Department
of Energy &
Climate Change

RHI Evidence Report: Reversible Air to Air Heat Pumps

Assessment of the Market, Renewable Heat Potential, Cost, Performance, and Characteristics of Non-Domestic Reversible Air to Air Heat Pumps (RAAHPs).

29th October 2014

Prepared for DECC by:

Eunomia Research and & Consulting Ltd.

Any enquiries regarding this publication should be sent to us at:

Department of Energy and Climate Change, 3 Whitehall Place, London SW1A.

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Executive summary

Introduction

1. As part of its wider policy measures to reduce domestic greenhouse gas emissions (GHG) to meet UK, EU and Internationally agreed targets, the UK Government wishes to decarbonise heat generation in the UK, which is responsible for one third of UK GHG emissions. Under the EU Renewable Energy Directive 2009 the UK government has a commitment to increase renewable energy use to 15 per cent by 2020. Renewable heat will contribute towards meeting this commitment, but currently heat demand from renewable energy sources stands at only 2.3%. To further encourage uptake of renewable heat, DECC has stated that it will assess the case for inclusion of a range of additional technologies that could be supported by the non-domestic RHI. One of the technologies under consideration for inclusion is 'reversible air to air heat pumps (RAAHPs).

2. In its most recent Consultation response, DECC stated that it had decided not to support heating only air-to-air heat pumps (AAHPs) due to the risk of incentivising the installation of separate heating and cooling AAHPs, rather than an RAAHP, which is likely to be more energy efficient.[1] In this consultation response, DECC highlighted that the potential for RAAHPs to make a cost-effective contribution to the renewable energy targets will be revisited as part of the 2014 review process, hence the focus of this study.

3. The objectives of this study can be summarised as follows:

   3.i. To define, quantify and segment the RAAHP market;

   3.ii. To provide information on costs and performance of RAAHPs to inform subsequent potential levelised cost modelling by DECC;

   3.iii. To provide analysis of techniques required to accurately measure and meter renewable heat output such that payments under the RHI can be made by Ofgem;

   3.iv. To determine whether Government intervention can be justified; and

   3.v. If so, whether the RHI or any alternative policy mechanism is most suitable towards delivering renewable heat capacity from RAAHPs.

Market Analysis to 2020

4. The RAAHP market is part of the broader Air Conditioning (AC) market, which is an established market in the UK. AC systems include single-split systems, multi-split systems and Variable Refrigerant Flow (VRF) systems. Approximately 90% of split systems are RAAHPs, whilst all VRF systems are RAAHPs.

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[1] DECC (2013) *Non-Domestic Renewable Heat Incentive - Improving Support, Increasing Uptake*, December 2013

5. The current number of existing non-domestic RAAHP installations is approximately 2.8 million, with 2.5 million single-split systems, 0.1 million multi-split systems and 0.2 million VRF systems. The sales of units are around 130,000 per annum, comprising of 110,000 single-split, 5,000 multi-split and 15,000 VRF systems sold in 2012.
6. The non-domestic market represents the majority of the total market, with an estimated 92% of the market share. The most common applications for RAAHPs include: hotels; offices; retail; leisure; and petrol stations. Often they will be utilised solely for cooling alongside an alternative heating source such as a gas condensing boiler. For buildings which are located such that they cannot get a connection to the natural gas grid ('off-gas grid'), however, they can be the preferred option for both heating and cooling.
7. The market is segmented by both the type of system (single-split, multi-split and VRF as already described) and by the method of operation. An RAAHP can be designed for the primary purpose of either cooling or heating. The research undertaken for this study indicates that cooling-led systems dominate the market (representing around 80%).[2] Irrespective of whether a system is heating or cooling-led, however, the market can be further split by systems which provide either full heating load (i.e. the entire needs of a building) or partial heating load (i.e. provision of some heating alongside another heating system). Our analysis indicates that around 70% of existing RAAHP installations provide both full heating and cooling loads, with a further 10% providing full heating load (with some cooling, depending upon the need of the given building).
8. The market has remained stable through the recession and is relatively mature, with relatively consistent prices year-on-year and established players. It is anticipated that the market will grow moderately over the period to 2020 without government intervention. Our analysis suggests that the number of operating RAAHPs in the UK will be around 3.2 million by 2020.
9. There are various barriers to further deployment in the UK. The main barriers include a lack of awareness and confidence in the technology, the prevalence of the natural gas network, large upfront capital investment and long pay-back period, and a preference for 'wet' heating systems.
10. There is also a limited degree of 'information failure' in that both some existing users of RAAHPs and some procurers of heating systems do not realise RAAHPs can provide heating..This is because, as mentioned above, the technology having historically been considered part of the AC market, which is usually more associated with cooling;
11. Whilst this information failure and market barriers exist, however, there does not appear to be any clear market failure that needs to be addressed by Government.

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[2] By 'cooling-led' systems, we mean those which are designed and sized according to cooling requirements, and therefore the heating capacity may (or may not) be included as part of the overall temperature control in the building. This is in contrast to 'heating led' systems, which are designed and sized according to heating requirements, and for which cooling capacity is of secondary concern (and although it may be included as part of the overall temperature control in the building, under no circumstances does it exceed the heating demand)

RAAHP Costs and List Prices

12. As the market is established, there are a wide variety of units available for all types of RAAHP system and it is possible to utilise many combinations of indoor and outdoor units. This means that there are well over 1,000 different product combinations available on the UK market. Furthermore, this does not account for the quantity of indoor units that can be added to an outdoor unit, which would increase the numbers even further.

13. Based on our analysis of list prices, mean capital costs (excluding installation) for combined systems are around £224/kW. Our research indicates, however, that installers are routinely offered a discount of between 25% and 42% on these list prices.

14. Under our central assumptions, installed costs are 46% higher than list prices. 76% of the price to the purchaser is for the unit, with the remaining 24% split equally between labour and consumables.

15. There appears to be very little short-term likelihood of cost reductions in capital prices, although there is a small possibility that less costly systems from China will influence the market prior to 2020.

16. Under our central assumptions, average annual maintenance costs are approximately £132 per unit per year, although the variation in this value is significant and depends on the size and nature of the system.

Renewable and carbon saving credentials

17. The performance of RAAHPs is critical to determining their carbon saving credentials. This performance relates to their efficiency in turning electricity into heat, which in the context of this study is most meaningfully expressed in terms of their seasonal performance factor (SPF).[3]

18. As a result of challenges associated with metering RAAHPs (discussed below), there is a large degree of uncertainty as to the real SPFs in the UK for RAAHPs. There is significant variation between data provided by manufacturers and that drawn from academic literature.

19. Our analysis suggests that for the purposes of this study, RAAHPs should be modelled to have SPFs in heating mode of between 2.5 and 3.2, with a mean of 2.8.

20. At this level of SPF, based on DECC’s long-run marginal grid factor of 0.3422 kg CO_2e/kWh electric, RAAHPs can provide 40% carbon savings compared to condensing gas boilers and 60% savings compared to oil-fired boilers.[4]

21. As a result of the common practise of heat recovery across VRF systems, much of the heat used across such systems cannot be considered as ‘renewable’ under the RHI.

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[3] Heat pump performance is also often expressed in terms of Coefficient of Performance (COP) or Seasonal COP (SCOP)

[4] DECC, and HM Treasury (2013) Appraisal Guidance: energy use and GHG emissions: Supporting tables 1-20 - supporting the toolkit and the guidance

Measuring Renewable Heat Delivered

22. In this study, five different approaches to measuring renewable heat have been developed for assessment against a range of acceptability criteria.

23. Due to heat recovery across VRF systems, it has been determined that none of the methods are suitable for determining renewable heat delivered by such systems.

24. The best potential option for single and multi-split systems is a form of ‘calibrated deeming’. Under this approach, input power is measured and converted to heat generated using the SPF.

25. Whilst calibrated deeming is affordable, it provides for only low accuracy as it relies upon calculated (rather than real) SPF values.

26. The analysis undertaken for this study suggests, therefore, that there are no methods for measuring renewable heat which are both highly accurate and affordable.

Potential for Government Intervention

27. Depending upon the nature and level of support under the RHI, the costs to DECC and level of support to applicants, could vary significantly. In the example scenarios modelled, this variation might be from £15 million to £607 million per annum.

28. As this is a mature market, support under the RHI could result in substantial costs associated with paying for heat from systems that would have been generated anyway.

29. Under our central assumptions, new systems delivering full heating load could potentially deliver a net benefit of 1.01 million tonnes CO_2e / annum. Again, under our central assumptions, systems that are ‘shifted’ (as a result of support under the RHI) from partial to full heating load could deliver a net benefit of 0.23 million tonnes CO_2e / annum.

30. At the end of the 20-year period of support under the RHI, our central assumptions suggest that RAAHPs could deliver annual CO_2e savings of around 20.3 million tonnes, although the low and high scenarios around this suggest that these benefits may vary significantly (from 2.7 to 61.4 million tonnes of CO_2e savings per annum).

31. There exists significant potential for a perverse incentive, whereby support under the RHI might encourage the use of more cooling (and thus carbon emissions) from systems providing full heating load, which would not have otherwise occurred.

32. There would be no perverse outcomes from supporting the shift of systems from partial to full heating load, although there would be significant challenges associated with setting tariff levels correctly (and with metering accurately).

33. There are several alternative policy mechanisms to the RHI (such as a ‘revolving’ loan fund or additional taxation of kerosene used by the commercial sector) which may merit further investigation by DECC.

Conclusions and Recommendations

34. Our analysis suggests that although there does not exist a clear justification for government intervention in the RAAHP market on the basis of market failures, support under the RHI may be justified to remove barriers to growth in the market and deliver potential significant CO_2 savings.

35. If RHI support was to be provided, however, DECC would need to very carefully design the tariff and associated policy detail to minimise the risks of:

    35.i. Significant amounts of funding being allocated to systems that would have been installed anyway;

    35.ii. Exerting pressure on the overall RHI budget by only providing support for certain types of system; and

    35.iii. Incentivising heating-led installations that provide full heating load, which may lead to incentivising additional cooling.

36. Achievement of such a policy design will be highly challenging without undertaking a range of further tasks including:

    36.i. Additional detailed analysis of metering approaches to determine as robust a methodology as possible. There is additional work required to more accurately assess SPFs to support the potential of calibrated deeming. Furthermore, a project working with manufacturers to develop a suitable approach to temperature control monitoring (whereby fan speed and air temperature are measured to give heat delivered) could potentially be justified;

    36.ii. Engagement with Ofgem in terms of determining whether these approaches to metering (either in combination) or separately, would allow it to make payments for renewable heat from RAAHPs; and

    36.iii. Identification and modelling of specific business sectors to determine those for which support under the RHI might deliver additionality, and within which the risk of the perverse incentive to encourage cooling might be minimised.

1 Introduction, Scope and Objectives

1.1 Background

Under the EU Renewable Energy Directive 2009 the UK government has a commitment to increase renewable energy use to 15 per cent by 2020. Renewable heat will contribute towards meeting this commitment, but currently heat demand from renewable energy sources stands at only 2.3%. DECC therefore wishes to increase deployment of renewable heat technologies. Renewable heat-only generation is supported by the RHI, currently supporting non-domestic heating applications, which will be expanded this year to cover domestic heating applications.

DECC has commenced a review of the impact of its current non-domestic RHI policy, to examine the success of the scheme and whether there is a need to revise the tariffs available. In addition, DECC has also stated that it will assess the case for inclusion of a range of additional technologies that could be supported by the non-domestic RHI. One of the technologies under consideration for inclusion is 'reversible air to air heat pumps (RAAHPs).

In its most recent Consultation response, DECC stated that it had decided not to support heating only air-to-air heat pumps (AAHPs) due to the risk of incentivising the installation of separate heating and cooling AAHPs, rather than a RAAHP.[5] This is due to the (probably remote) possibility of applicants seeking to run both a heating system and cooling system simultaneously, which would increase both energy and heating demand (and therefore RHI payments), or the potential to incentivise installing a heating AAHP alongside a RAAHP providing only cooling but which could have provided heating, resulting in inefficiency. In this consultation response, DECC highlighted that the potential for RAAHPs to make a cost-effective contribution to the renewable energy targets will be revisited as part of the 2014 review process, hence the focus of this study.

1.2 Study Scope and Objectives

The following sections focus upon framing the key research questions from the Invitation to Tender (ITT) document issued by DECC. These have been further developed to reflect the specific challenges associated with the RAAHP sector, which have been summarised in each of the appropriate sections.

1.2.1 Definition, Quantification and Segmentation of the RAAHP Market

A challenging issue associated with this study is to define and quantify a market, which is just one element of a wider, long established market. RAAHPs are an established technology and have been used for air conditioning applications in the UK for over three decades. As such, they form part of the Air Conditioning (AC) market (which itself is part of the Heating, Ventilation and Air Conditioning (HVAC or sometimes HEVAC) market). Annual sales figures and total cumulative deployment figures are usually reported at the level of the AC market, which does not differentiate between different technologies used for AC purposes. For example, some AC

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[5] DECC (2013) *Non-Domestic Renewable Heat Incentive - Improving Support, Increasing Uptake*, December 2013

units may be non-reversible AAHPs, and these would be counted the same as RAAHPs. Most active participants within the market, therefore, are unused to considering RAAHPs as a market distinct from the AC market as historically there has been no need to make this distinction.

Even if the RAAHP market is well defined there remains a need to determine how the market segments.

In many instances an RAAHP unit will be installed for a cooling only application, but also be capable of heating. It may never be used for heating but is still an RAAHP. At the same time, some units sold will be RAAHPs, but have the 'switching' mechanism disabled to prevent the unit from being used in a reversible manner. It would be relatively simple to reinstate such a mechanism to enable reversible operation, and therefore the unit might still be classified as an RAAHP.

These issues highlight the types of challenge regarding both defining and segmenting the market. The following research questions have been explored to try and focus this report on addressing these issues. Those identified as additional questions to those identified by DECC in the ITT are highlighted in **bold**:

- **Nature of the Market**
  - What proportion of the AC market is represented by RAAHPs?
  - How does this vary across system sizes?
  - How many RAAHPs are used for heating, either as the primary or secondary function?
  - How does this vary across system sizes?
- Scale of the Market
  - What is the current market scale?
  - What is the market potential to 2020?
  - What are the barriers to deployment?
- Market Segmentation
  - What are the typical applications?
  - Where are fossil fuel heating systems installed in preference to an RAAHP system?
  - What would the displaced counterfactual technologies be?
- Government Intervention
  - Is it beneficial to intervene in the market?
  - If so, is the RHI the right policy to intervene with?
  - What potential is there for gaming in the market?

1.2.2 RAAHP Costs and Prices

In contrast to the challenges associated with quantifying and characterising the RAAHP market, there are far fewer issues surrounding the costs and prices of RAAHPs. There is, however, a significant challenge in identifying costs to the detail of those requested in the ITT, and as such, the data provided within this study focuses on *prices* rather than costs, and we have therefore focused the research questions on the key areas within which it is possible to gather information. An approach based on price is also more relevant in the context of meaningful comparison of RAAHPs with other technologies, including the counterfactual.

In addition, there is a challenge associated with identifying prices accurately, as our experience is that the manufacturer's list price, or that quoted direct for one installation, will be substantially higher than that charged to installers, with this then reflected in the prices experienced by purchasers. This is particularly relevant where installers are purchasing multiple units as part of a wider sales agreement. Additional questions have therefore been added to try and identify this issue.

The following research questions have been explored to try and focus this report on addressing these issues. Those identified as additional questions to those identified by DECC in the ITT are highlighted in **bold**:

- What is the price of a heat pump installation?
  - Price of the heat pump equipment
  - Price of the installation
  - Operating costs
  - Maintenance costs
- **What discounts on list prices are available to installers (for multiple units)?**
- What opportunities are there for cost reductions?
  - What would drive this?
- **What prospects are there for increasing costs or prices in the market?**
  - What would drive this?

1.2.3 RAAHP Performance

Performance of RAAHPs is defined by the Coefficient of Performance (COP) and/or the Seasonal Performance Factor (SPF). The COP gives the efficiency of a system at a particular point in time, whilst the SPF calculates this over the course of a year, taking into account seasonal variations. The SPF therefore takes into account that changes in ambient temperature throughout the year have a significant impact on the system at any particular point in time.

The actual COP and SPF figures are known to differ from figures published by manufacturers, which are usually based upon performance in ideal 'test' conditions. In addition, it is understood that the technologies usually installed in the UK are less efficient (and lower cost) than those available in other countries—for example Japan—where the emphasis is on the delivery of greater efficiencies due to higher relative electricity costs. Again, the following research questions have been explored to try and focus this report on addressing these issues. Those identified as additional questions to those identified by DECC in the ITT are highlighted in **bold**:

- What are the renewable and carbon saving credentials?
- **To what extent do operational COP/SPF figures vary compared to published data?**
- What proportion of energy could be considered renewable?
- **How does the performance of RAAHPs available in the UK compare to other countries utilising this technology?**

1.2.4 Measurement Techniques

Measurement and metering techniques for renewable heat provided by RAAHPs are particularly challenging, as there is no clear approach to identifying heat delivered. This problem reflects the nature of the technology in delivering heat through air rather than through water, where the mass flow can be readily quantified. This issue is addressed via the following single research question (although a range of potential solutions have been explored in response):

- What measurement technique(s) would be sufficient for RHI metering?

