The Contribution of Reversible Air-to-Air Heat Pumps to the UK's Obligation under the Renewable Energy Directive (2009/28/EC)

A Delta-ee Report for the Department for Business, Energy and Industrial Strategy

Final Report

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1. Executive Summary

1.1. Context, scope and research questions

The United Kingdom has an obligation under the European Union's Renewable Energy Directive to meet 15% of its total final energy consumption and 10% of its energy used for transport from renewable sources by 2020. Under current policies, meeting the binding 15% target for the final energy consumption has been broken down onto the UK's energy sectors as follows:[1]

- 30% of renewables in the electricity sector
- 12% of renewables in the heat sector
- 10% of renewables in the transport sector

In 2016, the UK met 6.2% of its heat demand with heat from renewable sources (~46 TWh out of a total heat demand of ~740 TWh). Hydronic heat pumps contributed about 4.6% to the renewable heat delivered in 2016 (~2.12 TWh out of the ~46 TWh of renewable heat overall), but this is equivalent to only ~0.3% of the UK's total heat demand of ~740 TWh.[2]

However, the Renewable Energy Directive does not limit the classification of heat from heat pumps as renewable to hydronic systems. Heat pumps using air as the main medium to deliver the heat to the end-user, often via an intermediary refrigerant circuit, are also eligible. But despite the market for reversible air-to-air heat pumps (RAAHPs) being more than 10 times as big as the market for hydronic systems in 2016, very little data exists on the necessary values required for the calculation of renewable heat from these products.

The main purpose for this study therefore was to enhance the understanding of the use of RAAHPs for heating in the UK and to deliver a first calculation of renewable heat from RAAHPs for the purposes of reporting to the European Union.

Key questions that needed to be answered for this task included an understanding of the currently installed capacity of RAAHPs in the UK and how many of these systems can be and are used for heating, how long they run in heating mode per year and how efficiently they operate. A set of secondary questions surrounding the costs of RAAHPs, maintenance costs and intervals as well as other variables were also analysed during this project.

1.2. Survey methodology, results and analysis

Methodology

In order to meet BEIS' requirement of a deeper understanding of the use of RAAHPs for heating in real life conditions (as opposed to theoretical planning frameworks), a multi-pronged research approach with a strong focus on end-user research was chosen for this project.

The different research approaches included:

- A telephone based survey of 100 SMEs which use RAAHPs for heating.
- An online survey of energy managers representing larger groups and companies active in the UK and using RAAHPs at some (or all of) their sites.
- Interviews of installers active in the UK air-conditioning market.
- Interviews with manufacturers active in the UK air-conditioning market.

[1] Note: Out of the three only the 10% of renewable energy in transport is a binding target, the others are the ambitions of Government for the different sectors which will allow to meet the binding target of 15% of renewables in the final energy consumption by 2020.
[2] All data based on Digest of United Kingdom Energy Statistics (DUKES) 2017: main chapters and annexes.

- Desk-based research including the analysis of previous scientific work in this area as well as market research of prices, efficiencies, etc.

Results

Our project found that on average 73% of all RAAHPs in operation at SMEs and larger companies are being used for heating in addition to their cooling functionality. The technical ability to both heat and cool is even higher, as all systems sold as standard air-conditioners on the UK market (as opposed to more specialised applications such as close control systems) can provide both services. 27% of systems are not being used for both heating and cooling (or heating only). These are either systems sold before 2013 (the last year in which cooling only products have been sold on the UK market) or systems where the heating functionality is not being used. The total installed capacity of RAAHPs which meet the Directive's minimum efficiency criterion and are used for heating is ~20 GW.

In terms of annual running hours in heating mode we found that companies in the average climate zone reported higher running hours than companies in the colder climate zones. This was due to the companies in the colder climate zones being much more likely to have another heating system installed alongside their RAAHP. In terms of full load equivalent hours (i.e. the theoretical amount of hours per year that the system needs to run at full load in order to provide the total heat demand in that year) we found the following operation hours:

Full load Equivalent Hours (FLE)	Single- & Multi-Split Systems	VRF Systems (with Heat Recovery)
Average Climate Zone	646	738 (686)
Cold Climate Zone	339	738 (225)

The efficiency of RAAHPs used for heating under UK conditions is a question that merits further research, possibly through field trials, as no quantitative data on this topic is currently available. This report therefore assumes that the average SPF of RAAHPs in the UK is 2.8, which is in line with an RHI evidence report by Eunomia (2014). Based on the analysis of the rated efficiency of products on the market in 2008 and 2017, we estimate that all single- and multi-split systems installed in or after 2006 as well as all VRF (Variable Refrigerant Flow) units currently still in operation are meeting the minimum SPF requirement of 2.5.

1.3. The contribution of RAAHPs to the UK's obligation under the Renewable Energy Directive (2009/28/EC)

Our calculation based on the values found through this research project shows that in 2016 RAAHPs contributed a total amount of 8,241 GWh of renewable heat to the UK target (of which 2,286 GWh were from heat recovery VRFs, which might not be eligible). In relation to the amount of renewable heat produced from heat pumps in 2016 reported in the latest DUKES report, this is an increase by a factor of 2.8-3.9, depending on whether the renewable heat from VRF units with heat recovery function are included or not. In total this will bring the renewable heat production from heat pumps in the UK to a level of around 10.4 TWh, or 1.4% of the UK's overall heat demand. In relation to the heat from renewable sources in the UK this constitutes an increase of around 18%, with all heat pump technologies providing about 19% of the total renewable heat produced in the UK.

The production of renewable heat from RAAHPs calculated in this report can also be seen as a conservative estimate. A sense-check using the European Commission's proposed approach for the development of a more accurate methodology showed that under this approach single- and multi-split units alone would be producing in excess of 12,400 GWh of renewable heat.

2. Regulatory and Technical Context of the Study

2.1. The UK's obligations under the Renewable Energy Directive (2009/28/EC)

The Renewable Energy Directive (2009/28/EC) set renewable energy targets for all EU member states to achieve. The UK's target is to source 15% of all energy and 10% of transport fuels from renewables by 2020. According to DECC's 2010 National Renewable Energy Action Plan to achieve this the following sectoral targets are suggested:

- 30% of renewables in the electricity sector
- 12% of renewables in the heat sector
- 10% of renewables in the transport sector

While the 2010 DECC Report describes these targets as "purely illustrative", in November 2015 the Secretary of State confirmed these targets as "the UK's plan".[3]

In terms of overall energy production, according to the latest Digest of UK Energy Statistics report[4], in 2016 8.9% of the UK's total final energy consumption came from renewable resources. In terms of renewable heat, 6.2% of the UK's total heat consumption originated from renewable resources in 2016. According to the targets trajectory set out in the National Renewable Energy Action Plan, the UK's renewable heat target for 2016 was 4%, the 2017 target 5% and the 2018 target 7%. Therefore the UK has already exceeded its 2016 and 2017 sub-targets for renewable heat. Overall, as of end of 2016, the UK is just over 50% of the way to achieving its 2020 Renewable Energy Action Plan renewable heat sub target.

Despite so-far exceeding DECC's 2010 National Renewable Energy Action Plan renewable heat sub-target, there have been doubts expressed as to whether the UK will reach the 12% renewable Heat target by 2020. This was highlighted in the 2016 Energy and Climate Change Committee's inquiry into 2020 renewable heat and transport targets.[5] In response to the inquiry Dunelm Energy, a consultancy, predicted only 5% of heat would be renewable in 2020; E.ON (a major energy supplier), the Institution of Civil Engineers (ICE) and the Renewable Energy Association (REA) all forecast 8–9%. None of the written submissions to the inquiry asserted the heat sub-target would be met; approximately 45% claimed it would be missed.

In terms of the renewable heat generated by heat pumps, in 2016 it increased by 17 per cent, from 156 ktoe to 182 ktoe.[6]

[3] Oral evidence taken on 10 November 2015, HC (2015–16) 544, Q2
[4] Digest of United Kingdom Energy Statistics (DUKES) 2017: main chapters and annexes.
[5] House of Commons Energy and Climate Change Committee 2020 renewable heat and transport targets, Second Report of Session 2016–17, HC 173
[6] Digest of United Kingdom Energy Statistics (DUKES) 2017: main chapters and annexes.

2.2. Reversible air-to-air heat pumps in the United Kingdom: Technologies considered for this study

The issue with RAAHPs is that they are usually categorised as being part of the broader air-conditioning market. This market includes other types of units that are often used solely for cooling, such as close control units or chillers. For the purposes of this study we have considered the following system types as being RAAHPs.

- Single-split air-conditioners: Systems where a single indoor unit is connected to a single outdoor unit, both ducted and un-ducted.
- Multi-split air-conditioners: Systems where multiple indoor units are connected to a single outdoor unit, with all units operating simultaneously.
- Variable refrigerant flow (VRF) / Variable Refrigerant Volume (VRV)[7]: Systems where multiple indoor units that can be in heating and cooling mode simultaneously are connected to one or more outdoor units.

The following air-conditioning types were not considered for the purposes of this study.

- Chillers: Despite an increase in reversible air-cooled chillers emerging on the market, cooling only systems are still predominant. It is also questionable whether a reversible chiller delivering heat through a water loop to an air-handling unit should be considered as being an air-to-water or an air-to-air heat pump. In addition to being out of scope for this project, ground cooled reversible chillers are eligible for the commercial RHI and are therefore expected to be included in these statistics.
- Close Control Units: CCU's are specialised cooling equipment which is targeted at applications where both temperature and humidity control is critical, such as the cooling of data centres and server rooms, medical operating theatres and clean room environments (labs, production lines, etc.). Whereas the systems might be used for heating in the latter two applications, it is not possible to determine how many of these systems are being used in these environments in the UK, which has led to the exclusion of this product type from our analysis.

According to most industry experts, virtually all air-air heat pumps sold today are reversible. However, there may be instances where a RAAHP is installed solely for cooling, despite having the ability to heat as well and there still exists a number of installed single- and multi-split air-conditioners that are non-reversible. Both reversible and non-reversible cooling only systems were excluded from the analysis by our research approach, which filtered respondents to only include systems which are used for heating.

[7] VRV HVAC systems were invented by Daikin during the early 1980's and they registered the VRV trade mark. VRF and VRV systems are the same technology and the terms are often used interchangeably

3. Research Scope & Methodology

3.1. Project Scope and Research Questions

The aim of this study was to provide a greater understanding of how reversible air-to-air heat pumps (RAAHPs) are used in the UK and in particular some detailed evidence on how much heating they provide throughout the year. To do so, the number and type of RAAHPs needed to be explored, as well as where they are installed and how they are operated. This information then leads into an assessment of what this means at a national level in terms of eligible renewable heat contribution under the scope of the EU's Renewable Energy Directive (2009/28/EC). There are four key pieces of information required for calculating the contribution of RAAHPs to the UK's obligation under Directive 2009/28/EC.

1. An understanding of how many RAAHPs are installed in the UK and, of these, how many are used for heating.
2. An estimate how many hours the RAAHPs used for heating are on average being run in heating mode.
3. Information on the average capacity (kW rating in heating mode) - and the distribution around this average - of RAAHPs in the UK used for heating.
4. A view on what proportion of the RAAHPs installed in the UK have a Seasonal Performance Factor (SPF) >2.5 (i.e. those that are considered renewable under the 2013 EU Guidelines on calculating the contribution from different sources of renewable heat).

A further aim for this study was for the results to be compatible with BEIS's research into the energy use in commercial buildings, the Building Energy Efficiency Survey (BEES). The end-user research therefore mirrored the terminology, geographical and sectoral segmentation of the BEES study.

3.2. Research questions as prioritised by BEIS

In order to support us in the design of the research and in particular the questionnaires, BEIS provided a prioritised list of the research questions. This was used to ensure that BEIS's key questions were prioritised in the surveys. The research questions, sorted by priority, are listed below.

First priority

Research questions of the highest priority were all those related to the reporting requirements for the UK's obligations under the European Union's Renewable Energy Directive. These are:

- The proportion of RAAHPs that can be used in heating mode (not necessarily those that are)
- The proportion of time per year that each RAAHP spends in heating mode
- The SCOP/SPF for the RAAHPs
- The installed heating capacity of the RAAHP
- The location of the RAAHP using the climatic data provided by BEIS.

Second priority

Second priority questions are all those which will enhance BEIS's knowledge base around RAAHPs, including in particular:

- Energy use
- Maintenance costs
- Installation costs.

Third priority

The third priority is given to questions which allow the data gathered from this project to be matched with the BEES dataset. For example:

- Industry/Commercial sector/sub-sector
- Number of employees
- Main heating fuel and use
- Floor area.

3.3. Methodology

In order to best reflect the complexity of the market situation and BEIS' wish to establish a robust view on the actual use of reversible air-to-air heat pumps in the field, a multi-pronged research approach combining an end-user focussed market research project, supported by industry interviews and desk-based research was chosen.

- The primary (end-)user research focussed on three main groups.
  - **Larger end users:** Organisations with professional energy management, were accessed through the Energy Managers Association (EMA). The research was carried out by using an online questionnaire as a high number of responses was expected.
  - **Smaller end-users (SMEs):** A telephone survey of a sample of 100 SMEs having an RAAHP used for heating was carried out by the market research agency fineline. Both Delta-ee's work on this survey and the online questionnaire was supported by market research specialist Miranda Mayes. The reason for using a telephone survey was that the end-users in smaller companies, which in their large majority will not be experts in the field of energy and heating, were considered less likely to be able to provide good responses to an online survey.
  - **Installers and maintenance companies**: Interviews with installers and maintenance companies was expected to provide insight into the types and efficiencies of systems installed, their design operation, and evidence of actual operation characteristics.
- **Industry market research** complemented the end-user market research through a series of in-depth interviews with selected manufacturers. As the willingness to share information in this group was rather low due to the information's commercial sensitivity, we mainly used the interviews as a sense-check for data obtained through some of the other approaches.
- **Desk-based research** was used where relevant (e.g. in order to estimate the total installed heating capacity of RAAHPs in the UK). This was based on published information, but also data provided to use by BEIS, in particular regarding market data for RAAHPs.

The results from the different research approaches were analysed and synthesised in order to ensure that the outcomes were appropriately weighted and as representative of the UK's business population as possible. A detailed description of the weighting method used for the SME survey results can be found in section 6.2.2. of this report. Due to an insufficient number of responses we did not apply a weighting to the results from the online questionnaire sent to EMA members.

4. Evidence from Desk Research

4.1. Previous studies

Thirteen separate sources were reviewed as part of a structured desk based research exercise. The reports reviewed included academic papers and articles, Energy Saving Trust Reports, DECC Reports and reports by the European Commission. The information was sourced primarily via searching relevant internet platforms as well as by referral from industry experts.

4.2. Findings

The sources reviewed were largely of little value to the current work. Much of the sources made little reference to air-air heat pumps or focused on cooling only. Previous studies in the UK, including the reports by DECC and the Energy Savings Trust, largely concerns domestic systems and air-water systems. The academic literature referred to us by external industry experts and found online also had little relevance to air-air systems operating in UK conditions.

The 2014 RHI Evidence Report by Eunomia[8] (written for DECC) stands out from the other reports, as it is the only source that explicitly investigates commercial RAAHPs used for heating in the UK. The report provides useful, yet outdated, values relating to the number of RAAHPs installed and annual sales volumes of RAAHPs in the UK. In an approach similar to the one taken in this report, the study is based on interviews with industry experts (mainly installers and manufacturers). One of the key findings of relevance for this report is the estimated seasonal efficiency of RAAHPs used for heating under UK conditions. Due to a lack of findings on this topic from our other research approaches, the central estimate of an average SPF of RAAHPs in heating mode of 2.8 across the UK will be used for the purposes of this study. This is a 32% reduction over the nominal SCOP of units currently on the market today.

[8] Cf. Eunomia (2014).

5. Evidence from Installer and Manufacturer Interviews

5.1. Installer Evidence

5.1.1. Sample size and description

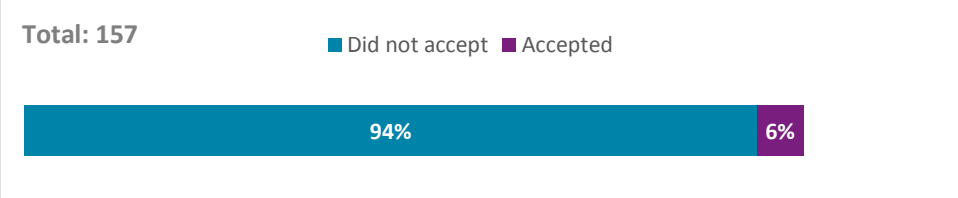
Telephone interviews were conducted with 10 installers who were identified using Delta-ee's existing contacts and online research. Installers identified from the online research were required to meet the following conditions:

- Specialise in air conditioning, and
- Perform air conditioning services themselves (as opposed to sub-contracting out).

Sample details

157 installers were contacted requesting a telephone interview, of which 10 accepted the request. Despite interviewing senior management and technical personnel, the general knowledge, engagement and willingness to share data and views of the interviewees varied widely.

FIGURE 1: OVERVIEW OF INSTALLERS CONTACTED FOR A TELEPHONE INTERVIEW



All of the installers were SMEs, with between 6 - 64 employees and turnover ranging from £350,000 - £12,000,000 respectively. The installers serve a variety of regions as illustrated in Figure 2. The majority (70%) of the installers interviewed perform all services associated to a RAAHPs' life-cycle, i.e. the design, installation and maintenance and decommissioning of RAAHPs. Single-split systems were the most commonly installed system, however, as detailed in Figure 3, the type of systems and relative proportions installed varied amongst installers. The installers operate within a wide variety of sectors, shown below.

- Residential (both high- and low-end),
- Retail,
- Offices,
- Education,
- Manufacturing,
- Distribution centres,
- Data centres,
- Sporting facilities,
- Rail networks,
- Pharmaceutical, and
- Hospitality.

FIGURE 2: NUMBER OF INSTALLERS INTERVIEWED, BY REGION THEY SERVE

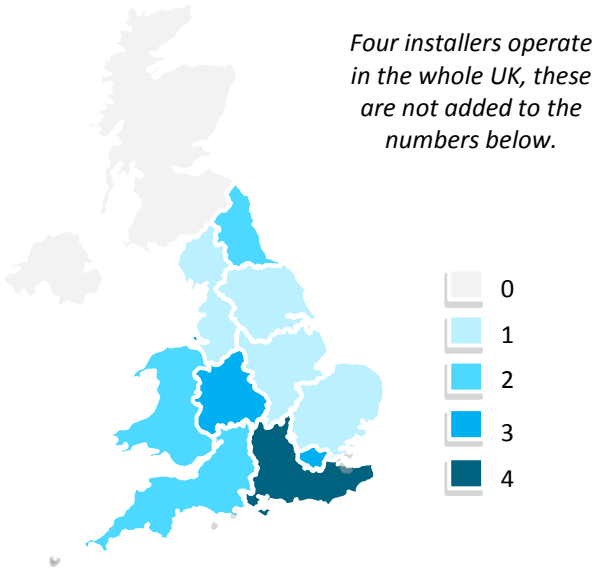
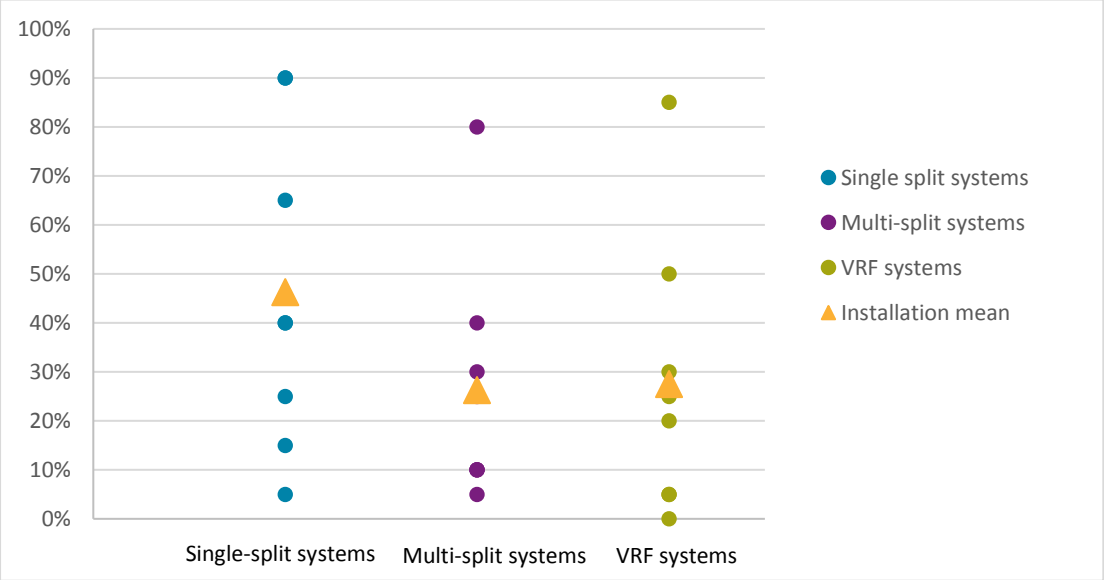


FIGURE 3: PROPORTION OF DIFFERENT RAAHP SYSTEMS INSTALLED

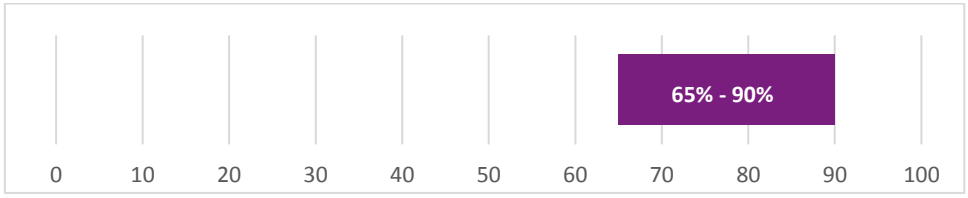
On average, the proportion of single-split systems, multi-split systems and VRF systems installed are 46%, 26% and 28% respectively. These proportions are based on the quantity of systems installed per installer.



