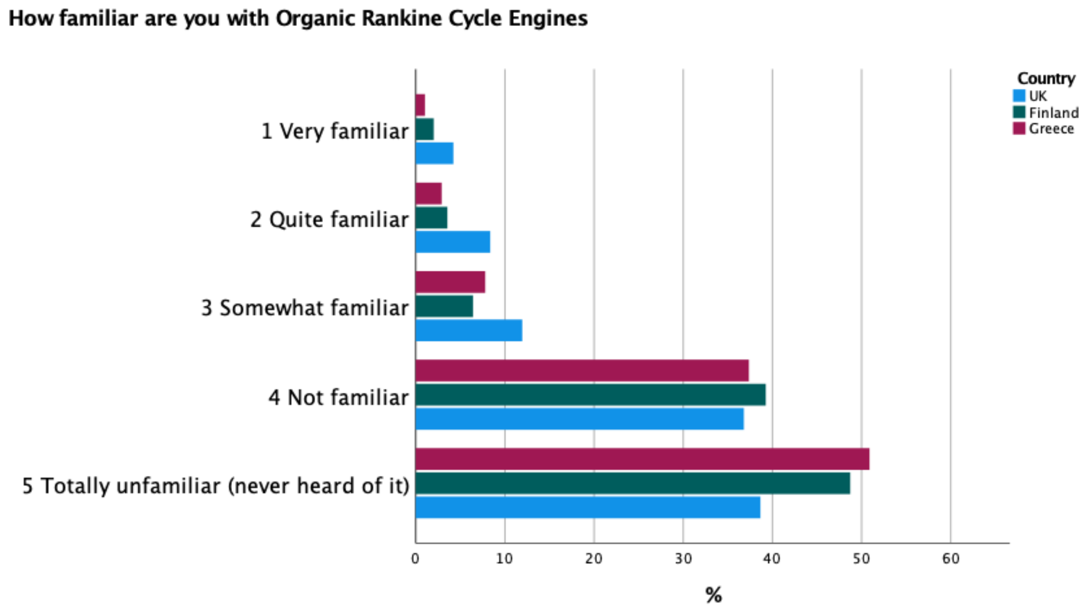
Familiarity with biomass was generally low with some variability between the three countries: with 19.1% of UK respondents "very familiar" or "quite familiar" with the technology, compared to only 10% in Greece and 9.3% in Finland. However, 58.3% of UK respondents, 73.9% of those in Greece and 76.8% of those in Finland were "not familiar" or had "never heard" of the technology. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(8df) = 123.863$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **weak relationship of 0.133 between biomass familiarity and the country**.



Familiarity with thermo electric generators was generally low with limited variability between the three countries: with 17.9% of UK respondents “very familiar” or “quite familiar” with the technology, compared to only 9.9% in Greece and 10.3% in Finland. However, 64.5% of UK respondents, 71.6% of Greek respondents and 68.7% of Finnish ones were “not familiar” or had “never heard” of the technology. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(8df) = 59.196$, $p < .001$. The effect size for this finding, using the Cramer’s V, was a **weak to no relationship of 0.092 between thermo electric generators familiarity and the country.**



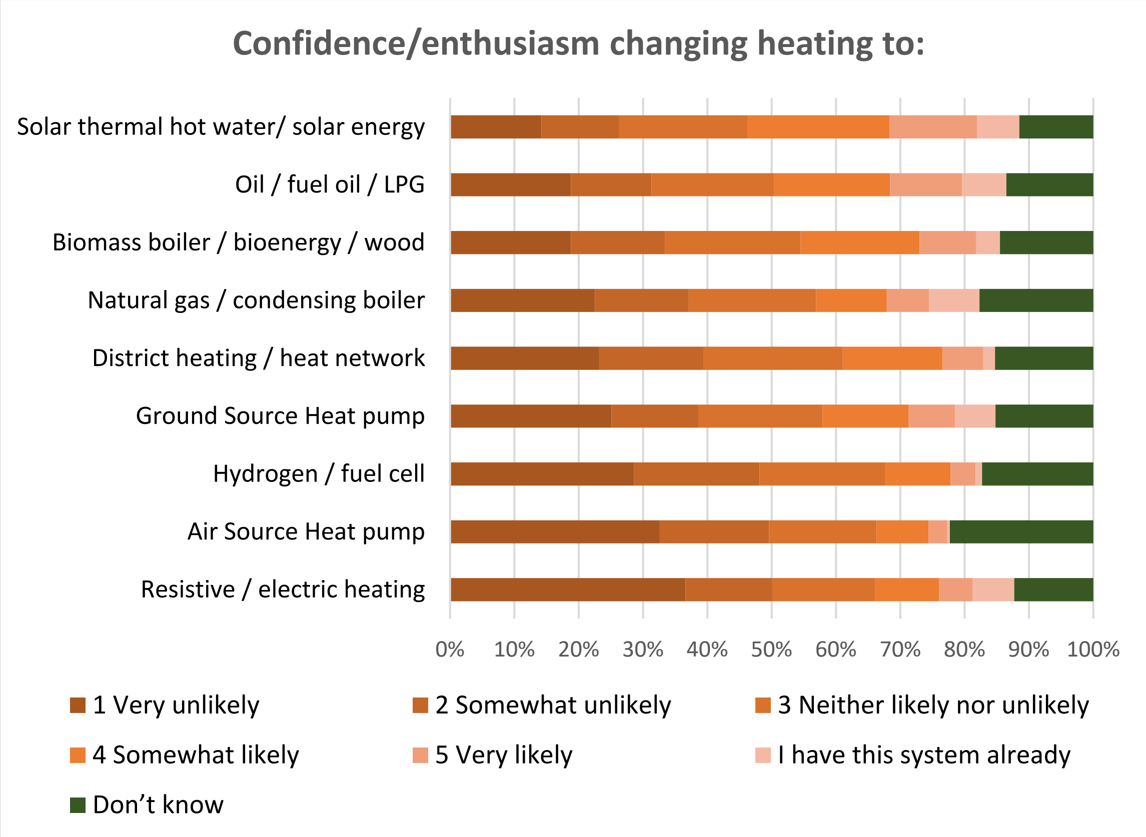
Familiarity with adsorption chillers was generally low with limited variability between the three countries. 72.3% of UK respondents, 81% of those in Greece and 85.4% of those in Finland were “not familiar” or had “never heard” of the technology. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(8df) = 78.469$, p < .001. The effect size for this finding, using the Cramer's V, was a **weak relationship of 0.106 between adsorption chillers familiarity and the country.**



Familiarity with organic Rankine cycle engines was very low with limited variability between the three countries. 75.5% of UK respondents, 88.3% of those in Greece and 88% in Finland were "not familiar" or had "never heard" of the technology. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(8df) = 111.992$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **weak relationship of 0.127 between organic Rankine cycle engines familiarity and the country.**

4.4 Confidence/enthusiasm in changing to renewable heating system

Respondents were subsequently asked to state their confidence or enthusiasm for changing their heating system to a range of alternatives, shown in the figure below. Solar thermal hot water / solar energy was viewed as the most popular with 35.7% of people either "somewhat" or "very" likely to adopt these systems, while resistive/ electric heating was the least popular with 50.1% "somewhat" or "very" unlikely to adopt these systems. ASHP's were also not a popular choice with 49.6% "somewhat" or "very" unlikely to adopt these systems.



Common concerns expressed by interviewees were a lack of knowledge about renewable HVAC systems and their cost:

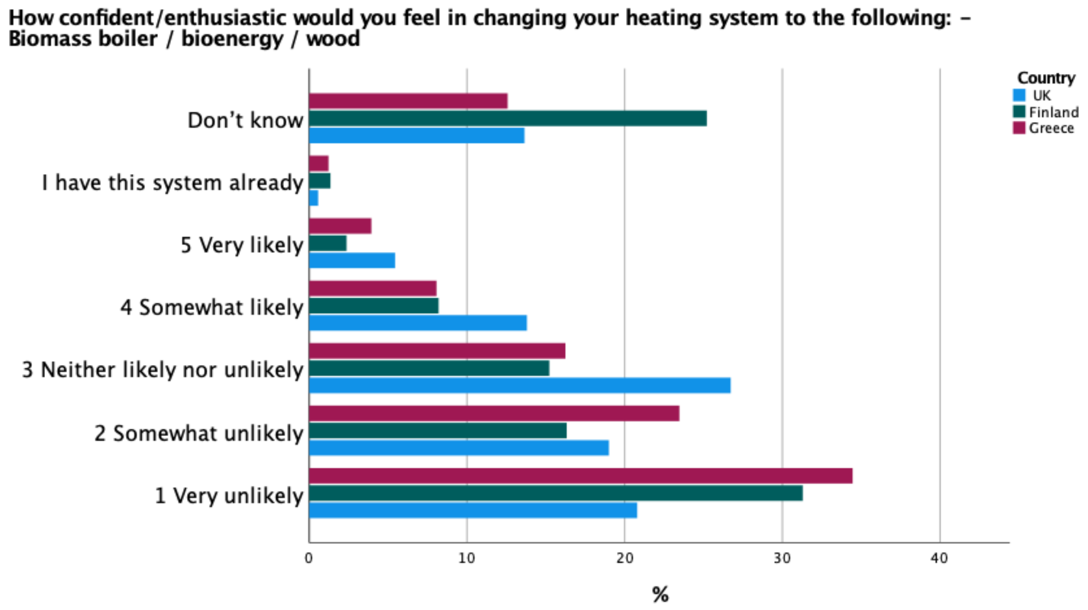
> *"What can I say for something that I don't know? I can't answer for something that I don't know how it will function. Which is the needed situation, which is the cost."* Greek household user (GU1H1)

Others expressed concern about the suitability of certain buildings for conversion to renewable systems:

> *"I think there would be challenges. In terms of age, this was built in the 1970s, so I don't know if that kind of system would fit. Putting modern technology in old systems can be difficult." Finnish office user* (FOU1)

In the following sections these responses are broken down by country, education level, income, and age, with a focus on the three core technologies of the SolBio-Rev system: solar thermal hot water / solar energy, biomass boiler/ bioenergy/ wood and ASHP.