2 Market Analysis to 2020

The key findings from this section can be summarised as follows:

- There are an estimated 2.75 million RAAHPs currently installed in the UK;
- An estimated 134,000 systems are sold each year;
- The market is estimated to be split as follows:
  - 70% of systems provide full heating load and full cooling load;
  - 10% provide full heating load with partial/no cooling load; and
  - 20% provide partial heating load with full cooling load.
- 80% of the market is therefore already delivering full heating load;
- The market is relatively stable, with significant barriers to new entrants, and little current incentive for innovation at the UK-level by large incumbents;
- Our analysis suggests that the number of operating RAAHPs in the UK will be around 3.2 million by 2020
- Whilst there is some degree of 'information failure', and a number of barriers to further deployment, there does not appear to be any clear market failure that needs to be addressed.

In the following sections, a number of references are made to interviews held with stakeholders, including manufacturers and installers. The list of those organisations contacted is included in Appendix A.

The following terms are also utilised throughout these sections and are defined here for clarity:

- **Heating-led systems:** These are systems which are designed and sized according to heating requirements. The cooling capacity is of secondary concern and although it may be included as part of the overall temperature control in the building, under no circumstances does it exceed the heating demand;
- **Cooling-led systems:** These systems are designed and sized according to cooling requirements, and therefore the heating capacity may (or may not) be included as part of the overall temperature control in the building;
- **Full heating load:** This is where the system provides the entire heating needs of a building/space, whether or not it has been designed with the cooling or heating load as a primary concern; and

- **Partial heating load:** This is where the system is providing some heating alongside another heating system, despite it being capable of delivering the full load.

2.1 Size and Nature of the Opportunity

The market for RAAHPs differs significantly from the other technologies already incentivised under the RHI in that it is already relatively well established. As mentioned above, however, the nature of the market is that it has not previously been defined as a distinct RAAHP market, but rather as part of the AC market, which sits within the wider HVAC market. For the following sections it is important to note that the following systems can be classed as RAAHPs:

- Variable Refrigerant Flow (VRF) systems;[6] and
- Split systems (both single and multi).

By their nature, all VRF systems utilise RAAHPs.[7] Not all split systems need to be reversible, however, in practice the vast majority of these systems utilise RAAHPs, with industry experts regularly quoting over 90% of split systems being RAAHPs.[8]

It is also important to note, however, that the nature of both split and VRF systems is that different indoor and outdoor units can be mixed and matched to create the desired characteristics. This means that an RAAHP market is characterised by both indoor and outdoor units.

2.1.1 Installation of New RAAHP Units

A number of different studies have described the installation of new RAAHPs in the UK. These offer massively varying estimates of new installations, which indicate that definitions of RAAHPs may vary significantly.

A study on behalf of the Committee on Climate Change (CCC) recently projected the number of non-domestic 'air to air, air source heat pumps' up to 2030, showing steady growth from around 5,000 units per annum in 2013 to 40,000 units in 2030.[9] A recent DECC report uses more conservative UK market projections, based on the Renewable Energy Action Plan, which show AAHPs rising from 600 units in 2012 to 1,207 units in 2030.[10] The estimates in both reports may be considered extremely conservative in light of a report published by a member of DECC's research team, which states that 200,000 RAAHPs were installed in the UK non-domestic sector in 2009 alone, which draws upon information from BSRIA.[11] Indeed, the source estimates that RAAHPs represented over 90% of heat pump (HP) installations in that year. None of these reports give an indication of the proportion of RAAHPs that are used for cooling, heating and cooling, or heating only. It is this proportion that is critical to understanding both the scale of the market and the potential opportunities. It is also likely that this definition is at the root of the

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[6] Sometimes referred to as Variable Refrigerant Volume (VRV) systems.

[7] It is technically possible that a VRF system with a water cooled condenser could be produced, however in practice it is fair to assume for the purposes of this study that all VRF systems are RAAHPs.

[8] It should be noted that there are split systems available that use a standard refrigeration cycle for cooling but have a conventional resistive element for heating. We do not consider these to be RAAHPs

[9] Frontier Economics (2013) *Pathways to High Penetration of Heat Pumps*, a study on behalf of the Committee on Climate Change October 2013

[10] Sweett (2013) *Research on the costs and performance of heating and cooling technologies*, Report for Department of Energy and Climate Change (DECC), February 2013

[11] Penny Dunbabin (2010) *The Market for Heat Pumps in the UK*, Report for IEA Heat Pump Centre Newsletter, 28, 2010, http://www-v2.sp.se/hpc/publ/HPCOrder/viewdocument.aspx?Action=View&RapportId=722

major differences in these numbers as it is anticipated that the number of heating-led RAAHPs installed is very low compared to the total number of RAAHP installations. It is therefore suggested that the estimates that are significantly lower than the published data may relate to heating-led systems and this is explored in greater detail in Section 2.2.1

Examining the industry sales figures released by BSRIA enables a rough assessment of the scale of the market by assessing the number of split and VRF outdoor units sold (see Table 1). Whilst the number of outdoor units will not exactly equate to the number of systems installed, most systems will operate with one outdoor unit and single or multiple indoor units. As can be seen this indicates that approximately 160,200 systems were installed in the UK in 2012.

System Type		Proportion Assessed as Reversible	Number of Units	Value (£)
Outdoor Units	<7kW	c.90%	76,100	31,800,000
	>7kW	c.90%	68,500	60,700,000
	VRF	100%	15,600	82,500,000
	Total		**160,200**	**175,000,000**
Indoor Units	Standard	c.90%	163,800	59,200,000
	VRF	100%	101,500	61,700,000
	Total		**265,300**	**120,900,000**

Table 1: UK sales of AC units that can be classified as RAAHPs (2012)[12]

It is suggested that this data is the most comprehensive and therefore should be utilised in order to assess the market and, therefore, the potential impact of introducing the RHI for RAAHPs. In order to do this, however, it is necessary to clarify how many installations are reversible and, of these, how many would be classified as 'non-domestic'. This analysis is shown in Table 2. [13] This shows that 145,800 reversible outdoor units are sold each year, and of these, about 134,100 are non-domestic units. This is therefore the major constituent part of the total market of 160,200 annual sales.

[12] These figures exclude US Ducted systems, which are a tiny proportion of the market

[13] This table focusses on outdoor units, as it is often the case that multiple indoor units are connected to an outdoor unit and therefore sales of indoor units do not give a good indication of number of systems installed.

System Type		Proportion Assessed as Reversible	Number of Units	Reversible Units	Of which, Non-Domestic Units
Outdoor Units	<7kW	c.90%	76,100	68,500	56,800
	>7kW	c.90%	68,500	61,700	61,700
	VRF	100%	15,600	15,600	15,600
	Total		**160,200**	**145,800**	**134,100**

Table 2: Sales of Non-Domestic RAAHPs

2.1.2 Existing RAAHP Installations

The number of existing air conditioning systems in the UK at the end of 2011 is given in The BSRIA Blue Book 2013, which has been summarised in Table 3. These figures indicate that there are some 3 million systems in operation. Assuming the market is mature, when compared to the annual sales data this indicates that a system is replaced once every 19 years, which is close to the standard estimate of the DECC RHI team of a 20 year lifespan, indicating that these datasets match well.

Packaged	Number of units	Classified as RAAHP?
Window/through the wall	37,000	No
Single splits	3,030,305	Yes (90%)
Multi splits	94,566	Yes (90%)
VRF	181,486	Yes (100%)
Roof tops	28,041	No
Indoor packaged small consoles (air cooled)	51,043	No
Indoor packaged large (air cooled)	4,107	No
Close control	123,655	No

Table 3: UK installed base of air conditioning equipment by number of condensing/plant units (end of 2011)[14]

[14] BSRIA(2013) *The BSRIA Blue Book 2013*,

2.1.3 Analysis of Published Figures

Taking the two BSRIA datasets identified in the previous sections, it is possible to derive estimates for the number of existing RAAHPs and the annual sales. These can then be used to determine the number of systems that may be affected by the RHI.

It is necessary to split the market out into non-domestic and domestic applications for the purposes of this report. Whilst there is no published data on this proportion, the industry trade body HEVAC estimates that 92% by number are for non-domestic applications. By assuming that all VRF and larger systems are non-domestic, it is possible to estimate the number of systems that may be classified as non-domestic RAAHPs. The results of this are shown in Table 4, whilst the split between heating and cooling-led systems is explored in Section 2.1.4.

		Number
Existing systems	Single-Split	2,490,000
	Multi-Split	80,000
	VRF	180,000
	Total	2,750,000
Annual Sales	Single-Split	113,000
	Multi-Split	5,000
	VRF	16,000
	Total	**134,000**

Table 4: Estimated non-domestic RAAHP market 2012

2.1.4 Development to 2020

ICF International indicates that the small AC market grew at roughly 11% per annum prior to 2010 and predicts growth rates of 6% per annum to 2015 and 4% per annum to 2020.[15] By contrast the BSRIA market figures indicate that the market has remained static over the period 2010–2012. It is likely that the market has remained largely static due to the recent recession and that there remains potential for growth as the wider economy improves. It is suggested, however, that the growth figures for the market indicated by ICF are perhaps too high for the market as has been defined in this study, and so slightly lower growth should be anticipated (in the absence of any government stimulus). Consequently, assuming a growth of the total number of installed RAAHPs of 2% per annum to 2020, the market will grow to 3.23 million installed units in 2020 without external support. This is summarised in Table 5.

[15] ICF International (2011) *Development of the GHG Refrigeration and Air Conditioning Model: Final Report*, Report for DECC, December 2011

System Type	2012	2020
Single-Split	2,490,000	2,920,000
Multi-Split	80,000	100,000
VRF	180,000	210,000
Total	**2,750,000**	**3,230,000**

Table 5: Estimated Market Scale in 2012 and 2020

2.1.5 Potential Market Threats

The RAAHP market is mature and established with many large manufacturers and service providers, which have been active for some years. The market appears to have remained stable throughout the most recent economic recession and is regarded as so by the manufacturers interviewed for this study. The following analysis explores five key market threats:[16]

1. **Threat of New Entrants**: There is a moderate threat of new entrants in to the market, mostly from Chinese manufacturers that are starting to export RAAHP technologies. There is the potential for these entrants to force prices down. It is anticipated, however, that the established reputations (and 'brand value') of the existing manufacturers will to some extent offset this challenge;
2. **Bargaining Power of Buyers:** The majority of buying within the market is via direct purchase by installers from manufacturers. These usually receive a discount of the order of 25-40% off of list prices due to the nature of the relationship between manufacturers and suppliers.[17] As the installer market is largely fragmented across a large number of independent organisations, bargaining power is low and thus not likely to drive substantial price reductions or performance improvements in the market;
3. **Threat of Substitutes:** There are very limited competing technologies that are capable of both heating and cooling and which do not require a wet heating system. Indeed, the manufacturers interviewed for this study suggested that RAAHP technologies are in fact substituting these technologies, rather than the reverse. Therefore it is likely that the market is not being significantly affected by threat of substitutes at the moment; however, new technologies such as magnetic or electro-caloric cooling may, with considerable development, become attractive in the future;
4. **Bargaining Power of suppliers:** There are relatively few suppliers (manufacturers), but enough to provide installers with some choice. Nonetheless, this small number manufacturers means that their bargaining power is strong; and

[16] These are based on the 'Five Forces', identified by Porter, that relate to industry competition. Michael Porter (1998) *Competitive Strategy: Techniques for Analyzing Industries and Competitors, June 1998*

[17] Personal Communication, RAAHP Manufacturer, May 2014

5. **Rivalry among competitors:** There is a clear rivalry between manufacturers regarding the installation, performance and operation of their equipment, with efficiency being the major focus of this rivalry. Whilst this has the potential to drive standards up, however, it is somewhat limited by the international nature of these businesses. Most manufacturers develop a set of heat pumps for the global market, with only moderate differences in software, controls and components for use in different climates. As a result, there is little opportunity for local innovation to meet local needs. As one manufacturer stated, whilst the UK is far more interested in efficiency than are many other markets, there is little incentive to drive innovation as the UK market is such a small proportion of the global market. Consequently, price setting is at the global level, without much local rivalry which could drive useful competition in the UK market.

The above analysis indicates that the market is largely established and that even where there is a drive for innovation, performance improvement or price reduction, the scope for achieving this is limited due to the global nature of the businesses involved. If new manufacturers were to provide low-cost systems of equal or better performance this may create the environment for change. It will be challenging, however, for any new entrant to acquire any market share due to the scale of efficiencies inherent in the large manufacturers' operations.

2.2 Market Segmentation

Information on the market segmentation of RAAHPs is extremely sparse, with no published indications of the split between domestic and non-domestic use. Similarly information on the ratio of units used for cooling only, combined heating and cooling, or heating only is also not available in published form. As already discussed, HEVAC indicates that c.92% of RAAHPs are non-domestic in application. With regard the nature of non-domestic applications, there was no clear indication from any respondent of what the proportions may be; however, a number of key sectors were identified by industry experts, including:

- Hotels;
- Offices;
- Retail;
- Leisure; and
- Petrol Stations.

2.2.1 Proportion of Systems Designed for Heating and Cooling

To enable DECC to determine the potential carbon benefits of RAAHPs, it is necessary to provide clarity on the modes of operation of systems coming onto the market.

There is no published data on the number of RAAHP systems that are operated primarily for heating as opposed to cooling. We have therefore explored this question via semi-structured interviews with manufacturers and installers, as well as through assessing the market estimates which were summarised in Section 2.1. There were four interviews conducted with manufacturers and eight interviews conducted with installers and other stakeholders. For the manufacturers this represents roughly half of the major manufactures in the UK, whilst for the installers and other stakeholders this is a small proportion of the total. Despite the significant proportion of major manufacturers that engaged, neither of the sample groups (manufacturers and installers/other stakeholders) reached saturation point, and therefore the following assessment should be seen as an incomplete summary of the views and experiences of manufacturers and installers in the UK.

The key findings from this analysis can be summarised as follows:

- The data available regarding the market is very limited and does not provide any indication of the potential scale of the market. BSRIA report a total of 160,000 systems installed per annum, however there is no way to determine how many of these are designed primarily for heating, or of those designed for cooling, how many deliver all of the heating load as well;
- A number of interview responses, however, referred to the potential split, which included the following assessments from installers:
  - One installer indicated that 50% of systems provided *some* heating (implying that 50% were cooling only);
  - Another installer indicated they installed systems roughly 50:50 for heating and cooling-led;
  - Another stated that the only time that they would design a heating-led system would be for a small space within a larger building; for example an office in a warehouse or a temporary lab at a university. The cooling function would then be additional to the heating, but in all other cases, the cooling would be the primary design focus. The installer estimated that this was roughly 10% of all installations;
- This can be compared with the following responses during interviews with manufacturers:
  - One manufacturer indicated that only a small proportion would be driven by the heating demand;
  - Another manufacturer suggested that almost all systems were designed for the cooling load as the heating load would be easily met if the system was sized in this way. This is because cooling efficiencies are generally lower than those for heating. They suggested that of all installations, 70% would provide all of both the cooling and heating need and perhaps only 10-15% of systems would be designed primarily for heating; and
  - Both of these, and other manufacturers indicated that there were insignificant numbers of systems that were cooling-only or heating-only.

It is assumed that manufactures are likely to have a broader view of applications than installers, as the latter are usually specialised and therefore see a relatively limited cross-section of applications. Manufacturers have less direct contact with system operators, but the breadth of their contacts within the industry, in particular their contact with multiple installers, means that they generally have a stronger understanding of the overall nature and behaviour of the market. As a result, greater weight has been accorded to the information provided by manufacturers.

As already noted, the interviews did not reach saturation and so the information available isw not comprehensive. Nonetheless, it is justifiable to utilise the interview responses to inform the development of scenarios which can be used to explore the potential impact of the RHI. It would not, however, be possible to utilise the information as the basis for detailed modelling.

Taking into account the issues identified above, the analysis indicates that cooling-led applications constitute the majority of all installations even though in the majority of cases they will also provide ***all*** of the heating demand. The figure of 10-15% for heating-led systems quoted above from one manufacturer is supported by the rationale given by one of the installers, who described the specific applications where heating-led systems would be installed. The limited nature of these applications indicates that a figure of c.10% would be realistic.

The above analysis suggests that segmentation of the market is as shown in Table 6. This segmentation suggests that 80% of the market already provides full heating load, with only 20% delivering a partial heating load (due to the systems being installed alongside alternative heating systems).

Primary Design Focus	Cooling Load (%)	Heating Load (%)	Market Share (%)	Heating Definition
Cooling	**100**	100	70	Full Load
Cooling	**100**	<100[18]	20	Partial Load
Heating	<100[19]	**100**	10	Full Load

Table 6: Split of RAAHP Market by Application

Having determined rough values for the proportion of systems operating in each different combination of modes, it is necessary to estimate the heat being generated in each instance. This is challenging because, as discussed in detail in Section 5, there has so far been no effective metering approach for RAAHPs that can be used to determine heat delivered. As a result we have focussed our efforts on the assumptions utilised by DECC in the RHI for non-domestic Air to Water Heat Pumps (ATWHPs) and Ground Source Heat Pumps (GSHPs).[20] These values are of the order of 200,000 kWh for ATWHPs and 300,000 kWh for GSHPs. It is proposed that, in absence of any other data, a nominal value c. 250,000 kWh is taken for systems operating primarily for heating as there is a wide diversity of RAAHP system sizes, with a range that reflects that of the ATWHP and GSHP figures. These figures are at the lower end of the assessed annual heat output determined by DECC for RAAHPs.[21] This appears, however, to be a realistic estimate, as the sales figures indicate that small systems are by far the largest segment of the market.