5.1.2. Use for heating

Figure 4 illustrates the percentage of RAAHPs that are used for heating in addition to cooling, based on information provided by three of the interviewees. This low response rate is due to the interviewees lacking knowledge regarding, and therefore being hesitant to provide a value for, the operation of RAAHPs for the whole of the UK. However, 80% of the interviewees believed that the RAAHPs that were personally installed by them are used for both heating and cooling to different degrees (except for specific use cases, such as unmanned technical rooms).

FIGURE 4: PERCENTAGE RANGE OF RAAHPS THAT ARE USE FOR HEATING IN ADDITION TO COOLING
It is important to note that the 65% value is based on actual recorded data (as part of CIBSE reporting) of 20 commercial installations, whereas the other two values (both 90%) are based on estimates.



5.1.3. Capacity

Information received regarding the average capacity of installed systems was generally poor, with the majority of installers stating that the range, even within sectors, was too large to provide a valid answer. This large range may be due to the fact that the installers operate within a wide variety of sectors, as well as the wide variety of building and room sizes and occupational patterns within these sectors. Consequently, the range of answers provided was very large, which resulted in the data being deemed ineligible for use in this project. However, interviews with installers confirmed the views expressed in our discussions with manufacturers, i.e. that RAAHPs are generally sized and specified with the cooling load in mind, with the heating capacity of the systems in most applications being deemed sufficient to meet the heating load in winter.

TABLE 1: RANGE OF TYPICAL RAAHP CAPACITIES FOR DIFFERENT APPLICATIONS

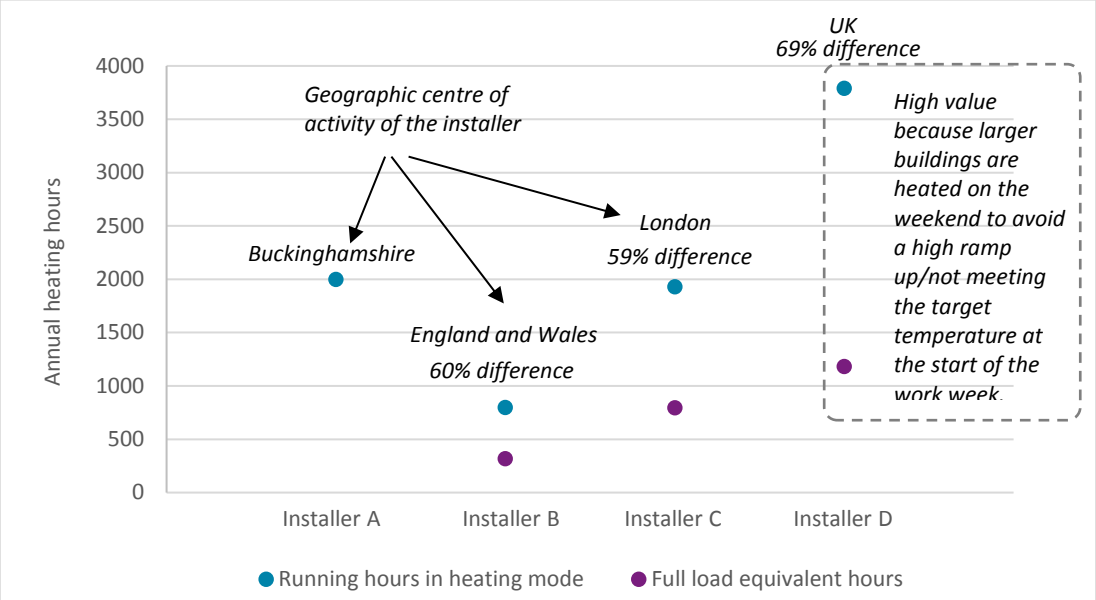
RAAHP application	Capacity range (kW)
Hotel rooms	2 - 3
Small retail	5 - 15
Large retail	Up to 300 (installed in cascades)
Small office	7 - 10
Large office	Up to 400 (installed in cascades)

5.1.4. Running hours in heating mode and resulting full load equivalent hours

As mentioned above, installers generally do not design systems from scratch or with heating in mind, instead using rules of thumb, manufacturer's design tools or other indicators. Hence, it is not a requirement to know either the running hours in heating mode or the resulting full load equivalent hours to size the system. As a result of this, most installers we interviewed did not have deep insight into these values. However, as shown in Figure 5, four installers provided an estimate of the average number of running hours RAAHPs in their region spend in heating mode and three installers provided an estimate of the full load equivalent hours. With an average of 2,130 hours spent in heating mode, the results from this survey provide slightly higher values than those found in our end-user research. This can be mainly attributed to a very high outlier of almost 3,800 hours per year that was given by one of the four respondents who seems to be mainly active in large office buildings. These need constant temperature control during winter times in order to not cool down too much over night or the weekend.

FIGURE 5: INSTALLER ESTIMATES REGARDING RUNNING HOURS IN HEATING MODE AND ASSOCIATED FULL LOAD EQUIVALENT HOURS OF RAAHPS FOR HEATING

- The low response rate to this question of only 30% for full load equivalent hours is comparable with the 40% achieved by Segers/Busker (2015).
- The mean running hours in heating mode are 2,130 and mean of the full load equivalent hours is 767.
- The average difference between running hours and full load equivalent hours is 63%.



5.1.5. Heating efficiency

Measuring efficiency performance in-situ is expensive and is not of interest to the customer, therefore it is rarely performed by installers resulting in a general lack of insight into efficiency – this is similar to what is detailed in the RHI Evidence Report: RAAHP (Eunomia, 2014). The SCOP values provided by five installers ranged from 2.5 – 5. These values were taken from manufacturer data and were not in-situ values. This, coupled with the low number of answers given, resulted in the data being deemed insufficient for use in this study.

5.1.6. Results on other questions from BEIS

Installation and maintenance costs

It is in installers' interests to keep track of and record installation and maintenance costs, therefore installers have insight into this value. Four installers provided answers regarding the installation costs for the three different system types, as detailed in Tables 2 and 3. The maintenance costs provided by the installers range from £70/year – £250/year, with a mean of £134/year for both single and multi-split systems. Maintenance costs for VRF systems are slightly higher and more variable. This is due to the majority of the required maintenance procedures being similar, yet the size variability associated with VRF systems means that it is more difficult to provide a narrow range of estimates. The range of values in the answers given above may be due to economies of scale (i.e. buildings with a high number of RAAHPs could potentially have a lower mean maintenance cost per system) as well as the number of visits per year or the type of maintenance carried out. However, the provided values indicate general agreement.

TABLE 2: INSTALLATION COSTS FOR THE THREE DIFFERENT RAAHP SYSTEMS

- One installer interviewed stated that the average installation cost of a split unit, regardless of size, is £1500. This supports the values provided by Installer 1.
- The base price provided by installer 1 may be to cover overhead costs (e.g. transport and installation)

	Installer 1	Installer 2	Installer 3
Single-split system (£)	1,500 + 500/kW	500/kW	685/kW
Multi-split system (£)	1,500 + 500/kW	1,000/kW	
VRF system (£)	2,750 + 250/kW	4,000/kW	

TABLE 3: PRICE FACTORS BETWEEN THE DIFFERENT INSTALLER PRICING RULES OF THUMB

- There is general agreement on the installation costs for both single and multi-systems (The small price factors between the cheapest and most expensive single and multi-split systems is likely to be due to the different quality of installed products), which is not the case for VRF systems.
- The large price factor for the VRF systems may be because Installer 1 is quoting the price of the outdoor unit, whilst Installer 2 is quoting the price of the outdoor and indoor unit plus full installation costs.

	2 kW AC	5 kW AC	12 kW AC
Single-split system (£)	1.0 - 2.2	1.0 - 1.6	1.0 - 1.4
Multi-split system (£)	1.0 - 1.1	1.0 - 1.25	1.0 - 1.6
VRF system (£)	-	-	1.0 - 14.1

Development of capacities since 2004 and going forward

50% of the installers interviewed suggested that the general trend, with all else being equal, is for smaller systems per m², which is primarily due to better building insulation. Other interviewees refused to comment, stated no change, or did not provide relevant responses. However, it is interesting to note that system capacity could increase in retrofits where the RAAHP becomes responsible for the full heating load (i.e. replaces the boiler or electric heating).

5.2. Manufacturer and Market Evidence

5.2.1. Description of the research approach

The gathering of evidence from manufacturers was based mainly on interviews with some of the key players in the UK air-conditioning industry as well as the analysis of data from manufacturer data sheets and price lists obtained through online research.

Results from this research were used to complement market statistics collected by the Building Services Research and Information Association (BSRIA), provided to Delta-ee by BEIS for the use in this research project. This market data was used in particular to estimate the heating capacity of RAAHP systems installed in the UK.

The UK's market for RAAHPs is highly competitive and fairly concentrated. Based on information from BSRIA, seven companies were responsible for more than 83% of all RAAHP sales in the UK in 2016.[9] During the research phase of our project we repeatedly reached out to a total of 10 market players. Out of this group of companies, which covers over 90% of the market, 3 were willing to engage with us on the topic (2 within the top 5 and 1 within the top 10 based on their sales volume). Given the high concentration and competitiveness in the market place and the commercially sensitive nature of the information requested from the manufacturers, this can be considered a good response rate and is similar to previous studies in this field.[10] In addition to the interviews with manufacturers we also spoke to Mike Nankivell, Chair of the air-conditioning plenary group within HEVAC, the heating, ventilation and air-conditioning body of FETA (Federation of Environmental Trade Associations). The research was carried out in semi-structured interviews which were used mainly to test findings from the other sources of evidence with regards to their plausibility.

In addition to the manufacturer interviews, data from more than 850 products by 6 manufacturers currently being available in the UK was analysed.[11] This data was gathered from manufacturer catalogues and price lists found through online research and was used to support the analysis of trends and correlations regarding the efficiency, capacity and costs of RAAHPs in the UK.

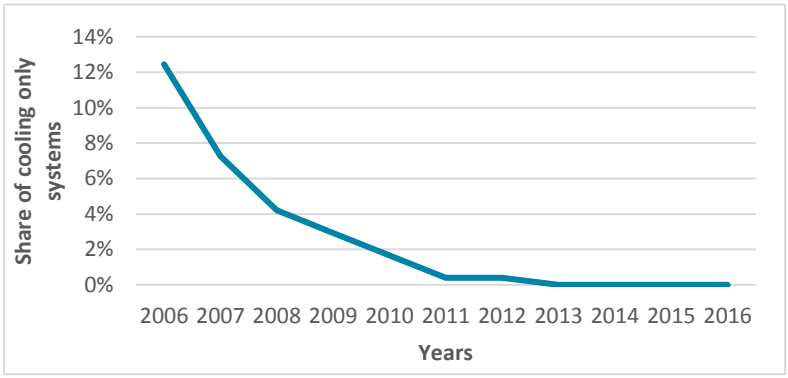
5.2.2. Use of RAAHPs for heating

All interviewees were unanimous in their opinion that:

- All RAAHPs installed in the UK today are technically able to provide both heating and cooling;
- RAAHPs are generally being sized for the cooling load, as this will allow them in most cases to also meet the heating load of the building;
- Whereas a sizeable number of RAAHPs is expected to be providing both heating and cooling, manufacturers generally don't have a good view on how many exactly are being used for heating and to which extent (i.e. whether all or just part of the heating load is being met).

The first finding is also being backed up by our product analysis, which did not find any cooling only products within the 857 unit sample, as well as by the BSRIA statistics that suggest that systems which are technically unable to provide heating have disappeared from the market for single- and multi-split systems entirely since 2013 (see below).

FIGURE 6: SHARE OF COOLING ONLY SYSTEMS IN THE TOTAL SALES OF SPLIT SYSTEMS



Source: Delta-ee based on data from BSRIA

[9] Own calculations, based on BSRIA (2017).
[10] Cf. Eunomia (2014).
[11] It should be noted that "availability" in this is defined as being listed in manufacturers' and distributors' catalogues and price lists and does not refer to the actual physical availability of these products in the UK.

5.2.3. Capacity

The distribution of outdoor unit sales by capacity bands as recorded by BSRIA for 2014 was combined with system data within these capacity bands from our product analysis in order to determine the average installed cooling and heating capacity of the different system types in the scope of this project. The results were then tested in interviews with the manufacturers and HEVAC, which confirmed the results of the data analysis.

TABLE 4: AVERAGE HEATING & COOLING CAPACITY OF RAAHPS SOLD IN THE UK IN 2014

System type	Average heating capacity (kW_H)	Average cooling capacity (kW_C)
Single- and Multi-splits	8.18 kW_H	7.08 kW_C
VRF	47.47 kW_H	42.75 kW_C

Some of the manufacturers suggested that there is a long-term trend towards smaller systems in the single- and multi-split market and larger systems in the VRF segment. This was due to an increasing thermal performance of buildings, which in the VRF segment is countered by an increase in building sizes. However, an analysis of sales data from 2007 compared with data from 2014 did not confirm this trend and we do not consider this anecdotal evidence as being of sufficient robustness for the purposes of this project.

5.2.4. Running hours in heating mode

Many manufacturers are "one removed" from the market and rely on installers and/or building (specification) engineers for the sizing of their products. They therefore only have a limited overview on the use of their products in the field. The main type of data were therefore rules of thumb the different manufacturers use e.g. to provide cost or payback calculators. Values obtained for the annual running hours in heating mode ranged from 1,000-2,730 hours, with a mean of 1,820 hours. The highest value provided was based on recommendations from Part L2 of the UK building regulations with regards to the use of heating in offices (195 days / 14 hours per day).

Some manufacturers offer remote monitoring services to their customers, which are likely to provide the data on average running hours and full load equivalent hours sought after in this project. However, due to the commercial sensitivity of this data as well as limitations imposed on manufacturers by confidentiality agreements between themselves and the clients of their monitoring services, no such data was obtained.

5.2.5. Heating efficiency

The in-situ performance of RAAHPs is difficult to measure[12] due to the phase change occurring during the heat transfer and any data on this topic is of a commercially sensitive nature. Therefore no data or commentary was received on this topic, other than that manufacturers do not expect their systems to exhibit significant differences in performance in the field compared to in the lab.

[12] Cf. Eunomia (2014).

Our analysis of 857 units currently on the UK market has shown that the average (S)COPs for RAAHPs are as follows:

TABLE 5: AVERAGE (S)COPS AND (S)EERS FOR RAAHPS IN THE UK

RAAHP type	Mean (S)COP*	Mean (S)EER*
Single-splits (all types <12 kW_C)	4.11	6.12
Multi-splits (all types <12 kW_C)	4.16	6.87
VRF	4.21	3.66

*Note: Under the EU's Energy Labelling Directive, the declaration of SCOP (Seasonal Coefficient of Performance) values for units >12 kW is only required from 2018 onwards. Values for VRF units are therefore referring to the COP/EER rather than the seasonal efficiencies. With regards to multi-splits, only SCOPs/SEERs (Seasonal Energy Efficiency Ratio) for systems <12 kW were recorded in order to maintain consistency in the dataset.

Different outdoor temperature profiles, indoor temperature settings, commissioning parameters and pipe lengths and insulation are all factors that affect the in-situ efficiency of RAAHPs. It is therefore not possible to draw conclusions from the lab-tested COPs and the calculated seasonal efficiencies. Further research into this topic, e.g. through field-trials, seems necessary.

5.2.6. Results on other questions from BEIS

Our analysis of the prices of more than 850 products has provided us with a very good view of the pricing of single-split RAAHPs in the market place. For multi-split and VRF systems the data is slightly less useful, as the prices gathered for these products are relating to the outdoor unit only. A full system pricing analysis for these types of RAAHP was not possible, as they can be equipped with a multitude of different indoor unit types and capacities (a 25 kW_C VRF outdoor unit could for example be providing energy to 5x5 kW_C or 2x12.5 kW_C indoor units). The price relations found from our analysis are detailed below.

TABLE 6: AVERAGE LIST PRICES OF RAAHPS IN THE UK (PER kW COOLING CAPACITY)

Single-split	Multi-split	VRF
244 £/kW_C (R^2=0.76)*	215 £/kW_C (R^2=0.89)*	218 £/kW_C (R^2=0.98)*

*Common statistical test for how well the data fits the line of best fit.

It is interesting to note that single-split systems are on average only a little more expensive than multi-split and VRF systems, despite the indoor unit being included in the price. However, there is a significantly higher variance in the costs of single-split units compared to the other types. The reason for this is that a lot of the differentiation in terms of price comes from the indoor units. Thus the average price shown here covers both different types of indoor units (e.g. wall-type, cassette, floor-standing, etc.) and different levels of product quality within a manufacturer's portfolio (entry-level to premium). This leads to a much greater variety in prices than when looking at multi-split and VRF units, where we compared outdoor unit prices only. In this case the only factor influencing the price difference of the products is the positioning of the manufacturer in the market as well as the type of system for VRFs (high efficiency/heat recovery vs small foot-print).

6. Evidence from End-User Research

Two groups of end-users were investigated – large commercial users (via the Energy Managers Association - companies with more than 250 employees), and small/medium commercial users (SMEs – companies with under 250 employees). The sector characteristics and research outcomes are presented in 6.1 and 6.2 below.