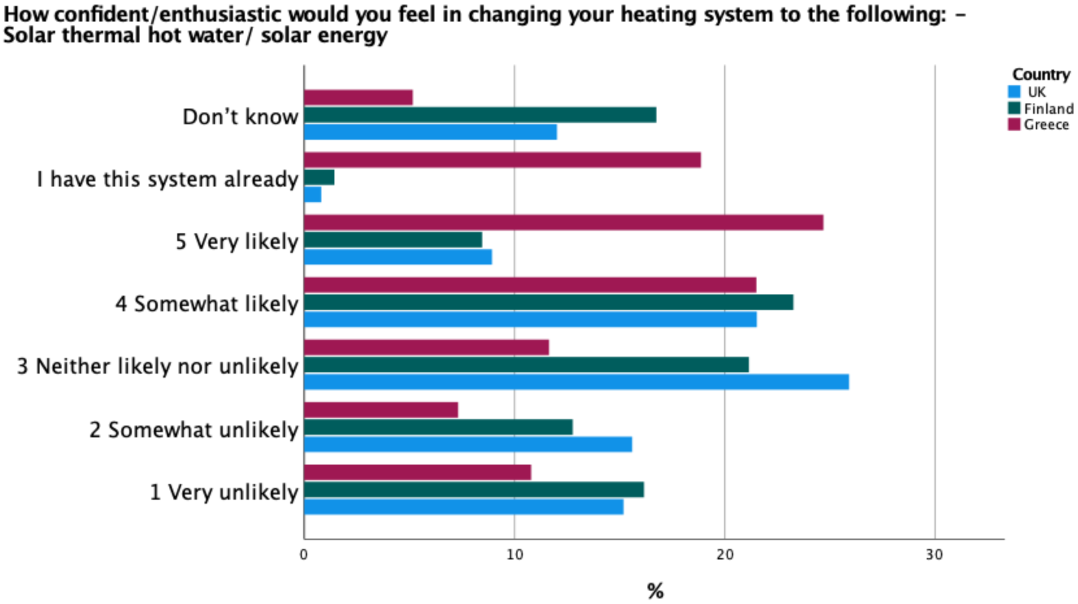
4.4.1 Country



Willingness to adopt biomass was generally low with some variability between the three countries. Respondents in Greece were the least enthusiastic about these systems with 58% either "unlikely" or "very unlikely" to adopt them compared to only 12% who were "somewhat" or "very likely". UK participants were the most enthusiastic about these systems with 19.2% who were "somewhat" or "very likely" to adopt them and 39.8% either "unlikely" or "very unlikely" to adopt them. An average of 17.3% of responses "don't know". Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(12df) = 216.376$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **weak relationship of 0.176 between the willingness to adopt biomass and the country.**

Several respondents viewed biomass negatively due to a desire to move away from combustion methods for heat:

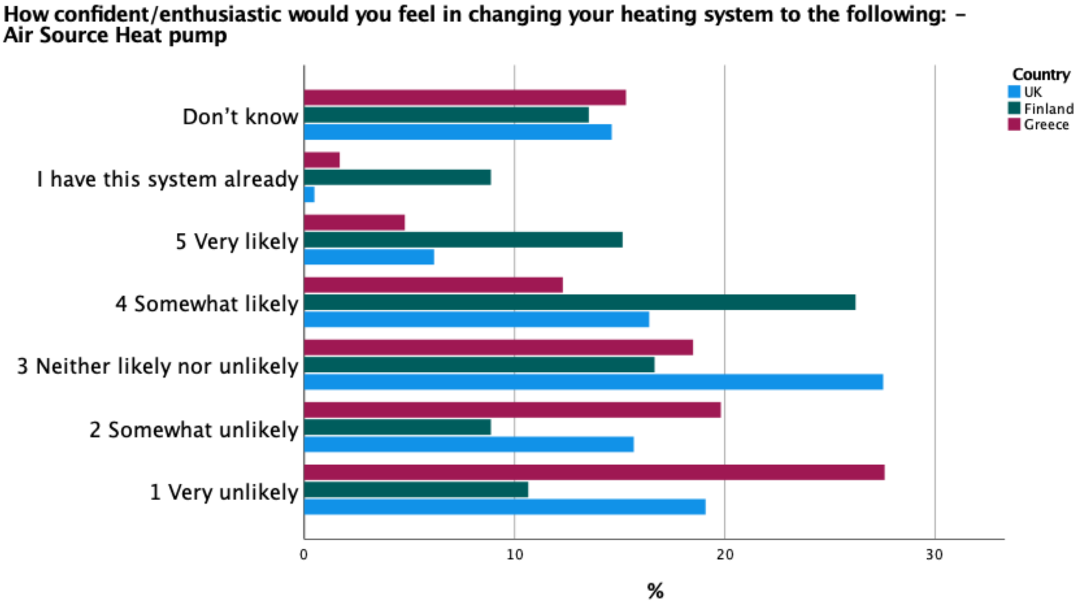
> "*We are not looking for fuel-burning technologies, such as biomass. So, it's not relevant for us*" - Finnish building designer (FD1)



Willingness to adopt solar thermal hot water / solar energy was generally high with significant variability between the three countries. Respondents in Greece were the most enthusiastic about these systems with 46.2% who were "somewhat" or "very likely" to adopt them compared to only 18.1% who were either "unlikely" or "very unlikely". UK and Finnish participants were less enthusiastic about these systems with 30.8% and 29% either "unlikely" or "very unlikely" to adopt them respectively. An average of 11.5% of responses were "don't know". Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(12df) = 666.822$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **moderate relationship of 0.310 between the willingness to adopt solar thermal and the country.**

Solar thermal was also viewed favourably by the Greek interviewees, many of whom were familiar with these systems and hoped they could be a template for other renewables:

> *"Something easy. I think as easy a solar water heater, who provides hot water. Especially in Greece that 10 months of the year, and I don't think that is an exaggeration, because even with a little bit of sun, you have water, and you save on the electricity. If this case was to correspond for the heating and the cooling, in a system that is more economic than the one that already exists with electricity and oil and with the lowest installation cost, I would be a fan of this change."* - Greek household user (GU1H1)

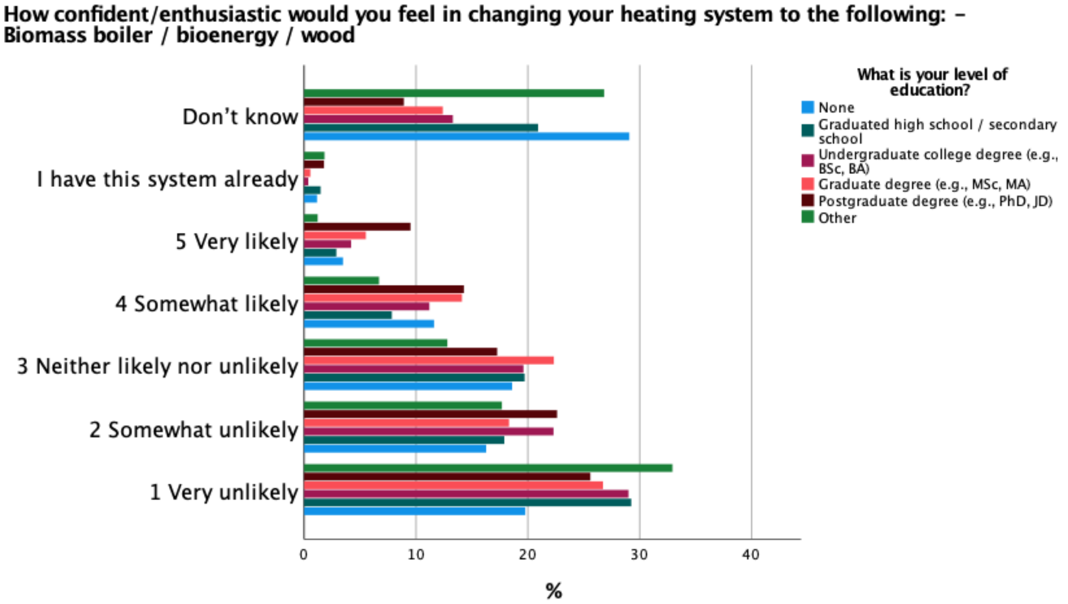


Willingness to adopt ASHP was relatively low with significant variability between the three countries. Finnish respondents were the most enthusiastic about these systems with 41.3% who were "somewhat" or "very likely" to adopt them compared to only 19.6% who were either "unlikely" or "very unlikely". UK and Greek participants were less enthusiastic about these systems with 34.8% and 47.4% either "unlikely" or "very unlikely" to adopt them respectively. An average of 14.5% of responses were "don't know". Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi 2(12df) = 450.417$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **weak relationship of 0.254 between the willingness to adopt ASHP and the country.**

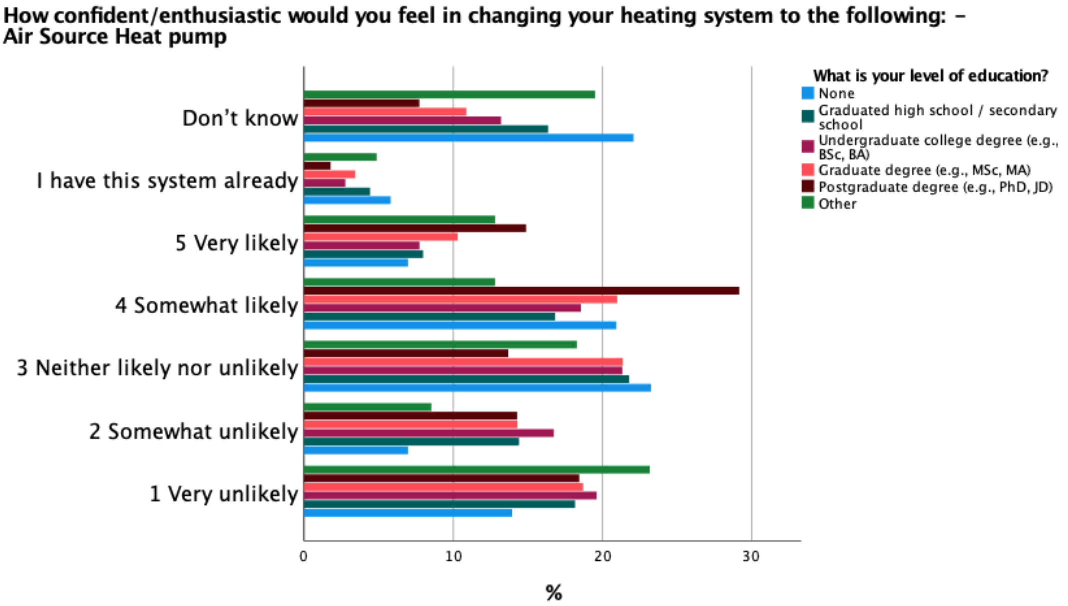
A key issue for heat pumps raised by the more technically minded respondents, was the low flow temperatures of heat pumps being an issue for less well insulated buildings:

> *"the problem we have on that site is they [ASHPs] only heat to 53 degrees. Now that they've obviously looked at removing insulation from a lot of buildings… we now don't meet the current demand of the U-values. So, obviously it doesn't just come as put a heat pump in and it works, you've then got to look at your double glazing, your insulation, so that you don't need to heat the rooms to as hot as what you normally would to combat, sort of, draughts and outside air temperature." UK Building manager* (UMH2)

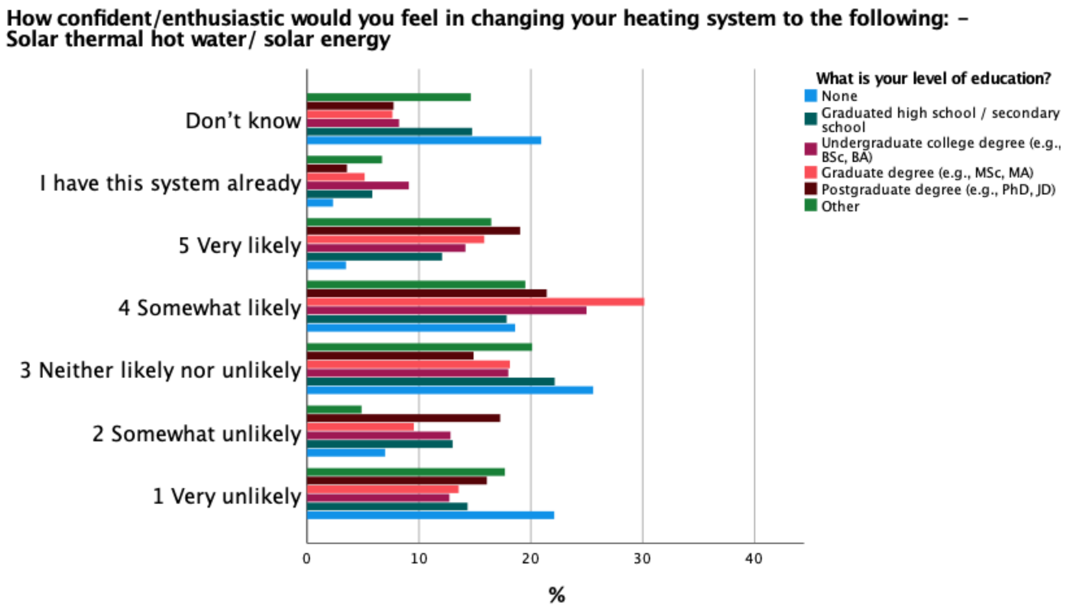
4.4.2 Education level



Education level was not shown to be a strong predictor of the willingness to adopt biomass systems. However, there was an observable trend in those who were "very likely" to adopt these systems with 9.5% of postgraduate degree educated respondents "very likely" compared to only 3.5% of those with no education and 2.9% of those who have only graduated high school. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi 2(30df) = 126.339$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **weak to no relationship of 0.085 between the willingness to adopt biomass and education level.**

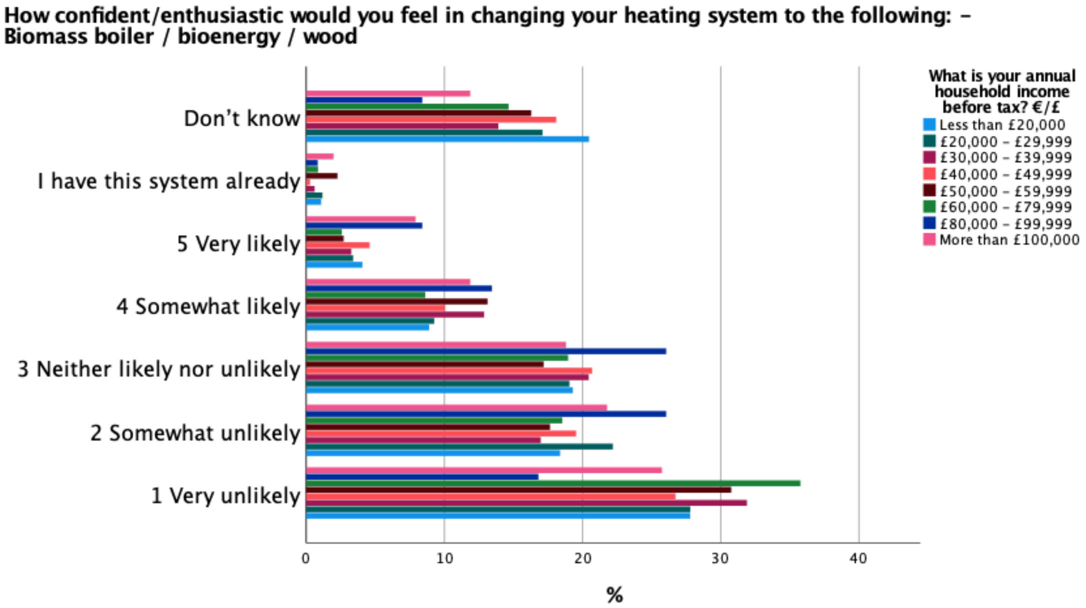


Education level was not shown to be a strong predictor of the willingness to adopt ASHP systems. However, there was an observable trend in those who were "very likely" to adopt these systems with 14.9% of postgraduate degree educated respondents "very likely" compared to only 7% of those with no education and 8% of those who have only graduated high school. Using a Chi Square test, these between country differences were shown to be statistically significant, χ2(30df) = 80.626, p < .001. The effect size for this finding, using the Cramer's V, was a **weak to no relationship of 0.068 between the willingness to adopt ASHP and education level.**

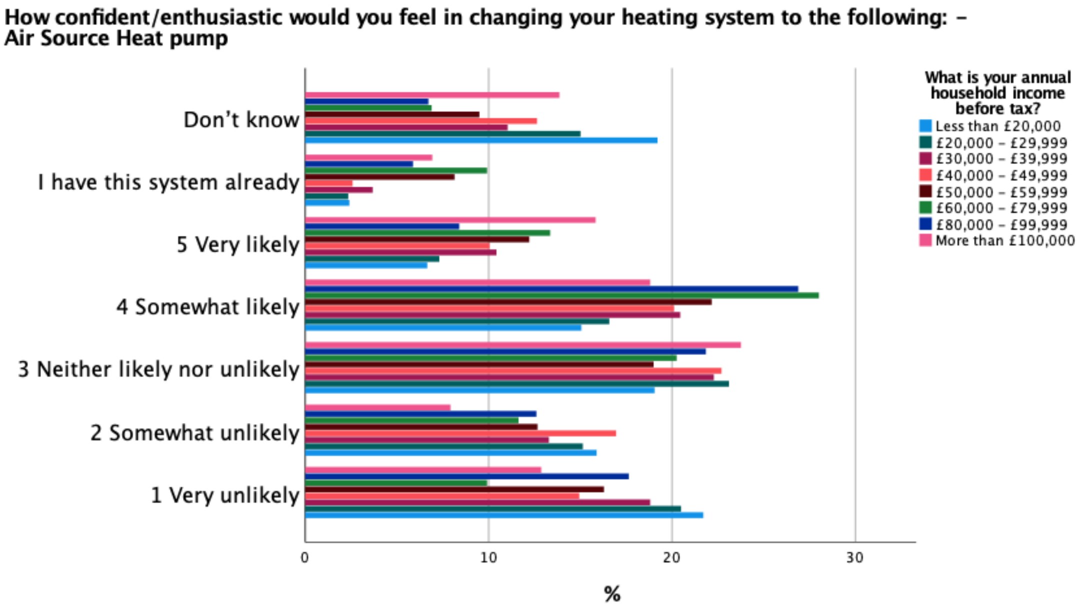


Education level was not shown to be a strong predictor of the willingness to adopt solar thermal systems. However, there was a notable trend in those who were "very likely" to adopt these systems with 19% of postgraduate degree educated respondents "very likely" compared to only 3.5% of those with no education and 12.1% of those who have only graduated high school. Using a Chi Square test, these between country differences were shown to be statistically significant, χ2(30df) = 140.590, p < .001. The effect size for this finding, using the Cramer's V, was a **weak to no relationship of 0.090 between the willingness to adopt solar thermal and education level.**

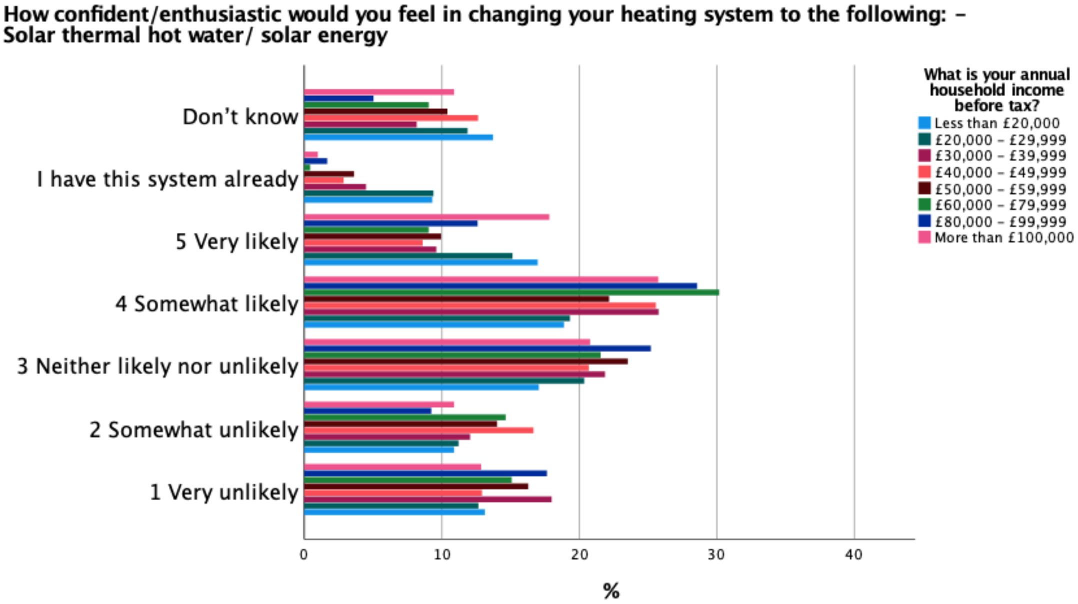
4.4.3 Income



Income level was not shown to be a strong predictor of the willingness to adopt biomass systems. However, there was a small trend in those who were "very likely" to adopt these systems with 7.9% of >£100,000/year and 8.4% of £80,000-£99,000/year households "very likely" compared an average of only 3.9%. Using a Chi Square test, these between country differences were shown to be statistically significant, χ2(42df) = 75.176, p 0.001. The effect size for this finding, using the Cramer's V, was a **weak to no relationship of 0.06 between the willingness to adopt biomass and income level.**