Whilst it would be desirable to link these loads to heating load factors, this is challenging to achieve as these factors are determined through analysis of performance of systems in the field. As described in detail in Section 5 there is no simple method of determining performance of RAAHPs in the field, and this prevents calculation of heating load factors for RAAHPs by simple means. In absence of such factors, it might be reasonable to assume similar factors to those achieved by ATWHPs. This is because both RAAHPs and ATWHPs discharge heat to the atmosphere (unlike GSHPs) so the variation in sink temperature experience by both would be similar in the same building.

[18] Technically the system would be capable of delivering the whole load in most circumstances, but the existence of an alternative heating system means that this is not fully utilised. The range could therefore vary between 0% and 100%

[19] The cooling function is a ‘bonus’ and would never meet the rated cooling load. It may or may not be utilised depending on the operator and nature of the building space. As the system has been designed primarily for heating it is assumed that there is no need for cooling identified

[20] DECC (2012) *Impact Assessment: Changes to the Current Non-Domestic Renewable Heat Incentive Scheme*, September 2012, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66606/6444-impact-assessment-on-changes-to-the-current-nondo.pdf

[21] DECC (2012) *Spreadsheet with Calculations Used to Derive Tariffs for the Non Domestic RHI Scheme,* September 2012

For systems where heating is being provided by an alternate system (such as a wet system) it is anticipated that the heating load will be much lower than those systems where they are the sole source of heating. It is unlikely in these circumstances that RAAHPs will deliver large quantities of additional heating, although they do have the capacity to increase heat delivery if required.

Given this uncertainty it is proposed to explore a range of values, from 10,000 kWh to 50,000 kWh annual heat delivered, with a central value of 25,000 kWh. As highlighted above, there is no existing information on loads due to the inability to meter RAAHPs, and so these estimates need to be employed with caution. The central estimates utilised for the subsequent analysis are shown in Table 7.

Operation Mode		**Proportion of Market**	**Existing Heating Load (kWh/year)**
Cooling	**Heating**		
Full Load	Full Load	70%	250,000
Full Load	Partial Load	20%	25,000
Partial Load	Full Load	10%	250,000

Table 7: Market Segmentation Estimates

Taking the estimated market segments identified above, the deployment of such systems to 2020 would take the form shown in Table 8. The information from both of these tables is used to model potential carbon benefits of RAAHPs in Section 4.

Operation Mode		**Total Operational Installations - 2012**	**Total Operational Installations - 2020**
Cooling	**Heating**		
100%	100%	1,930,000	2,260,000
100%	<100%	550,000	650,000
<100%	100%	280,000	320,000
Total		**2,750,000**	**3,230,000**

Table 8: Estimated Market Split by Operation in 2012 and 2020

It should be noted that all of the above assumptions are very uncertain since as to date there has been no thorough audit of the existing installed RAAHPs. This is because there does not appear to have been a need to split out cooling and heating operation prior to this study. It is clear therefore that a far better understanding would be derived from a more detailed research project dedicated to determining the nature of existing RAAHP installations, and how these installations are operated. This would not be an insubstantial undertaking due to the scale of the market.

2.3 Counterfactuals

The determination of counterfactual technologies is perhaps more challenging in an established market where RAAHPs will often be the main (or only) choice in many circumstances. As a result, the counterfactual mix analysis has been focussed on where additional systems will be added to the sector.

During interviews for this study, industry stakeholders have clearly indicated that RAAHPs will generally be installed in two particular ways:

- For cooling-led systems both on-gas grid and off-gas grid; and
- For heating-led systems off-gas grid.

2.3.1 Cooling-led Systems

For cooling-led systems, there is the potential to increase the amount of heating delivered by the system, displacing heating from a counterfactual technology. This displacement is likely to occur from both condensing gas boilers on-gas grid, and a mix of oil and gas boilers off-gas grid. Therefore the mix of these two technologies needs to be determined.

The proportion of these systems that are installed on-gas grid is not recorded and published, and therefore it is highly uncertain what mix would be justifiable in these circumstances. It is therefore suggested to take the estimate utilised by DECC for ATWHPs and GSHPs in non-domestic buildings of 50% gas and 50% oil as a central estimate and vary this by 20% for high and low scenarios in order to account for uncertainty.[22] This is reflected in the subsequent analysis in Section 6.2.2. Though this differs from the total split of on- and off-gas grid buildings, it is assumed that the higher average cost of heating off gas means these are more likely to be replaced with other systems such as RAAHPs.

2.3.2 Heating-led Systems

For heating-led systems the challenge is simpler as it is assumed that at least initially the off-gas grid will be where most displacement of counterfactuals occurs. Therefore DECC's estimate for ATWHPs and GSHPs of 50% gas and 50% oil is also utilised in this situation.[23] Once more it is recommended to use a variation of 20% in order to indicate the uncertainty in this figure, though it is perhaps less uncertain than for the cooling-led systems.

2.4 Justification for Government Intervention

2.4.1 Analysis of Potential Market Failures

There is only one significant market failure relating to RAAHPs, and that is of 'information failure'. This occurs in two ways:

- Some operators do not realise that their installed RAAHP system can provide heating as well as cooling:

[22] DECC (2012) *Impact Assessment: Changes to the Current Non-Domestic Renewable Heat Incentive Scheme*, September 2012, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66606/6444-impact-assessment-on-changes-to-the-current-nondo.pdf

[23] DECC (2012) *Impact Assessment: Changes to the Current Non-Domestic Renewable Heat Incentive Scheme*, September 2012, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66606/6444-impact-assessment-on-changes-to-the-current-nondo.pdf

In theory it should be relatively easy to educate system operators to be aware of the heating function of RAAHPs. This is complicated, however, because the design and installation is usually conducted by third parties and so it would be necessary for the third party to pass on any information or literature about the functions of the installed system. This is not within the control of manufacturers and is where the major challenge lies. Furthermore, there is limited benefit of any such approach to the manufacturers themselves as the systems have already been purchased and thus no additional financial gain would come from the use of the heating function.

- Some people selecting heating systems are not aware of the capabilities of RAAHPs and therefore they are often not considered:

  This issue would best be addressed in the non-domestic sector via broad campaigns that raised the awareness of the business population, such that those selecting heating systems sought out further information on RAAHPs. As there may be some additional return for manufacturers in this respect, it may be something that is worth their consideration.

It is feasible that both of these information failures could be, to some extent, corrected by the manufacturers through additional marketing campaigns. There would be limitations to the impact of this approach for both failures, but particularly with regard to the first due to the role played by third party installers and the lack of perceived benefit to the manufacturer.

Neither of these market failures necessarily justify government support, as information failure does not require the use of an incentive to correct it. It is noted, however, that use of an incentive often does improve awareness of information within the market, helping to correct such failures.

In addition to information failure, as discussed in Section 2.4.2, a number of other barriers exist in relation to deployment of RAAHPs. In this analysis, only the ‘awareness and confidence’ issue relates to the market failure identified here, yet the others also play a significant role in limiting the growth of the market.

2.4.2 Barriers to Deployment

Whilst the market for RAAHPs is an established one, there nonetheless exist barriers to the further deployment of these systems. An analysis of the barriers to deployment for RAAHPs is presented in Table 9, and is drawn from studies undertaken on behalf of DECC and the CCC, with additional analysis by Eunomia.[24] [25] This analysis focusses on the deployment of RAAHPs for heating (either as the primary or secondary function).

As described in Table 9, a number of stakeholders suggested that the key barrier to the deployment of RAAHPs for heating-led installations is the availability of cheap natural gas from the national grid. Indeed, installers report that they often install an RAAHP for cooling and a gas boiler for heating in the same building on the gas grid, which shows the challenges faced in developing the heating-led market. A related barrier is that there exists a lack of awareness among some operators that their cooling system can also deliver heat. Furthermore, installers of AC (including RAAHP) equipment are often different to those installing heating boilers, and

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[24] NERA Economic Consulting, and AEA (2009) *The UK Supply Curve for Renewable Heat*, Report for Department of Energy and Climate Change, July 2009

[25] Frontier Economics (2013) *Pathways to High Penetration of Heat Pumps*, on behalf of the Committee on Climate Change, October 2013

therefore such systems are often not properly integrated and thus can often be operating in conflict. This split between heating and cooling provision can mean that is difficult for operators to identify that there is the potential to use RAAHPs for heating.

This analysis demonstrates that although many barriers exist, there is not a conclusive need for government intervention as there is no clear market failure that needs to be addressed. It is clear, however, that intervention may be desirable to remove barriers to greater deployment if such deployment is deemed to be beneficial.

Barrier	Description	Potential Mitigation(s)	RAAHP Specific Issues
Major Barriers			
Awareness and confidence.	Awareness of technology is limited, and where known there exist uncertainties around performance. Non-monetary costs such as time taken to research the technology and hassle associated with installation can limit uptake.	Public awareness programmes and promotion of existing installations etc.	This issue is perhaps slightly less relevant for RAAHPs than for other heat pump types, as non-domestic settings are often well acquainted with AC systems. There may be issues, however, regarding operators of cooling-led installations being unaware of the heating capabilities of their RAAHP unit(s).
Prevalence of Gas Distribution Network.	Gas fired heating systems serve approximated 75% of UK housing, and the ratio of gas to electricity prices lengthens the payback on investment in HPs.	Permanent inhibitor on the number of systems installed in areas connected to the gas network.	This is perceived as the fundamental barrier facing all alternative solutions. The possibility of mitigation is modest as the gas network is very unlikely to reduce in size.
Capital investment & payback.	Lifetime costs of heating-led HPs are typically higher than conventional alternatives such as gas and oil boilers.	Grant support, favourable loan schemes, RHI.	This is the focus of potential support for RAAHPs under the RHI.
Preference for ‘wet’ systems.	Many consumers in the UK prefer the nature of heat from wet systems (underfloor heating, radiations etc.) leading to other systems being selected ahead of RAAHPs even if they are the most cost-effective.	Expose consumers to spaces heated by RAAHPs.	This issue solely relates to RAAHPs as all other types of heat pumps utilise ‘wet’ systems.
Additional Barriers			

Introduction of smart metering.	Heating demand mirrors electricity demand profile meaning HPs would pay higher electricity prices under variable tariff contracts.	Introduce special tariffs for heat pumps. Increase thermal storage of systems to allow off-peak usage.	This has not been a barrier thus far, and would be the same for all heat pump technologies (except Gas Driven Heat Pumps).
Space and aesthetics.	HPs take up more space than conventional heating systems.	Further technology development to reduce installation size.	This is unlikely to be a significant barrier if RAAHPs are the most economically viable option. Furthermore RAAHPs have far lower space requirements than ground source systems.
Suitability of building (including noise).	Properties must be relatively energy efficient for RAAHPs to be effective. Planning limits on noise and objections from local residents can limit uptake.	Installation of energy efficiency measures driven by Energy Performance Certificates (EPC) Display Energy Certificates (DECs).	Given the wide distribution of cooling-led installations it is anticipated that noise and wider planning constraints are not a significant barrier for RAAHPs.

Table 9: Barriers to deployment of RAAHPs

3 RAAHP Costs and Prices

The key findings from this section can be summarised as follows:

- Based on list prices, mean capital costs (excluding installation) for combined systems are £224/kW;
- Installers are routinely offered a discount of between 25% and 42% on list prices;
- Under our central assumptions, installed costs are 46% higher than list prices. 76% of the price to the purchaser is for the unit, with the remaining 24% split equally between labour and consumables;
- There appears to be very little short-term likelihood of cost reductions in capital prices, although there is a small possibility that less costly systems from China will influence the market prior to 2020;
- Under our central assumptions, average annual maintenance costs are approximately £132 per unit, although the variation in this value is significant and depends on the size and nature of the system.

3.1 Capital Costs and Prices

3.1.1 List Prices

The cost of systems is dependent on the type of systems:

- Single-split systems are relatively easy to cost as they comprise a single outdoor unit and a single indoor unit; and
- Multi-split and VRF systems are much more challenging to provide cost assessments for, as they will comprise potentially up to 50 indoor units for each outdoor unit, leading to many different permutations.

As the market is an established one, there are a very large variety of units available. As it is possible to utilise many combinations of indoor and outdoor units there are a large number of combinations that can be utilised, meaning that there are well over 1,000 different product combinations available on the UK market. Furthermore, this does not account for the quantity of indoor units that can be added to an outdoor unit, which would increase the numbers even further. The number of systems and combinations highlights that the market is mature, with a variety of products available, all at similar prices.

In gathering cost data we have tried to deliver a cross-section of the available systems, representing different system power ratings in particular. This data is presented separately in a data collection template submitted to DECC and has been provided for the following three different unit combinations reflecting the diverse reporting of information by manufacturers:

- Combined systems incorporating a single outdoor unit and one or more indoor units;
- Outdoor units; and
- Indoor units.

This information focuses on published or 'list' prices rather than those including installation. Modelling of this list price data is shown in Table 10. This analysis indicates a mean price of £224 per kW capacity for combined systems (with £138 per kW capacity for indoor units and £189 per kW capacity for outdoor units).

Type of Unit	Mean Capacity	Mean Price/kW	Number of Records
Combined[26]	5.80 kW	£224	34
Indoor[27]	6.30 kW	£138	47
Outdoor[28]	37.50 kW	£189	55

Table 10: Mean Costs from Data Collected for 159 Units

3.1.2 Installed Prices

This list price data highlighted above has been augmented by interviews and examination of installation data as part of this study. In interviews it was revealed by manufacturers that installers are routinely offered a discount of between 25% and 42% on list prices for RAAHP units. One manufacturer also stated that the installed costs charged to the purchaser would then be 2.1 to 2.3 times the discounted unit price charged to the installer. Of the additional price they estimated that 50% would be for consumables and 50% for labour. An *example* summary of this calculation is shown in Table 11, which shows that 76% of the price to the purchaser is for the unit, and that the total price is 32% greater than the list price.

Unit List Price	Price Paid by Installer	Price Charged by Installer			
		Total	Unit	Consumables	Labour
£100	£60	£132	£100	£16	£16
		100%	76%	12%	12%

Table 11: Example of Differences between List Prices and Installed Prices[29]

The analysis in Table 11 shows that the installer will charge £100 for a unit, but actually only have paid £60. The difference of £40 is theoretically the margin for the installer, although in practice this will include an element of contingency and overheads and so is very unlikely to be

[26] This is a set of units that comprise at least one indoor and one outdoor unit, and therefore can be considered a complete system when connected together.

[27] This is a unit that is mounted internally and delivered the conditioned air to the space to be heated/cooled.

[28] This is a unit that is mounted outside and rejects and/or obtains heat to/from the atmosphere.

[29] These have been chosen as indicative values to facilitate ease of analysis – it is not suggested that they represent an expected price for a system. Additionally, this scenario is for the replacement of an existing system, as building works are not required. In such a situation the unit cost would be a substantially smaller proportion of the total costs.

entirely profit. In contrast, it appears that the installer makes little or no margin on consumables or labour.

Taking all of the values provided by manufacturers, analysis of the full range of installed prices is provided in Table 12.

Scenario	Discount to Installer	Subsequent Increase Charged to Purchaser	Resulting Uplift on List Price for Installed System
High Uplift	25%	230%	73%
Central Uplift	34%	220%	46%
Low Uplift	42%	210%	22%

Table 12: Calculated Range of Uplifts on List Prices Charged for Installed Systems

3.1.3 Potential for Cost Reductions and Increases

All interviewees indicated that there was little or no likelihood of cost reductions in capital prices up to 2020. This is due to the established nature of the technology, and whilst there does exist significant competition in the sector, this is between the established players, which are unlikely to seek to significantly cut prices. That said, as discussed in Section 2.1.5, there are a number of new entrants (largely from China) emerging in the sector, which are beginning to challenge the established Japanese firms, and they may seek to do so on price. At this stage it is difficult to determine how this might be manifested, although one interviewee indicated that the Chinese heat pumps were beginning to match the established technologies in terms of quality indicating that there is the potential for changes to occur in the market over the coming years.

Nonetheless, as highlighted in Section 2.1.5, we anticipate that the impact will most likely be relatively limited as the established nature of the technology means that there are likely to be only minor improvements that can be made, with the primary differentiator coming from the cost of Chinese labour. As a result it is suggested that government should not anticipate significant cost reductions in the sector, which should guide any thinking with regard to potential tariff degression.

3.1.4 Consideration of Hassle Costs and Risk Premium

Aside from capital and operating costs, which need to be taken into consideration by DECC in potentially attempting to set RHI tariffs for RAAHPs, thought also needs to be given to what are termed ‘hassle’ costs and ‘risk premium’.

Hassle costs are those associated with the time input required for project identification, appraisal, and commissioning of new renewable heating systems, which might be applicable over and above those associated with the counterfactual. Risk premium refers to any additional incentive which is required to convince businesses to switch to less proven technologies or feedstocks.

A range of documentation, which has been developed by DECC or on behalf of DECC, towards setting RHI tariffs (using the levelised cost method) appears to take into consideration a range of different types of hassle and risk costs, albeit apparently using slightly different approaches.[30]

[30] DECC (2009) *The UK Supply Curve for Renewable Heat*, AEA and NERA on behalf of DECC, July 2009; DECC (2012) *RHI Phase II – Technology Assumptions: Key Technical Assumptions for Selected Technologies,* AEA on

In some cases, these include both 'upfront' hassle costs, such as those mentioned above, but also 'ongoing' hassle costs, which might refer to any additional ongoing maintenance and administration required over and above that for the counterfactual.