6.1. Results of the research with energy managers (representing the large commercial sector)

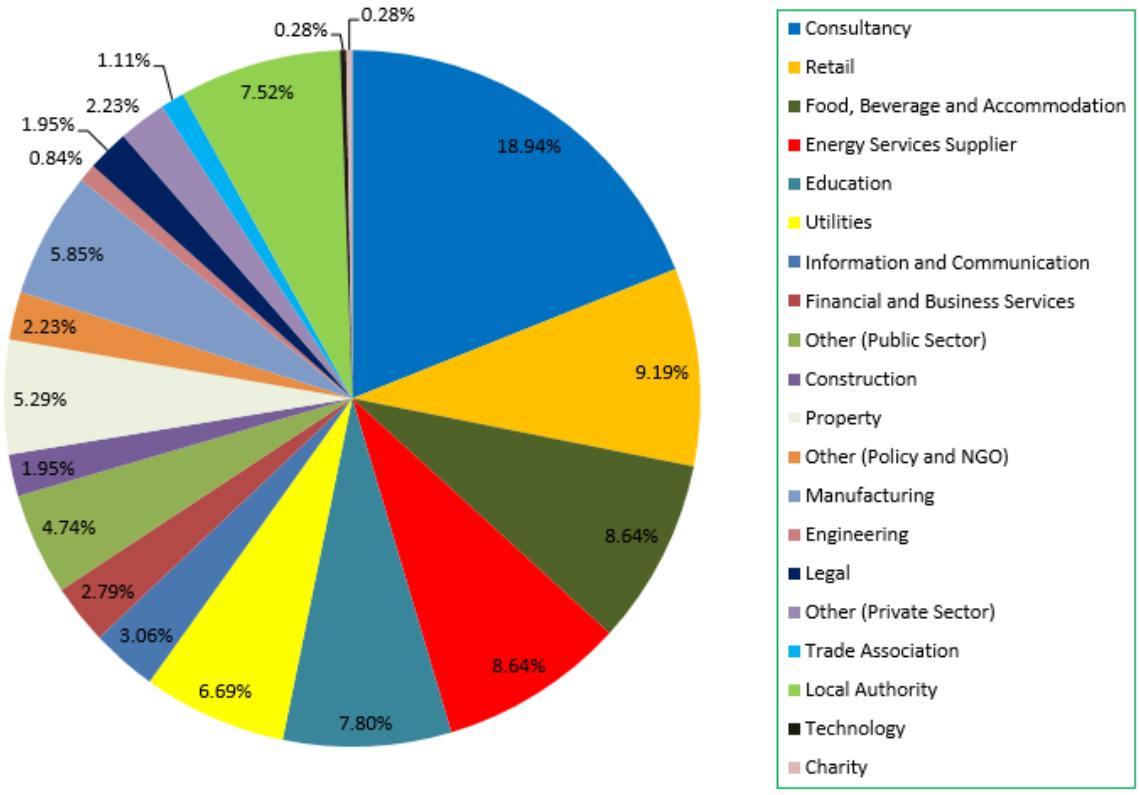
6.1.1. Sample size and description

An online survey was carried out with energy managers working in the large commercial sector, via the Energy Managers Association (EMA), in order to understand their use of RAAHP. To assess how representative the responses are of the sector as a whole, we first characterise the whole UK sector, and then focus on our sample.

Characteristics of the large commercial sector

The large commercial sector (for the purpose of this study) covers businesses with more than 250 employees across all UK industry sectors. The EMA has around 2,000 members deemed to be relevant to the study. Its members are energy managers or those working with energy across a broad spectrum of sectors, including for example, energy, food and retail, as shown in Figure 7. The companies from which the EMA's members come tend to be large enough to warrant a dedicated person being employed to manage energy use (unlike in the SME sector).

FIGURE 7: MEMBERSHIP OF ENERGY MANAGERS ASSOCIATION, BY INDUSTRY



Source: EMA, 2017

The EMA has no specific data on regional spread of its membership, but an indication can be drawn from the proportion of large businesses in each region highlighted in BEIS 2016 (Business Population Estimates for the UK and Regions, 2016). This indicates that in London and the South-East, there is a higher proportion of large businesses per head of population than in the rest of the UK (2 large businesses of >250 employees per 10,000 adults as opposed to 1 large business per 10,000 adults).

FIGURE 8: REGIONAL DISTRIBUTION OF LARGE BUSINESSES ACROSS THE UK

There is a higher proportion of large businesses in London and the South-East compared with the rest of the UK.

Source: BEIS, 2016, Business Population Estimates for the UK & Regions

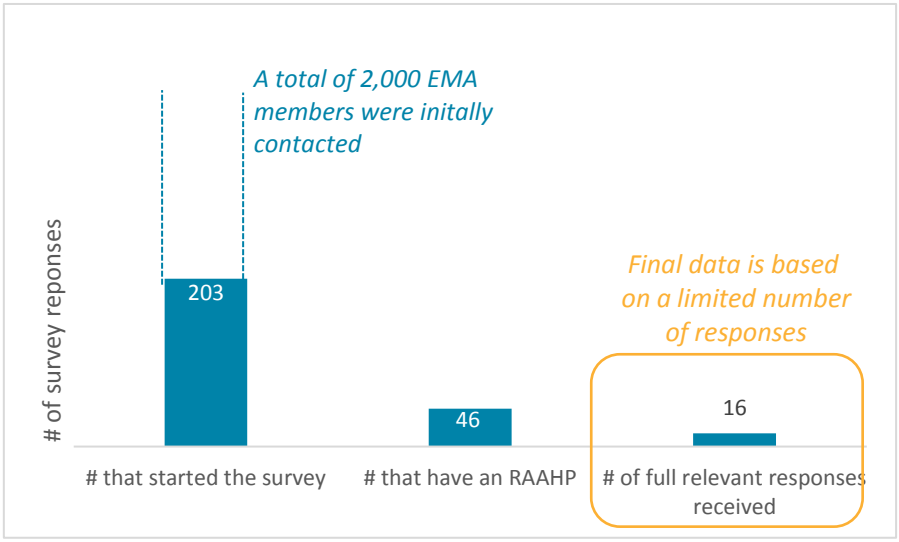
Details of the sample

Selection of relevant responses

16 meaningful responses were received from a survey sent out to 2,000 EMA members (only members considered "relevant" to the study). There were unexpected challenges receiving survey responses via the EMA, meaning that the final sample size is not statistically significant for the UK. The results provided are therefore indicative only.

FIGURE 9: SELECTION OF RELEVANT RESPONSES

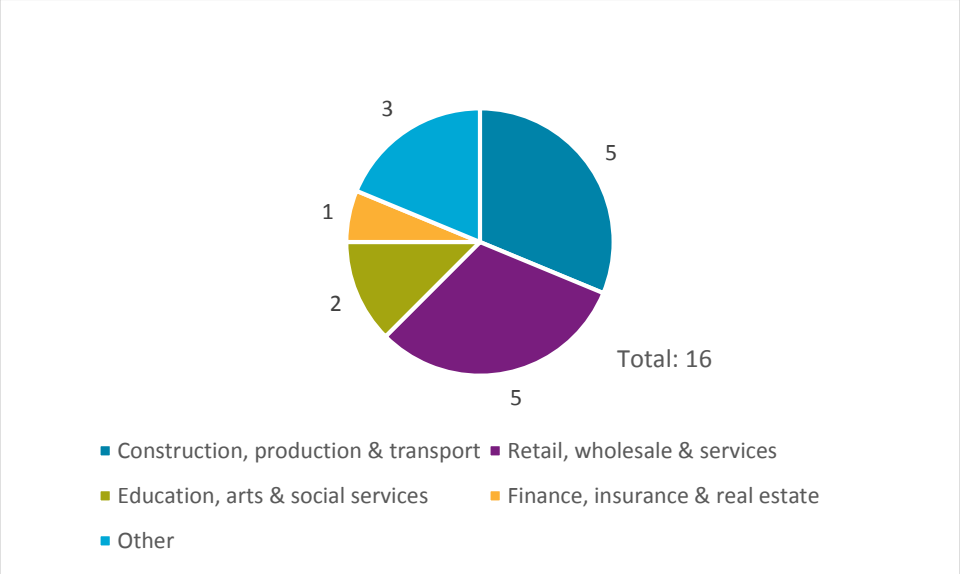
From 2,000 possible responses, 203 began completing the survey, of whom 46 were relevant in that they had an RAAHP. However, only 16 of these provided enough further information to add meaningful data, with the remainder either not completing many questions, or answering "don't know".



Spread of industry sectors covered by sample

FIGURE 10: SECTOR REPRESENTATION OF FINAL SAMPLE

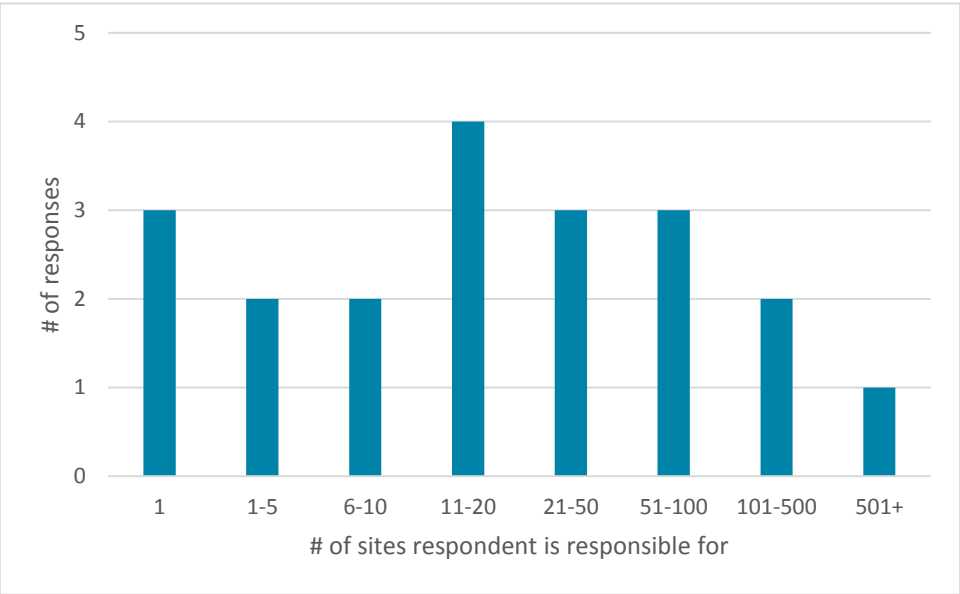
Due to the limited number of responses, industry sectors have been grouped together for analysis as shown below. The majority are from construction, production and transport, and retail, wholesale and services.



Size range of companies covered by the sample

There is not enough data to provide an accurate answer on the company size, but we can get an indication of company by assessing the number of sites each respondent is responsible for. As seen in Figure 11, there is a relatively even spread across the range of "number of sites".

FIGURE 11: INDICATION OF COMPANY SIZE BY ASSESSING NUMBER OF SITES EACH RESPONDENT IS RESPONSIBLE FOR

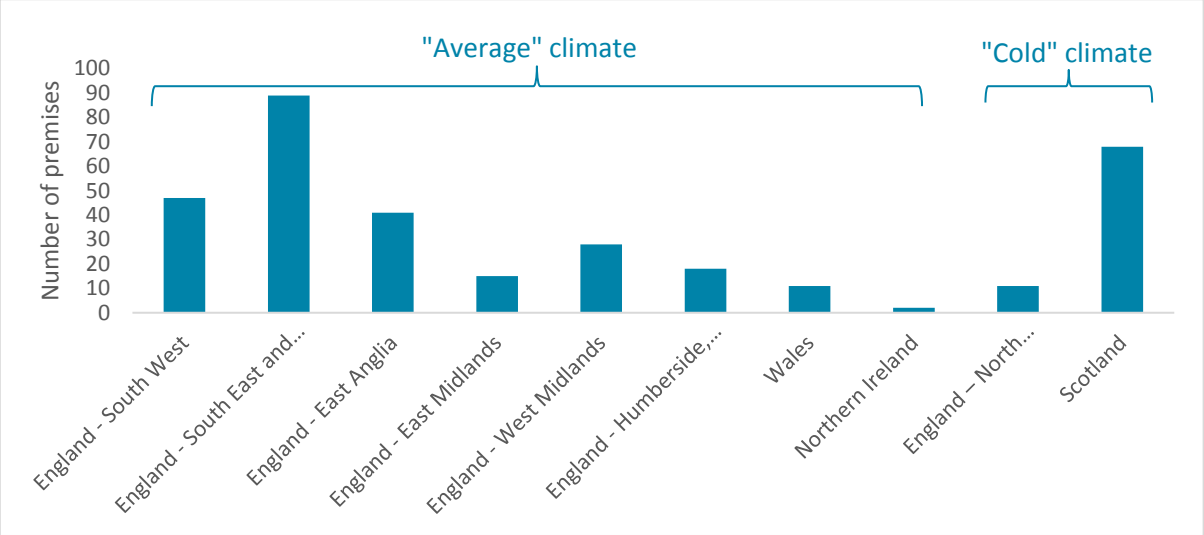


Regional spread of companies covered by the sample

The regional spread of sites for which survey responses represent is relatively representative of the spread in the UK as a whole – with the greatest number of sites in the London / South-east region (see Figure 12 below). Our sample is a little over-represented in the "average" climate zone (i.e. we have many responses related to sites in Scotland), which we consider in later analysis.

FIGURE 12: REGIONAL SPREAD OF SITES FROM WHICH DATA WAS SAMPLED

The majority of responses were for a company with multiple sites, so this graph breaks down each site as a single data point to assess geographical spread.

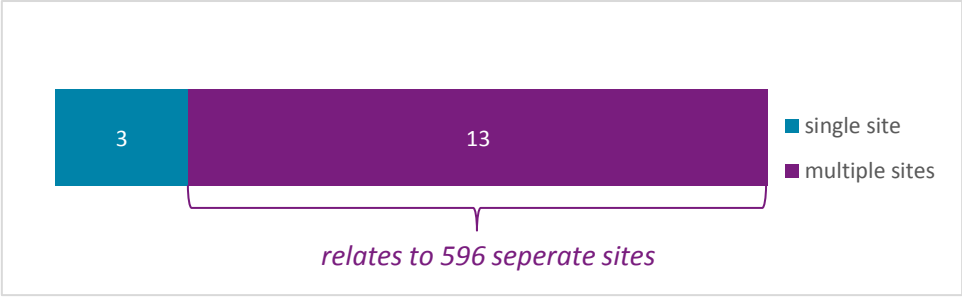


Do survey responses relate to single or multiple sites?

The majority of responses are from energy managers responsible for – or with involvement in – the running of RAAHP at several sites. This means that although the sample size is 16, the total number of sites for which the survey responses relate to is much larger at 599 (3 single sites, plus 13 responses from a combined total of 596 sites). This means the data can carry more weight (see Section 6.1.5 for discussion of how this was dealt with).

FIGURE 13: NUMBER OF RESPONSES RELATING TO SINGLE SITE VERSUS MULTIPLE SITES

The sample was dominated by companies whose responses related to RAAHPs installed at more than one site.

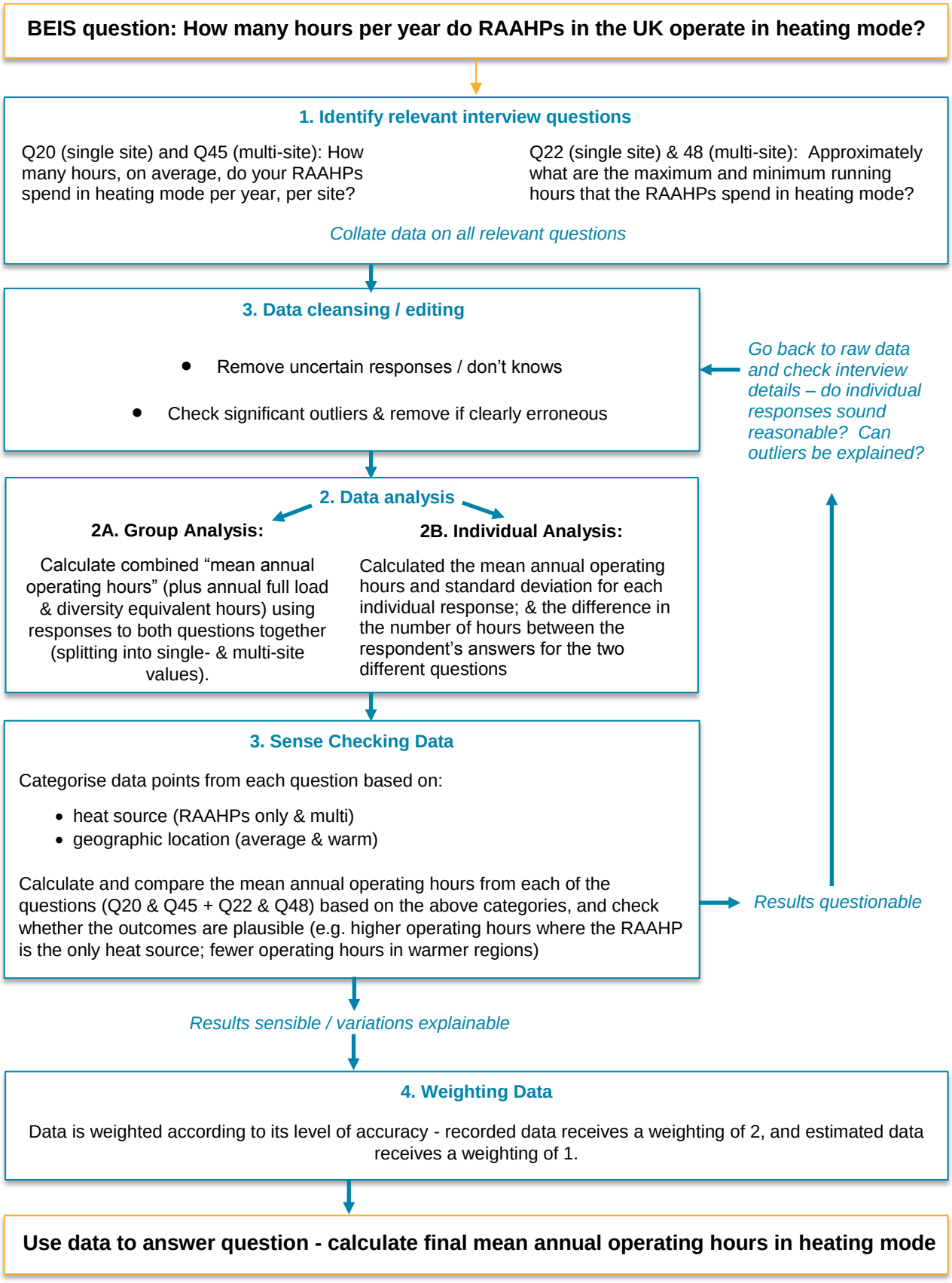


6.1.2. Data processing and analysis

Raw data processing

The only question from BEIS for which we have sufficient data to enable conclusions to be drawn, is that related to the annual operating hours for the RAAHP. We describe in Figure 14 the steps taken to process this data, to illustrate our data processing methodology.

FIGURE 14: DATA PROCESSING METHODOLOGY – EMA DATA



Data cleansing / editing

The following list highlights the specific data editing carried out.

- Three data points for "annual running hours" and seven data points for "maximum / minimum running hours" appeared to actually represent *daily* instead of *annual* running hours. The values were in the range 8-20 hours, which is very few hours in a year, but in-line with what we would expect daily running hours to be. We assessed the responses to other questions by these respondants, and they were consistent with a "wrong" interpretation of the question as asking about daily rather than annual running hours. Data was accordingly scaled up to annual rather than daily values and fed into our data set.
- Data points were removed where the answer was "don't know" or blank.

Data Analysis - Calculating full load equivalent running hours

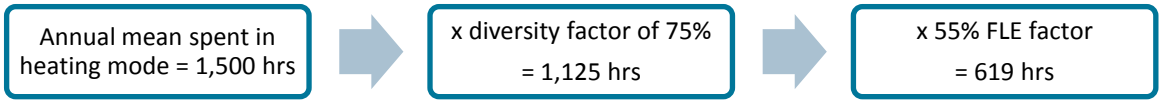
The concept of full load equivalent running hours represents the total hours the RAAHP would have to run on full load to consume its annual energy consumption in a given mode (heating or cooling). Based on the consistency of the estimates of FLE hours in heating mode provided by the installers (see page 14) and the fact that these estimates have been confirmed by several of the manufacturers we interviewed, we have applied a methodology proposed by one of the installers to calculate this value. The method applied is as follows.

- a diversity factor (time spent in ON-mode) of 75% is applied first, which represents the share of the time that the compressor in the outdoor unit is working in relation to the time that one or several indoor units are set to heating mode.
- **A full load factor of 55%** during the time the compressor is on is then applied to the resulting time in ON-mode. This is calculated from the assumed distribution of time spent at different operating capacities as shown in the table below (and sense checked during our research). It means that, for example, for 10% of the RAAHP's running time, the compressor runs at full (100%) capacity; for 30% of the RAAHP's running time, the compressor runs at 75% of its full capacity, and so on. When we combine the different operating capacities and weight them according to the proportion of the total runing time which they apply to, we get full load equivalent factor of 55%.