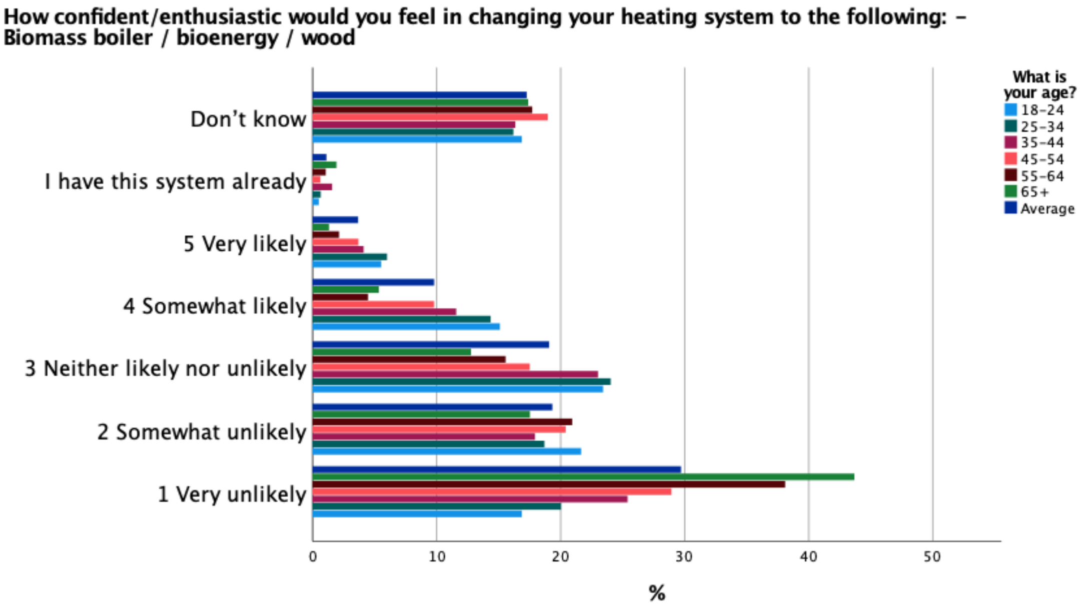


Income level was not shown to be a strong predictor of the willingness to adopt ASHP systems. However, there was a small trend in those who were "very likely" to adopt these systems with 15.8% of >£100,000/year households "very likely" compared an average of only 8.8%. Using a Chi Square test, these between country differences were shown to be statistically significant, χ2(42df) = 180.941, p <.001. The effect size for this finding, using the Cramer's V, was a **weak to no relationship of 0.093 between the willingness to adopt ASHP and income level.**

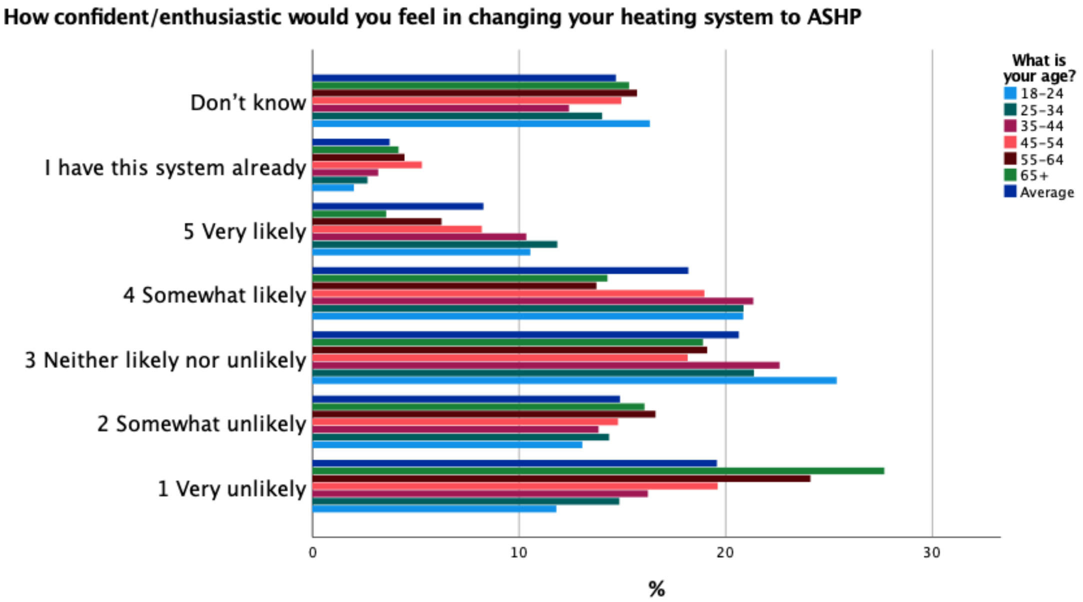


Income level was not shown to be a strong predictor of the willingness to adopt solar thermal systems, with no observable trends. Using a Chi Square test, these between country differences were shown to be statistically significant, χ2(42df) = 158.407, p <.001. The effect size for this finding, using the Cramer's V, was a **weak to no relationship of 0.087 between the willingness to adopt solar thermal and income level.**

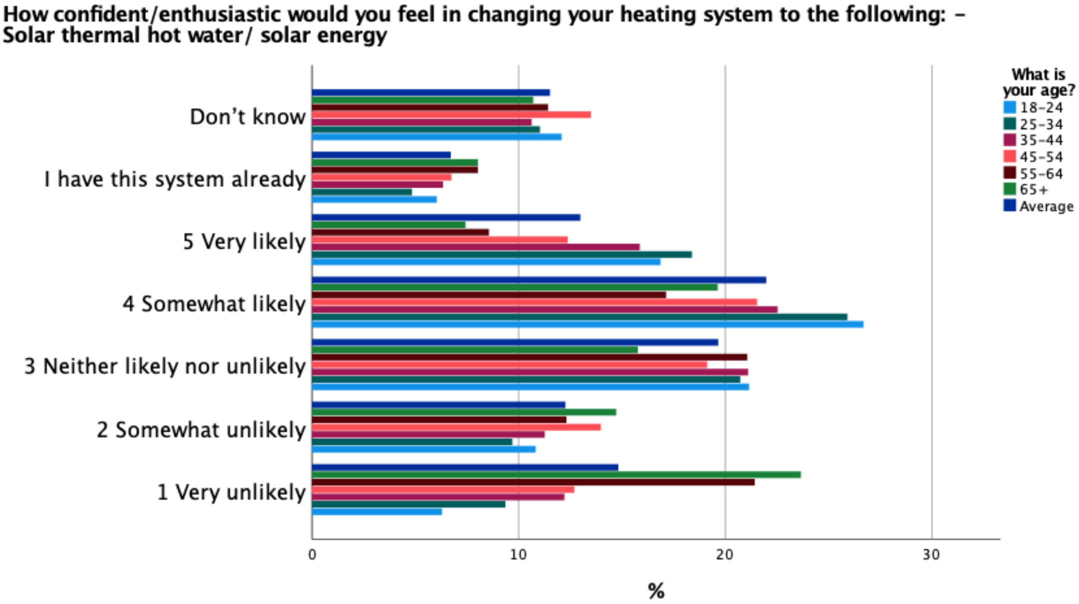
4.4.4 Age



Age was shown to be a mild predictor of the willingness to adopt biomass systems. While 34.8% of 18-24s and 38.4% of 25-34s we either “very likely” or “somewhat likely” to adopt these systems, compared to only 17.6% of over 65s. 43.7% of over 65s were “very unlikely” to adopt these systems. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(30df) = 235.022$, $p < .001$. The effect size for this finding, using the Cramer’s V, was a **weak relationship of 0.116 between the willingness to adopt biomass and age.**



Age was shown to be a weak predictor of the willingness to adopt ASHP systems. While 27.7% of 18-24s and 43.8% of 25-34s we either very likely or somewhat likely to adopt these systems, compared to only 23.5% of over 65s. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(30df) = 132.849$, $p < .001$. The effect size for this finding, using the Cramer’s V, was a **weak to no relationship of 0.087 between the willingness to adopt ASHP and age.**

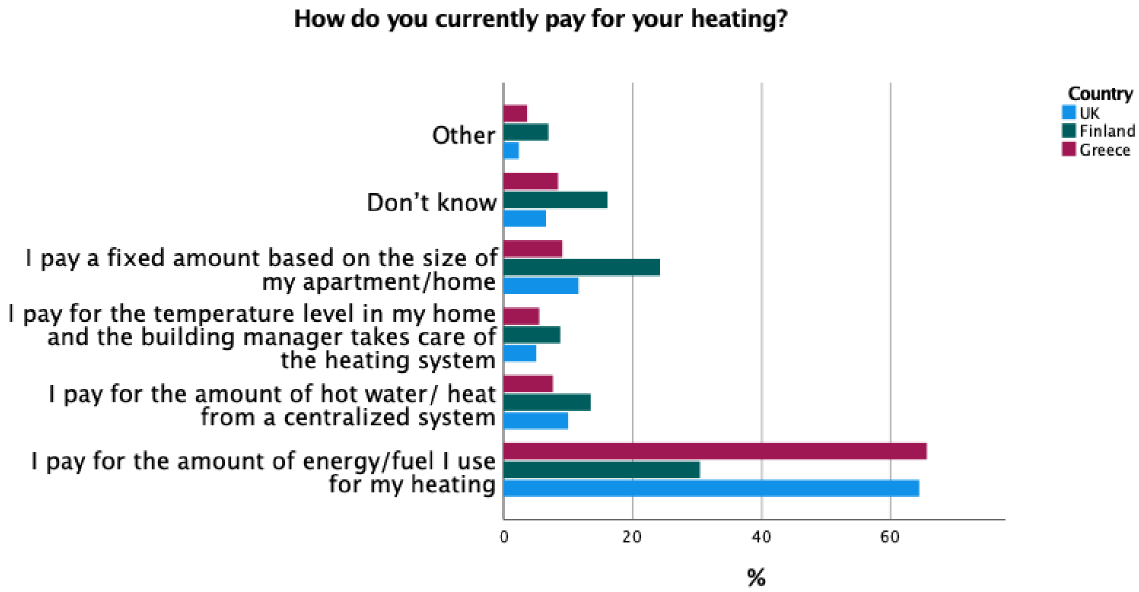


Age was shown to be a moderate predictor of the willingness to adopt solar thermal systems. While 44.6% of 25-34s we either very likely or somewhat likely to adopt these systems, only 28.4% of over 65s were. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(30df) = 177.088$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **weak relationship of 0.101 between the willingness to adopt solar thermal and age.**

4.5 Business & finance models

Following investigation of user preferences for the core technologies of SolBio-Rev we then examined the existing business models by which users current receive their energy services, before investigating their preferences for alternatives. Finally, we explored how users would prefer to pay for a replacement HVAC system and who they felt should have responsibility for making this change.