Whilst detailed assessment and recommendations as to how DECC should model hassle and risk premium for RAAHPs is outside the scope of this study, the following issues are worthy of discussion to inform the analysis:

- Variations across different types of system: and
- Variation between RAAHPs and other renewable heating technologies (RHTs).

These issues are discussed in detail in Sections 3.1.5 and 3.1.6.

3.1.5 Variations across different types of RAAHPs

Given the variation in the rationale for installation of RAAHP described in Section 2.1, it is useful to consider whether there might be differences in hassle costs or risk premium across installations. To do this, it is important to consider the counterfactual. The vast majority of RAAHPs are likely to be cooling-led (albeit they will also provide heat) and thus replace existing air conditioning systems (which may or may not be RAAHPs). The initial hassle factor associated with implementing such replacements will therefore usually be minimal or zero.

The ongoing hassle associated with operating the heating element of the RAAHP, however, could be relatively large in situations whereby the user needed to manage this alongside the heat output from a wet system fuelled by a boiler. In such situations, the profile of risk premium is very similar; whilst the installation of the system is not likely to represent a significant risk, there is likely to be some uncertainty around operating the system in heating mode, to which some risk premium might be applied.

As described above, the small number of systems which are 'heating-led' are only likely to occur where no existing wet system exists, for example, in light industrial and commercial buildings. Once again, therefore, the initial hassle costs are likely to be minimal or zero. Furthermore, as such systems are usually very simple 'plug and play', ongoing hassle costs will be similarly low and risk premium is also likely to be close to zero.

Consequently, we believe the only level of variation in hassle costs and risk premium across different types of system relates to the difference in ongoing hassle costs between systems which are cooling-led and heating led systems.

3.1.6 Variation between RAAHPs and other Renewable Heating Technologies

Given the differences in nature of the heat provided and the reasons for using RAAHPs, it is useful to consider whether the level of hassle costs or risk premium related to RAAHPs might differ from those related to other RHTs.

As described above, the hassle costs and risk premiums associated with the use of heat from RAAHPs are likely to be relatively low (because they are not replacing wet systems), albeit ongoing hassle costs and risk premium for cooling-led systems may be higher, whereby these are also providing heating. The situation is somewhat different for most other RHTs, as the technologies will be replacing fossil fuelled heating (rather than existing air-conditioning). Consequently both hassle costs and risk premiums are likely to be lower for RAAHPs than for biomass, solar thermal and also for ground and air to water heat pumps.

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behalf of DECC, February 2012; DECC (2013) *Research on Costs of Heating and Cooling Technologies*, Sweett Group on behalf of DECC, February 2013

Should any RHI tariff be set at such a high level that replacement of wet systems with heating-led RAAHPs takes place, then the situation would be somewhat different. In this case, we would expect both hassle costs and risk premiums to be higher for RAAHPs than for other technologies.

3.2 Operating Costs

In this section, we have considered the costs of maintenance and repair, which are based on information provided by manufacturers and installers regarding the frequency of maintenance and failure of systems and estimates of associated costs.

3.2.1 Maintenance Costs

Whilst there is substantial data on capital costs via published list prices, there are significant limits to the data available regarding maintenance. This is because it is application-specific and also relates to the frequency of maintenance determined to be acceptable to the operator, which may not meet manufacturer recommendations. As a result, manufacturers have estimates for basic costs of maintenance, but no simple published figures. Consequently, the analysis in this section is derived from assumptions made by industry experts to arrive at a range of potential annual maintenance costs.

It is recommended by manufacturers that an RAAHP system is serviced once a year except where there are particularly challenging circumstances (for example where the system is in a coastal location and salt can quickly damage key parts). Whilst manufacturers recommend annual maintenance, our experience suggests that some operators will not service systems at this frequency. As a result, we have used a range of service frequencies to model maintenance costs, ranging from once every 6 months (for challenging locations) to once every 24 months where operators are not concerned about maintenance.

The costs associated with maintenance are simple to determine as it is usually entirely covered in the day rate charged by the technician. The consumables used in the maintenance process are limited and so it is easy to incorporate them into the day rate. Day rates will vary from roughly £300 for local technicians to £500 for technicians from the manufacturer. The time taken to maintain a system will partially depend on scale, but also on the number of units on a single site. So, whilst a sizeable system at a site with no other systems may take half a day to maintain, it is equally feasible to service four small systems in a day if they are at the same site. All of these variables have been used to calculate a range of maintenance costs for systems, which are shown in Table 13.

Scenario	Number of Months between Service	Day Rate Charged	Days Required to Service	Cost per Annum per Unit
High Cost	6	£500	0.5	£500
Central Cost	12	£400	0.33	£132
Low Cost	24	£300	0.25	£38

Table 13: Calculated Range of Annual Maintenance Costs

The large range of costs presented in Table 13 indicates the variation that can exist in maintenance costs for different systems depending on a number of factors. It is interesting to note that one manufacturer quoted a cost of £3.60 per installed kW per annum for maintenance costs. Taking the mean system rating of 5.8kW determined in the analysis in Table 10, this gives annual costs ranging from £5 to £71/kW, indicating that the £3.60 figure may well be accurate for systems where maintenance can be effected in a very efficient manner. It should be noted that the higher figure (£500) would relate to very challenging circumstances and therefore should be used with caution.

3.2.2 Repair Costs

It is not surprising that systems will sometimes unexpectedly fail and require repair. As the technology is mature, however, the Mean Time Between Failure (MTBF) for such systems is similar to the lifespan. This long MTBF means that in many cases failure may well result in a new heat pump being installed, which would not be a repair and therefore not represent an operational cost.

Furthermore, repair costs can be markedly different depending on the failure in question, the size and nature of the system and the required remedy. It is therefore challenging to develop a standardised analysis. For example, for small systems there is little benefit from replacing individual parts in a compressor due to the high labour costs that would be required compared to the price of a new compressor. By contrast it may well be cost-effective to strip down and repair a large compressor in a substantial VRF system.

As a result of these issues, we have not attempted to determine an accurate operational cost relating to repairs for RAAHPs.

4 Renewable and Carbon Saving Credentials

The key findings from this section can be summarised as follows:

- There is a large degree of uncertainty as to the real SPFs in the UK for RAAHPs, albeit this situation is likely to improve slightly as a result of the provisions of the EU Renewable Energy and Ecolabel Directives;
- Our analysis suggests that RAAHPs should be modelled to have SPFs of between 2.5 and 3.2, with a mean of 2.8;
- At this level of SPF, based on DECC's long-run marginal grid factor of 0.3422 kg CO_2e, RAAHPs can provide 40% carbon savings compared to condensing gas boilers and 60% savings compared to oil-fired boilers;
- As a result of the common practise of heat recovery across VRF systems, much of the heat used across such systems cannot be considered as 'renewable' under the RHI.

The renewable and carbon saving credentials of RAAHPs are determined by a number of factors:

- Their efficiency in turning electricity into heat (COP/SPF/SCOP);[31]
- The carbon factor of the grid at the time of heat generation; and
- The counterfactual scenario (what system they have replaced).

The following assessment examines each of these elements to determine the carbon saving credentials of RAAHPs. These are compared with similar systems such as Ground Source Heat Pumps (GSHPs) and air to water / Air Source Heat Pumps (ATWHPs).

4.1 Types of Performance/Efficiency Measures

There are a number of different measures of performance and efficiency that can be used for heat pumps. Each has advantages and disadvantages. Table 14 outlines the nature of each of these measurements and their relevance for this study.

[31] SCOP = Seasonal Coefficient of Performance (COP)

Measure	Definition	Notes
Coefficient of Performance (COP)	$\frac{Heating\ Output\ (kW)}{Power\ Input\ (kW)}$	This is a measure of instantaneous performance
Seasonal Coefficient of Performance (SCOP)	$\frac{Heating\ Output\ (kW)}{Total\ Power\ Input\ over\ the\ Season\ (kW)}$	This takes a seasonal mean of the COP values
Seasonal Performance Factor (SPF)[32]	$\frac{Heat\ Energy\ Output\ (kWh)}{Total\ Input\ Energy\ to\ Heat\ Pump\ (kWh)}$	This is very similar to SCOP, except it measures efficiency using energy delivered rather than instantaneous power

Table 14: Types of Efficiency Measurements

In order to determine a carbon factor, the performance of a system over the course of a whole year needs to be identified. Both SCOP and SPF could potentially be used to determine this, though they arrive at annual performance in slightly different ways:

- SCOP utilises a mean of the ratio of power output to power input; and
- SPF uses the ratio of total energy output over total energy input.

The biggest impact of this difference in calculation method for the two measures is that the SCOP does not directly take into account the impact of heating at different times in the year, unless it is weighted to do so. The SPF figure automatically adjusts for when in the year the system is being used as the energy output and input are both logged, and so the efficiency of the system at the time of heating is captured. This is important as during colder periods, systems are less efficient (in heating) than at other times of year as the temperature differences between inside and outside are greater. As heating is generally needed more during colder periods, it is the performance of systems during these periods that is most relevant in determining the overall performance of a system. As a result, it is preferable to have SPF figures where possible, but failing this SCOP figures will provide a (possibly optimistic) approximation of SPF figures.

The COP figures, however, will not provide such insight as they are only instantaneous measurement of performance in specific conditions. The SCOP and SPF figures are therefore the ones that attempt to describe the experience of operators in the field. The variation of these figures in the field from those published is explored in Section 4.2.

4.2 Variance in SCOP and SPF Figures

The performance of RAAHPs in the field is critical to determining their carbon saving credentials. Manufacturer SCOP figures and SPF figures are calculated according to agreed

[32] There are many ways of calculating SPF (denoted SPFH1 to SPFH4) and each of these would yield a different result for a single heat pump; however the nature of the data provided is that where there is data, the nature of the calculation used to derive the SPF is invariably not provided. As a result, throughout the rest of the report, this measurement is solely referred to as SPF.

sets of international standards and are then reported in published literature and, where required, provided on product labelling. Calculations for determining RAAHP performance are set out in the Renewable Energy Directive (RED) - Directive 2009/28/EC. This outlines standardised approaches for determining performance figures for three climate regions: cold, average and warm as well as listing default values for each heat pump technology.[33]

In addition to the calculations required under the RED, the Ecodesign Directive (Directive 2009/125/EC) will determine the nature of labelling used to illustrate the calculated SCOP values for RAAHPs as they will be classified as air-conditioning systems.[34] A mock-up of a label presenting this data produced by Fujitsu is shown in Figure 1. The three different regions are clearly demarcated on the map for the associated SCOP figures.

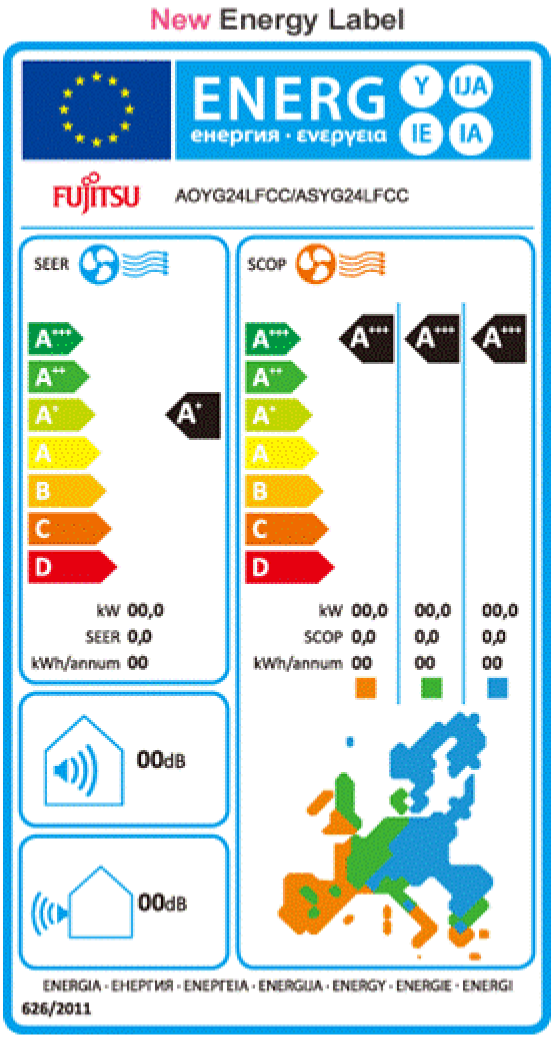

Figure 1: Example Label from Fujitsu

It is suggested that the alterations in SCOP calculation requirements and labelling will lead to improved accuracy as it will be possible to take into account variation in climate to a greater extent than is currently the case.

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[33] European Commission (2013) Commission Decision Establishing the Guidelines for Member States on Calculating Renewable Energy from Heat Pumps

[34] European Commission (2009) Directive 2009/125/EC of the European Parliament and of the Council Establishing a Framework for the Setting of Ecodesign Requirements for Energy-Related Products

Nonetheless there remains uncertainty over the variation between such calculated figures and performance in the field. A number of studies have sought to identify these differences for ATWHPs and GSHPs, but the results are highly location specific with results reporting lower, similar and better efficiencies.[35] [36] This serves to highlight the influence of climate on SCOP and SPF figures. Studies for RAAHPs do not exist as there is a lack of metering options as discussed in detail in Section 5.

In the interviews undertaken for this study, installers unanimously reported that the figures calculated and provided by manufacturers were accurate and effective for design of systems, enabling them to size systems correctly. This indicates that the calculated figures are of the correct magnitude, though does not guarantee accuracy. The fundamental challenge is that each installation site will have unique characteristics that will affect performance, and this cannot be captured using a standardised approach.

In summary, it has been very difficult to identify the variation of SCOP and SPF figures from published data due to the uncertainties in measurement of performance. As a result, as set out in Section 4.3, we have taken a conservative approach to published SCOP and SPF figures used to derive the carbon factors associated with RAAHPs. It is suggested, however, that the improved calculations as required by the RED and reporting requirements that are likely to be part of lot 6 of the Ecodesign directive will have a notable improvement on relevance and accuracy of SCOP figures for the UK situation.

4.3 Carbon Factor of RAAHPs

For technologies that utilise electricity, such as RAAHPs, the carbon benefit/cost associated with the generation of one kWh of heat can be determined from the efficiency of the system and the carbon factor associated with the generation of the electricity used. As already described, the efficiency can be determined either from SCOP or preferably from SPF figures; however SPF figures are rarely reported due to the challenging nature of measuring performance.

Due to the lack of SPF figures generally available, the SCOP figures can provide a guide as to the likely range of SPF efficiencies associated with RAAHPs. Under the SCOP calculations there are default values of 2.7 for the South West of England and 2.6 for the North East of England, which have been derived by the EU Commission.[37]

Additionally, DECC has previously determined that RAAHPs are capable of an SPF of up to 3.2 3. in the published RHI Calculations.[38]

Taking into account that the SCOP figures may be slightly higher than the SPF figures, it is suggested that a low value of 2.5, central value of 2.8 and high value of 3.2 would reflect the information available at this point in time. The low SPF of 2.5 is marginally below that of the European Commission (EC) SCOP figures to account for the different nature of the SCOP and SPF calculations. A central SPF of 2.8 takes into account that the performance of RAAHPs can be substantially greater than the EC default values (which appear to be quite conservative), whilst the high SPF of 3.2 reflects the ability of systems to be highly efficient when used effectively in an advantageous climate.

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[35] Staffell, I. (2009) A Review of Domestic Heat Pump Coefficient of Performance, *Selected Works*

[36] Fraunhofer ISE (2011) *Heat Pump Efficiency: Analysis and Evaluation of Heat Pump Efficiency in Real-Life Conditions*, May 2011, http://wp-effizienz.ise.fraunhofer.de/download/final_report_wp_effizienz_en.pdf

[37] European Commission (2013) Commission Decision Establishing the Guidelines for Member States on Calculating Renewable Energy from Heat Pumps, 2013

[38] DECC (2012) *Spreadsheet with Calculations Used to Derive Tariffs for the Non Domestic RHI Scheme,* September 2012

Unlike the data for SCOP and SPF, there is a reasonable quantity of information available regarding COP figures. As part of this study a good amount of data on COP figures was obtained, however it has not been included so as not to distract from the SPF and SCOP values, which are those most relevant to the study. It is worth noting, however, that the range of SPF figures identified (2.5-3.2) compares with an academic study which assessed the COP figures measured for systems in use around the world, which reported COP figures broadly between 2.5 and 5.0.[39] It is reasonable to expect that the lowest SPF may be similar in magnitude to the lowest COP as if the COP was calculated during winter it would be lower, and more representative of the performance of a heating system (which is used most often in winter). Therefore a low-end figure of 2.5 for SPF appears reasonable in this light. It is not possible to make such a judgement at the high end of the scale as COP figures can rise to very significant levels in hotter periods.

The carbon factors associated with the grid are published by DECC and can be utilised for this analysis. These take two forms:

- **The Grid Average**: This is the carbon generated from the electricity grid based on the proportion of supplying technologies at any given point in time; and
- The **Long-Run Marginal**: This value is based on the additional capacity that is added at the margins of the grid and is therefore a lower figure than the grid average when the grid is decarbonising. Taking the long-run marginal will therefore tend to give a conservative estimate of benefits.