Proportion of running time	Operating capacity
10%	100%
30%	75%
30%	50%
30%	25%

- Combining these two factors provides us with a factor of 41.25% for the full load equivalent hours of RAAHPs used for heating in the UK.

Example calculation of FLE running hours for heating:



The above assumptions have been confirmed by interviews with installers and manufacturers during this research as being realistic estimates reflective of reality.

Sense checking

After initial data cleansing and analysis (as illustrated above), each remaining individual data point was displayed on a scatter plot according to system type and geographical location. This enabled identification of further significant outliers or anomalies in the data. Where such data points were identified, the source interview was investigated to assess the data point validity, and the outcome taken into consideration when coming to calculate the final mean running hours figure (see Section 6.1.5).

Comparison of RAAHP only and multi-system data points

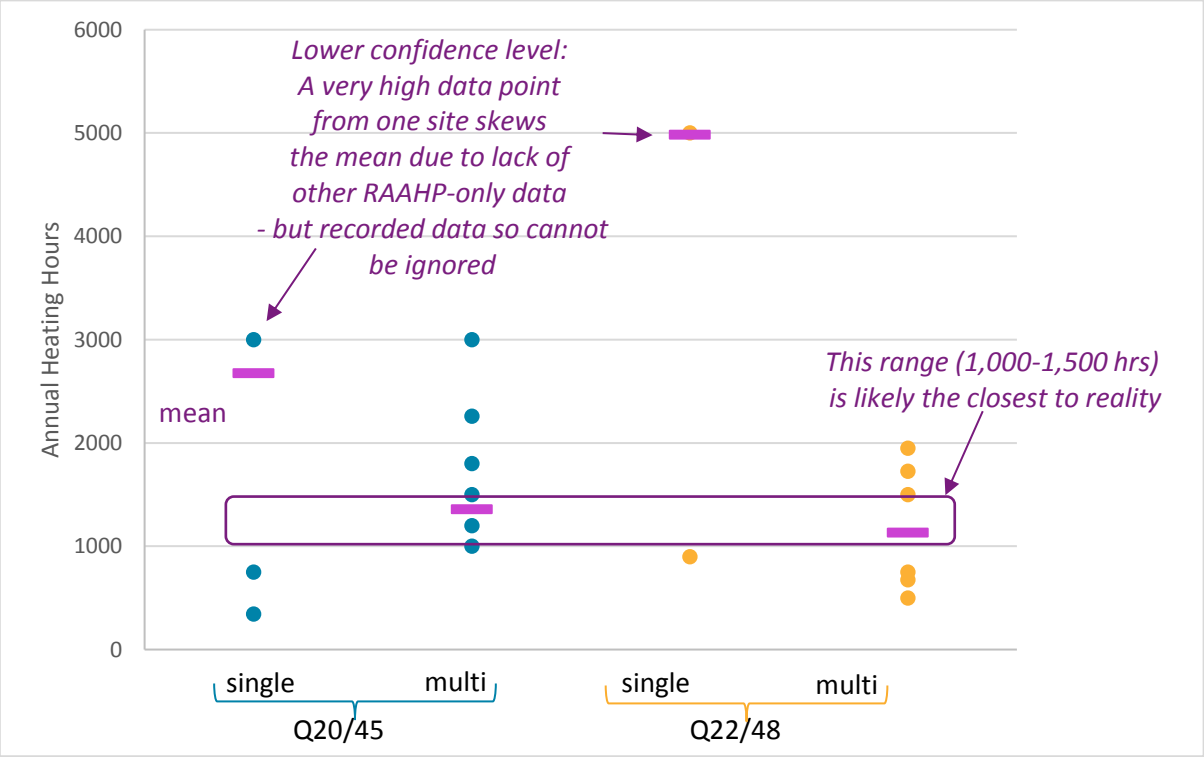
The comparison of RAAHP only systems and multi-systems in the scatter plot (Figure 15) highlights that we have insufficient data for RAAHP-only systems to give a meaningful answer. There are only 3 data points, of which one provides a value significantly higher than all the others, so the confidence level in the data is low. However, this data was claimed to be from "recorded data", so it cannot be ignored in our analysis. The confidence level in the multi-system data is higher because we have more points in a similar range. We would expect RAAHP-only systems to have higher running hours, but perhaps not as much higher as our data indicates.

FIGURE 15: COMPARISON OF DATA SPREAD ON ANNUAL OPERATING HOURS FOR HEATING – BY SYSTEM TYPE (RAAHP-ONLY OR MULTI SYSTEM)

The graph illustrates the data received in response to the two different interview questions which all addressed annual operating hours:

- Q20 (single site) and Q45 (multi-site): How many hours, on average, do your RAAHPs spend in heating mode per year, per site?
- Q22 (single site) & 48 (multi-site): Approximately what are the maximum and minimum running hours that the RAAHPs spend in heating mode?

Results are compared between systems where the RAAHP is the only heating system ("single"), and those where the RAAHP is installed alongside one or more other systems to provide heating ("multi").



Comparison of average and cold climate data points

As seen in Figure 16, the data is relatively closely aligned in this scatter plot, with the exception of four outliers which in fact all relate to a single survey response (the same one which created outliers in the

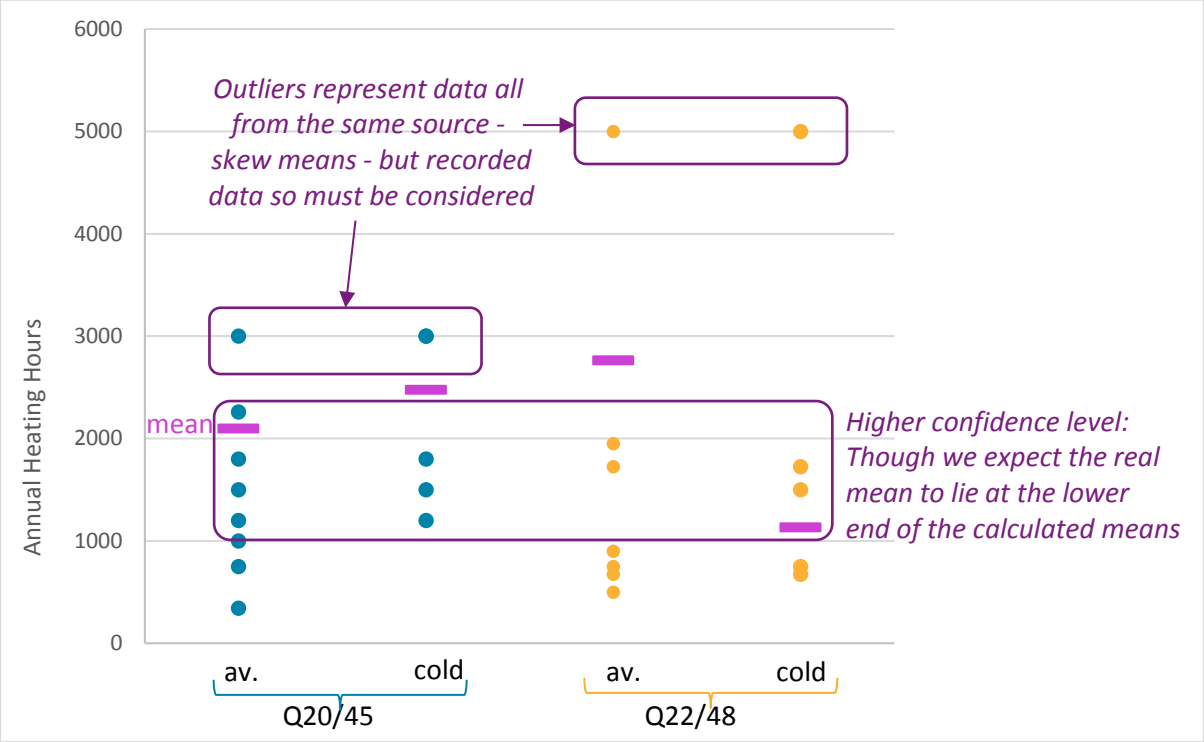
above graph). Again, they cannot be ignored as they apparently come from recorded data rather than estimations, but nevertheless their influence on the mean should be treated with caution. We expect therefore, the real means to lie at the lower end of those shown in the scatter plot.

FIGURE 16: COMPARISON OF DATA SPREAD ON ANNUAL OPERATING HOURS FOR HEATING – BY GEOGRAPHICAL LOCATION (COLD OR AVERAGE CLIMATE)

The graph illustrates the data received in response to the three different interview questions which all addressed annual operating hours:

- Q20 (single site) and Q45 (multi-site): How many hours, on average, do your RAAHPs spend in heating mode per year, per site?
- Q22 (single site) & 48 (multi-site): Approximately what are the maximum and minimum running hours that the RAAHPs spend in heating mode?

Results are compared between sites with a cold ("cold" = Scotland and northern England) or average ("av." = mid- and southern England) climate.



Data weighting

Weighting according to data accuracy

Raw data was attributed greater weight (valued at 2) if it had come from recorded data as opposed to estimated data (valued at 1).

Weighting data from multiple sites and single sites?

Data analysis was carried out to assess the impact of *weighting* each data point according to the number of sites for which it related to (e.g. if there were 100 sites, the data point is effectively multiplied by 100). However, this approach was changed in favour of an *unweighted* approach, treating each data point as one point, regardless of whether it related to a single site or several sites. This is because:

- *In such a small sample, weighting by number of sites magnifies data discrepancies, skewing the mean:* The number of sites for which each point relates to ranges from a single site, to 100s of sites. Therefore, with such a small data set available (16 responses), weighting data points according to number of sites can seriously impact the calculation of the mean. For

example, if a single data point is significantly higher or lower than the other data points, but relates to many sites, it creates a mean value which is not representative of the whole data set.

- *Data unweighted by number of sites creates a mean value most in line with the wider market view:* The final calculated mean values from data which is *unweighted* by number of sites, is much more in line with the indicative mean values drawn from the views of the wider market (installers, manufacturers and other stakeholders), interviewed for this project. This acts as a sense-check for our data analysis and indicates that the unweighted data is most representative of reality.

Weighting by business size and sector

It was decided that due to the very limited number of responses to the survey, and limited spread of business size and sector, weighting by these variables did not add value.

6.1.3. Use for heating

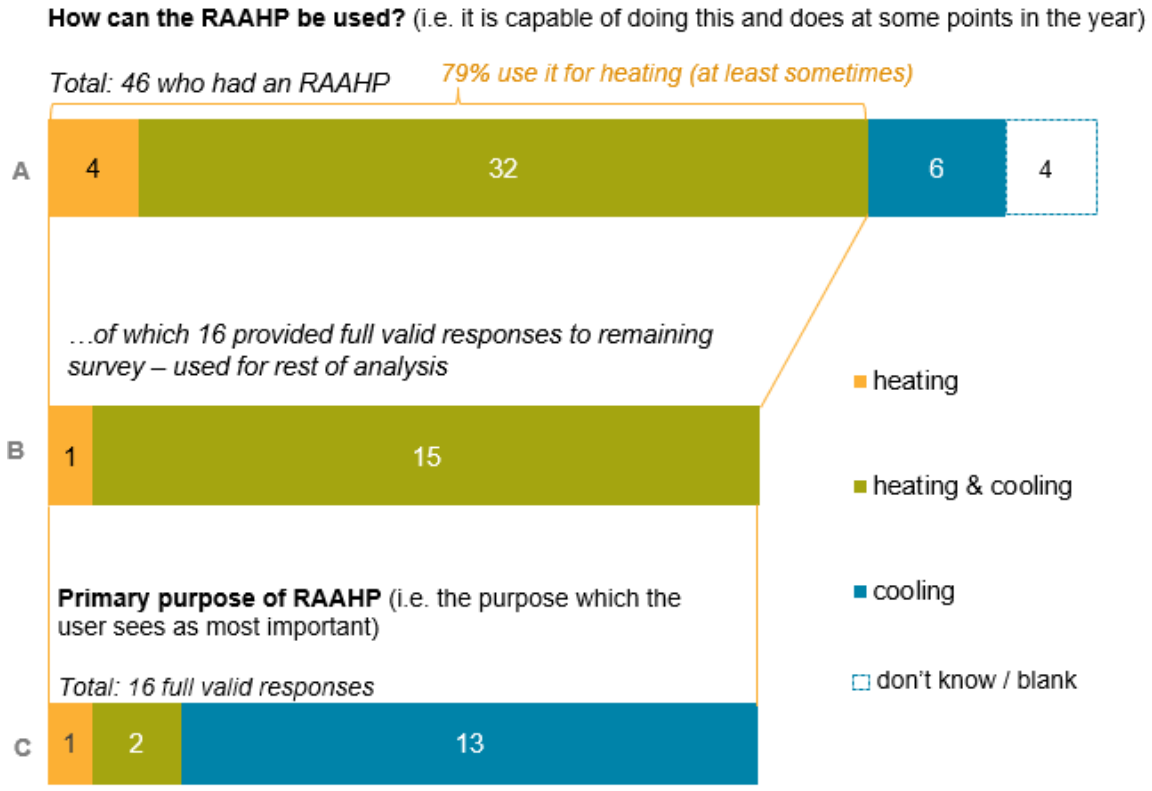
RAAHPs are widely used for heating – but their primary purpose remains cooling

The majority of respondents said that the system was designed for both heating and cooling, and the majority use it for heating at least at some points throughout the year. However, a clear message from the interviews was that the majority saw the *primary purpose* of the RAAHP as for space cooling.

FIGURE 17: USE & PURPOSE OF THE RAAHP

What the charts show: Charts A & B illustrates whether the RAAHP is used for heating, cooling or both at any time during the year. This would include very minimal use. Chart C illustrates the respondents' opinion on what the *primary* purpose of the RAAHP is (what it is used most for).

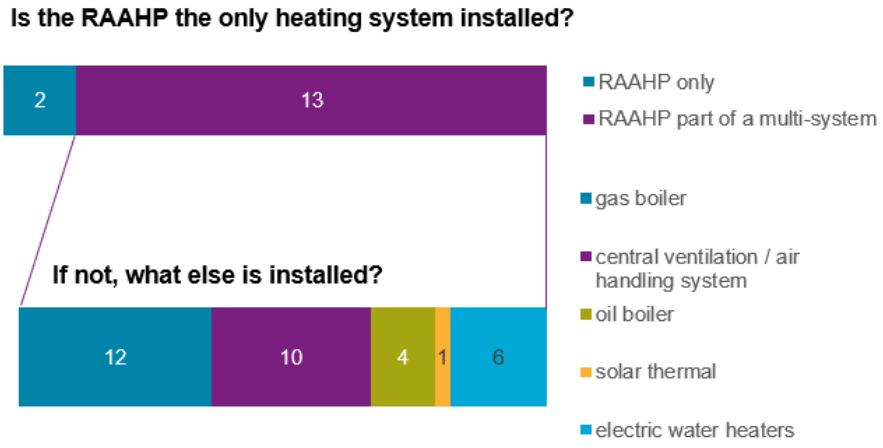
Which respondents are covered: Chart A shows responses from the 46 respondents who have an RAAHP (at one or more sites). 4 of these respondents had an RAAHP but did not offer information on its use). The remaining 42 includes some respondents who did not complete the remainder of the survey, or who were discounted from further analysis for other reasons. Chart B & C represents the 16 responses which were used for the rest of the data analysis because they were relevant to BEIS (i.e. used the RAAHP for heating), and provided full valid responses to the majority of the survey.



Most RAAHPs do not provide all the heating, and are installed alongside another heating system

It can be seen that the majority of responses indicated the RAAHP was part of a multi-system with primarily gas boilers and/or central ventilation or air handling systems. Given the response in Figure 17 above, that the primary purpose of RAAHPs is usually cooling, it is likely that the second system generally provides a large share of the heating needs.

FIGURE 18: RAAHP AS A SINGLE HEATING SYSTEM OR INSTALLED ALONGSIDE OTHER SYSTEMS



6.1.4. Capacity

The data for this value was insufficient to draw meaningful conclusions for this project.

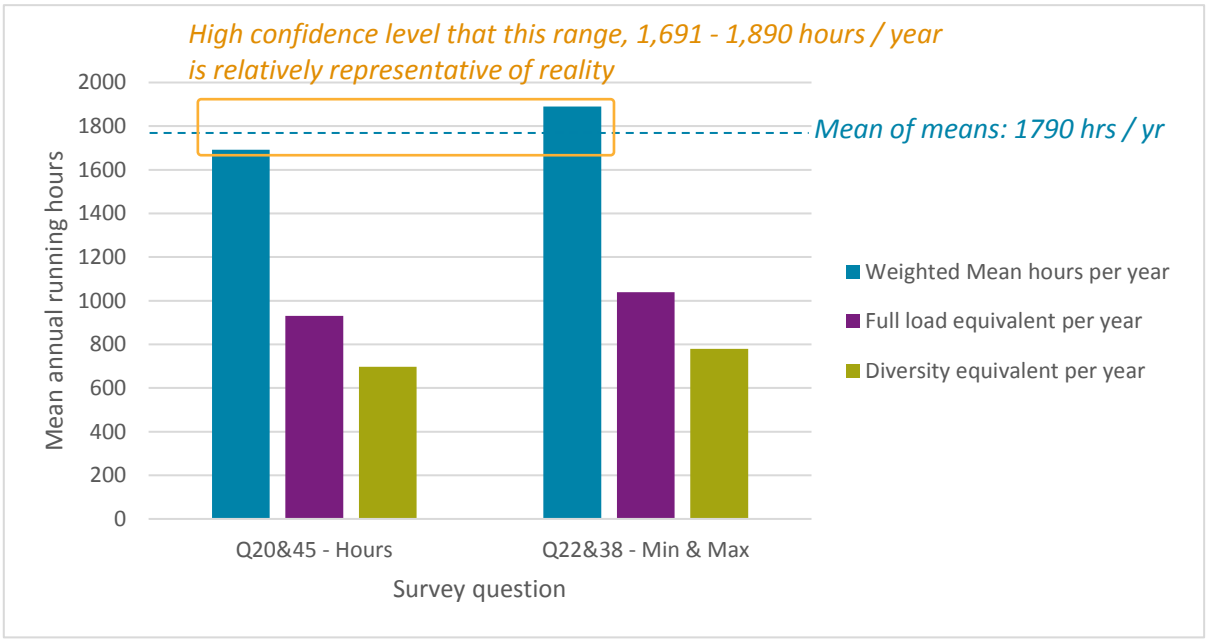
6.1.5. Running hours in heating mode

How many hours, on average, do RAAHPs spend in heating mode per year?

As discussed in 6.1.2, we carried out extensive data cleansing, analysis, and sense-checking to create an "annual running hours" data set as accurate as possible. From this processed data set, means have been calculated and highlighted in Figure 19 below. The data range (1,691-1,890 hours per year) coming from the two different survey questions, tallies well with the outcomes of our wider research, so although our data has been limited, *we believe this is a good indication of real mean annual running hours*.

FIGURE 19: MEAN ANNUAL OPERATING HOURS, FULL LOAD EQUIVALENT & DIVERSITY EQUIVALENT

This compares the mean operating hours calculated from responses to two different question types – firstly respondents were asked how many hours a year their system was in heating mode, and secondly, they were asked to indicate the minimum and maximum hours per year it usually was in heating mode.

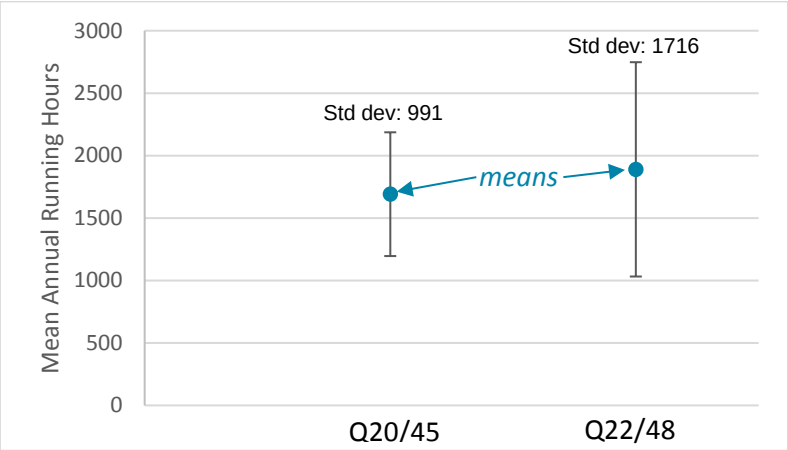


What is the distribution around the average value?