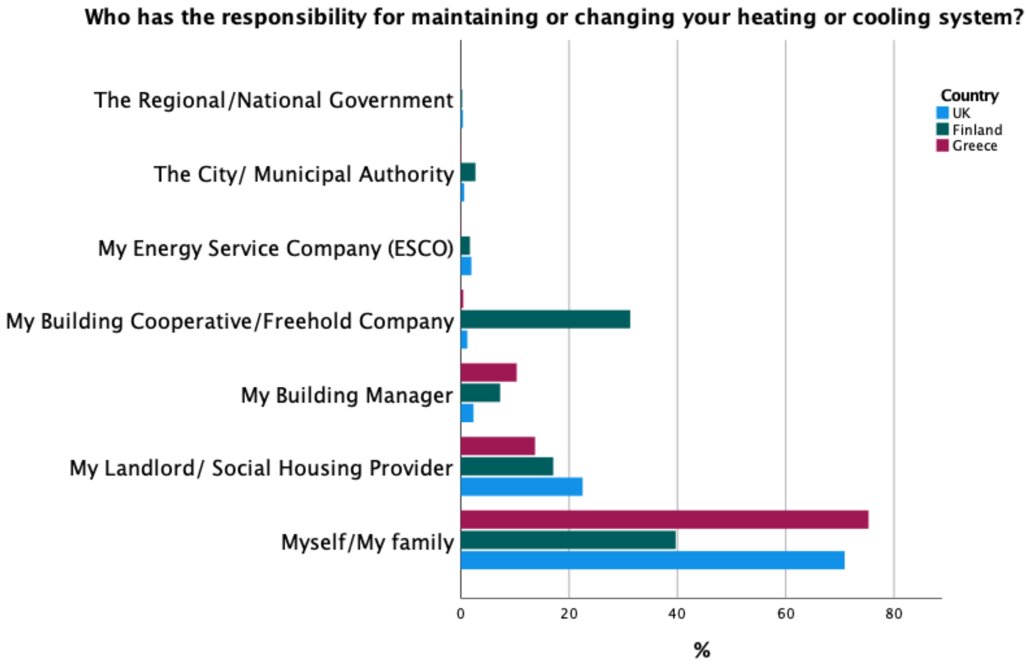
4.5.1 Existing business model by country



In general, the largest share of responses were users that "pay for the amount of energy/fuel I use for my heating", however there was significant between country variation with 64.4% of UK and 65.6% of Greek respondents providing this answer, compared to only 30.5% in Finland. Instead, 24.2% of Finnish respondents indicated that they "pay a fixed amount based on the size of my apartment/home". Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(10df) = 397.868$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **weak relationship of 0.239 between the current heat business model and country.**

Despite being less common in the survey, most of the multifamily residents we interviewed pay a fixed amount for heating, bundled into a service charge and a variable cost for metered electricity:

> *"The heating when it starts from the apartment building is inside the shared bills that we pay each month, which include more things like cleaning etc. And it depends on much time the winter lasts, it's all inside the shared bills, according to the heating part. Regarding to the cooling part, I have PPC, and its bill comes every two-months."*- Greek household user (GU1H1)

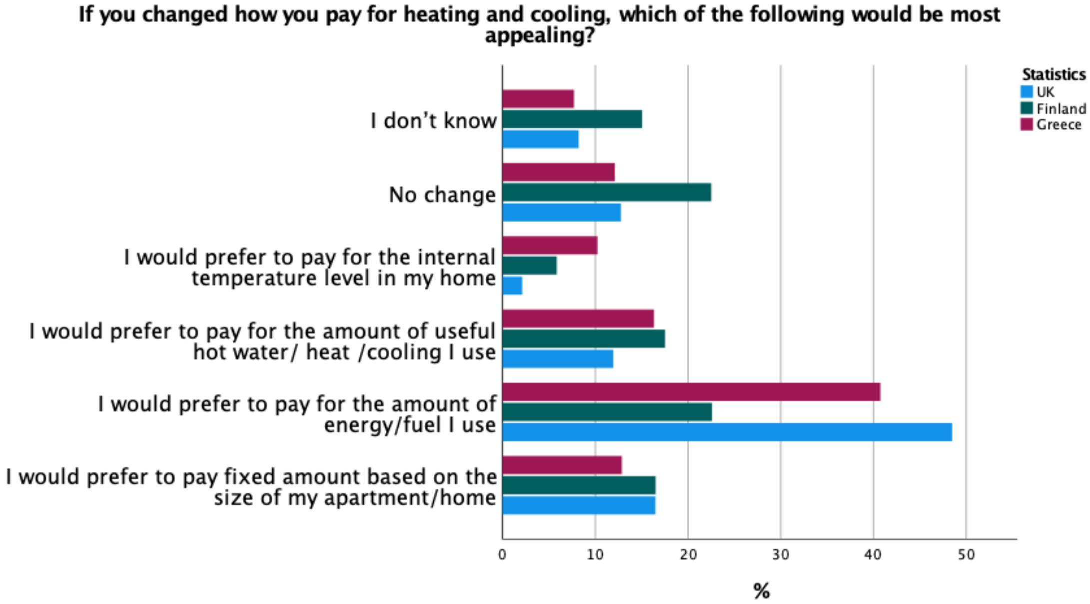


In general, the largest share of responses stated that "myself/my family" is/are responsible for maintaining or changing the HVAC system. However, there was significant between country variation with 70.9% of UK and 75.3% of Greek respondents providing this answer, compared to only 39.7% of those in Finland. Instead, 31.3% of Finnish respondents indicated that it was their "Building cooperative/ freehold company" that had this responsibility. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi 2(10df) = 928.411$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **moderate relationship of 0.365 between who has responsibility for the HVAC system and country.**

Again, most of the households we spoke to were from multifamily buildings where maintenance for a centralised heating system was delegated to a building manager or company:

> *"If it's a major outage, let's say one of the boilers was to fail, touch wood it doesn't, then we get a call from the out-of-hours team if it's out of hours. If it's in hours, it comes through as a normal work request. We go over, we look at it. Because we are actually hiring the boilers on behalf of the council, we call in the hire company if it's actually a fault with the boiler itself... So, they'll be on site within four hours to investigate and try and remedy a repair. If parts are needed, they get the parts to site, and it gets repaired."* UK building manager (UMH2)

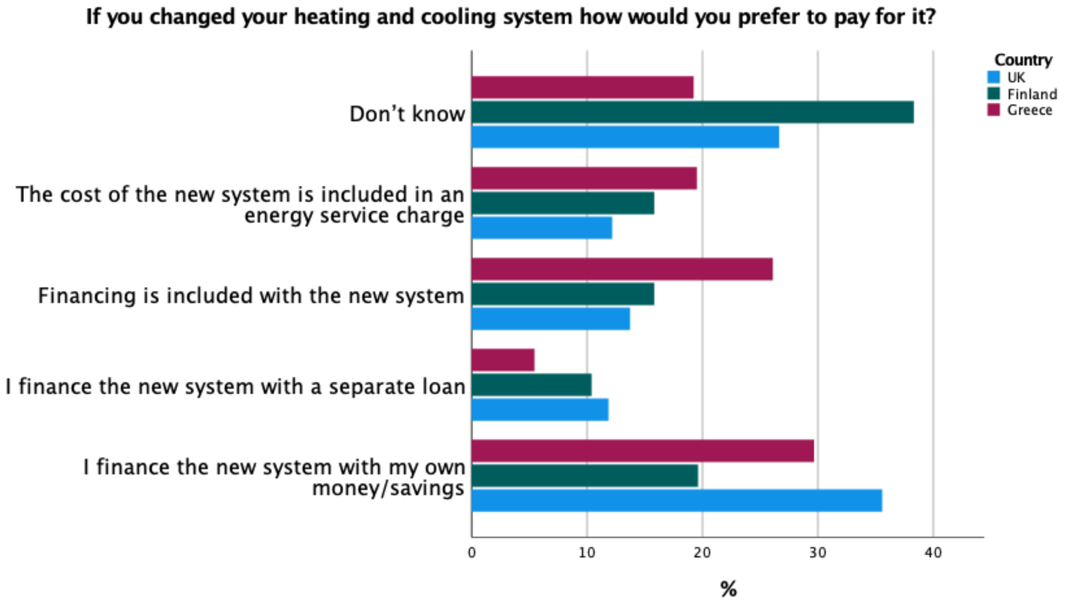
4.5.2 Views on new business and finance models by country



In general, the largest share of responses were users that would prefer to "pay for the amount of energy/fuel I use for my heating", however there was some between country variation with 48.5% of UK and 40.8% of Greek respondents providing this answer, with 12.8% and 12.1% stating "no change" respectively. 17.5% of those in Finland indicated that they would prefer to "pay for the amount of useful hot water / heat/ colling I use", with 22.5% requesting no change. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(10df) = 285.241$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **weak relationship of 0.203 between the preferred HVAC business model and country.**

Indeed the desire to pay based on volumetric usage was mostly shared by the interviewees, especially those in Greece and the UK, using the analogy of a mobile phone contract:

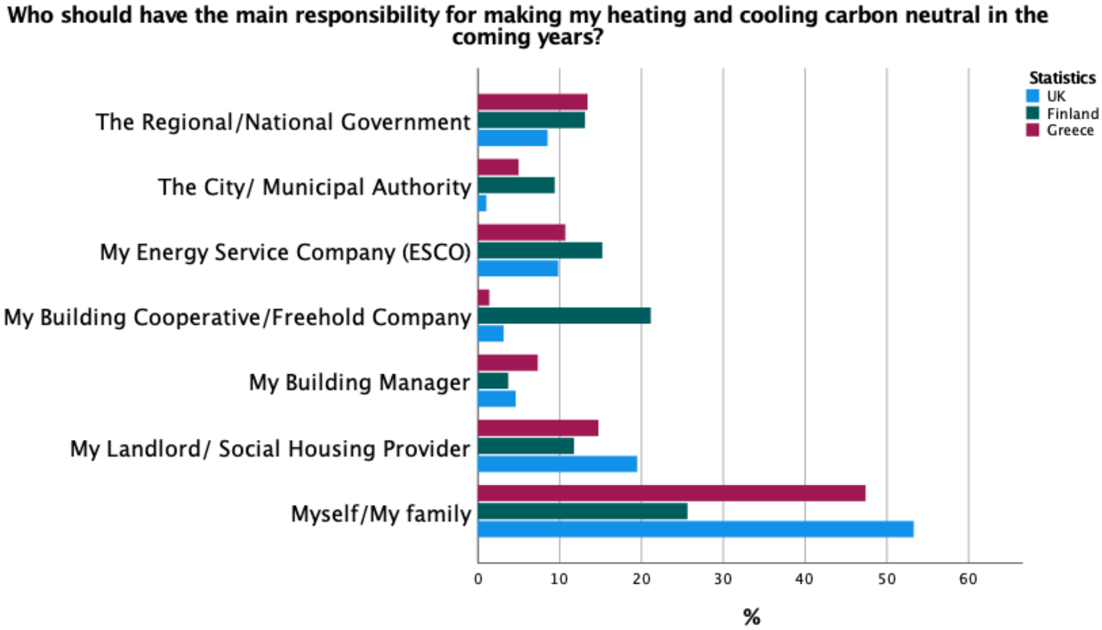
> *"I haven't got one of them [fixed term phone contract], I pay as you go on my phone. I put a fiver on every now and again and that suits me. Actually, no, I don't like the idea of [an energy service charge] I don't want to do that, I'm a curmudgeonly old git, basically, and I like to just pay for what I've used after I've used it. If I had my own way, I'd still be paying quarterly by cheque, basically."* - UK household user (UU1H1)



A range of preferences were expressed for the financing of a new HVAC system. A large number of responders "don't know" how they would pay for a new HVAC system, however there was some between country variation with 38.3% in Finland, 26.6% in the UK and 19.2% in Greece providing this answer. 26.1% of Greek respondents indicated that they would prefer a bundled offering where "financing is included with the new system" compared to only 13.7% of UK respondents and 15.8% in Finland. 35% of UK respondents, 19.6% of those in Finland and 29.7% in Greece stated they would prefer to "finance the new system with their own money/ savings". Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi 2(8df) = 229.199$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **weak relationship of 0.182 between the preferred HVAC finance model and country.**

A Finnish respondent also emphasised the importance of government subsidies and programmes in improving the economics of low carbon options.

"So, they look at the cost of heating currently and what it would cost in the future with a heat pump system. That's the trigger. Then of course what has accelerated it is that the Housing Finance and Development Centre of Finland ARA grants energy subsidies and that has also accelerated the market, so such subsidies make such investments even smarter and more profitable. "- Finnish building designer (FD1)



In general, the largest share of respondents stated that "myself/my family" should have responsibility for making their HVAC system carbon neutral in the coming years. However, there was significant between country variation with 53.3% of UK and 47.4% of Greek respondents providing this answer, compared to only 25.6% in Finland. Instead, 21.2% of Finnish respondents indicated that it should be their "Building cooperative/ freehold company" with 15.2% arguing it should be an ESCO which should have this responsibility. Using a Chi Square test, these between country differences were shown to be statistically significant, $\chi2(12df) = 590.818$, $p < .001$. The effect size for this finding, using the Cramer's V, was a **weak relationship of 0.291 between who should have responsibility for making their HVAC system carbon neutral and the country.**

While ESCOs and cooperative management models were considered to be an obvious route by many of the Finnish interviewees, they were seen as much less well established by the expert respondents in Greece:

"There are a few ESCOs in Greece, but I think we have problems in terms of financing and also…the way the ownership... in Greece is fragmented …, so, it's the same thing with the facilities management scenario. It's very difficult to make decision at a local level if you… have 10 different property owners in a block [to agree] to make this particular building block more efficient. To get funding is difficult and even if you get the funding… It's not straight forward process... and there is a lot of confusion. So, when there is confusion a lot of people, they don't touch it at all. So, from my experience I haven't seen...I have seen couple of ESCOs present but with no great reach in term of results." - Greek building designer (GD1)

5 Discussion

Our survey and interview data highlight significant differences in heating and cooling practices and preferences across the three studied countries, ranging from the type of systems to how people pay for their energy consumption [7]. While participants in the UK have a rather individualistic approach; having individual gas boilers and preferring to finance new heating system changes on their own [25], Finland has a much more communal approach in both system provision and payment options [39]. Greece falls somewhere in between the two.

In terms of relevance to the SolBio-Rev system, people's knowledge and preferences vary too. Solar thermal is well known in Greece, and heat pumps in Finland, with less knowledge of both in the UK. A move away from combustion and burning materials in heating makes biomass less desirable in Finland, where people in our interviews said they prefer heating options that are the least amount of hassle in terms of fuel storage and heating supply. Even in a Nordic location like Finland, heat pumps are becoming more and more popular and increasingly being installed as they also offer options for cooling. In the UK, meanwhile, cooling is less discussed and air conditioning is not as common as is the case in Greece. These findings are also supported by previous studies, highlight the importance of pre-existing experience and engagement – especially at the community level – for the adoption of renewable energy systems [40] and energy efficient practices [41].

In all three countries, control of heating and cooling systems varies too, particularly in the type of heating and cooling system that people have, and who has the most responsibility for its operation. In general, the UK and Finland tend to have more sophisticated controls, whereas simple "on-off" controls predominate in Greece. Our research suggests people tend to have the greatest satisfaction with greater levels of control, particularly smart controls. Indeed, as found by Sovacool et al., [42] this increased control from smart systems is enables different set temperatures between rooms or times of day to enable alternative preferences between household members or for practices such as clothes drying.

For a system like SolBio-Rev, our findings raise questions surrounding which cultural and geographical locations would suit the system best, and what policy support would be needed. We will explore the issue of policy in Task 6.3, but issues such as affordability, installation and supply chain development also need to be considered. Our findings for example confirm other research in that energy poverty is the highest in Greece, and is a continuing issue in the UK [43]. In Finland, while not recognised in official policy as such (yet), there is evidence too that for some parts of the population, affordability of energy is an issue. This leaves questions as to who will want, and who can afford, renewable energy systems such as SolBio-Rev – emphasising the importance of business models which enable their up-front cost to be deferred over time [44]. This also links to the desire to mitigate climate change, as our survey showed that in general people in Greece expressed greater willingness to pay for carbon free energy (also observed by Ntanos et al., [45]), compared to those in the UK and in Finland. This is an important factor as many in Greece still rely on oil as a heating fuel, and tended to find energy comparatively expensive. In addition, issues like building design and infrastructure need consideration. Most respondents in all countries said that their homes were moderately or averagely energy efficient. However, Eurostat [10] [11] degree days statistics indicate that households in Finland have a much lower relative energy demand than the UK, with Greece

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[10] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20190620-1;

[11] https://ec.europa.eu/eurostat/web/products-datasets/product?code=nrg_chdd_a

closer to the average, suggesting that the concept of "energy efficiency" is subjective between countries.

While there was only a minor observable trend, there was some evidence that wealthier and more educated people were keener to adopt the key technologies of SolBio-Rev. This was especially the case for the small number of people who said they were "very likely" to adopt biomass, solar thermal and heat pump systems. This suggests that postgraduate educated households who earn >€80,000/year may be important early adopters of these systems. Age was also shown to be a factor in willingness to adopt these systems. Younger respondents were more likely to be "very likely" to adopt these systems and less likely to be "very unlikely" to adopt them. Interestingly it was the 25-34 age group not the 18+ who were most positive and least negative and the 65+ age group who were the most negative and least positive. These demographic features are also consistent with literature on the early adopters of 'sustainable small-scale energy solutions' [46]

A key means of overcoming these issues of energy system affordability are energy service business models which can bundle up the high capital cost of systems such as SolBio-Rev into long term service plans, where the savings from lower operational costs can contribute to system financing [47]. However, most of our respondents currently paid for volumetric usage of primary energy and had personal responsibility for system maintenance and replacement. When asked if they would prefer to pay for the useful heat or cooling services, the majority for respondents in all three countries indicated that they would prefer to keep a similar arrangement with very few respondents electing to pay for useful energy or final energy/comfort services. Further, a large share of respondents indicated they would prefer to use their own money to fund a new system, although Greek respondents were more likely to prefer inclusive finance or a bundled service charge.

These preferences for the *status quo* were therefore reflected in the fact that most respondents saw the transition to low carbon HVAC systems as the responsibility of their own household, or in the Finnish case their building cooperative. This reticence of the majority towards new energy business models was also found in a UK wide survey by Hall et al., [48] who argue "already affluent, educated and engaged consumers will capture the benefits of low carbon business model innovation and exacerbate existing socio-economic inequalities".

6 Conclusion

This deliverable reported the findings from WP6 Task 6.1 based on a literature review and data from interviews with various groups (households, building managers and building designers) and a survey of households in Greece, Finland and the UK. Our background research identified potential for significant variability in household energy demand, behaviour and social practices between different households, beyond the building's physical characteristics:

- Variations from modelled to actual energy performance - the 'energy performance gap'- can be as much as 300%
- Studies have identified around one third of energy demand variability within identical homes is attributable to the household makeup (single person, couple, single parent), with round two thirds of this variability is due to variance in occupant behaviour
- Modelling this variability is extremely difficult and results from a multitude of overlapping factors relating to material, social economic and cultural dimensions

There are also likely to be significant differences in the energy demand profiles of the three countries in this study above and beyond that which can be explained by climate alone:

- Greece's household energy demand is only 66% of the EU average, while the UK's is 104% of the EU average, despite having highly similar (56% and 55%) share of degree days (i.e., equivalent heating/cooling needs). Equally, while Finland's degree days are 318% of the EU average, household energy demand is only 187% of this average – suggesting Finnish homes/households are more efficient than the UK.
- Finland has a higher share of single-family households who tend to use significantly less energy than larger family units. Greece has the highest share of co-habiting adults and due to a much higher share of households with three or more adults (20% of households), suggesting a trend for multiple family generations to co-habit. The UK has a higher share of single parent households (10%) than Finland (7%) and Greece (1%) are more likely to be at risk of energy poverty than co-habiting couples and therefore may underutilize heating or cooling

Our survey and interviews subsequently showed considerable variation in heating and cooling systems, practices and user preferences between countries:

- The dominant heating regime varied by country with natural gas boilers dominant in the UK, district heating/ heat networks in Finland and oil/ fuel oil/ LPG in Greece
- Opening windows was the dominant cooling regime, although a large share of Greek households also had air conditioning - uncommon in both the UK and Finland
- Users had higher satisfaction with more advanced heating controls i.e., smart thermostat and controls (smartphone app) and or multiple room thermostats/ thermostatic radiator valves and programmers
- Natural gas boilers were viewed as the most reliable systems, while heat pumps and solar thermal systems were said to have a much lower reliability. However, users of heat pumps also had the highest share of constant winter thermal comfort – a somewhat contradictory finding
- The UK had the lowest energy bills of the three countries, even though the UK has higher household energy demand and electricity prices than Greece. Finland and Greece had similar mean energy bills despite Finland's much higher degree days
- Greek households were most likely to identify as being in energy poverty and were also most likely to have lower thermal comfort in both winter and summer. When

considering that Greeks have higher energy costs than the UK but <1/3 of the UK and Finland's mean income, we can infer that much of these issues arise from a high ratio of energy costs to income in Greece
- Greek households also expressed the highest concern for the climate impact of their HVAC systems and the highest willingness to pay for low carbon energy – despite their lower incomes and higher relative energy costs

Our survey and interviews also found differences in knowledge and willingness to adopt the key renewable energy systems contained within SolBio-Rev as well as the acceptance of different business and financing models. These differences were observed between the three countries as well as by other demographic factors including, age, income and education:

- Prospective users ranked "lower running costs" as the most important feature of a new HVAC system with "control over temperature" ranked second. By contrast respondents viewed "low disruption during the install" as the least important factor, with "reduced CO_2 emissions/ climate change impact" ranked second lowest. These findings may have important implications for SolBio-Rev is marketed.
- Familiarity with solar thermal systems was highest in Greece, while familiarity with ASHP was highest in Finland. Familiarity with biomass heating was much lower, and familiarity with the other SolBio-Rev technologies was very low across all countries.
- Generally, willingness to adopt these systems correlated with pre-existing knowledge in the national context, suggesting that the social acceptance can be improved through information campaigns and advocacy from early adopters
- Solar thermal was the most popular of the core SolBio- Rev technologies, with ASHP in the middle and biomass the least popular. Data from the interviews suggest that many participants were concerned over the impact of biomass systems on air pollution, the sustainability of the feedstock and the storage requirements of pellets
- Higher educated, higher income and younger (specifically 25-24) respondents were more likely to adopt SolBio-Rev's core technologies. This suggests that these groups may be an important early adopter demographic for these systems
- Most respondents were not keen on changing their heat business model away from a volumetric utility supply model towards a business model based on useful or final energy services. This has important implications for SolBio-Rev as centralised systems which incorporate microgeneration, typically involve heat and cooling sold as a service
- Many respondents also saw the replacement and financing of their HVAC system as their own responsibility. However, Greek respondents were also more interested in integrated financing and Finnish respondents also saw an important role for their housing cooperative in making this change
- These findings suggest a range of business models and financing mechanisms may need to be trialled in different countries once the SolBio-Rev system is at the commercial stage

This report highlights important variability in user preferences and the pre-existing national HVAC regimes in which a system like SolBio-Rev will be deployed. These findings suggest a one size fits all approach to commercialisation of this technology may not be successful. Instead, an approach that is sensitive to the unique national, cultural and building specific context, with tailored marketing and different business and financing models is likely to be required. Further, building energy models which apply uniform energy demand profiles will provide only a limited and simplistic account of the actual energy demand of buildings. Therefore, heuristic assumptions for energy demand from standard building archetypes and occupancy groups should be qualified by the large variance that will occur within these groups.

Our findings will feed into Task 6.2 and Task 6.3 as well as other parts of the SolBio-Rev project, especially WP8 in relation to different business models, as well as to WP3 in relation to building energy models in Europe. In future phases of WP6 we aim to build on the findings of this deliverable and integrate these into the design process (D6.2). This will include a focus on building case studies in the three study countries as potential use cases for the system, and the specific constraints and opportunities these present. Following from this work we will investigate how the current EU policy environment can be make more conducive to the adoption of low carbon heat systems such as SolBio-Rev, before providing some policy recommendations (D6.3).

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Appendix 1 – Interview List & Questions

Interview	Interviewee identifier	Interview date	Shorthand Interview code
Finland			
1	FIN_Office User_01	05/10/2020	FOU1
2	FIN_Office User_02	05/10/2020	FOU2
3	FIN_Building Manager_01	06/10/2020	FM1
4	FIN_Office User_03	06/10/2020	FOU3
5	FIN_Building services_01	07/10/2020	FBS1
6	FIN_Household User_01	27/11/2020	FHU1
7	FIN_Household User_03	14/12/2020	FHU3
8	FIN_Household User_05	20/01/2021	FHU5
9	FIN_Building Manager_02	09/02/2021	FM2
10	FIN_Building services_02	12/02/2021	FBS2
11	FIN_Household User_02	30/11/2020	FHU2
12	FIN_Household User_04	12/01/2021	FHU4
13	FIN_Household User_06	04/02/2021	FHU6
14	FIN_Building Manager_03	25/02/2021	FM3
15	FIN_Heating system designer_01	26/03/2021	FD1
Greece			
16	Greece_USER1_BG_1	24/10/2020	GU1H1
17	Greece_USER2_BG_1	24/10/2020	GU2H1
18	Greece_USER3_BG_1	06/11/2020	GU3H1
19	Greece_MNGR_BG_1	06/11/2020	GM1H1
20	Greece_USER1_BG_2	21/01/2021	GU1H2 (X2)
21	Greece_USER2_BG_2	30/03/2021	GU2H2
22	Greece_MNGR_BG_3	24/02/2021	GM1O
23	Greece_USER1_BG_3	08/03/2021	GU1O
24	Greece_USER2_BG_3	12/03/2021	GU2O
25	Greece_USER3_BG_3	13/03/2021	GU3O
26	Greece_DSNR_1	12/04/2021	GD1 (X2)
27	Greece_DSNR_2	13/04/2021	GD2
UK			
28	UK_USER1_BG_1	14/12/2020	UU1H1
29	UK_USER2_BG_1	17/12/2020	UU2H1
30	UK_MNGR1_BG_1	24/11/2020	UMH1
31	UK_MNGR2_BG_2	10/12/2020	UMH2
32	UK_DSNR_1	18/01/2021	UD1
33	UK_DSNR_2	25/01/2021	UD2
34	UK_DSNR_3	26/01/2021	UD3 (X2)
35	UK_USER1_BG_2	27/01/2021	UU1H2
36	UK_USER2_BG_2	01/02/2021	UU2H2
37	UK_USER3_BG_2	02/02/2021	UU2H2
38	UK_USER1_BG_3	12/05/2021	UU1O (X2)
39	UK_USER2_BG_3	17/05/2021	UU2O
40	UK_MNGR1_BG_3	22/06/2021	UM1O

SolBio-Rev Interview questions: Household

1. **Perceptions of current system**
   1.1. How is your home heated?
   1.2. How is do cool your home ?
   1.3. Do you know how these systems work?
      1.3.1. Prompt: Do you know which energy resource it uses (gas, oil, renewable)
   1.4. What do you like and dislike about it?
2. **Perceptions of control**
   2.1 Who usually controls the system?
   2.2 Do you find the controls easy to use?
   2.3 Do you think you have sufficient control?
   2.4 Does this create any challenges/conflicts?
   2.5 Is the system reliable?
   2.6 Can you maintain a comfortable temperature throughout the year?
   2.7 Who has responsibility for maintaining the heating and cooling system?
      2.7.1 What happens if it breaks down, who pays for this?
3. **Perceptions of renewable heat and cooling**
   3.1 To what extent are you familiar with renewable heating and cooling systems?
   3.2 Could you describe your understanding of these?
      3.2.1 Solar hot water
      3.2.2 Heat pumps
      3.2.3 Biomass
   3.3 What do you see as the key challenges of these systems?
   3.4 How about benefits?
   3.5 If you were to change your heating/cooling to a renewable system what would be the most important features for you to change?
4. **Perceptions of business models**
   4.1 How do you currently pay for your heating and electricity?
   4.2 To what extent would a monthly fixed price contract with usage limits– like a mobile phone contract - appeal to you?
   4.3 Would you consider giving away some control over the systems in your home if this meant lower bills?
   4.4 What would be your ideal arrangement for funding, controlling and maintaining the energy systems in your home?

SolBio-Rev Interview questions: Building manager

1. **Perceptions of current heating and cooling system**
   - 1.1. Could you tell me how the building is heated?
   - 1.2. How is the building cooled?
   - 1.3. Could you describe how these systems work?
     - 1.3.1. Prompt: Do you know which energy resource it uses (gas, oil, renewable)
   - 1.4. What do you like and dislike about it?

2. **Perceptions of control**
   - 2.1 How are the systems controlled?
   - 2.2 Do you have any control?
     - 2.2.1 Do you find the controls easy to use?
     - 2.2.2 Do you think you have sufficient control?
   - 2.3 Does this create any challenges/conflicts?
   - 2.4 Is the system reliable?
   - 2.5 Can users maintain a comfortable temperature throughout the year?
   - 2.6 Who has responsibility for maintaining the heating and cooling system?
   - 2.7 What happens if the system breaks down?
     - 2.7.1 Who fixes it?
     - 2.7.2 Who pays for it?

3. **Perceptions of renewable heat and cooling**
   - 3.1 To what extent are you familiar with renewable heating and cooling systems?
   - 3.2 Could you describe your understanding of these?
     - 3.2.1 Solar hot water
     - 3.2.2 Heat pumps
     - 3.2.3 Biomass
   - 3.3 What do you see as the key challenges of these systems?
   - 3.4 How about benefits?
   - 3.5 If your building heating/cooling was using a renewable system, what would be the most important features for you?
   - 3.6 What issues do you see in changing the systems in this building to renewable heating and cooling?

4. **Perceptions of business models**
   - a. How do the building's users currently pay for their heating and electricity?
     - i. To what extent would offering a fixed price contract for comfort/temperature – like mobile phone - appeal to you?
       - 1. What additional capabilities would you need to deliver this?
   - b. Do you think this would appeal to the residents?
   - c. What would be your ideal arrangement for funding, controlling and maintaining the energy systems in your building?