It is the Long-run marginal factor which has been utilised in this study. For a RAAHP operating in 2014, for example, the carbon factor associated with 1kWh of electricity consumed is 0.3422 kg CO_2e / kWh electric for a commercial setting.[40] [41] Taking the 0.4kWh electric consumed by the heat pump then gives a carbon factor of 0.1369 kg CO_2e / kWh thermal (delivered heating).

4.4 Comparison with Carbon Factors of GSHPs and ATWHPs

It is useful to note the similarities and differences with other forms of heat pump. As already described, DECC assumes an SPF of 2.5 for ATWHPs. This compares closely to the values assumed by the EU Commission of 2.6 for average climates and 2.7 for warm climates. Taking a value of 2.6 for the SPF leads to a moderately higher carbon factor than derived for the central estimate used in this study for RAAHPs. GSHPs, however, are assumed to have a greater SPF of 3.5 by the EU Commission which leads to a lower carbon factor for GSHPs of 0.098 kg CO_2e / kWh thermal. The comparison of these systems is shown in Table 15.

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[40] DECC, and HM Treasury (2013) Appraisal Guidance: energy use and GHG emissions: Supporting tables 1-20 - supporting the toolkit and the guidance

[41] This is the long-run marginal value, which has been used for the reasons outlined in the main text.

Heat Pump Type		Assumed SPF	Carbon Factor (kg CO_2e / kWh thermal)	RAAHP Central Carbon Factor as Percentage of Technology[42]
RAAHP	Low	2.5	0.137	
	Central	2.8	0.122	
	High	3.2	0.107	
ATWHPs		2.6	0.132	93%
GSHP		2.9	0.098	125%

Table 15: Comparison of Heat Pump Carbon Factors in 2014

The comparison indicates that RAAHPs are only marginally less beneficial than GSHPs (which require substantially more infrastructure in order to operate) and are roughly 10% more beneficial than ATWHPs. This analysis is based on a number of assumptions and so the absolute values should not be used for any detailed calculations, nonetheless the magnitude of these values indicates that RAAHPs can potentially be used as a carbon saving technology. It should also be noted that if the EU Commission default values were used for all systems, there would be no difference between ATWHPs and RAAHPs.

4.5 Analysis of Counterfactuals

In order to put these figures into context and determine whether RAAHPs save carbon, it is necessary to examine the counterfactual technologies that RAAHPs would replace. These need to be split into two groupings, as the manner in which heat is delivered will make a difference to the technology that is replaced:

- **Systems primarily designed for heating:** These systems are currently utilised off-gas grid, and so the counterfactual is likely to be an oil-based system in the first instance. If it is desirable, however, for such systems to penetrate into the gas-grid market then gas boilers should also be examined as a counterfactual.
- **Systems primarily designed for cooling:** These systems will deliver some heat, but may do so in tandem with another heating system (oil, gas, renewable etc.). It is therefore difficult to identify what the counterfactual for such systems may be. Indeed in many cases it may be a renewable technology, such as biomass or other non-reversible heat pumps. As other heat pumps are already included in the analysis, however, for simplicity we have modelled oil and gas boilers as the counterfactual technology in these instances.

It is therefore necessary to examine the carbon factors associated with oil and gas boilers for comparison to the RAAHP carbon factor of 0.122 kg CO_2e / kWh. These can be derived from carbon factors published by DECC.[43] This analysis is outlined in Table 16.

[42] This figure shows how the carbon factor for other heat pump technologies compares to the carbon factor for RAAHPs. For example the carbon factor for ATWHPs is 93% of that for RAAHPs, indicating that ATWHPs are 7% less beneficial per kWh heat delivered than RAAHPs.

Counterfactual Technology	Efficiency	Carbon Factor Per Unit[44] (kg CO_2e / kWh thermal)	Carbon Factor (kg CO_2e / kWh thermal)	Additional Carbon Output per kWh compared to RAAHPs[45]
Natural Gas	88%	0.1841	0.210	72%
Burning Oil[46]	83%	0.2456	0.298	144%

Table 16: Summary of Counterfactual Technologies

This analysis clearly shows that RAAHPs provide significant carbon savings compared to natural gas and oil. As a result, it is clear that utilisation of these technologies where they would replace carbon intensive counterfactual technologies would clearly be beneficial.

This does not, however, account for the reversible nature of these heat pumps. If an RAAHP is installed instead of a heating-only system, the operator is confronted by an opportunity to use the cooling aspect of RAAHPs in periods of hot weather. This would not have been the case with a gas or oil boiler. If this function is utilised then additional carbon is generated that may not have been generated otherwise, i.e. the user might not have employed an alternative form of cooling. It is very difficult to quantify to what extent this would happen, but a simple calculation can show the potential effects. Assuming an SPF in cooling of 3.0, this gives a carbon factor associated with cooling of 0.114 kg CO_2e / kWh. If the system was used for a cooling load factor 30% of the heating load factor, with the impact of cooling added to the heating carbon factor, this would lead to an effective annualised carbon factor of 0.156 kg CO_2e / kWh. This is a significant increase in carbon factor, bringing the total benefit to only around 25% better than natural gas (0.210 kg CO_2e / kWh) rather than 40%. If the cooling load were to increase up to three quarters of the heating load, the carbon factor would be equivalent to that of natural gas. This is a very rough calculation, but illustrates the potential danger of incentivising RAAHPs in a way that would encourage additional cooling.

4.6 Renewable Credentials

The above analysis demonstrates that RAAHPs deliver carbon savings when they do not lead to *additional* cooling that would not have otherwise been generated. This therefore needs to be carefully considered in the segmentation of the market and in designing any form of intervention.

The proportion of the heat delivered by these systems that can be classed as renewable will vary depending on the type of system under consideration. A summary of the systems and the proportion of heat delivered that can be counted as renewable is presented in Table 17.

Both single-split and multi-split systems can only operate in cooling or heating mode at any one point in time. This means that when heat is being delivered it is coming from the outdoor unit,

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[43] Carbon Trust (2013) *Conversion Factors: Energy and Carbon Conversions 2013 Update*, June 2013, http://www.carbontrust.com/media/18223/ctl153_conversion_factors.pdf

[44] This is the carbon factor for the fuel if burned 100% efficiently.

[45] This value is the additional carbon factor above the RAAHP central carbon factor, giving an indication of the difference in carbon performance of the systems

[46] Often known as kerosene

which is from a renewable source and can therefore be described as 100% renewable. Therefore if it can be determined when the system is in heating mode, the level of renewable heat can potentially be determined.

By contrast, VRF systems can effectively move heat around a building with some indoor units operating in cooling mode, whilst others operate in heating mode. This form of operation means that very complex flows of heat can exist in a building, preventing clear determination of where heat has originated from and therefore it is not possible to determine the proportion of heat that is classified as renewable. This issue is compounded by a lack of metering options to measure this changing proportion as discussed in detail in Section 5.7.

In summary it is useful to highlight that whilst recovered heat would not be considered renewable, and therefore would not be supported by the RHI, in principle, DECC does not want to discourage systems being designed as to be energy efficient.

System Type	Proportion of Heat Delivered Considered as Renewable
Single-Split	100%
Multi-Split	100%
VRF	Unknown

Table 17: Differences in Renewable Heat Proportion by System Type

4.7 Performance Compared to other Countries

Whilst all interviewees were asked about how performance varied around the world, there was little knowledge about this issue, with most informants expecting this to be broadly similar due to the international nature of the markets. One manufacturer indicated, however, that they selected the more energy efficient units for sale in the UK due to the emphasis on energy efficiency here, albeit this is a single anecdotal data point.

Again this issue is compromised by the lack of accurate method of measuring performance in the field. It is also compromised by a lack of independent case studies enabling true comparability of results.

5 Measuring Renewable Heat Delivered

The key findings from this section can be summarised as follows:

- Five different approaches to measuring renewable heat are assessed against a range of acceptability criteria, the five approaches were:
  - Fully deemed,
  - Calibrated deeming,
  - Refrigeration circuit monitoring,
  - Refrigeration control monitoring, and
  - Temperature control monitoring;
- None of the methods are suitable for determining renewable heat delivered by VRF systems;
- The best potential option for single and multi-split systems is a form of 'calibrated deeming'. This option is affordable, but provides for only low accuracy as it relies

Determination of the quantity of renewable heat delivered by an RAAHP is required if RAAHPs are to be supported by the RHI. This is perhaps the most significant challenge associated with bringing this technology within the scope of support from the RHI, for the following two reasons:

- Measurement of the amount of heat delivered requires an assessment of the volume and temperature of air delivered over time. In contrast to water, which is contained within a pipe with little density variation (meaning that heat delivered can be more easily measured in air to water and ground source installations), it is very challenging to identify the mass flow of air; and
- VRF systems will often move heat around within a building, with only some heat being drawn from outside the building. As discussed in Section 4, this poses a significant challenge to identifying the 'renewable' element of the heat delivered (as opposed to recirculated heat or that drawn from refrigeration units, for example) which could be supported by payments from Ofgem under the RHI.

To determine a solution to the above issues, five possible approaches were agreed with DECC for initial consideration:

- **Fully deemed**: The heat load is estimated by the installer and payments are based on this heat load estimate;
- **Calibrated deeming**: Input power is measured and converted to heat generated using the SPF;

- **Refrigeration circuit monitoring**: Pressures and temperatures are monitored at each stage of the refrigeration cycle to derive the work done by the system. The work done can then be used to determine the heat delivered;
- **Refrigeration control monitoring**: Heat delivered is estimated using the position of the expansion valve and compressor power; and
- **Temperature control monitoring**: The fan speed and air temperature are measured to give heat delivered.

Each of these approaches is examined in detail in Sections 5.1 to 5.6.

In examining each of these options, accuracy and cost are the key considerations:

- **Accuracy**: The level of accuracy of an option will determine how accurate payments are and therefore how effective the RHI would be if based on a particular metering technique. Options that are less accurate would also potentially open the process to challenge from applicants who feel they are being underpaid, which could lead to administrative costs and bad publicity. Our approach has been to assess the accuracy of an approach against the best method for assessing RAAHP performance in a laboratory environment. This has been drawn from the academic literature, which indicates that an accuracy of roughly +/-5% is possible using invasive probes.[47] Such an approach is not feasible for in situ systems unless built in from the start. It also requires extensive numbers of probes and wiring, which would be prohibitive for many installations (the Coriolis mass flow meter alone costs over £3,000). However, this has been used as the benchmark for what could be achievable, against which other approaches are measured. It is broadly equivalent to Option 3 (**refrigeration circuit monitoring)**.
- **Cost**: It is important that the addition of metering to a system does not raise costs excessively to the point that it would take several quarters of RHI payments to pay off the capital expenditure for metering. This could significantly reduce the number of applicants for the RHI, reducing the potential impact of the incentive. The issue of costs will vary significantly depending on the nature and scale of the RAAHP system. Taking as an example a metering approach that requires each indoor unit to be monitored by two temperature probes and an electricity meter (Option 5), it is possible to give an indication of these differences. For a small single split system, such a metering arrangement would not be excessive in cost, as wiring would be limited and installation costs would be relatively low. By contrast a large multi-split/VRF system with a significant number of indoor units spread over a wide area would require a very large number of probes, meters and, critically, wiring, which would also require greatly increased installation costs. Whilst it may be the case that the larger system would deliver more heat and therefore RHI payments would be greater to pay for the increased costs, this cannot be certain. In particular, if the larger system moves a significant amount of heat around within the building, and this is determined to be non-renewable for the purposes of the RHI, the renewable heat

[47] Tran, C.T., Rivière, P., Marchio, D., and Arzano-Daurelle, C. (2012) Refrigerant-based measurement method of heat pump seasonal performances, *International Journal of Refrigeration*, Vol.35, No.6, pp.1583–1594

delivered may be quite small, making investment in metering too costly. For this assessment, we have used as a baseline cost that which has been deemed to be acceptable by Ofgem in our work to determine metering for reversible ground source and reversible air source heat pumps. This has been that an additional one or two probes or meters would be acceptable, but that more would potentially become prohibitive. This will be used as the benchmark for 'acceptable' costs.

5.1 Option 1 - Fully Deemed

Description of Method	The heat load of the room(s) to be heated by the system is estimated by the installer. This would involve assessment of: • The room size(s); • Temperature set points; • Air changes; • Occupation levels; and • Typical weather Once the heat load is estimated, this would form the basis of payments, which would not vary as there is no element of metering involved.
Accuracy	DECC estimated an accuracy of +/- 100%, which is supported by industry experts.
Costs	This method would cost nothing for manufacturers, but could be expensive for purchasers as administration will require additional installer time.
Identification of Renewable Heat	Yes – though only by assuming a fixed quantity

Table 18: Option 1 - Fully Deemed

There is a clear challenge associated with the potential changes that may occur subsequent to the point at which the heat load is assessed. This could be due to a very large number of factors, many of which are very difficult to account for in any deeming process. As a result, this approach could result in up to 100% overpayment if the system was not utilised at all. Similarly, if for example occupancy was to rise substantially, then payments may end up being far below those which would be correct. This level of uncertainty would clearly receive substantial criticism from the industry and be open to challenges where operators may seek to alter the heat load factor depending on changes in circumstances. This would lead to a system that could be very challenging to administer whilst also providing overpayments.

These challenges indicate that this would not be an acceptable approach to determining renewable heat delivered for RHI purposes and so this option is not considered further.

5.2 Option 2 - Calibrated Deeming

Description of Method	The power being supplied to the heat pump can be measured when the unit is operating in heating only mode using a 'two-channel' electricity meter.[48] Such a meter would need to be added to a system by an installer and would not be part of the manufactured system. The energy used can then be converted to heat supplied utilising the manufacturer's SPF or SCOP figures.
Accuracy	DECC estimated an accuracy of +/- 10%. This may be optimistic due to the significant variations in published SPF and SCOP figures and those exhibited when systems are operated in the field. Additionally, there are other issues that reduce efficiency—such as leaked refrigerant—which need to be taken into account. As a result a reduced accuracy of +/- 20% is suggested.
Costs	There would be material and part costs to fit the electricity meter and control line for meter. This would also require fitting of the meter and certification of operation.
Identification of Renewable Heat	Yes – single-split/multi-split systems No –VRF systems, as no account is taken of heat moved within the system

Table 19: Option 2 – Calibrated Deeming

This approach does provide some measure of metering, however, the metering is indirect and relies on a fixed relationship between energy utilised and heat delivered. This raises two challenges:

- How this option would take into account variations in performance due to a number of factors; and
- Whether the SCOP and/or SPF figures that would be utilised to translate the energy used to heat delivered are sufficiently accurate.

Variations in performance of an RAAHP would not be reflected by this approach, as the metering is only of the energy supply to the heat pump, not the output heat. Therefore, the relationship between the two can change without this being picked up by the metering approach. For example, if a heat pump has leaked refrigerant and has less refrigerant charge than the design level, then it will operate at lower COP figures than when fully charged. The level of reduction in performance is significant, such that if 25% refrigerant loss has occurred, the operational COP will be 20% less than when operating at full charge.[49] This is both a

[48] A two-channel meter can record the changes in two electrical signals at the same time. As a heat pump will be switched from cooling to heating and vice-versa by an electrical signal, this can be monitored by one channel to determine when the system is in heating mode. When it is in heating mode, the second channel can then monitor the electrical power used by the system. As a result the meter only counts the electricity used when in heating mode.

[49] Findings from Eunomia study for DECC regarding Refrigerants in Heat Pumps. Due to be published in spring 2014.

common occurrence (9% of non-domestic systems leak each year, losing an average of 42% of charge when they do)[50] and a substantial reduction in performance that would lead to reduced heat delivered per kWh input energy. It is theoretically possible to utilise information about how much refrigerant has been used to recharge a system to determine drop in performance over a period of time; however, this would require cooperation from maintenance companies and a standardised relationship of performance reduction to refrigerant charge. This would add to the complexity of the approach, and thereby add to the costs if this were to be included.

Another issue that may have a significant impact on performance is a change of source and sink temperatures. This could very easily occur with changes to the environment in which the outside unit is located (for example, if foliage grows or is planted, temporary or permanent structures are erected etc.) and, more likely, if the target indoor temperature is altered away from that which was used to derive the SPF or SCOP figure. A rule of thumb utilised within the industry is that for every 1°C additional temperature required, a loss of 2-3% efficiency is experienced. This highlights that substantial losses in performance would be experienced for moderate changes in target temperatures. If this method were to be used, therefore, there may be a need to calculate the SPF/SCOP figure using moderately higher target temperatures than would be expected to counteract this possibility.

If these issues were left unaddressed, it is likely that this metering approach could lead to overly high payments being made to systems that were underperforming compared to their deemed SCOP or SPF figures. It could also lead to underpayments being made to systems where the SPF/SCOP achieved was greater than that calculated for the system. It is likely that the approach of making conservative calculations would be the most reliable method of dealing with such issues as it will otherwise be unlikely that a fair distribution of RHI funds could be achieved given that each system will encounter different operating conditions.

As already explored in Section 4, the accuracy of SCOP and SPF figures is also critical to this approach, as a small over/underestimate of efficiency could lead to a very large disparity in payments over the course of the RHI. Whilst it is understood that actual performance often falls short of manufacturer performance figures, the extent to which this is the case is unclear in the case of RAAHPs. This is primarily because there is no clear metering method utilised to determine performance in the field. Indeed, it is very challenging to identify performance in laboratory conditions. As a result this method would either require acceptance of manufacturer's published figures or a programme of testing that utilised a robust metering approach to determine the differences between actual and manufacturer performance figures for a wide variety of RAAHPs in different operation modes.