The scatter plots in Figures 20 and 21 highlight the wide distribution of data points around the mean. When we consider the entire range of data collected from our survey, the "annual running hours" range from 500 to 5,000 per year, with "maximum annual running hours" up as high as 7,500 (from "recorded data"). This gives associated high standard deviations, as seen below. This indicates the vast data spread and therefore inherent uncertainties in drawing distinct conclusions. While we are satisfied that the mean values presented are reasonably representative, as discussed above, it is clear that further research and/or monitoring is necessary to increase confidence level in the results.

FIGURE 20: STANDARD DEVIATIONS AROUND THE MEAN RESPONSES ON RUNNING HOURS

The graph shows the mean annual running hours calculated from responses to the two different questions, and highlights standard deviation around each mean. It can be seen that the standard deviation is much higher around Q22/48 – this is influenced by one single data point at 5000 hours from recorded data.



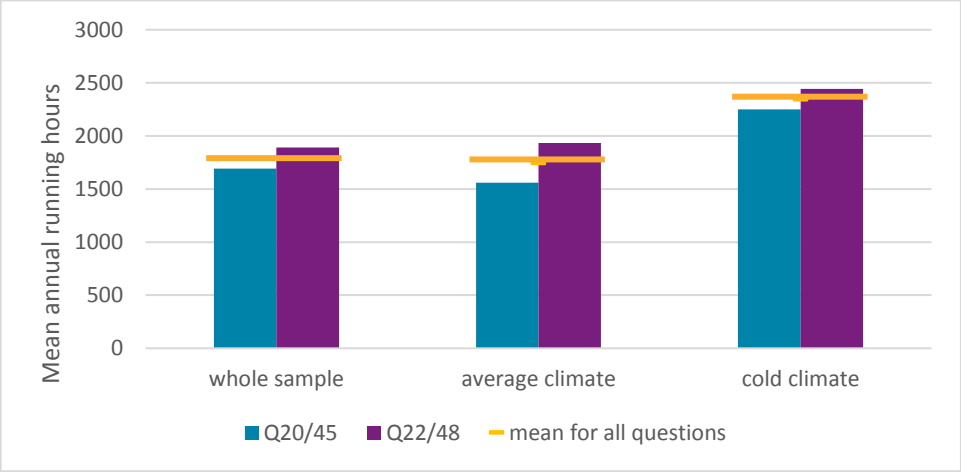
Variation by geographic location

Our data shows generally higher running hours in the cold than in the average climate regions, as may be expected. However, caution must be taken in drawing conclusions from this, due to the limited sample size, and the fact we have no data granularity where we have a response which relates to several sites in both climate zones. This means the same running hours figure is applied across both average and cold climate zones if the respondent has a site on each zone. Only just under half of responses are specific to a single climate zone.

FIGURE 21: VARIATION IN ANNUAL RUNNING HOURS BY GEOGRAPHIC REGION

The graphic shows the means calculated from all the responses to the two survey questions on running hours, for the whole sample, and divided by "average" climate (South/central England and Wales), and "cold" climate (Scotland/northern England). Where a response was given for a multi-site company, the response is counted once in each region.

- 9 responses are double counted in cold & average climate
- 1 response relates only to a cold climate site
- 7 responses relate to only average climate sites



Variation by end-user sector, building type, number of employees, system type (split / VRF) system capacity

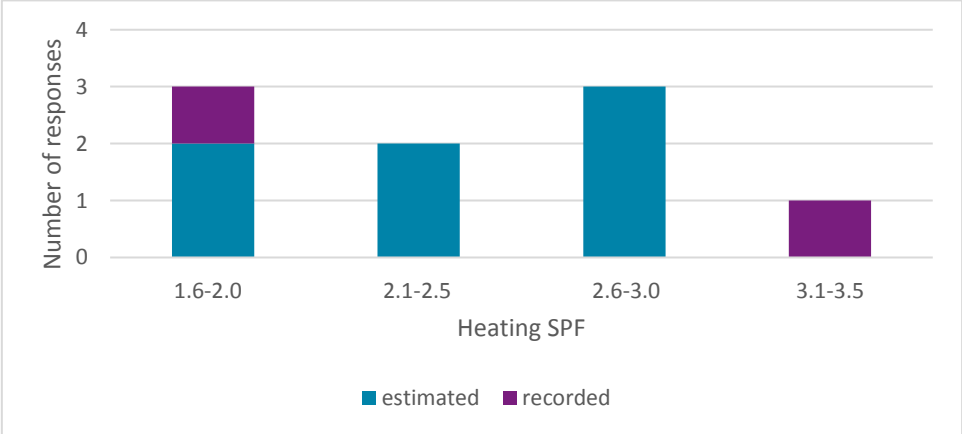
Due to lack of data, it is impossible to draw conclusions about variations in the mean according to any of these factors.

6.1.6. Heating efficiency

There is insufficient data to draw meaningful conclusions on this topic. 9 responses were given which were spread over a range of SPFs. The 2 responses which were based on "recorded" as opposed to "estimated" data showed an SPF both at the lower and upper end of the scale. Further research or field testing is required to draw an accurate conclusion about heating efficiency.

FIGURE 22: HEATING EFFICIENCY RESULTS FROM LIMITED SAMPLE

This is based on just 9 responses, so conclusions should not be drawn from this data without extensive further research (e.g. monitoring or trials).



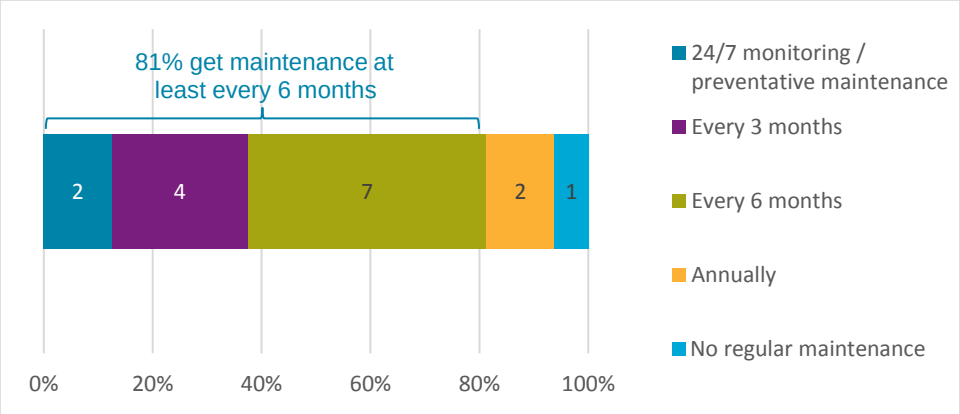
6.1.7. Results on other questions from BEIS

Maintenance – most receive it at least twice a year

Of the 16 relevant responses, 15 said they got regular maintenance on their RAAHP. Although it is a small sample, given that nearly everyone did get regular maintenance, 81% of which got this at least every 6 months, it is likely to be relatively representative of the wider sector.

We know from wider research that most HPs (& indeed other heating/cooling systems) sold into the B2B market tend to be sold alongside maintenance contracts. In addition, the F-Gas Regulation has requirements for regular leak checks which will apply for at least some of our respondents. This leak check is typically built in to a regular maintenance check.

FIGURE 23: HOW REGULARLY IS MAINTENANCE CARRIED OUT ON YOUR RAAHP?



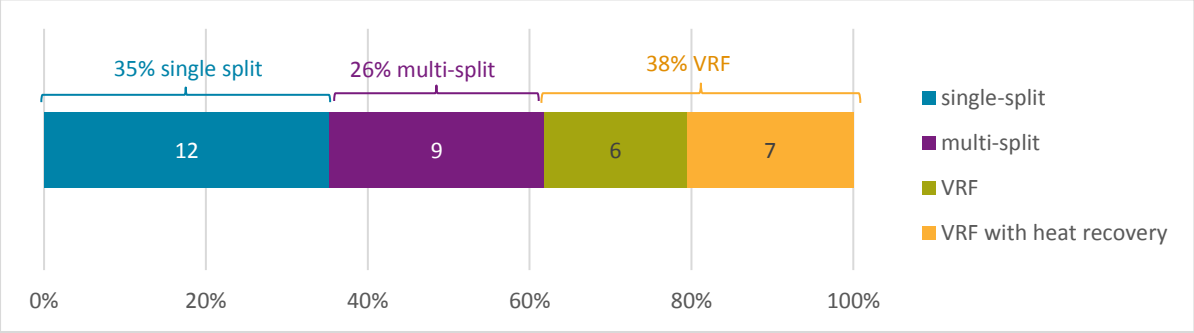
Insufficient responses were received on maintenance costs to present any meaningful results or draw conclusions.

Preferred type of RAAHP – VRF just ahead

VRF (including VRF with heat recovery) and single-splits are the most popular choice amongst respondents, with the multi-splits following. The data includes multiple system types from single respondents, and it can be seen from the data that 50% of all responses had a VRF or a VRF plus single/multi-split; and 50% no VRF (only split). The small size of the sample and the relatively even spread between the different options, however means it is not clear how representative this is. There was insufficient data to draw conclusions regarding variations in annual running hours or performance as a result of RAAHP type.

FIGURE 24: WHICH TYPE OF RAAHP IS INSTALLED?

This covers responses from the 16 valid respondents, including multiple responses from a single respondent (referring to systems installed at different sites, or where more than one system is installed at a single site).



Compared to the total UK sales of RAAHP products, this is an overrepresentation of VRF-type systems (which only represented a share of around 11% of the sales volume in 2016). However, this can be explained by the fact that due to their larger capacities, VRF systems are more commonly found in larger buildings and thus more often in the target group of the energy managers survey.

6.2. Results from the Small / Medium Enterprise (SME) survey

6.2.1. Sample size and description

A survey was carried out in association with *fineline market research*, with 100 SMEs, to understand their use of RAAHPs. To understand how representative our survey responses are, we first provide some background on the overall sector below, and then compare the coverage in our sample, identifying any gaps.

Characteristics of the UK SME sector

An SME is defined as a firm with ≤250 employees. According to the *Business Population Estimates (BPE) for the UK and Regions 2016*, the 5.5 million SMEs in the UK represent 99% of all businesses in every main industry sector. The vast majority of these SMEs are small, with less than 10 employees. Only 5% have more than 10 employees, and only 1% have more than 50. More than half of SME's are in five industry sectors, as highlighted in Figure 25. Regionally, the highest proportion of SMEs per person is found in southern England, as shown in Figure 26.

FIGURE 25: PROPORTION OF SMES ACROSS UK INDUSTRY SECTORS (NUMBER OF BUSINESSES)

We highlight the top 5 sectors for SMEs, showing the number of SMEs in each sector, of a total of 5.5 million SMEs. Other* includes Information & Communication; Transportation & Storage: Education; Manufacturing; Arts, Entertainment & Recreation; Accommodation & Food; Agriculture, Forestry & Fishing; Real Estate; Finance / Insurance; Mining & Quarrying; Electricity, Gas & Aircon Supply; Water; Sewerage.

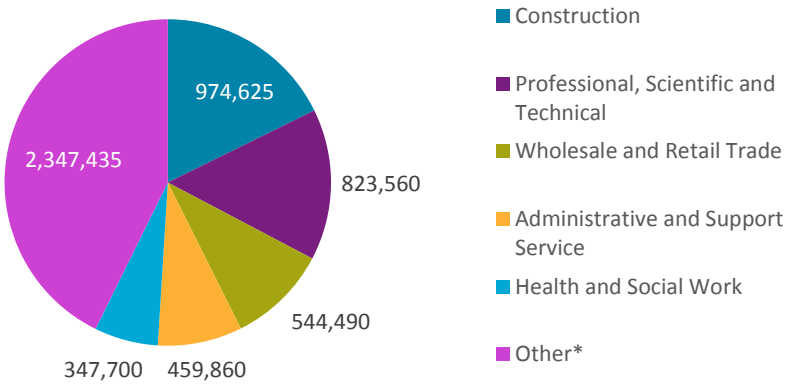
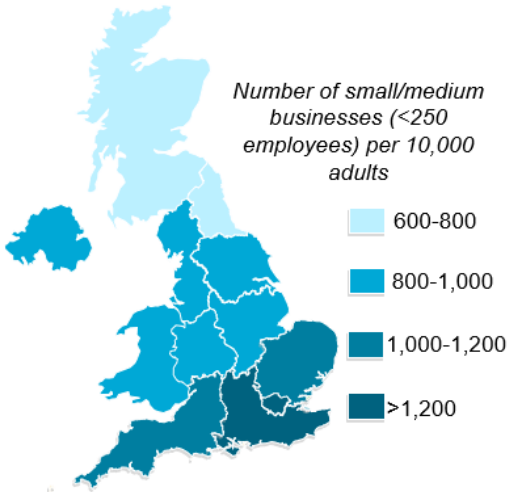


FIGURE 26: REGIONAL DISTRIBUTION OF SMES ACROSS THE UK

The highest proportion of SMEs are in southern England, with the density of businesses reducing northwards.



Source: BEIS 2016, BUSINESS POPULATION ESTIMATES FOR THE UK AND REGIONS 2016

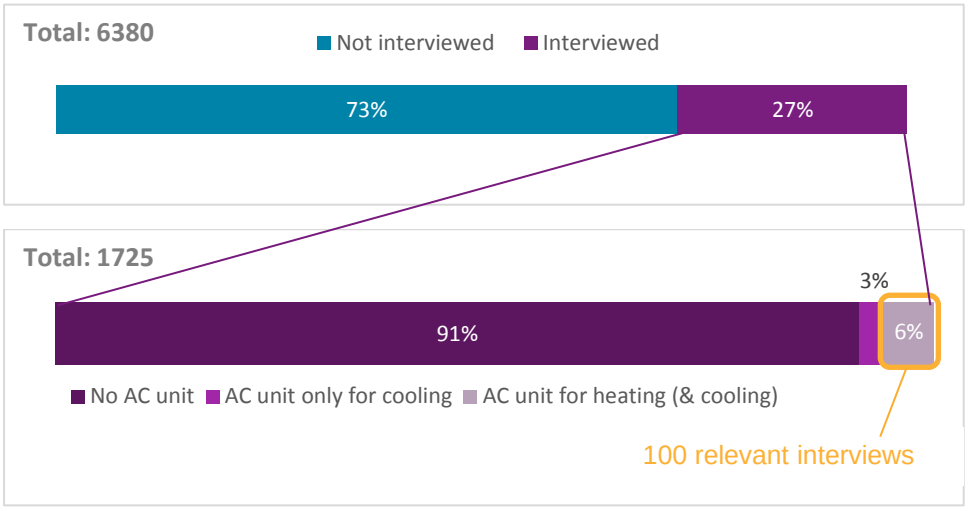
Details of sampling

Selection of relevant responses

100 relevant interviews were completed, from an initial total of 6380 SMEs contacted for interview. Figure 27 illustrates how these 100 were selected.

FIGURE 27: SELECTION OF 100 RELEVANT INTERVIEW RESPONSES

- 73% of the 6380 SMEs contacted were not interviewed about AC – they were either unresponsive, not available for or refused an interview, or on further investigation were not relevant to the study (e.g. non-UK based). AC was discussed with the remaining 1725.
- The majority (91%) of those interviewed about AC were ruled out because they had no AC system.
- A further 3% were ruled out because the AC was only for cooling, which is not relevant to BEIS.
- This left 100 relevant SME interviews.



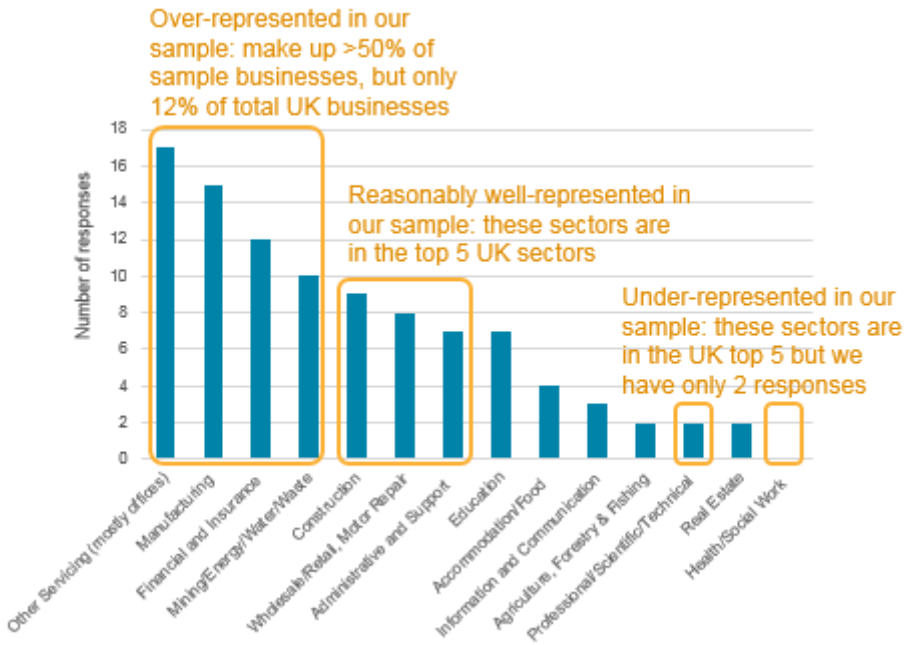
Spread of industry sectors covered by the sample

The 100 relevant SMEs were from a range of industry sectors as highlighted in Figure 28, and business sizes as shown in Figure 29. In order to draw any conclusions from our survey which can be applied across the UK, it is important to assess how representative our survey respondants are of the UK SME sector. While we believe there is reasonable representation of the UK SME sector from the survey responses, some key disparities between our respondants and the UK sector should be borne in mind. Firstly, some sectors are more significant in our sample than in the UK SME sector as a whole, and responses are missing from other sectors which are significant in the UK as a whole. Further, our sample over-represents medium-sized businesses (with over 50 employees), which make up only 1% of UK businesses but 40% of the survey responses.

See Section 6.2.2 *Data Weighting* on page 41 for an explanation of our approach to deal with this disparity.

FIGURE 28: INDUSTRY SECTORS FROM WHICH RESPONSES WERE RECEIVED

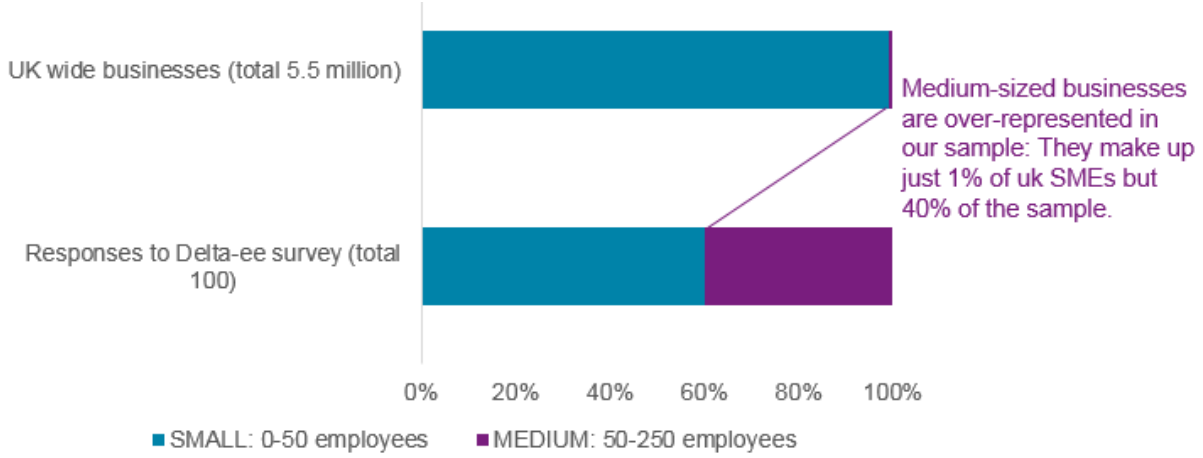
The chart shows representation of different industry sectors in the Delta-ee survey responses. The commentary in the chart indicates how representative the sector breakdown is in comparison to the UK SME sector as a whole.