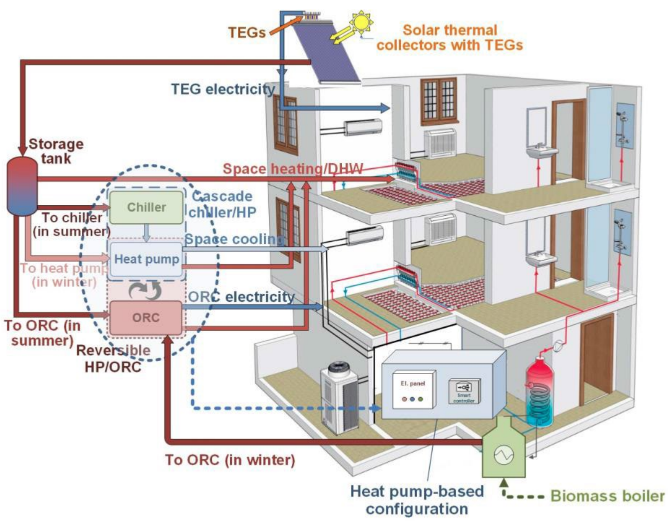
SolBio-Rev Interview questions: Building Designer

1. **Perceptions of current heating and cooling system**
   1.1. Could you decribe some of the typical heating and cooling systems you specify for multi-family housing?
      1.2. What about offices?
      1.3. What are the key factors informing these design choices?
      1.4. How is this being affected by energy and climate change targets?
      1.5. What are the main issues with these systems moving forwards?

2. **Perceptions of control**
   2.2 How are the systems in new homes you design typically controlled?
      2.3 What about older homes?
      2.4 How is user contol integrated into the design process?
      2.5 To what extent do you see a tension between user control and optimal system operation?

3. **Perceptions of renewable heat and cooling**
   3.1 To what extent are you familiar with renewable heating and cooling systems?
      3.2 Could you describe your understanding of these?
         3.2.1 Solar hot water
         3.2.2 Heat pumps
         3.2.3 Biomass
      3.3 What do you see as the challenges of these systems?
      3.4 How about benefits?

****Share diagram of SolBio-Rev system****



      3.5 What do you see as the challenges and benefits of an integrated system such as SolBio-Rev?
      3.6 What issues do you see in integrating this system into the buildings you design?

4. **Perceptions of business models**
    4.1. Could you describe your understanding of energy service contracts or ESCO models?
    4.2. What are some of the challenges in adopting these models on the projects you work on?
        4.2.1. What issues do you see in shifting control away from users to building managers or ESCOs?
    4.3. What additional capabilities/resources would you need to deliver this?
    4.4. What would be your ideal arrangement for funding, controlling and maintaining the energy systems in the buildings you design?

Appendix 2 - Survey Questions

S0. What type of home do you live in?	1. Single House (detached or semi detached)
	2. Flat (multifamily apartments)
	3. Flat (converted flat/house divided into flats)
	4. Terrace House
	5. Studio Flat.
	6. Other

Programmer: ask all

S1. What statement best described your housing situation.	1. I own the property I live in
	2. I am renting from a social landlord/ municipality
	3. I am renting from a private landlord
	4. It's a family house/ parents' house
	5. Other

Programmer: ask all

S2. Who has the responsibility for maintaining or changing your heating or cooling system?	1.Myself/My family
	2.My Landlord/ Social Housing Provider
	3.My Building Manager
	4.My Building Cooperative/Freehold Company
	5.My Energy Service Company (ESCO)
	6.The City/ Municipal Authority
	7.The Regional/National Government

Programmer: ask all

<u>Question</u>	<u>Answer list</u>
Q1_1 How many people, including yourself, live in your current home?	Open Numerical value Programmer: add numeric bar: From 1 to 10 and 10+
Q2_1 How many children live in your current home?	Open Numerical value. Programmer: add a numeric bar like this: No Children 1 2 3 4 5 6+
Q3_What is your level of education?	0. None
	1. Graduated high school / secondary school
	2. Undergraduate college degree (e.g., BSc, BA)
	3. Graduate degree (e.g., MSc, MA)
	4. Postgraduate degree (e.g., PhD, JD)
	98. Other

Q4_What is your age?	1. 18-24
	2. 25-34
	3. 35-44
	4. 45-54
	5. 55-64
	6. 65+
Q5_How do you identify your gender?	1. Male
	2. Female
	98. Other
Q6_What is your annual household income before tax?	1. Less than £20,000; 2. £21,000 - £29,999 3. £30,000 - £39,999 4. £40,000 - £49,999 5. £50,000 - £59,999 6. £60,000 - £79,999 7. £80,000 - £99,999 8. More than £100,000
Q7_My home is...	1.Owned-outright without a mortgage
	2.Owned with a mortgage
	3.Rented from a private landlord
	4.Rented from social housing / local authority
Q8a_What is the primary way you currently provide heat in your home?	a. Natural gas boiler
	b. Biomass boiler
	c. Wood burner/fireplace
	d. Ground Source Heat pump
	e. Heat pump
	f. District heating / heat network
	g. Fuel cell
	h. Oil / fuel oil / LPG
	i. Solar thermal / solar PV
	j. Resistive / electric heating
	KK. Other
	PP. Don't know
Q8b_What is the way you currently provide hot water in your home?	a. Natural gas boiler
	b. Biomass boiler
	c. Wood burner/fireplace
	d. Ground Source Heat pump
	e. Heat pump
	f. District heating / heat network
	g. Fuel cell
	h. Oil / fuel oil / LPG

	i. Solar thermal / solar PV
	j. Resistive / electric heating
	KK. Other
	PP. I don't know
Q9_Is your heating system individual to your home or is a communal system in your building?	1.Individual
	2. Communal
Q9A. How reliable are these systems?	1.Very reliable
	2.Somewhat reliable
	3.Neutral
	4.Somewhat un-reliable
	5.Very un-reliable
	6.Don't know
Q10_ What are the main ways you currently keep your home cool? **Select up to 3 options**	1. Open Windows
	2. Air Conditioning
	3. Shutters/ blinds
	4.Fixed Fans
	5.Room Fans
	6.Ducted Ventilation System
	7.Mechanical Ventilation with Heat Recovery
	8.Passive Stack Ventilation
	9.Reversible Heat Pump
	10. Change clothing
	11. Close windows and use thermal mass of building
	97. None
	98. I don't know
Q11_How well insulated/ energy efficient is your home? **Programmer: Lickert scale bar from 1 to 5**	5. Very energy efficient
	4. Moderately energy efficient
	3. Averagely energy efficient
	2. Moderately energy in-efficient
	1. Very energy in-efficient
	98 I don't know
Q12_To what extent can you remain warm during the colder months of the year?	1.I am always able to remain warm while at home
	2.I am mostly able to remain warm while at home
	3.I am sometimes able to remain warm while at home
	4.I am never able to remain warm while at home
Q13_To what extent can you remain cool	1.I am always able to remain cool while at home
	2.I am mostly able to remain cool while at home

during the warmer months of the year?	3.I am often unable to remain cool while at home
	4.I am always unable to remain cool while at home
Q14_What type of control do you have over your current heating, hot water and cooling system?	1.None
	2.Decided by building manager/owner
	3.Simple "on/off" control
	4.Single Room Thermostat
	5.Multiple Room Thermostats/ Thermostatic Radiator Valves
	6.Single Room Thermostat and Programmer
	7.Multiple Room Thermostats/ Thermostatic Radiator Valves and Programmer
	8.Smart Thermostat and Controls (Smartphone App)
Q15_How satisfied are you with the level of control you have over your heating and cooling? Licker scale bar 1to 5	5.Very Satisfied
	4.Satisfied
	3. Neither satisfied nor unsatisfied
	2.Somewhat Unsatisfied
	1.Very Unsatisfied
Q16_For you, what are the most important features of heating and cooling systems? (Please rank in order of importance where 1 is most important and 6 is least important)	1.Greater control over temperature
	2.Simplicity of Controls
	3.Lower running costs
	4.Improved air quality/ventilation
	5.Low disruption during the install
	6.Reduced CO2 emissions/Climate Change Impact
Q18_How familiar are you with the following renewable energy technologies?	1.Very familiar
Q18_1 Solar Hot Water	2. Quite familiar
Q18_2 Air Source Heat Pumps	3. Somewhat familiar
Q18_3 Biomass Boilers	4. Not familiar / 5. Totally unfamiliar (never heard of it)
Q18_4 Thermo Electric Generators	
Q18_5 Absorption Chiller	
Q18_6 Organic Rankine Cycle Engine	

Q19 How confident/enthusiastic would you feel in changing your heating system to the following:	5. Very likely 4.Somewhat likely 3.Neither likely nor unlikely 2.Somewhat unlikely 1.Very unlikely 98.[Don't know] 95.I have this system already
Q19_1 Natural gas / condensing boiler	
Q19_2 Biomass boiler / bioenergy / wood	
Q19_3 Ground Source Heat pump	
Q19_4 Air Source Heat pump	
Q19_5 District heating / heat network	
Q19_6 Hydrogen / fuel cell	
Q19_7 Oil / fuel oil / LPG	
Q19_8 Solar thermal hot water/ solar energy	
Q19_9 Resistive / electric heating	
Q20_Aproximatley how much do you currently spend on energy bills per month?	£ __________ 98. I don't know
Q20b._How do you currently pay for your heating?	1. I pay for the amount of energy/fuel I use for my heating
	2. I pay for the amount of hot water/ heat from a centralized system
	3. I pay for the temperature level in my home and the building manager takes care of the heating system
	4. I pay a fixed amount based on the size of my apartment/home
	5. Don't know
	98.Other
Q21_Please state the extent to which you agree with the following statement: "I find it difficult to afford my energy bills"	1. Strongly disagree
	2. Disagree
	3. Neither agree nor disagree
	4. Agree
	5. Strongly agree
	Don't know
	5.Very important

Q23_ How important to you is it for your heating and cooling to be carbon neutral in the coming years?	4.Somewhat important
	3.Neutral
	2.Less important
	1.Not important
Q23B. How much more would you be willing to pay carbon for free energy?	1.0%
	2.<10%
	3.<20%
	4.<30%
	5.<40%
	6. 50% or more
Q24A. If you changed how you pay for heating and cooling, which of the following would be the most appealing?	1. I would prefer to pay fixed amount based on the size of my apartment/home
	2. I would prefer to pay for the amount of energy/fuel I use
	3. I would prefer to pay for the amount of useful hot water/ heat /cooling I use
	4. I would prefer to pay for the internal temperature level in my home
	5. No change
	98. I don't know
Q24B. If you changed your heating and cooling system how would you prefer to pay for it?	1.I finance the new system with my own money/savings
	2.I finance the new system with a separate loan
	3.Financing is included with the new system
	4.The cost of the new system is included in an energy service charge
	98. Don't know
Q25. Who should have the main responsibility for making my heating and cooling carbon neutral?	1.Myself/My family
	2.My Landlord/ Social Housing Provider
	3.My Building Manager
	4.My Building Cooperative/Freehold Company
	5.My Energy Service Company (ESCO)
	6.The City/ Municipal Authority
	7.The Regional/National Government