Accepting the standardised SCOP or SPF figures would clearly pose a challenge in that whilst they are calculated correctly given particular conditions, the UK conditions often vary substantially from these theoretical conditions and there would be no way to match the published figures to local conditions.. As discussed in Section 4, the new approach to calculating SPF/SCOP figures outlined by the European Commission may, however, lead to figures that are better matched to the UK climate. Even then, however, this would only give two figures (one for the south west and one for the north east) which provides relatively little in the way of options.

[50] Eunomia Research & Consulting (2014) *Impacts of Leakage from Refrigerants in Heat Pumps*, Report for DECC, March 2014, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/303689/Eunomia_-_DECC_Refrigerants_in_Heat_Pumps_Final_Report.pdf

It may therefore be desirable to develop a a programme of tests to determine differences between quoted efficiencies and operational efficiencies. This could then be used to inform any factors that could be applied to published figures. This would, however, be both costly and time consuming, as this programme would need to occur over the course of a year in order to ensure that the annualised figures were based on at least 12 months' data. Furthermore, the results of such a study may well be contentious unless the study provided adequate coverage of all system types and all climate variations experienced in the UK.

As a result it is suggested that this option could be used for the RHI, but there would need to be a clear approach to ensuring that the SPF/SCOP figures provided a sufficiently accurate reflection of performance to facilitate accurate RHI payments.

5.3 Option 3 – Refrigeration Circuit Monitoring

Description of Method	Multiple temperature and pressure sensors could be placed at each of the stages in the refrigeration cycle. These would enable pressure and enthalpy to be calculated for the system, which could then be used to determine the work done by the system (kW) when combined with an assessment of the electricity provided to the compressor. When measured over time, this would give the energy delivered as useful heat by the system in kWh.
Accuracy	DECC estimated an accuracy of +/- 10%. Third party systems such as ClimaCheck state +/-5% accuracy. Industry experts indicate that +/-10% is realistic.
Costs	Utilisation of a third party system is expensive (ClimaCheck costs around £3,000.). It is anticipated that retrofitting sensors would also incur significant costs. Additionally, retrofitting sensors to an existing system would also be challenging as many units are sealed and this would introduce warranty and maintenance issues which may increase other costs. However, there is a possibility that manufacturers could develop an internal system that would be very much cheaper.
Identification of Renewable Heat	Yes – single-split/multi-split systems No –VRF systems, as no account is taken of heat moved within the system

Table 20: Option 3 – Refrigeration Circuit Monitoring

This option is relatively accurate as it monitors the theoretical work done by the heat pump in real time, proving an evolving assessment of heat delivered which reflects changes in heat load factor and sink and source temperature fluctuations. However, the quantity of meters required makes this an expensive option. Additionally, there are concerns about the use of third party equipment where there are limited options available.

This is the most accurate of the options considered as it utilises the pressure-enthalpy cycle to derive useful work done, which can be readily converted into delivered heat. The study by the Centre of Energy and Processes in Paris indicated that this approach had an accuracy of c.5%

compared to its reference method, which itself had an accuracy of c.5%. This indicates that an assumed accuracy of +/-10% is realistic.

The significant challenge associated with this option is in fitting the meters in a simple and affordable way. The ClimaCheck system utilises this approach, but costs in the region of £3,000. If such a system were to be used for a large number of RAAHPs then it would potentially bring the system cost down; however, it is still anticipated to be expensive in comparison to total RAAHP cost.

Any such costs would need to be offset by the RHI payments, which may render this approach largely redundant as much of the money would go to offsetting this cost rather than incentivising renewable heating. In addition, the use of third party equipment from a single or limited number of providers would potentially raise competition issues. It is therefore suggested that third party systems are too expensive for use in the RHI. The other approach would be to install individual sensors in a system. This could potentially be cheaper, but will still cost a substantial amount due to the quantity of sensors required, potentially extensive cabling, the associated monitoring system, and the installation costs. In addition, there are substantial concerns about the fitting of such sensors to what are often sealed units, thereby invalidating warranties or posing maintenance challenges which may further raise costs in the future.

It is, however, conceivable that manufacturers could facilitate this metering approach by providing the pressure and temperature readings along with the compressor power in a way that can be monitored reliably. This would be relatively simple where these measurements are already made (no new meters or probes would be required), thereby only requiring a small amount of additional software. Manufacturers have indicated that temperature and pressure is measured in some of their systems and that there is the potential to utilise these to develop a manufacturer-led measurement approach. However, there is real uncertainty regarding how accurate this would be. Additionally, it is unlikely that this would be possible for all systems as the smaller, cheaper systems often do not have the temperature and pressure sensors included in order to keep costs down. It is very unlikely that this situation could be altered as these systems are designed and produced in very large numbers for global markets and the manufacturers are reluctant to add cost to the units for just one country.

This indicates that whilst a manufacturer-led approach is technically feasible, and could potentially be affordable, it may be limited in scope to larger systems.

5.4 Option 4 – Refrigeration Control Monitoring

Description of Method	The expansion valve position is measured and compressor flow or power is also monitored. A standardised algorithm can then be utilised to determine heat delivered based on these variables.
Accuracy	DECC received estimates from manufacturers of accuracies in the region of +/- 20% (for steady state). Industry experts suggest that this is optimistic, in particular due to the significant complexity associated with flow through an orifice.
Costs	There would need to be additions to the user interface to provide this information, including updates of software. There would also need to be some form of certification of the software to ensure that it was accurately calculating delivered heat.
Identification of Renewable Heat	Yes – single-split/multi-split systems No –/VRF systems, as no account is taken of heat moved within the system

Table 21: Option 4 – Refrigeration Control Monitoring

This method utilises the position of the expansion valve to determine flow through the compressor. In a heat pump this flow will be dynamic, and therefore the flow will be altering over time. In such circumstances, the nature of the flow is very complex, with no reliable correlation between valve position and mass flow through the orifice. As a result, it is suggested that this approach has the potential to be significantly inaccurate. It was indicated in a manufacturer response to DECC, however, that improved accuracy could be achieved through investment, raising costs. It is anticipated that this would also require significant time to develop, which would limit the potential impact over the lifetime of the RHI.

Development of the algorithm also poses a challenge, as it is unlikely that manufacturers would freely give any algorithms they have access to. It is feasible to develop an algorithm independent of the manufacturers, but this could lead to subsequent challenges and would likely take significant time for manufacturers to sign up to. It is possible that manufacturers could be required to provide algorithms, but determining which one(s) were utilised would then require agreement of all manufacturers to implement. This does not rule out this option per se, but does indicate that it would not necessarily be easy to achieve.

It is also suggested that there would need to be clear certification of any software used to determine heat delivered using this approach, as any variation in the algorithm could lead to widely varying heat delivered calculations. This is feasible, but would add to the expense of installation.

Fundamentally, the high inaccuracy of this approach (+/- 20% at very best, but more likely +/-30% or even +/-40%) should render it unsuitable for the RHI as very significant underpayments and overpayments could occur.

5.5 Option 5 – Temperature Control Monitoring

Description of Method	The air mass flow is determined from the indoor unit fan speed (and an estimate of area and density of the air) and the energy in the air mass flow is determined from temperature sensors.
Accuracy	DECC estimates accuracies in the region of +/- 20%. Industry experts suggest that this could be feasible, though this does not account for the effects of changes in air density or reductions in fan performance due to fouling and ageing.
Costs	For substantial systems there would be an extensive number of meters that would need to be fitted and associated wiring. As with Option 4, there would need to be additions to the user interface to provide this information, including updates of software. There would also need to be some form of certification of the software to ensure that it was accurately calculating delivered heat.
Identification of Renewable Heat	Yes – single-split/multi-split systems No –VRF systems, as no account is taken of heat moved within the system

Table 22: Option 5 –Temperature Control Monitoring

There are two elements of this approach: measurement of temperatures using thermocouples and determination of air mass flow through fan speed. Both of these elements carry challenges:

- Temperature measurements:
  - Thermocouples provide a standard ΔT (minimum temperature difference that can be measured accurately) of about 5K (equivalent to 5°C). Modern VRF systems allow small adjustments to the output of the fan coil units to satisfy the load. Therefore the ΔT may become quite small at low loads, certainly in the region of 5K. This therefore may lead to significant inaccuracies for many systems.
  - Additionally, it is unlikely that the air flow running through a fan coil will be at a uniform temperature as there will be a variation of temperature in the coil itself. Therefore, it is unlikely that a single measurement would give an accurate indication of the temperature of the whole flow.
- Mass flow determination:
  - Changes in air density need to be determined from the measured ΔT and calculation. This is relatively accurate, but is nonetheless an approximation.
  - Fan performance is assumed to be constant. This will not be the case, especially if systems are fouled or deteriorate as they age and convert electricity less efficiently.

None of these issues prevents the utilisation of this approach; however, they do indicate that an accuracy of +/-20% is perhaps the best that could be achieved using standard equipment.

However, with larger systems there would also need to be significant numbers of remote sensors and a large amount of wiring to link all of the metering systems back to a central point.

This would make testing, calibrating and maintaining the system difficult, and would certainly add substantially to the cost.

It is possible to utilise this option for the RHI, but the costs and accuracy challenges may lead to poor take up and/or to challenges. Additionally, depending on the definition of renewable heat, this approach may not be suitable on its own for deriving the quantity of heat that is renewable, as heat could be moved within a system and be recorded while not being from a source classified as renewable.

A variant of this approach would be to include hot-wire probes to monitor velocity of the air instead of monitoring the power into the fan.[51] This would remove the issues regarding fan inefficiency, but would increase the costs associated with sensors, and would potentially require greater maintenance. The measured accuracy of this method was +/-10% from the baseline, which itself is estimated to be +/-5% in accuracy, giving a total figure of around +/-15%. This seems to confirm the assumption that utilising the fan power rather than hot wire probes would lead to an accuracy of the order of +/-20% accuracy. Whilst utilising hot wire probes would be more accurate it is not anticipated that this is a viable solution for long-term monitoring due to the nature of the probes and the potential maintenance issues.

If this approach were to be utilised, it has been indicated by one manufacturer that it would be feasible to develop an add-on module. It was suggested that this would take c.12 months to develop and cost c.£100–£200 per unit. If it were to include an air flow meter rather than measure the fan power, it is anticipated that this could increase costs to c.£250-£300 per unit.

5.6 Option 6 – Combination of Options 2 and 5

It is conceivable that a combination of two or more approaches may facilitate the removal of some of the deficiencies identified. In reality this is most likely to be achieved with Options 2 and 5, due to the relative accuracy of these approaches and their relative affordability. Combining the two approaches would enable them to be cross-referenced in a way that may indicate where anomalies have occurred; however, there would be no clear benefit beyond this as, despite these options being relatively accurate, they still offer significant uncertainty. Additionally, the combination of the two options does not improve the assessment of renewable heat for multi-split systems.

5.7 Summary of Options

Table 23 summarises the options that have been described in this section. Table 23 provides a broader overview of suitability. As can be seen from the analysis, there is no clear option that is both adequately accurate and adequately affordable for use. The method with greatest accuracy is prohibitively expensive, whilst the affordable options are prohibitively inaccurate. There is therefore no clear option that would readily facilitate RHI metering and, by extension, tariff payments.

5.7.1 VRF Systems

As described above, all of these options are unsuitable for determining renewable heat delivered for VRF systems (except for Option 1, which is not discussed further due to accuracy issues). This is because such systems can move heat from one area to another. None of these approaches would facilitate the determination of what proportion of the delivered heat was

[51] Tran, C.T., Rivière, P., Marchio, D., and Arzano-Daurelle, C. (2013) In situ measurement methods of air to air heat pump performance, *International Journal of Refrigeration*, Vol.36, No.5, pp.1442–1455

obtained from this source rather than a renewable source and therefore split out renewable heat for payment.

It should be noted that similar issues have already been encountered through the existing incentives for GSHPs. Ofgem had to determine the proportion of heat delivered by GSHPs that can be considered renewable when heat is being injected back into the ground for later recovery. This led to the development of a set of 'multipliers' that are applied to different types of installations to determine eligible heat. Whilst it has been feasible to develop multipliers for GSHPs, it is suggested that the complexity of multi-split and VRF systems, whereby heat is cycled within the system, is too great for such a fix to be operated.

It is therefore surmised that there is no way to meter such systems effectively.

5.7.2 Single-split and Multi-split Systems

Based on our experience working with Ofgem, we determined that any system with an accuracy of worse than +/-20% was unsuitable for the RHI due to the potential for challenges to the approach and the potential that these approaches would lead to the RHI payments not being well linked to the benefits being sought. As a result Options 1 and 4 have been ruled out on this basis.

Turning to the other end of the scale, the only option with acceptable accuracy is Option 3 (around +/-10%), which is prohibitively expensive for smaller systems. As a result it is deemed unsuitable for small systems. However, in some situations it may be cost-effective for very large systems, although if it were to be utilised for such systems the issue around the number of third party systems available may need to be addressed.

Option 2 was determined to have poor accuracy, but was not ruled out. It is a cost-effective approach for all sizes of equipment and therefore the determination of whether this method could be used would rest on whether an accuracy of +/-20% is sufficiently accurate for RHI payments.

Similarly Option 5 also has poor accuracy, and has substantial costs for larger systems due to the wiring and installation required; however, it may be feasible in smaller systems. This would be determined by the exact prices, and once again by whether an estimated accuracy of +/-20% was determined to be sufficiently accurate.

It is potentially feasible that different options could be used for different sized systems; however, this would only be justified where accuracy was the driving reason. For example, it may be beneficial to utilise Option 3 metering for large systems where the cost would not be prohibitive. This would lead to greater accuracy for these systems. Due to the high cost of this method, however, it would not be suitable to apply it to smaller systems, and instead it could be possible to utilise Option 2 or Option 5 which are cheaper but less accurate.

5.7.3 Collaboration with Manufacturers

Having explored the foregoing possibilities with manufacturers, there is clearly a willingness to help where practicable. However, there was a strong preference among both manufacturers and installers for Option 2 (calibrated deeming) or even Option 1 (fully deemed). There was a mixed reception to the development of an add-on unit to enable Option 5 to be utilised, and there was also indication that for some RAAHPs it would be potentially possible to develop a method using Option 3. However, both these possibilities are limited by practical considerations:

- For Option 5 there is a limit to the accuracy of the system, which will not be negated by a manufacturer designed system; and

- For Option 3 not all units have the necessary sensors built in. To change this would be very costly for the big international manufacturers who would have to alter their designs, increasing cost, which would not be practicable for a small market such as that of the UK.

From interviews with manufacturers it appears that they would be willing to work to facilitate a proposed solution if the proposed solution was both viable and advantageous to the manufacturers (i.e. it led to additional systems being deployed). However, increasing deployment would require tariff levels that may not be feasible (see Section 6.1) and therefore it is likely that manufacturers will not be keen to make costly alterations if the additional take-up is likely to be low.

5.7.4 Summary

It is therefore suggested that it is only viable to meter single-split and multi-split systems, but that the methods for metering such systems are insufficiently accurate (based on current experience of working with Ofgem to determine adequate metering approaches). If it were possible to utilise these approaches (Options 2 and 5) in a way that satisfied Ofgem, however, they could potentially be developed further. Of the two Options that could be utilised, Option 2 is far more viable than Option 5 and should be seen as the preferred option.

Measures to this end could potentially include research into actual operating SPF values to improve the calibrated deeming method, or the development of a reliable version of Option 5 that incorporated a velocity sensor.

Option	Accuracy	Costs	Suitability				
			Accuracy	Costs (Large)[52]	Costs (Small)	Suitable for RHI	Reasoning
1. Fully Deemed	+/-100%	£Low	✘✘✘	✓✓	✓✓	✘	Insufficient accuracy
2. Calibrated Deeming	+/-20%	£Moderate	✘	✓	✓	?	Accuracy poor Acceptable costs
3. Refrigeration Circuit Monitoring	+/-10%	£Expensive	✓	-	✘✘✘	?	Acceptable accuracy Prohibitive costs for small systems
4. Refrigeration Control Monitoring	+/-30%	£Moderate	✘✘	✓	✓	✘	Insufficient accuracy
5. Temperature Control Monitoring	+/-20%	£Substantial	✘	✘	-	?	Accuracy poor Costs may be acceptable

Table 23: Summary of Metering Options and their Suitability for the RHI

[52] Costs are split between small and large for illustrative purposes – there has been no technical definition to achieve this. Large systems can be understood to be multi-split/VRF RAAHPs which operate across significant distances; Small systems can be understood to be single-split systems heating a limited space.

6 Potential for Government Intervention

The key findings from this section can be summarised as follows:

- Depending upon the nature and level of support under the RHI, the costs to DECC, and level of support to applicants, could vary significantly. In the example scenarios modelled, this variation might be from £15 million to £607 million per annum;
- As this is a mature market, support under the RHI could result in substantial costs associated with paying for heat from systems that would have been generated anyway;
- Under our central assumptions, new systems delivering full heating load could potentially deliver a net benefit of 1.01 million tonnes CO_2e / annum. Again, under our central assumptions, systems that are 'shifted' (as a result of support under the RHI) from partial to full heating load could deliver a net benefit of 0.23 million tonnes CO_2e / annum.
- Over a 20-year period of support under the RHI, our central assumptions suggest that RAAHPs could deliver around 20.3 million tonnes of CO_2 savings, although the low and high scenarios around this suggest that these benefits may vary significantly.
- There exists significant potential for a perverse incentive, whereby support under the RHI might encourage the use of more cooling (and thus carbon emissions) from systems providing full heating load, which would not have otherwise occurred.
- There would be no perverse outcomes from supporting the shift of systems from partial to full heating load, although there would be significant challenges associated with setting tariff levels correctly (and with metering accurately).
- There are several alternative policy mechanisms to the RHI (such as a 'revolving' loan fund or additional taxation of kerosene used by the commercial sector) which may merit further investigation by DECC.