Size range of companies covered by the sample

Our sample consisted of 40% medium-sized businesses (50-250 employees), and 60% small businesses (<50 employees). This is in contrast to the overall business population in the UK where only 1% of businesses are medium-sized or bigger, the vast majority being small.

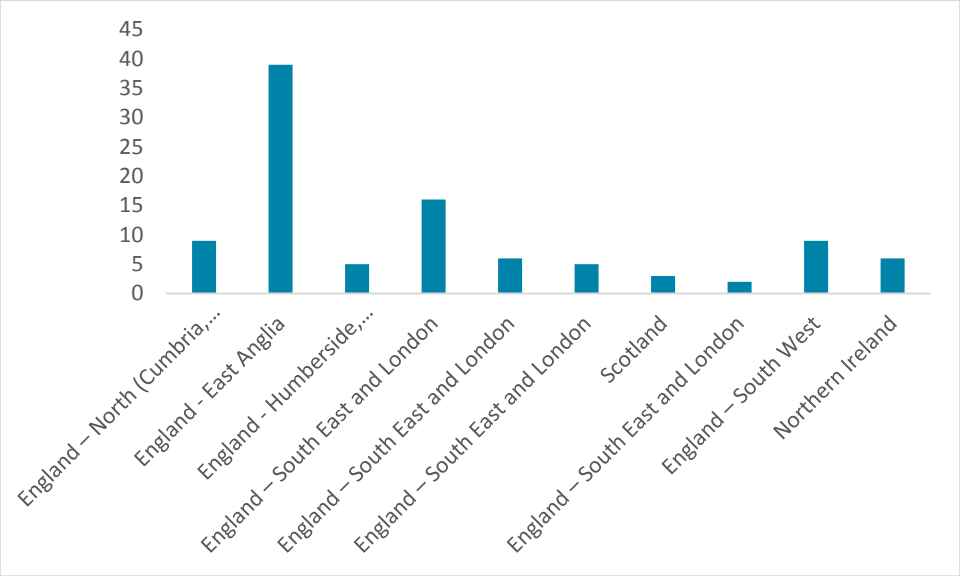
FIGURE 29: COMPARISON OF THE SIZE OF SMES WHO RESPONDED TO THE SURVEY, AND THE SIZE OF SMES IN THE UK AS A WHOLE



Regional spread of companies covered by the sample

The majority of responses were received from the South – particularly the south-east and London. Comparing this data spread to the UK distribution of SMEs shown in Figure 30, it is reasonably representative, where London and the south-east has by far the highest density of SMEs.

FIGURE 30: REGIONAL SPREAD OF SURVEY RESPONSES



Do survey responses relate to single or multiple sites?

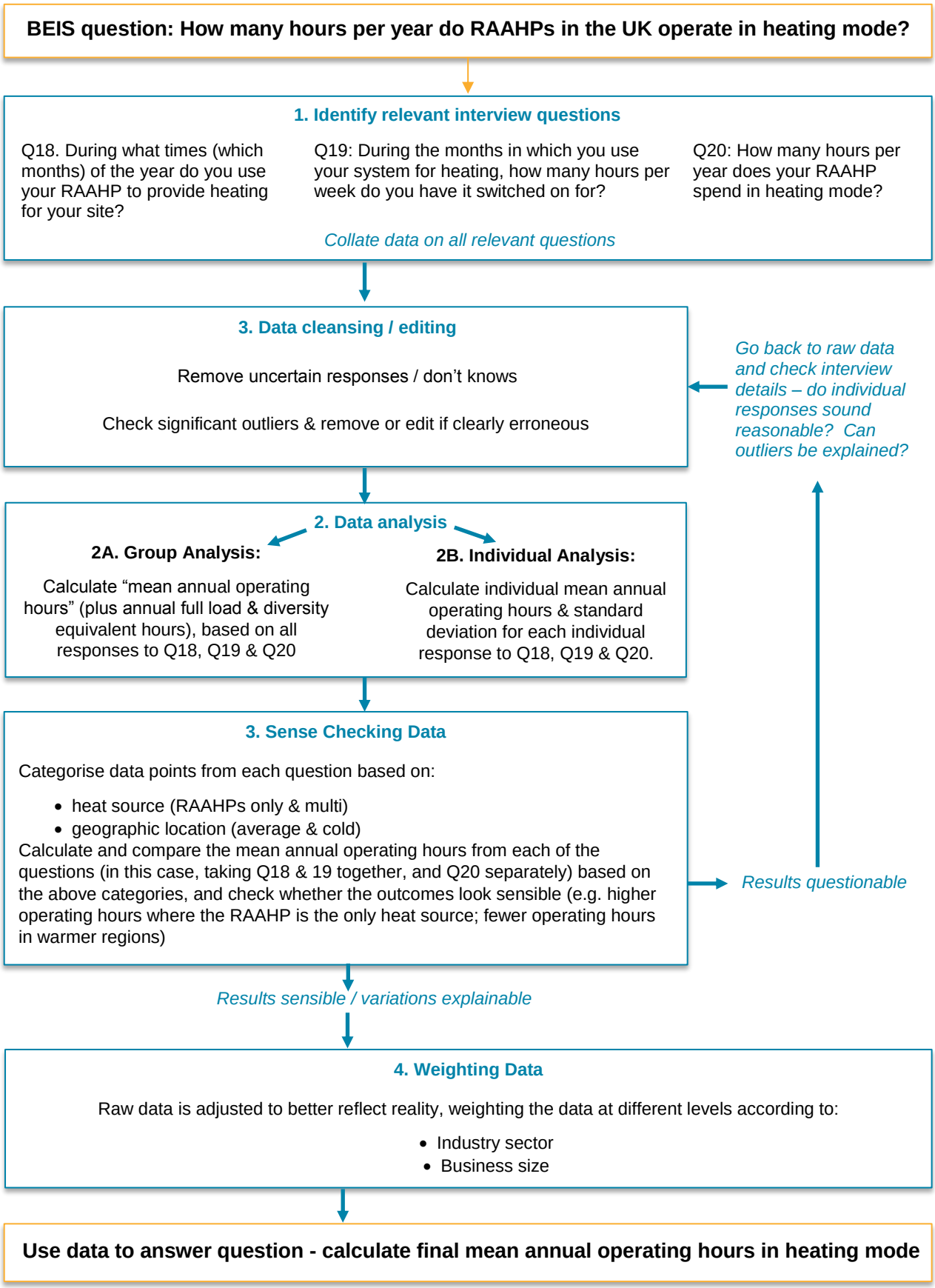
The majority of SME responses related to a single site - 69 of the 100 relevant interviews from the raw data.

6.2.2. Data processing and analysis

Raw data processing

The only question from BEIS for which we have sufficient data to allow conclusions to be drawn, is that related to the annual operating hours for the RAAHP. We describe in Figure 31 the steps taken to process this data, to illustrate our data processing methodology.

FIGURE 31: DATA PROCESSING METHODOLOGY – SME DATA



Data cleansing / editing

The following list highlights the specific data editing carried out:

- Responses given as “don’t know” were removed.
- For the question “how many hours is your RAAHP switched on for?”, five ‘outlier’ responses were removed – where the hours were incredibly high and did not correlate with other information given in the interview.

Data analysis – Calculating Full Load & Diversity Equivalent running hours

For a note on how we calculated the full load equivalent hours, please refer to the explanation provided on page 25.

Sense checking

We illustrate below the spread of raw data from our sample. The results (outputs from which are illustrated in Figures 32 and 2) show several points of interest.

- It is encouraging that the “mean” data across all questions, regions and system types lie in the same running hours range, between ~900 and 1,600 hours per year.
- The responses are in line with expectations considering whether the RAAHP is the single heating system or part of a dual system – the data ranges are lower for dual systems, presumably because the RAAHP meets less of the demand than where it is the only heating system. However, more data would still be required to draw clear conclusions.
- The responses are not in line with expectations regarding geographical location, with the results from the cooler climate showing lower running hours – the opposite of what may be expected. This is on the one hand due to the fact that we have many more data points in the “average” as opposed to the “cold” climate zone (so with more data the results could well change) as well as to the fact that in the data points for the cold climate zone systems which are not the only type of heating system installed are more common than in the data points from the average climate zone.

FIGURE 32: COMPARISON OF DATA SPREAD ON ANNUAL OPERATING HOURS FOR HEATING – BY INTERVIEW QUESTION AND SYSTEM TYPE (RAAHP ONLY OR DUAL SYSTEM)

The graph illustrates the data received in response to the three different interview questions which all addressed annual operating hours:

- Q18 & 19 are taken together because they both refer to *months* of the year: Q18 During what times (which months) of the year do you use your RAAHP to provide heating for your site?; Q19: During the months in which you use your system for heating, how many hours per week do you have it switched on for?
- Q20: How many hours per year does your RAAHP spend in heating mode?

Results are compared between systems where the RAAHP is the only heating system ("single"), and those where the RAAHP is installed alongside one or more other systems to provide heating ("multi").

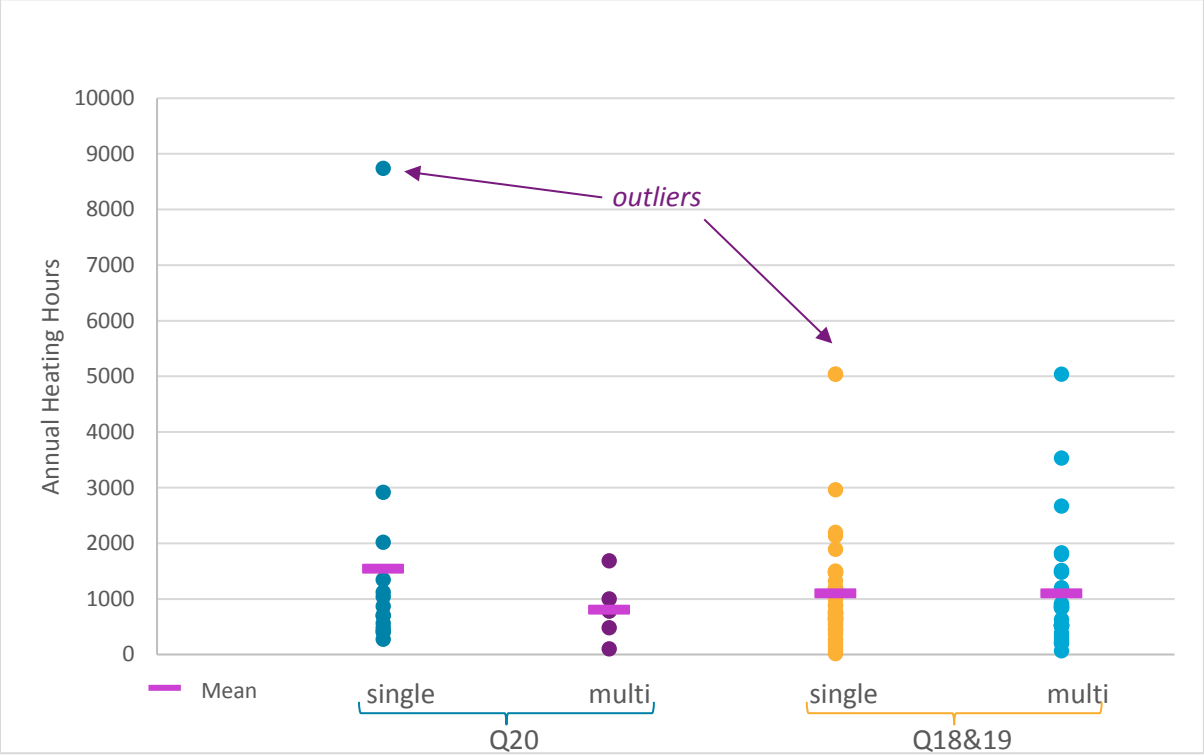
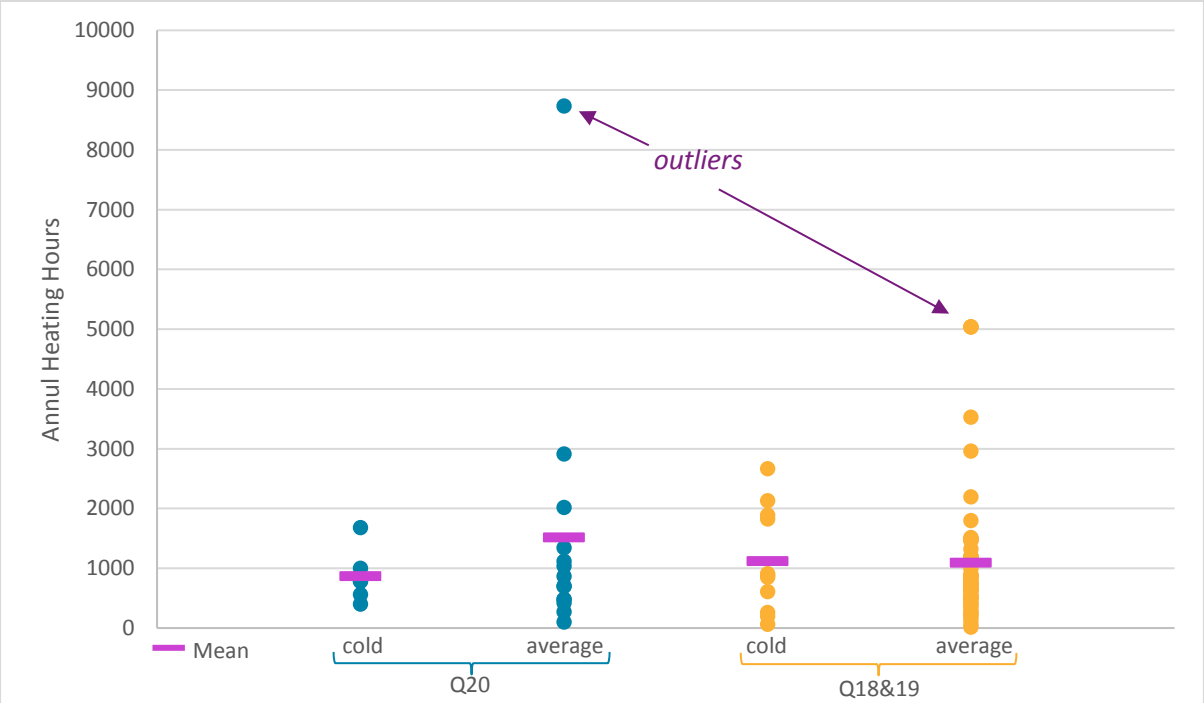


FIGURE 33: COMPARISON OF DATA SPREAD ON ANNUAL OPERATING HOURS FOR HEATING – BY INTERVIEW QUESTION AND GEOGRAPHICAL LOCATION (COLD OR AVERAGE CLIMATE)

The graph illustrates the data received in response to the three different interview questions which all addressed annual operating hours:

- Q18 & 19 are taken together because they both refer to *months* of the year: Q18 During what times (which months) of the year do you use your RAAHP to provide heating for your site?; Q19: During the months in which you use your system for heating, how many hours per week do you have it switched on for?
- Q20: How many hours per year does your RAAHP spend in heating mode?

Results are compared between sites with a cold ("cold" = Scotland and northern England) or average ("av." = mid- and southern England) climate.



Data weighting

Figure 28 and 29 highlight where there are disparities between the characteristics of the sample data and the UK SME population (e.g. in terms of sector representation and business size) – see 6.2.1 *Spread of industry sectors covered by the sample.* In order for our SME data to be representative of the UK SME sector as a whole, we have weighted our data according to business size and sector.

We have tested two different weighting methodologies (V2 and V4), which are described below. The main difference between methodologies is the grouping of company size, with V2 using only 2 categories and merging together all companies <50 employees into a single group. V4 splits the <50 category into <10 and 10-50. There are also some differences in the industry sector groupings.

Having assessed the outcomes of both types of weighting, particularly with regards to the resultant annual running hours calculation, Delta-ee considers V2 to be the more robust, for the following reasons.

- **Lack of data in the <10 employee category:** V4 should technically provide the most realistic result, because companies of <10 employees make up by far the largest proportion of all SMEs (>95%), and should be afforded a higher weighting accordingly. However, our survey received only 20 responses from this sector in total, only 5 of which could provide an answer to Q20 regarding running hours. To weight these responses strongly is likely to heavily skew the data for such a small sample.
- **Sense-check data fits better with V4:** The annual running hours indicated from interviews with installers and other stakeholders (carried out to "sense-check" our data) fits well with the mean annual running hours calculated based on our survey results using V2 weighting. In contrast, the running hours calculated from the V4 weighting gives significantly lower running hours. This *could* be indicative of the fact that smaller companies use their RAAHP systems less. The five responses we have had indicate this could be the case – but Delta-ee would be more comfortable with more data points, because this sector must then be weighted very strongly at 95.4%, and therefore skews the data significantly.
- **Delta-ee would recommend further research directed at the <10 employee companies** (who are important because the make up the majority share of SMEs). Firstly, it would help to understand whether smaller companies really use their RAAHP less than larger ones, as our research indicates. It would also help to clarify whether there is a significantly lower proportion of smaller companies owning RAAHPs (our research indicated that <10 employee companies are much less likely to even have an RAAHP - 95% of those with <20 employees did not have an RAAHP as compared with 90% and 87% for the larger business size categories).

Weighting methodology V2

We used the SME data from the business profiling data produced by BEIS (Business Population and Estimates, 2016) to weight the interview responses by *size* and *sector*. The following size and sector groupings were used to make the weighting as robust as possible given the relatively low overall sample of 100 achieved interviews.

TABLE 7: WEIGHTING BY BUSINESS SIZE (METHODOLOGY V2)

Business size	Weighting (represents proportion of businesses of each sector grouping in UK as a whole)
<50 employees	99.3%
50-249 employees	0.7%

Sample outcome codes were also checked against employee size data provided within the list sample to see whether any weighting was required due to non-response bias. However, non-response levels (which included refusals and company policy not to do surveys) were virtually identical across size bands at 11% (<50 employees) and 12% (50-249 employees) so no further weighting was applied.

TABLE 8: WEIGHTING BY SECTOR (METHODOLOGY V2)

Due to the limited sample size, sectors were grouped together to reduce weighting errors being exaggerated.

- "Construction, Finance & Real Estate" includes: Construction; Financial and Insurance Activities; Real Estate Activities
- "Production, Transportation & Storage" includes: Agriculture, Forestry and Fishing; Mining and Quarrying; Electricity, Gas and Air Conditioning Supply; Water Supply; Sewerage, Waste Management and Remediation Activities; Manufacturing; Transportation and Storage
- "Retail, Wholesale & Service Activities" includes: Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles; Accommodation and Food Service Activities; Information and Communication; Professional, Scientific and Technical Activities; Administrative and Support Service Activities; Education; Other Service Activities; Central & Local Government

Business size	Weighting (represents proportion of businesses of each sector grouping in UK as a whole)
Construction, Finance & Real Estate	24%
Production, Transportation & Storage	16%
Retail, Wholesale & Service Activities	60%

Weighting methodology V4

We used the SME data from the business profiling data produced by BEIS (Business Population and Estimates, 2016) to weight the interview responses by *size* and *sector*. The following size and sector groupings were used to make the weighting as robust as possible given the relatively low overall sample of 100 achieved interviews.

TABLE 9: WEIGHTING BY BUSINESS SIZE (METHODOLOGY V4)

Business size	Weighting (represents proportion of businesses of each size grouping in UK as a whole)
<10 employees	95.4%
10-49 employees	3.9%
40-249 employees	0.7%

Sample outcome codes were also checked against employee size data provided within the list sample to see whether any weighting was required due to non-response bias. However, non-response levels (which included refusals and company policy not to do surveys) were virtually identical across size bands at 11% (<19 employees), 11% (20-49 employees) and 12% (50-249 employees) so no further weighting was applied.