The potential for intervention is affected by a number of issues including:

- Whether a system is delivering the whole heating load for a space or is secondary to another system;

- Whether the system recovers heat from non-renewable sources; and
- Whether it is feasible to meter the system.

As discussed in Section 5, it is suggested that it is not feasible to meter VRF systems and that metering of single-split/multi-split systems to a standard suitable for the RHI would be highly challenging. Without adequate metering it is highly unlikely that the RHI would be a suitable mechanism for intervention; however, the potential for intervention is explored in the following sections.

6.1 Incentivising Additional Heating

There is a very clear difference between systems which provide the total heating load for a space and those which are utilised alongside another heating system. Incentivising these two different types of installation is likely to require different levels of intervention:

- **Partial Load (20% of the Market):** It is likely that relatively low levels of incentive would be required to increase the use of this form of heating. This is because it is anticipated that the heat pump would have been installed without any support, and therefore a small incentive may have a significant impact on use of the heating function where it would not otherwise be used – i.e. that it would encourage the replacement of the alternative heating system that the RAAHP has been installed alongside. It is anticipated that this would therefore reduce the use of standard heating systems such as gas and oil boilers. At low levels of incentive, however, it is unlikely that many new RAAHP providing the full heating load would be installed solely because of the RHI; and
- **Full Load (80% of the Market[53]):** To incentivise systems that will provide the full heating load of a building it is likely that tariff levels higher than those required to incentivise systems currently providing partial load would be required. However, it is not clear that these would need to be as high as the tariff levels currently offered for GSHPs and AWHPs under the RHI as the existing market indicates that there is potential for making marginal gains through smaller incentives.

6.1.1 Illustrative Scenarios for Current Rate of Installation

Given the scale of the market, even with a small incentive there are challenges associated with the very large numbers of systems that would be eligible for support. Table 24 shows *example* scenarios of what it would cost to deliver the RHI for single-split and multi-split systems that would be installed regardless of introduction of the RHI.

[53] 70% of the market provides full heating and full cooling loads; 10% of the market provides full heating and partial cooling loads, both of which therefore provide a full heating load.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Nature of scenario	Only partial heating load systems are awarded RHI	Both types of systems are awarded RHI	Only partial heating load systems are awarded RHI	Both types of systems are awarded RHI
Proportion of full heating load systems awarded RHI	0%	50%	0%	50%
Proportion of partial heating load systems awarded RHI	50%	50%	50%	50%
No. of systems eligible each year	11,800	59,200	11,800	59,200
Generated heat per system (kWh)[54]	25,000	205,000	25,000	85,000
Tariff Level (£/kWh)	0.05	0.05	0.02	0.05
Total heat delivered (GWh)	296	12,144	296	5,035
Cost of new systems accepted on to RHI in one year (£m)	15	607	6	252
Annual support per applicant (£)	1,250	10,250	500	4,250
Cumulative cost to DECC (£m)	£1,500	£60,700	£600	£25,200

Table 24: Example Costs to DECC of Funding Single-Split and Multi-Split Systems which would have been Installed Regardless of the RHI

Assumptions were made in order to facilitate this analysis. These were that:

- Applications are made for five years between 2015 and 2020. All of these systems are then funded for 20 years, i.e. the cost of one year is multiplied by 20 to give the cost for all the systems installed in that year. This is then multiplied by 5 to give the total cost for the systems installed in all five years. As a result the cumulative costs are 100 times greater than the cost of new systems accepted in one year;

[54] Reported as an aggregated figure for both full heating load and partial heating load systems.

- It is assumed that that legacy applications would not be accepted (if they were the size of the impact would be many times greater); and
- That the assumptions used for 'generated heat per system' in Scenarios 1 to 3 are those drawn from DECC's IA for the Non-Domestic RHI.55 The 'generated heat per system' value for Scenario 4 is based on a judgement regarding the size of single-split systems.

Each scenario is discussed in detail in the following paragraphs:

- **Scenario 1:** This scenario is based on the incentivisation of systems which provide partial heating load with a low incentive. It assumes that 50% of partial heating load systems that would have been installed anyway are awarded the RHI. The associated tariff level (£0.05/kWh) is moderate and delivers 296 GWh of heat per annum whilst costing £15m per year. This heat is not additional heat as it is not related to "new" entrants. Each applicant would receive on average £1,250 over the course of a year. It is clear that even with no uptake from systems providing full load heating there would be a significant cost to DECC over the course of 20 years of up to £1.5 bn for systems that would have been installed anyway.[56] Whilst it is acknowledged that the incentive is there to increase the heat generated by these systems and so there would be additional gains, this analysis does not seek to project the amount of heat which might be delivered by the RHI.
- **Scenario 2:** This scenario assumes that 50% of systems providing full load heating and 50% of those providing partial load heating are awarded RHI payments (again at a tariff of £0.05/kWh). This leads to a much higher (and probably realistic) generation of heat. 12.144 TWh are generated from the installations in each given year, with each applicant receiving around £10,250 per year (averaged across the two types of installation). This leads to a very high cost to DECC, with the 20 year cost assessed to be £60.7 bn. Clearly these costs are very high for systems that would have been installed anyway.
- **Scenario 3:** This scenario mirrors scenario 1, but provides a much lower tariff of £0.02/ kWh. This results in the same heat generated as in Scenario 1, but costs significantly less. At £500 of support per annum, however, it is somewhat unlikely that many users would apply, unless they knew that they would generate significantly more than the assumed average.
- **Scenario 4:** This scenario is similar to scenario 2, but it assumes a far lower heat load of 100,000 kWh/year for full heating load systems. This is based on the number of single-split systems which are sold and their relatively small size. It is intended to show how a lower heat load will impact upon spend. As can be seen, despite the reduction in heat delivered, the costs to DECC of supporting systems that would have been installed regardless of the RHI are still substantial. So while the heat load

[55] DECC (2012) *Impact Assessment: Changes to the Current Non-Domestic Renewable Heat Incentive Scheme*, September 2012, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66606/6444-impact-assessment-on-changes-to-the-current-nondo.pdf

[56] Assuming that new systems can only be added to the scheme for the first five years (2015-2020)

is important in determining the magnitude of the potential costs, the large number of installations means the costs could be substantial even if the heat loads are low.

These scenarios are provided to illustrate the challenges of incentivising the RAAHP market, which can be summarised as follows:

- If the tariff level is low there will be few applicants and it is unlikely that it will make a significant difference to delivery of additional heat from partial load systems, except where there is the potential for production of very significant quantities of heat. This may be an acceptable approach, but as highlighted above, would not incentivise medium and small installations;
- If the tariff level is moderate there is the scope for very high costs associated with heat that would have been delivered regardless of the RHI being implemented. This is a real risk and the setting of a tariff which is too high would potentially cause significant challenges to the budget for the RHI given the scale of the market; and
- These calculations are based on a steady state market, but it is likely that with tariff levels of a significant level the market would grow. This would deliver additional heat, but costs could escalate from the very high baseline already identified.

The existing market, and the significant number of installations, which would take place in the absence of the RHI, therefore makes the use of RHI to incentivise additional heating from partial load systems very challenging. This suggests that the RHI is not well tailored to this specific market, even if the metering issues could be remedied. An instrument that could be targeted specifically at installations that were not utilising the full heating capacity would be preferable if it were possible to design and implement such a policy mechanism. Similarly, if only *additional* installations delivering full-load heating could be incentivised this would clearly be beneficial. These issues are discussed further in Section 6.5.

6.2 Scale of Impacts from Intervention

The potential impacts of support under the RHI need to be assessed in two ways:

- Impacts associated with increasing the number of systems delivering full heating load; and
- Impacts associated with reducing the proportion of systems only delivering partial heating load (and shifting these into delivering full heating load)...

For this analysis, we have primarily focussed on a process of determining the impact of changing one system and, where possible, have provided an indication of the scale of impacts based on estimates of what quantity of change may be achievable. The following analyses is conducted for single-split and multi-split systems (i.e. VRF systems are excluded).[57]

6.2.1 Impacts from Increasing the Number of New Systems Delivering Full Heating Load

There are a significant number of factors that will determine the potential impact of incentivising systems delivering full heating load with RAAHPs. These factors are all included in Table 25, which provides three scenarios (with low, medium and high) benefits. As discussed in Section 2.2, the most important issue is that in incentivising installations that would not have been

[57] This is due to the inability to meter such systems and therefore it is anticipated that they would not be part of any incentive.

installed anyway there is the risk of additional cooling being utilised. As described above, most of these factors currently need to be estimated due to the lack of information regarding the performance of RAAHPs in the field. Additionally, as the market is already established, there are uncertainties about the level of growth that might be achieved. As a result, these calculations should be used as only a broad guide for the levels of impact that may be delivered.

Perhaps the most notable issue is that the ‘Low’ scenario produces very low net CO_2e benefit. This is primarily due to this scenario utilising quite a high element of additional cooling–i.e. cooling that would not have taken place had the counterfactual technology been in place. The assumption used in this instance is that a cooling load, which is 60% that of the heating load, is taken up, all of which is additional to what would have otherwise been generated. For more detail on this calculation see Section 4.5.The result indicates how critical it would be to ensure that RAAHPs were incentivised in a way that minimised the use of additional cooling.

The other major factor is the level of deployment, which would be determined by the method and level of incentive provided for RAAHPs. This again highlights that the tariff level for any RHI intervention would be critical, as if the tariff was set higher to increase growth substantially it would also likely to be very attractive to operators who would have installed systems anyway, which would lead to significant costs for heat that would primarily have been delivered anyway.

Incentivising systems delivering full heating load will also incentivise the use of greater heat from systems currently providing only partial heating load, and therefore it is important to combine these results with those offered for moving from partial heating load to full heating load in Section 6.2.2.

	Unit	Low Benefit	Central Benefit	High Benefit
Carbon Factor (Heating)	$kgCO_2e/kWh$ thermal	0.137[58]	0.122[59]	0.107[60]
Carbon Factor (Additional Cooling)	$kgCO_2e/kWh$ thermal	0.068[61]	0.034[62]	0.0[63]
Carbon Factor (Total)	$kgCO_2e/kWh$ thermal	0.205	0.156	0.107
Counterfactual Carbon Factor	$kgCO_2e/kWh$ thermal	0.237[64]	0.254[65]	0.272[66]
Net Carbon Benefit	$kgCO_2e/kWh$ thermal	0.031	0.098	0.165
Annual Heating Delivered	kWh thermal/ year	200,000	250,000	300,000
Net CO_2e Benefit per system	$kgCO_2e$/year	6,254	24,404	49,371
Percentage Increase in New Installations		1%	2%	3%
Number of Annual Installations[67]		20,600	41,200	61,800
Total Additional Heat Generated	TWh thermal/year	4.12	10.30	18.54
Net CO_2e Benefit[68]	Thousand Tonnes CO_2e/year	130	1,010	3,050

Table 25: Example Impacts of Incentivising New RAAHPs Delivering Full Heating Load

[58] Based on SPF of 2.5

[59] Based on SPF of 2.8

[60] Based on SPF of 3.2

[61] Assumed cooling load of 60% that of heating (i.e. high usage of additional cooling)

[62] Assumed cooling load of 30% that of heating (i.e. moderate usage of additional cooling)

[63] Assumes that no additional cooling is utilised

[64] Based on 70% Gas; 30% Oil

[65] Based on 50% Gas; 50% Oil

[66] Based on 30% Gas; 70% Oil

[67] Quoted to 2 s.f.

[68] Quoted to 2 s.f.

6.2.2 Impacts from Reducing the Proportion of Partial Heating Load Systems

As per the delivery of new systems providing full heating load, there are a number of factors that affect the impacts of incentivising the shift from partial heating load to full heating load. These, however, combine in a slightly different way as the shift does not require expansion of the market. As with the factors in Section 6.2.1, most of these have to be estimated due to the nature of available data at this time. Therefore, the following calculations in Table 26 need to be viewed as *examples* of the magnitude of potential impacts, not estimates based on any empirical data.

There are no potential reductions in benefit due to additional cooling as these systems are all already delivering a full cooling load. It is therefore unlikely that cooling demand would be increased due to a heating incentive. The dependence of the results on the number of systems included remains, however, and it is clear that making it attractive to as many operators as possible would deliver substantial benefits. The above analysis assumes that there are no retrospective applications permitted. If such applications were permitted then the benefits would be likely to grow at a far quicker rate and this should be considered in the design of any intervention.

Again, the impact of the amount of secondary heat delivered is clearly very substantial, and therefore this will play a significant role in determining the impact of incentivising RAAHPs in this manner. The above analysis, however, indicates what would happen given very substantial changes in the market. It is anticipated that this would occur over a period of time and not be an immediate ‘switch on’ benefit. The speed of this change would depend on whether legacy applications would be allowed, thereby opening up the incentive to the large number of existing installations, or whether it would be limited to new applications, in which case the process would likely be much slower, perhaps over the course of 20 years (the lifespan of such systems).

	Unit	Low Benefit	Central Benefit	High Benefit
Carbon Factor (Heating)	$kgCO_2e/kWh$ thermal	0.137	0.122	0.107
Counterfactual Carbon Factor	$kgCO_2e/kWh$ thermal	0.237[69]	0.254[70]	0.272[71]
Net Carbon Benefit	$kgCO_2e/kWh$ thermal	0.100	0.132	0.165
Annual Additional Heating Delivered	kWh thermal/ year	190,000	225,000	250,000
Net CO_2e Benefit per system	$kgCO_2e/year$	997	3,296	8,229
Rise in Proportion of Systems Delivering Full Heating Load over 20 years		20%	30%	40%
Total Number of Additional Systems Providing Full Heating Load[72]		102,000	153,000	204,000
Number of Additional Systems Providing Full Heating Load Each Year		5,000	8,000	10,000
Total Additional Heat Generated	TWh thermal/year	0.97	1.72	2.55
Net CO_2e Benefit for One Year's Increase[73]	Thousand Tonnes $CO_2e/year$	97	227	420

Table 26: Example Impacts of Incentivising moving from Partial to Full Heating Load

6.2.3 Total Benefits from Intervention

There are clear potential benefits associated with Government intervention in this market, both to incentivise new full heating load systems and a switch from partial to full heating load among

[69] Based on 70% Gas; 30% Oil

[70] Based on 50% Gas; 50% Oil

[71] Based on 30% Gas; 70% Oil

[72] There is approximately 50% of the market that does not currently utilise heating. Quoted to 2 s.f.

[73] Quoted to 2 s.f.

existing systems. As identified in Sections 6.2.1 and 6.2.2 the potential benefits are of the order of:[74]

- 1,010,000 tonnes CO_2e per annum for incentivising new full-heat load RAAHPs;[75] and
- 227,000 tonnes CO_2e per annum for incentivising switching from partial to full heating load RAAHPs assuming no retrospective applications are permitted.

Combining the two impacts over the course of 20 years would lead to potential benefits of:

- 20.3 million tonnes CO_2e per annum saving each year by the end of the 20 years; and
- 214 million tonnes CO_2e cumulative saving over twenty years.

These substantial potential benefits must be placed in the context of the significant variations identified in Section 6.2. Taking these into account, the potential annual savings at the end of a 20 year period would be as follows:

- **Low scenario:** 2.7 million tonnes CO_2e per annum;
- **Central Scenario:** 20.3 million tonnes CO_2e per annum; and
- **High Scenario:** 61.4 million tonnes CO_2e per annum.

This high variation needs to be taken into account when determining the nature of any potential intervention and indicates the sensitivity of the potential benefits to key variables.

6.3 Heating Only Air-Air Heat Pumps

It is important to note that many manufacturers are concerned that intervention with the RHI in the RAAHP market will prevent development of other market segments. In particular, heating-only Air-Air Heat Pumps (AAHPs) were discussed in this context during interviews. It is understood that DECC has not considered support under the RHI for this technology as there is the theoretical potential for using them concurrently with a cooling system, thus negating the potential benefit associated with such a system through additional cooling, or the potential to incentivise installing a heating AAHP alongside a RAAHP providing only cooling but which could have provided heating, resulting in inefficiency. It should be noted, however, that focusing on heating-only AAHPs would technically eliminate some of the metering challenges associated with RAAHPs.

The above said, there would still be a technical challenge associated with those heating-only AAHPs which have previously been RAAHPs, but which have a switch to ensure they operate in heating-only, meaning that they can be returned to reversible operation. As a result, an installed heating-only AAHP could not be guaranteed to be operating solely in a heating function.

6.4 Perverse Incentives and Unintended Consequences

The major perverse incentive that may be encountered is where installation of new heating-led systems leads to additional cooling that would not have been utilised otherwise. This perverse

[74] These are taken from the central estimates and quoted to 2 s.f.

[75] This figure is for the addition of systems over one year. Therefore over time there would be compound effects. For example, if the annual additions over each year of a five year period were the same there would be cumulative benefits of the order of 3,500,000 tonnes CO_2e.

incentive has already been addressed extensively above. It is only associated with heating-led systems, as for cooling-led-systems the incentivisation of heating would not lead to increased cooling.