TABLE 10: WEIGHTING BY SECTOR (METHODOLOGY V4)

Due to the limited sample size, sectors were grouped together to reduce weighting errors being exaggerated.

- "Construction, Production, Transportation", includes: Construction, Agriculture, Forestry & Fishing, Manufacturing, Mining & Quarrying, Electricity etc., Transportation and Storage
- "Retail, wholesale, hospitality and service activities", includes: Accommodation and Food Service Activities, Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles, Administrative and Support Service Activities, Information and Communication, Professional, Scientific and Technical Activities
- "Other" includes: Education, Arts, Entertainment and Recreation, Financial & Insurance Activities, Real Estate Activities, Human Health and Social Work Activities, Other Service Activities (incl. non-profit), Central & Local Government

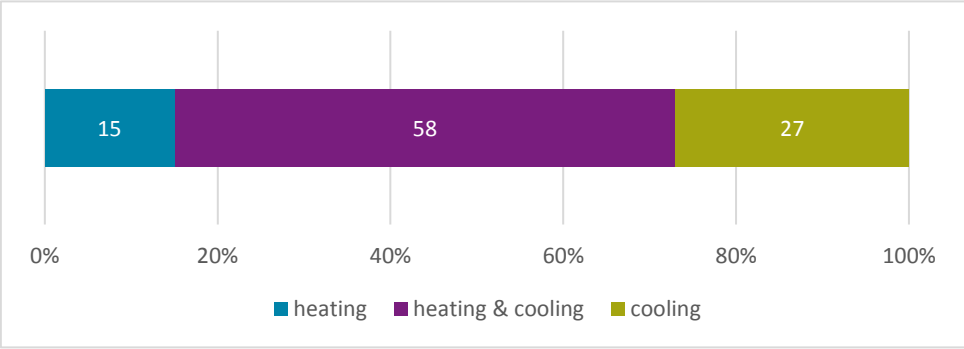
Business size	Weighting (represents proportion of businesses of each sector grouping in UK as a whole)
Construction, Production, transportation	31%
Retail, Wholesale, Hospitality and Service Activities	42%
Other	27%

6.2.3. Use for heating

The majority use the RAAHP for heating and cooling

Our final sample consists of 100 respondents who use their RAAHP for heating at least at some points throughout the year. An additional 48 of those interviewed had an RAAHP but used it for cooling only. The data presented below represents data weighted by sector and business size as discussed above.

FIGURE 34: PRIMARY PURPOSE OF RAAHP



The RAAHP is the only heating system in two thirds of cases

The majority of responses (weighted) indicate that the RAAHP is the only heating system installed, with around a third having another system installed. Where another system is installed, gas boilers, electric heaters and central ventilation / air handling systems are the most common additional heating system.

FIGURE 35: IS THE RAAHP THE ONLY HEATING SYSTEM INSTALLED?

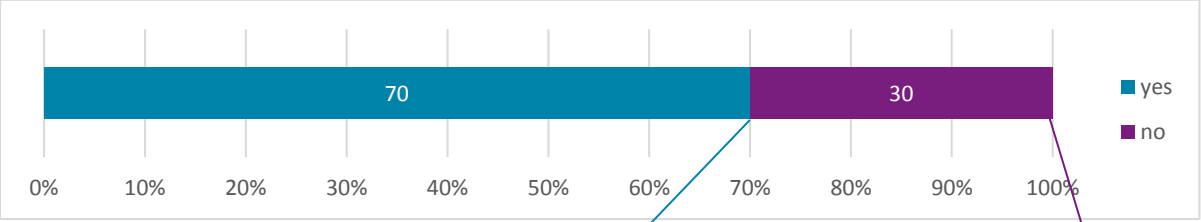
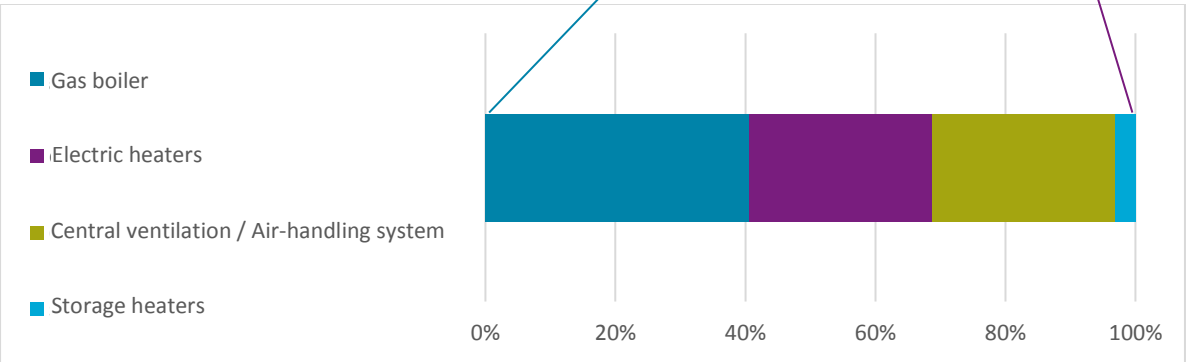


FIGURE 35A: WHAT OTHER SYSTEM IS INSTALLED? (*)



*Note: The heat source for the radiators/underfloor heaters is not clear, as these were answers given in free text (

6.2.4. Capacity

There is insufficient data to answer this point, as in 85 of the 100 relevant interviews, the system capacity was not known.

6.2.5. Running hours in heating mode

How many hours, on average, do RAAHPs spend in heating mode per year?

Our survey asks specifically "how many hours does your RAAHP spend in heating mode per year", and the weighted average (from V2 weighting methodology) of all responses to this question gives an overall mean annual running hours figure of 1,294 hours. We illustrate how this weighted mean was calculated in the following table. The column "weighted # of responses" shows the weighting algorithm assigned to that survey response, dependent on the sector and business size, as discussed in 6.2.2, page 44 (V2 weighting methodology).

Survey response (running hrs / yr)	# of responses	Weighted # of responses	Weighted running hrs / yr (running hrs/yr * weighted #responses)
400	1	1.13	=400*1.13 = 452
784	1	2.06	=784*2.06 = 1615.04
1344	1	0.2	=1344*0.2 = 268.8
1680	1	1.13	=1680*1.13 = 1898.4
…plus 16 other data points…			
Total running hours	*Total # responses*	*Weighted total # responses*	*Mean weighted running hrs/yr*
33,669.53	20	26.028	=33,669.53/26.028 = **1,293.584159**

This mean figure is in line with the expected running hours range from our wider research, so we are confident it is a good indication of real running hours – although obviously further data points would strengthen this conclusion.

Points to note are:

- If we assess the range of responses, the majority of respondents have given figures in a lower range, between 500-1000 hrs / year range. This is indicative of the fact that there is wide data spread, with a small number of data points giving figures well above the majority, but pushing up the average.
- A majority of respondents did not know their annual running hours – this is indicative of the challenges associated with this type of data collection as opposed to running trials / monitoring programmes.
- There is a relatively wide range of data when comparing different survey questions, as seen in Figure 36 which shows raw data.

FIGURE 36: MEAN ANNUAL OPERATING HOURS (WEIGHTED DATA)

The chart highlights the range of annual running hour ranges indicated by the weighted data set.

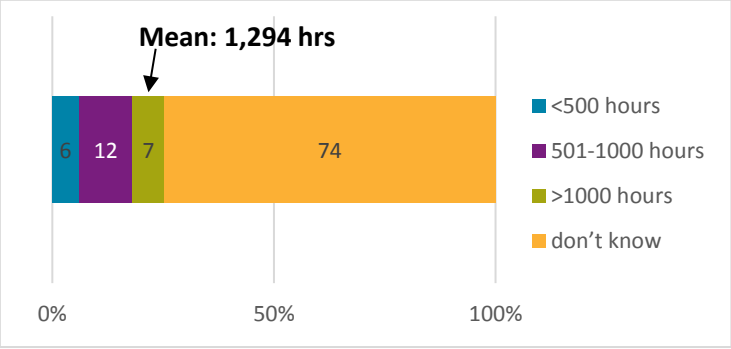
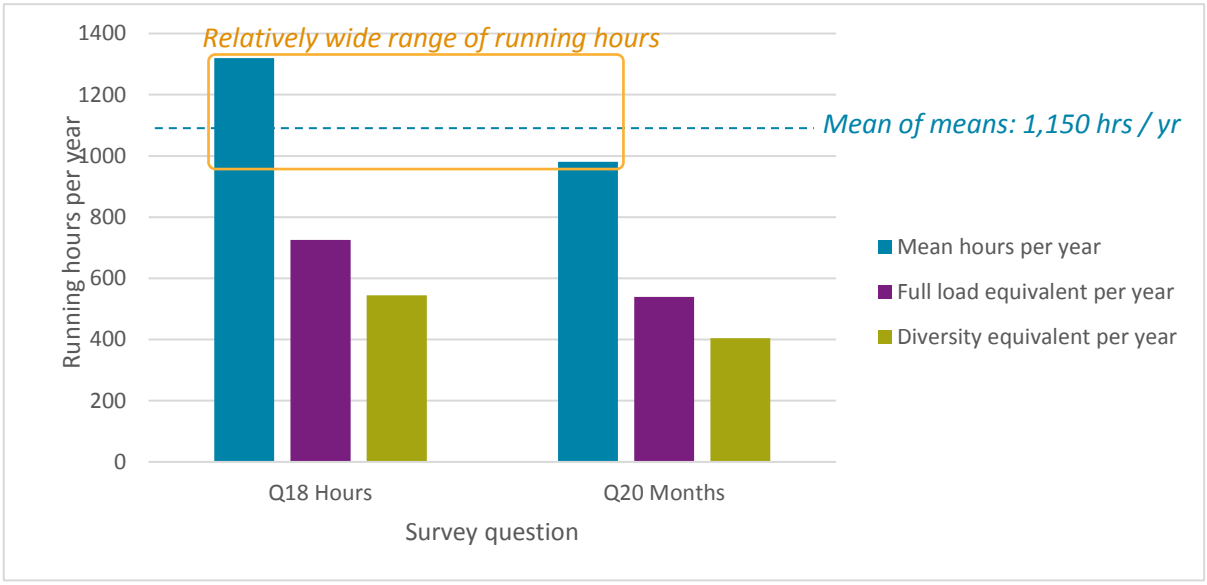


FIGURE 37: MEAN ANNUAL OPERATING HOURS, FULL LOAD EQUIVALENT & DIVERSITY EQUIVALENT (FROM RAW DATA)

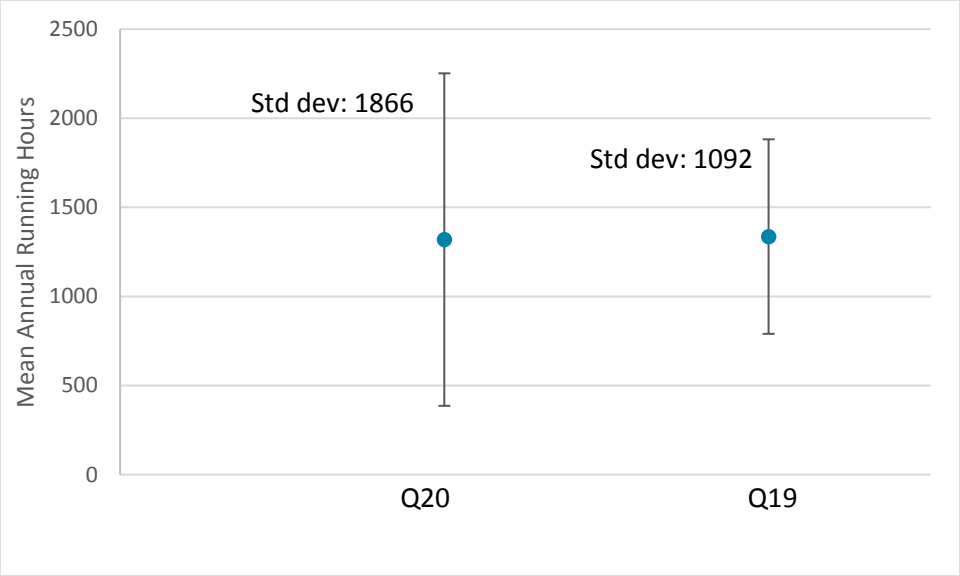
This is based on the raw data, and compares the mean operating hours calculated from responses to two different question types – firstly respondents were asked how many hours a year their system was in heating mode, and secondly, they were asked how many months it was in heating mode. The data range (1,319-981 hours per year) coming from the two different survey questions, is based on 33 survey respondents who were able to answer one or both of the questions.



What is the distribution around the average value?

The scatter plots in Figure 32 and 33 highlight the wide distribution of data points around the mean. Figure 38 below highlights the relatively high standard deviations in the data. When we consider the entire range of data collected from our survey, the "annual running hours" range from 100 to almost 8,760 per year. This indicates the vast data spread and therefore inherent uncertainties in drawing distinct conclusions. It is clear that further research and/or monitoring is necessary to increase confidence level in the results.

FIGURE 38: MEAN ANNUAL RUNNING HOURS AND STANDARD DEVIATIONS FROM RAW DATA



Variation by Geographic location

Annual running hours in the average climate zone are higher than in the cold zone, as seen in Figure 39.

This result is counterintuitive - it would be expected that, if all else is equal, lower running hours would be found in the cold climate zone. The difference can be explained in the following ways:

- A higher proportion of RAAHPs in the cold climate zone were installed alongside other systems for heating, which would explain the lower running hours.
- There is a question mark over the magnitude of the difference in running hours between climate zones however. By looking into the raw data, it can be seen that one single data point in the average climate zone gives 8,736 hours, pushing the (raw data) mean up to 1,513. If this single data point were removed, the raw data mean would drop to 987. While the single point is a significant outlier, the survey response as a whole is consistent and makes sense, and it is difficult to justify removing it. It should be borne in mind when drawing conclusions that the magnitude of difference between zones may be a lot lower than our data indicates.

FIGURE 39: VARIATION IN (WEIGHTED) MEAN ANNUAL RUNNING HOURS BY CLIMATE ZONE
This chart is based on the weighted data set, 26 responses.

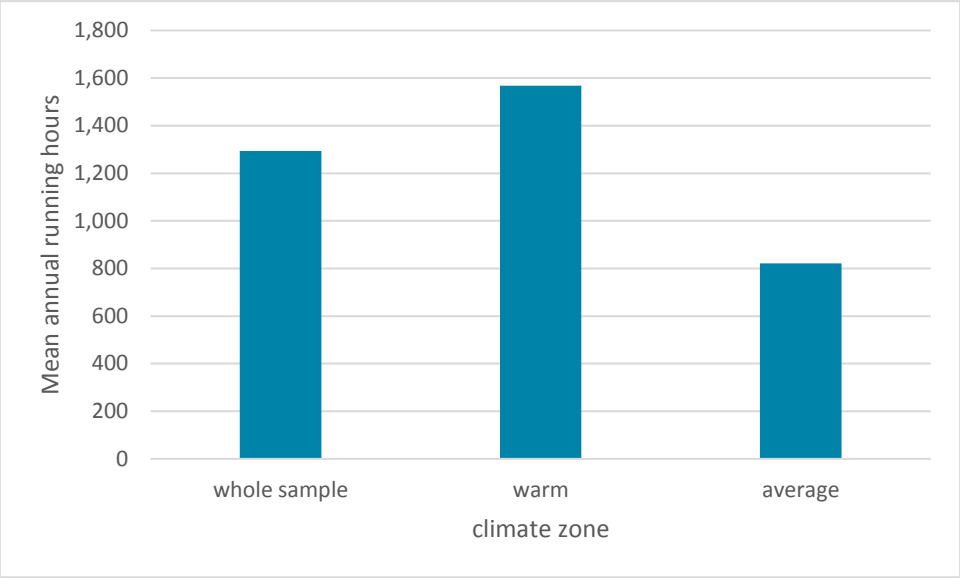
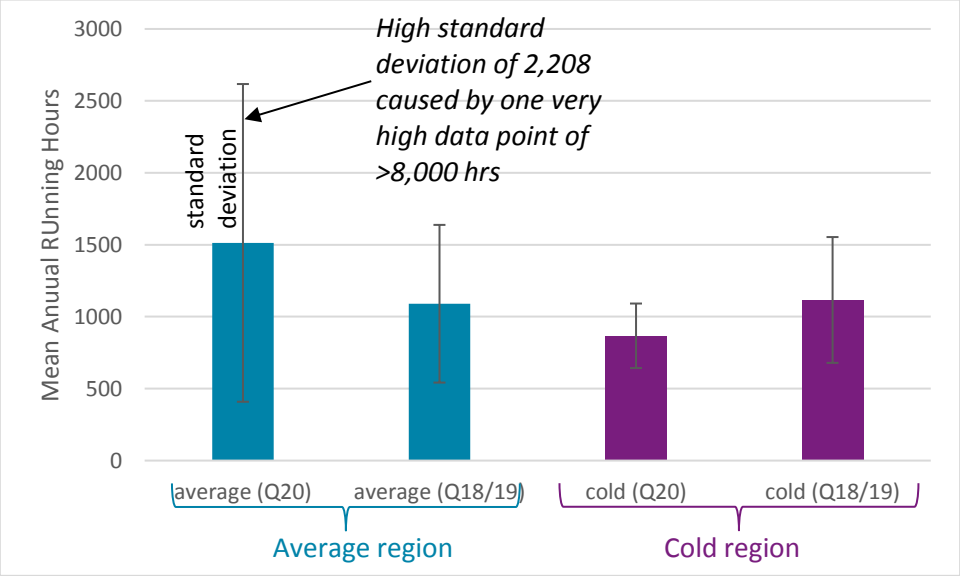


FIGURE 40: ANNUAL MEAN RUNNING HOURS IN AVERAGE AND COLD CLIMATE ZONES (INCLUDING STANDARD DEVIATIONS) – FROM RAW DATA



Variation by end-user sector, building type, number of employees, system type (split / VRF) system capacity

Due to lack of data, it is impossible to draw conclusions about variations in the mean according to any of these factors.

6.2.6. Heating efficiency

There is insufficient data to answer this point, as in 97 of the 100 relevant interviews, the system efficiency was not known.

6.2.7. Results on other questions from BEIS

Maintenance

The majority (85%) receive regular maintenance, of which over 60% receive maintenance every 6 months or more. This is a clear indication that in reality, the great majority will carry out regular maintenance, certainly on an annual basis.

FIGURE 41: IS REGULAR MAINTENANCE CARRIED OUT ON RAAHPS?

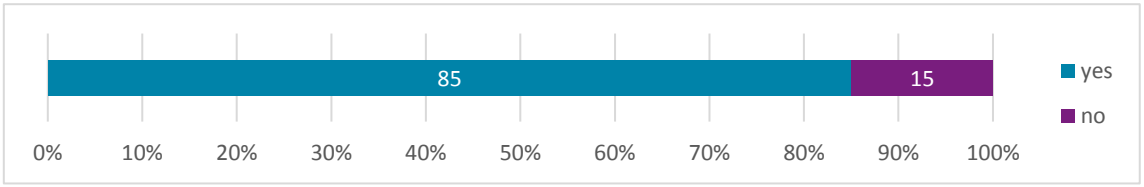
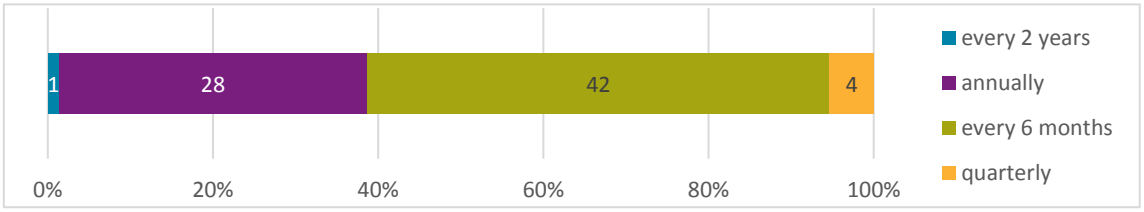


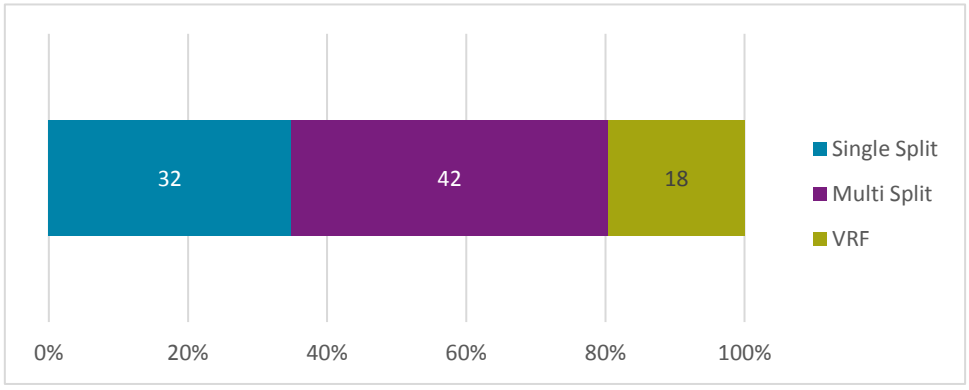
FIGURE 42: WHERE REGULAR MAINTENANCE IS CARRIED OUT, HOW OFTEN IS THIS?



Type of system:

Single and multi-splits are the RAAHP of choice at 80%, with 20% choosing a VRF system.

FIGURE 43: WHICH TYPE OF RAAHP IS MOST POPULAR WITH SMES?



7. Conclusions from the Evidence Gathering and Impacts on the United Kingdom's Renewable Heating Contribution from Reversible Air-to-Air Heat Pumps

7.1. Conclusions from the evidence gathering

Data for the calculation of the renewable heat production from RAAHPs has been gathered in a multitude of ways in this project. In the following section this data is being compared and analysed and recommended values for the calculation of renewable heat from RAAHPs in the UK non-residential building stock are proposed.

7.1.1. Use for heating

The use of RAAHPs for heating as well as their ability to deliver heat as well as cold were part of the first priority questions for BEIS, as they are directly linked to the calculation of renewable heat from RAAHPs under the EU's Renewable Energy Directive. The below table summarises our findings on this topic from the various different research approaches used.

TABLE 12: SUMMARY OF FINDINGS REGARDING THE USE OF RAAHPS FOR HEATING

Desk Research	The RHI evidence gathering study from Eunomia (2014) suggested that **100% of RAAHPs are being used for heating and that up to 80% of them provide the full heating load of the building**. Given the findings of our in-depth end-user research as well as the fact that at least until 2013 there were still cooling only models being sold in the UK **we don't consider that this value should be retained**.
Installer Research	According to our installer interviews **65-90% of systems in the field are used for heating as well as cooling**. It is important to note that the lower value of 65% is based on actual recorded data (as part of CIBSE reporting) of 20 commercial installations, whereas the higher value of 90% is based on an estimate.
Manufacturer & Market Research	Our discussions with manufacturers did not yield specific values with regards to the share of systems in the field which are used for heating. However, the **interviewees agreed that the majority of all systems are used for both heating and cooling**. The analysis of more than 850 products from 7 manufacturers showed that **in 2017 all units available on the market are reversible and therefore technically able to provide both services**. This finding is supported by data from BSRIA, which shows that **since 2013 cooling only have completely disappeared from the market**.
SME Research	The end-user interviews of our SME telephone survey showed that, **of the small number of companies which have an RAAHP installed, more than two thirds (68%) are using it for heating** in addition to cooling. 70% of these respondents had no other type of heating system installed, which suggests that RAAHPs provide the full heating load in a large share of this segment.
Large end-user (EMA) Research	Despite the response rate of the large end-user survey being very low, the **results indicate that RAAHPs are being used for heating in larger businesses in 78% of all cases**.

Across all approaches we have found fairly similar results, suggesting that the majority of RAAHPs in the UK are being used for both heating and cooling.

As the data from our SME and EMA surveys is likely to be the most accurate published data on this topic to date **we have retained a value of 73% of all systems (the mean of the values from the two surveys) as being used for providing part or all of the heating load**. A correction for systems which are technically incapable of heating (i.e. cooling only systems) was not applied, as these systems are deemed to already be included in the 27% of systems which are used for cooling only.

7.1.2. Capacity

Neither the end-user nor the installer research provided useful indications with regards to the average installed capacity of RAAHPs in the UK. We therefore focused our research efforts on the capacity distribution of over 850 products currently on the UK market, gathering this information from price lists and product catalogues. This was combined with BSRIA data on the sales of RAAHPs by capacity band. As the BSRIA data is referring to cooling capacity, an analysis of the relation between heating and cooling capacities of RAAHPs was carried out. This analysis found that there is the following very strong linear relation between the rated capacities of these two values: $P_{cooling}$ = 0.8977 * $P_{heating}$ (R^2 = 0.9995).

The resulting averages for single- and multi-split systems as well as VRF type products were then discussed with manufacturers in order to sense-check them. The following values were retained and confirmed as being a reasonable estimate by the manufacturers we interviewed:

TABLE 13: AVERAGE CAPACITIES OF RAAHPS INSTALLED IN THE UK

System type	Average heating capacity (kW_H)
Single- & Multi-splits	8.18 kW_H
VRF systems	47.47 kW_H

We also tested with installers and manufacturers whether there was or is a trend towards larger or smaller systems. Interviewees on both sides largely agreed that there is a trend towards a lower P_{rated}/m^2 due to better insulation levels. However, this trend does not show in the data from BSRIA, which seems to be much more driven by the development of the economy (a positive market environment means larger new builds, means higher overall capacities). We have therefore not included such a trend in our renewable heat calculations.

To scale the average heating capacity per unit up to a total heating capacity for the UK, BSRIA market data was used. This showed that the total installed number of single- and multi-splits prior to 2016 was almost 3.5m. Similarly, their sales figures show that 155k single- and multi-splits were installed in 2016, taking the total number of installed to 3.6m. Although some of these were likely replacements, due to the efficiency cut off it was safe to assume that those being replaced would not have counted towards the total capacity that is eligible under the Renewable Energy Directive. Also, using the sales data it was possible to estimate that just under 50% of RAAHPs were installed after 2006; before which it is assumed that none of the RAAHPs meet the requirement of having a SPF>2.5.

From the surveys, it was found that 73% of RAAHPs can be used in heating mode (27% are cooling-only). Combining this information with that in Table 13 gives:

$$\frac{(3{,}628{,}201 \times 0.4993 \times 8.18\ kW_H \times 0.73)}{1{,}000{,}000} = 10.82\ GW$$ (single- and multi-splits)

7.1.3. Running hours in heating mode

One of the key templates for this research project, the 2015 paper by Reinoud Segers and Henri Busker on the "Equivalent full load hours for heating of reversible air-air heat pumps"[13] had a research methodology strongly focused on the design and specification stage of the products, by relying on installer interviews. One key concern for BEIS was to determine the "real" in-situ use of RAAHPs for heating, rather than relying on values from heat loss calculations or other methods used by the professionals to assess this question. Due to this focus on the actual use in the field, the research efforts were heavily skewed towards end-users, which limited the usability of the results in several of the more technical research questions, such as the installed capacity or the seasonal efficiency of the products.

On the question of annual running hours in heating mode our end-user research with SMEs (telephone survey) and energy managers (online questionnaire) yielded some interesting and robust results, which are summarised in the below table:

TABLE 14: SUMMARY OF FINDINGS REGARDING THE ANNUAL HOURS SPENT IN HEATING MODE

Desk Research	n/a
Installer Research	Only four opinions on the annual running hours in heating mode were received from our interviews with installers. The mean value for hours in heating mode from this research was 2,130. In terms of full load equivalent hours, the responses suggested a factor of 0.36 to be applied (i.e. 767 h_{FLE}). One installer also provided us with a calculation methodology which is described in more detail in chapter 6, which provides an FLE equivalent of 41.25% of the time spent in heating mode.
Manufacturer & Market Research	The values obtained from our SME and energy manager research as well as the calculation methodology were tested during our research. Whereas the running hour values were unanimously considered as being reasonable estimates, one manufacturer thought that the proposed factor of 41.25% FLE per hour spent in heating mode was too high and should more be in the region of 25-30%. However, the value of 41.25% was retained, as it found most agreement amongst the interviewees.
SME Research	Our SME survey provided mean running hours in heating mode of 1,293 across the UK (533h_{FLE}). When split by climate zone, a slightly counter-intuitive trend emerged, where respondents in the cold climate zones reported lower annual running hours than those in the average climate zone. This was explained by the fact that a much higher share of these respondents had another source of heating installed alongside their RAAHP. The values retained for the two climate zones are detailed below.
Large end-user (EMA) Research	The energy managers responding to our survey provided a significantly higher mean running hour value of 1,790 hours per year. Due to the fact that most of the respondents in this survey were responsible for several sites located across all UK climate zones, we were not able to determine the variation by climate zone for this value.

Regarding the average running hours question, we retained the following values for the calculation of renewable heat from RAAHPs in the UK.

[13] Segers/Busker (2015).

TABLE 15: ANNUAL RUNNING HOURS SPENT IN HEATING MODE BY TYPE OF UNIT AND CAPACITY

System type	Average climate	Cold climate
Single- & Multi-splits	1,567 hours in heating mode → 646 full load equivalent hours	821 hours in heating mode → 339 full load equivalent hours
VRF systems	The higher value of 1,790 hours was retained for VRFs, as these systems are more common in larger buildings. As a significant amount of VRF systems in the market are heat recovery systems, the following FLE hours were used in the calculation: with HR – 686 without HR – 738 (see page 56 for a more detailed reasoning behind this assumption)	Following a similar approach as for the VRFs in the average climate zone, the following FLE values have been used in the calculation: with HR – 225 without HR – 738

7.1.4. Heating efficiency

As already discussed in the "RHI Evidence Report: Reversible Air to Air Heat Pumps"[14], the in-situ efficiency of RAAHPs is very difficult to measure, which is why there is currently no in-situ efficiency data available for the UK. After our analysis of the SCOP of several hundred single- and multi-split systems showed that the average SCOP is around 4.1, we therefore chose to use the same central SPF estimate as suggested in the Eunomia report, which is 2.8. This is a 32% reduction on the average lab-tested SCOP of systems being sold today and in our view provides a sufficient "margin of error" to be deemed reliable.

We have analysed system efficiencies of products sold in 2008 with the equivalent products (by type and capacity) on the market in 2017 and using inter- and extrapolation of this data we estimated that all single- and multi-split systems installed in or after 2006 should meet the minimum SPF criterion. Based on a similar analysis for VRF systems we assume that all VRF type installations currently in operation meet this minimum SPF.

[14] Eunomia (2014)

7.2. Analysis - The contribution of RAAHPs to the UK's obligation under the Renewable Energy Directive (2009/28/EC)

The calculation of the contribution of RAAHPs to the UK's obligation under the Renewable Energy Directive (2009/28/EC) is based upon the rules for the calculation of renewable energy from heat pumps set out in article 5(4) in conjunction with Annex VII of said Directive as well as the further explanation and guidance on this calculation from the "Commission Decision of 1 March 2013 establishing the guidelines for Member States on calculating renewable energy from heat pumps from different heat pump technologies [...] (2013/114/EU)".[15]

The calculation methodology set out in the Commission Guidance is as follows:

$$E_{RES} = Q_{usable} \times (1 - 1/SPF)$$

Where

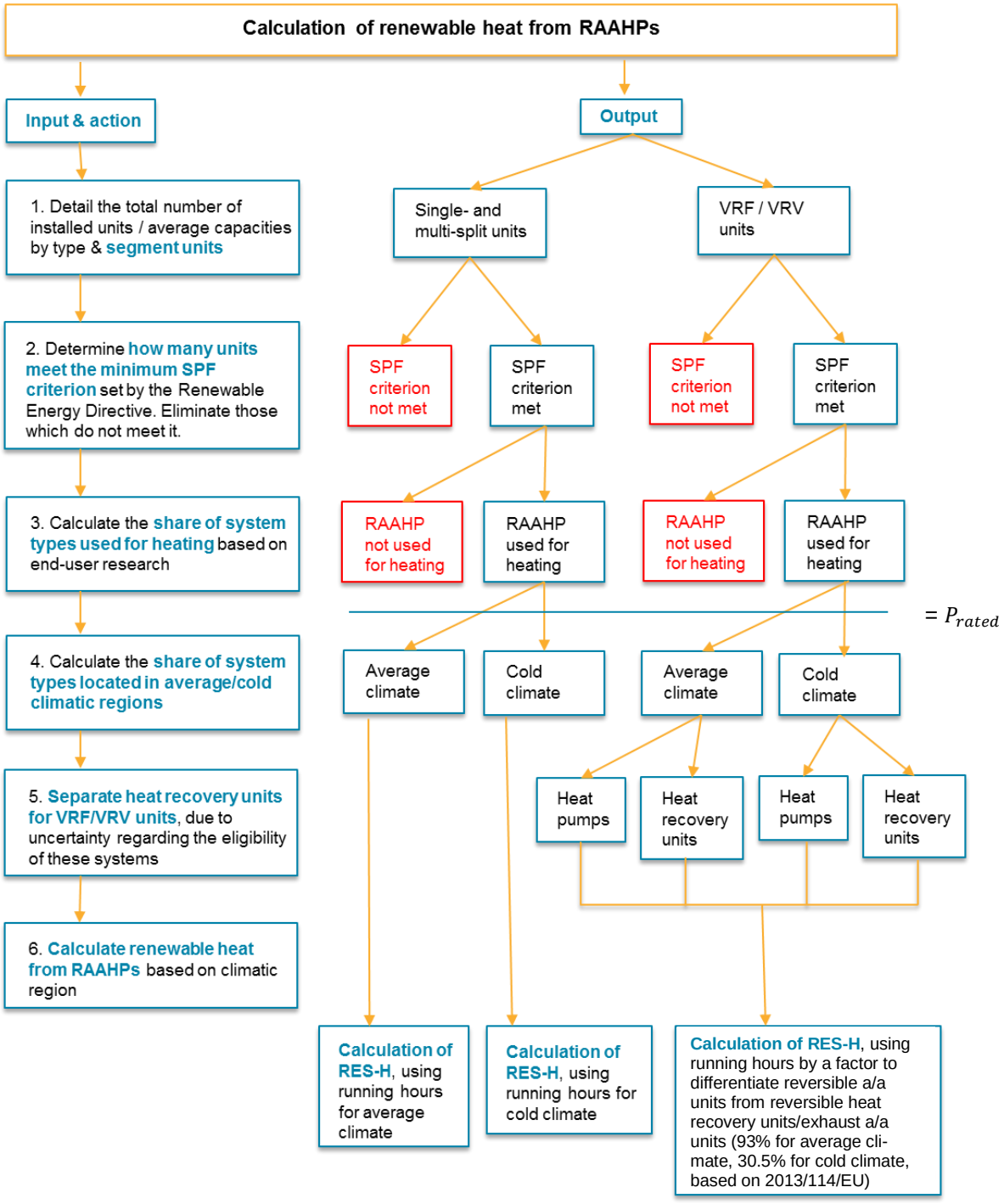
$$Q_{usable} = H_{HP} \times P_{rated}$$

H_{HP} is defined in the Guidance as "[...] the assumed annual number of hours a heat pump has to provide heat at rated capacity to deliver the total usable heat delivered by heat pumps, expressed in h"[16], whereas P_{rated} "[...] means the cooling or heating capacity of the vapour compression cycle or sorption cycle of the unit at standard rating conditions"[17]. The "'SPF' shall mean the estimated average seasonal performance factor, which refers to the 'net seasonal coefficient of performance in active mode' (SCOP net) for electrically driven heat pumps [...]"[18].

The Commission Guidance also sets out a number of reference values for the calculation of inputs, in particular for H_{HP} and SPF in both the average and cold climate zone which cover the UK. Based on this methodology we have calculated the renewable heat from RAAHPs following the methodology shown in figure 44 below.

[15] European Parliament and Council (2009) & European Commission (2013).
[16] European Commission (2013).
[17] As above.
[18] As above.

FIGURE 44: FLOW CHART OF THE CALCULATION OF RENEWABLE HEAT FROM RAAHPS



This calculation deviates in several points from the hypothetical example calculation proposed in the Commission Guidance.[19]

- We have decided to apply the correction factors for the use of RAAHPs for heating directly to the installed rated capacity, rather than the running hours, as this is more accurate. However, this should not have an impact on the results of the calculation.
- We have also introduced a split of RAAHPs into two sub-categories (single- & multi-splits and VRFs) as these two types of systems differ in several of the key values such as the average capacity per system or the estimated share of units meeting an SPF > 2.5.
- Another reason for splitting the calculation by RAAHP system types was that we introduced a further differentiation of the VRF systems, as around 61% of these not only use ambient air to provide heating, but also waste heat recovered inside the building when there is a simultaneous heating and cooling load (e.g. when there is a sunny day within the heating season requiring cooling on the south side of an office building, while the north facing offices still need to be heated. As the energy recovered from the cooling process would have been rejected into the atmosphere if a "normal" air-conditioning system were installed, we consider this energy to be eligible for being considered as waste heat or exhaust air.
  In order to reflect the uncertainty around how much of the waste heat is from renewable heat gains (e.g. solar gains and body heat) and how much is from other systems, we have applied correction factors. These factors have been calculated based on the H_{HP} guidance values provided by the European Commission for reversible air-air units (710h in average and 1970h in cold climate) and exhaust air-air units (660 in average and 600 in cold climate). The correction factors applied to the running hours in heating mode are therefore 93% for the average climate and 30.5% for the cold climate zone. This is in line with our findings that RAAHPs in colder climate areas of the UK (North England and Scotland) are more often installed alongside another source of heating and that therefore a smaller share of the heat recovered from inside the building should be considered as being from a renewable source.
  As the question how to treat heat recovery type VRFs is still out for discussion (Segers/Busker (2015) do not address this topic at all), we are proposing the above approach as a means to conservatively reduce but not completely disregard the renewable heat contribution of these systems.

Our work also differs from some other approaches to this topic, in particular the work carried out by R. Segers and H. Busker for the Dutch Centraal Bureau voor de Statistiek (Central Statistics Office) in 2015.[20] One of the main difference of this report compared to the report for the Netherlands is the strong focus this report has had on identifying the real use of RAAHPs by end-users in the field, as opposed to using data from systems "as planned" by installers. Another key difference is the consideration this report gives to the fact that a large number of VRF systems are of the heat recovery variant and are therefore likely to not be elibigle for inclusion in the data on renewable heat from RAAHPs.

[19] See European Commission (2013), Annex, Point 4.
[20] Segers / Busker (2015).

Based on the analysis of the information gathered in our research and the above approach to calculating the heat from renewable energies, the following results have been obtained:

TABLE 16: RESULTS FROM THE CALCULATION OF RENEWABLE HEAT FROM RAAHPS IN THE UK IN 2016

	Single- & Multi-splits		VRF			
	Average climate	Cold climate	Average climate without heat recovery	Cold climate without heat recovery	Average climate with heat recovery	Cold climate with heat recovery
P_{rated} (GW)	9.628	1.19	3.185	0.394	4.981	0.616
H_{HP} (h)	646	339	738	738	686	225
$= Q_{usable}$ (GWh)	6,219	403	2,350	290	3,417	139
E_{RES} (GWh)	3,998	259	1,511	187	2,197	89
Total E_{RES} (GWh)	8,241 (of which 2,286 from units with heat recovery function)					

Our research indicates that in 2016 a total of 8,241 GWh of renewable heat was produced by reversible air-to-air heat pumps. Of this, 2,286 came from VRF units with heat recovery function. In relation to the amount of renewable heat produced from heat pumps in 2016 reported in the latest DUKES report, this means an increase by a factor of 2.8-3.9, depending on whether the renewable heat from VRF units with heat recovery function is included or not.

The production of renewable heat from RAAHPs calculated in this report can also be seen as a conservative estimate. A sense-check using the European Commission's hypothetical example of a more accurate calculation methodology showed that under this approach single- and multi-split units alone would be producing in excess of 12,400 GWh of renewable heat. This is because the only change made in this example is regarding the annual running hours, which are increased We therefore consider our approach to estimating the renewable heat provided by RAAHPs in the UK to be erring on the side of caution.

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