There is also the potential for operators to run heating for longer than required in order to claim any output-based incentive, which could then be subsequently offset by the cooling function. However, the likelihood of this occurring is no greater than that of the overuse for financial gain of other technologies already supported by the RHI, with ventilation from separate technologies used to offset the additional heat. It is anticipated that this would not be a major issue as it would cause significant comfort issues.

Similarly, it would be conceivable that if it were permissible operators could install two separate systems to operate in cooling and heating simultaneously. Once again, however, this is highly unlikely as the additional capital costs of a second system and the additional running costs would offset any additional gain from the incentive, unless the incentive was very high.

The installation of an RAAHP in a new building would contribute to an improvement of the energy performance as measured by the Building CO_2 Emission Rate (BER) which must be measured as part of the building regulations. The BER figure is compared to a theoretical figure called the Target CO_2 Emission Rate (TER) as outlined in Part L of the building regulations.[76] As utilising an RAAHP would reduce the BER figure, there is the potential for installation of such systems to lead to a lowering in the quality of the building shell whilst still meeting the TER. The extent to which this might occur is unclear, however, it is suggested that the impacts would likely be similar to those currently experienced with ATWHPs and GSHPs which have been incentivised through the non-domestic RHI, and where RAAHPs are already utilised in such buildings. Therefore, whilst this issue requires further investigation for a full understanding of the potential impacts, it is suggested that this could be explored through heat pump systems that have already been installed in new buildings since the introduction of the updated Part L regulations in 2010.

There is, of course, the potential opposite effect of the Part L requirements, which is that RAAHPs could be utilised instead of a carbon-intensive heating source in order to ensure the TER is met. This could potentially lead to increased uptake of RAAHPs. However, given that this is an established technology which is relatively low-cost, it is anticipated that some of this potential will already have been realised. It is also very difficult to quantify to what extent this may occur, as there are a number of other low-carbon technologies available and it is uncertain to what extent a developer would choose RAAHP technology over others.

Finally, if only single-split systems were incentivised, there is the possibility of operators installing multiple single-split systems if the tariff was sufficiently high, eliminating the efficiencies (which include heat recovery) inherent in multi-split and VRF systems. However, as it is recommended that tariff levels be kept at a low if they are used at all, it is suggested that this would not be a widespread issue.

It is therefore suggested that the only significant potential for perverse incentives is the use of more cooling where it would not have otherwise occurred, whilst the unintended consequence of reducing building shell performance should be explored further through examining the existing interaction of heat pumps with calculating the BER for new buildings.

[76] HM Government (2010) *Conservation of Fuel and Power in New Buildings other than Dwellings*, January 2010, http://www.planningportal.gov.uk/uploads/br/BR_PDF_AD_L2B_2011.pdf

6.5 Other Potential Approaches to Government Intervention

It may be feasible to identify other interventions that could increase RAAHP uptake without the drawback of paying for a large proportion of heat that would have been generated without that intervention.

One possibility would be to target interventions at specific sectors (for example retail) where substantial cooling is utilised and heat often wasted. This is not renewable heat, but reuse of waste heat would nonetheless displace carbon-intensive technologies and may provide a substantial carbon benefit. It is therefore recommended that opportunities to reuse waste heat using RAAHP technologies are explored, albeit it is recognised that this could not be done within the scope of the RHI.

Alternatively, if it is determined that other options are not suitable, it may well be more advantageous to allocate additional RHI budget (in the form of higher tariffs) to other types of heat pumps, such as those already incentivised by the non-domestic RHI. This is because, in many cases, a 'wet' system is preferable to recipients as a source of heat and this can be delivered by ATWHPs and GSHPs in buildings that may otherwise have been serviced by a RAAHP without any notable lowering in performance. Capex can be somewhat higher, however, as a result of the need for installation of new radiators or underfloor heating to take into consideration lower operating temperatures than for traditional fossil fuelled heating systems.

A simple but more 'radical' approach to stimulate take-up of RAAHPs in the off-gas market, and one which would largely eradicate the hassle costs outlined in Section 3.1.4, would be to apply greater taxation to fuel oil or kerosene used for commercial purposes, as there is only currently very low duty (around 11p/litre) applied compared with that for road diesel (58p/litre). Ultimately, however, most EU Member States have similar taxation regimes for fuel use by businesses, and although this is in conflict with recommendations from the EC, it is unlikely that the UK (or any other Member State) will change this approach without EC-led legislation, for fear of making domestic industry uncompetitive. RAAHPs, however, are used largely by the commercial sector, for which heating costs are a far smaller element of overheads, and thus perhaps such a move should be considered by Government. Similarly a tax on new fossil fuel boilers could be an alternative approach, as this could focus specifically on influencing decision-making with regard to new installations.

Furthermore, based on the assumption that installation of RAAHPs (rather than gas or oil boilers) for heating purposes could deliver significant carbon benefits (as explored in Section 6.2), DECC might consider development of a 'revolving' loan fund, whereby businesses are lent a proportion of the value of an RAAHPs at a low interest rate. Such an approach avoids the issues associated with metering of renewable heat, and would also encourage the efficient use of heat recovery across split systems as described above, which would be potentially disincentivised by the RHI, as discussed in the context of perverse outcomes in Section 6.4. Such a fund would also be relatively cost neutral to DECC in that businesses would be required to pay back the loan, facilitating the opportunity for these funds to be subsequently lent to further companies. A problem associated with such an approach, however, is that whilst it would remove the barrier presented by metering, it could be very challenging to ensure that such systems were actually used for heating (and not just cooling). It may be possible, however, to mitigate this risk by restricting eligibility to buildings which did not have an alternative heating system installed. This could perhaps be enforced by Ofgem's technical audit programme for the Non-domestic RHI.

7 Conclusions and Recommendations

The key question to address here is whether RAAHPs represents a suitable technology for support under the RHI.

Our analysis suggests that although there does not exist a clear justification for government intervention in the RAAHP market on the basis of market failures, support under the RHI may be justified to remove barriers to growth in the market and deliver potential significant CO_2 savings.

If RHI support was to be provided, however, DECC would need to very carefully design the tariff and associated policy detail to minimise the risks of:

- Significant amounts of funding being allocated to systems that would have been installed anyway;
- Exerting pressure on the overall RHI budget by only providing support for certain types of system; and
- Incentivising heating-led installations that provide full heating load, which may lead to incentivising additional cooling.

Achievement of such a policy design will be highly challenging without undertaking a range of further tasks including:

- Additional detailed analysis of metering approaches to determine as robust a methodology as possible. There is additional work required to more accurately assess SPFs to support the potential of calibrated deeming. Furthermore, a project working with manufacturers to develop a suitable approach to temperature control monitoring (whereby fan speed and air temperature are measured to give heat delivered) could potentially be justified;
- Engagement with Ofgem in terms of determining whether these approaches to metering (either in combination) or separately, would allow it to make payments for renewable heat from RAAHPs; and
- Identification and modelling of specific business sectors to determine those for which support under the RHI might deliver additionality, and within which the risk of the perverse incentive to encourage cooling might be minimised.

Appendix 1 – Rapid Evidence Assessment Summary

Ref ID	Title	URL	Topic	Useful for Research	Rationale
1	The UK Supply Curve for Renewable Heat - Study for the Department of Energy and Climate Change		Modelling supply curves for renewable heat in the UK up to 2020 under high and low growth scenarios.	Yes	Some barriers to market growth are relevant to commercial RAAHPs
2	Detailed analysis from the first phase of the Energy Saving Trust's heat pump field trial Evidence to support the revision of the MCS Installer Standard MIS 3005 Issue 3.1		Analysis of 83 heat pumps in residential properties	No	ASHPs are tested are Air-to-Water HPs
3	Detailed analysis from the second phase of the Energy Saving Trust's heat pump field trial		Details and analysis of 38 interventions made to the heat pumps covered in previous report (ref id 2) and 6 new heat pumps.	No	ASHPs are tested are Air-to-Water HPs
4	Low carbon heat market set for rapid growth - but how can you engage your customer?		Summary of findings from a survey of installers of low carbon heat microgeneration units.	No	Not concerned with RAAHPs, findings are specific to other technology.
5	Energy Saving Trust The heat is on: heat pump field trials phase 2		Summarised version of ref id 3.	No	ASHPs are tested are Air-to-Water HPs

6	Pathways to high penetration of heat pumps REPORT PREPARED FOR THE COMMITTEE ON CLIMATE CHANGE	Frontier-Economics-Element-Energy-Pathways-to-high-penetration-of-heat-pumps.pdf	Analysis of cost effective path to achieve desired update of heat pumps. Market and policy review, pathways to increasing market, barriers to uptake and policies to deliver uptake.	Yes	Includes projections of installations of non-domestic Air-to-Air Air Source Heat Pumps on p66
7	Research on the costs and performance of heating and cooling technologies	Heating Study - DECC__Sweett_Group_.pdf	Analysis of cost and performance data of low and zero carbon heating and cooling technologies collected from industry.	Yes	Contains cost and performance data on 5 air to air heat pumps.
8	RHI Phase II – Technology Assumptions Key Technical Assumptions for Selected Technologies	RHI_Phase_II_-_technology_assumptions - AEA DECC.pdf	Key assumptions for modelling in RHI Phase II project.	Yes	Contains industry market information.
9	Adsorption heat powered heat pumps	_	A review of the state of the art of adsorption heat powered heat pumps.	No	Document states that no reversible ATA adsorption HPs are on the market and so is not relevant to the study
10	Advanced Biofuel Feedstocks – An Assessment of Sustainability	_	The sustainability of biofuel feedstocks.	No	Not relevant to heat pumps.
11	Advanced fuels: call for evidence	_	Advanced fuels: biofuels, waste derived fuels etc.	No	Not relevant to heat pumps.
12	Domestic Renewable Heat Incentive	_	The final policy for the domestic Renewable Heat Incentive (RHI), proposed tariffs for the applicable technologies.	No	Domestic only and not ATA HPs
13	Heat pumps for cooling and heating	_	Heat pump technologies and market penetration in Austria, Finland, France,	No	Not relevant to

			Netherlands and Spain.		research questions.
14	Inside view into the Japanese heat pump market	_	History of the Japanese heat pump market	No	No specific performance data. Not UK market.
15	Meta-analysis of European heat pump field trial efficiencies	_	Meta-analysis of SPF of ground to water and air to water heat pumps.	No	Not relevant to ATA HPs
16	Heat pumps – a renewable energy technology?	http://www.rehva.eu/fileadmin/hvac-dictio/04-2011/rj4_10-12.pdf	Decision by EC to classify aerothermal, geothermal and hydrothermal energy as renewable and its implications for heat pumps	Yes	Contains contribution from heat pumps to achieve the designated RES share in heating and cooling for UK and other member states.
17	Mapping Renewable Energy Pathways towards 2020 - EU ROADMAP	http://www.repap2020.eu/fileadmin/user_upload/Roadmaps/EREC-roadmap-V4_final.pdf	Renewable energy industry report on EU and member state National Renewable Energy Action Plans	Yes	Contains targets for heat pumps with UK RES from the National RES industry Roadmap and the National Renewable Energy Action Plans
18	Non-Domestic Renewable Heat Incentive - Improving Support, Increasing Uptake	_	Government response to 3 consultations in 2012/13 and a call for evidence on specific technologies.	No	Not relevant to research questions.
19	Performance of a gas engine heat pump (GEHP) using R410A for heating and cooling applications	_	Performance results of GEHP	No	Not relevant to ATA HPs.
20	Renewable Heat Incentive - New technologies:	_	Criteria for new technology considered	No	Not relevant to

	process towards eligibility		for inclusion within the RHI		research questions.
21	Heat pumps United Kingdom World renewables 2013	_	Market analysis of existing UK HP market.	No	Not ATA HPs.
22	The Gallagher Review of the indirect effects of biofuels production	_	Review of the indirect effects of biofuels production	No	Not relevant to research questions.
23	The potential for Renewable Gas in the UK	_	The potential for Renewable Gas in the UK	No	Not relevant to HPs
24	UK Renewable Energy Roadmap	_			
25	Default values of seasonal performance factors for heat pumps	decc.pdf	System efficiencies for ground source and air source HPs. Suggestion of incorporating them into default values for SAP assessments.	No	Not ATA HPs.
26	Rules of Thumb - Guidelines for building services (5th Edition)	bsria rules of thumb.pdf	Source of approximate engineering design, environmental performance and project cost data for building services projects. Has COP and SPF of HPs but not RAAHPs.	No	Not relevant to research questions. See 'Other information'
27	VRF based Air Conditioning Systems - performance, installation and operating notes	bsria+vrf.unlocked.pdf	This Technical Note describes the three different types of Variable Refrigerant Flow (VRF) based air conditioning systems available in the UK. In particular, it indicates their likely installed performance when subjected to typical UK operating conditions, some key installation quality recommendations and some common problems to be avoided in specification, installation and operation.	Yes	Contains COP for one heating only VRF (i.e. AAHP) under different loads and seasonal conditions

28	The BSRIA Blue Book 2013	bsria.pdf	Stats reference for building services.	Yes	Contains breakdown of HVAC UK market 2011
29	Planning of domestic air source heat pumps to mitigate noise impacts	_	Planning of domestic air source heat pumps to mitigate noise impacts	No	Not relevant to research questions
30	Evaluation of the energy performance and thermal comfort of an air conditioner with temperature and humidity controls in a cooling season	_	Performance of a new algorithm for cooling control of VRF or VRV systems	No	Not relevant to research questions
31	Simulation of variable refrigerant flow air conditioning system in heating mode combined with outdoor air processing unit	http://www.sciencedirect.com/science/article/pii/S0378778813006245	Validating simulation of VRF with experimental data	Yes	Contains measured COP of a VRF system
32	Analysis of retrofit air source heat pump performance: Results from detailed simulations and comparison to field trial data	http://www.sciencedirect.com/science/article/pii/S0378778810003385		No	Domestic only
33	The performance of air-source heat pumps in current and future offices	http://www.sciencedirect.com/science/article/pii/S0378778808000947		Yes	Cost saving modelling of RAAHPs in 2 office scenarios
34	Air–air heat pumps evaluated for Nordic circumstances IEA Heat Pump Centre Newsletter, 24 (2006), pp. 18–25	http://www-v2.sp.se/hpc/publ/HPCOrder/ViewDocument.aspx?RapportId=407		Yes	Independent laboratory tests of RAAHPs
35	Performance evaluation of an integrated automotive air conditioning and heat pump system	http://www.sciencedirect.com/science/article/pii/S019689040500124X		No	Applies to automotive A/C and heating
36	Performance evaluation of a compact air-to-air heat pump	http://www.sciencedirect.com/science/article/pii/S01968904		No	Relates to heating of small residential

		96000568		spaces only
37	In situ measurement methods of air to air heat pump performance	http://www.sciencedirect.com/science/article/pii/S0140700713000790	Yes	Does not measure COP or SPF
38	Refrigerant-based measurement method of heat pump seasonal performances	http://www.sciencedirect.com/science/article/pii/S0140700712000680	Yes	Method to measure SPF in RAAHPs
39	Study on Running Performance of a Split-type Air conditioning System Installed on a University Campus in Suburban Tokyo	http://www.irbnet.de/daten/iconda/CIB8339.pdf	Yes	Comparison of measured COP with rated value
40	Energy and economic comparisons of air-to-air heat pumps and conventional heating systems for the Turkish climate	http://www.sciencedirect.com/science/article/pii/030626199390035N	No	Residential space experiments only. Turkish context. Financial case relates to costs in Turkey.
41	Energy and economic comparisons of domestic heat pumps and conventional heating systems in the British climate	http://www.sciencedirect.com/science/article/pii/0306261986900656	No	Outdated - data from 1986.
42	Experimental investigation of a multi-function heat pump under various operating modes	http://www.sciencedirect.com/science/article/pii/S0960148112004430	No	Relates to HPs constructed for cooling, heating and hot water.
43	Performance of an air to air heat pump in a temperate climate	http://www.sciencedirect.com/science/article/pii/0140700781901080	No	For temperate climate, published in 1981
44	Reversible heat pump model for seasonal performance optimization	http://www.sciencedirect.com/science/article/pii/S03787788	No	No experimental data. Air to Water HP

		10002239		
45	Experimental Investigation of Multifunctional VRF System in Heating and Shoulder Seasons	http://www.sciencedirect.com/science/article/pii/S1359431114001227	Yes	Daily performance factors of VRF systems under different uses
46	Domestic air-conditioner and integrated water heater for subtropical climate	http://www.sciencedirect.com/science/article/pii/S1359431102002284	Yes	COP of multi-functional VRF
47	The future role of heat pumps in the domestic sector	http://www.eci.ox.ac.uk/publications/downloads/fawcett11b.pdf	Yes	UK ASHP sales, and capital and running costs of different heat sources with annual savings compared with electricity
48	Ventilation and Air Conditioning Market Report – UK 2013-2017 Analysis	http://www.amaresearch.co.uk/Ventilation_Air_Conditioning_13.html	Yes	Value of HVAC UK Market
49	Trends in the UK market for air-conditioning	http://www.modbs.co.uk/m/fullstory.php/aid/10540/Trends_in_the_UK_market_for_air-conditioning.html	Yes	Value & sales of UK HVAC and VRF
50	UK Market Update	http://www.forburyinvest.com/fileuploads/BSRIA%20(2).pdf	Yes	Contains HVAC and heat pump market figures
51	UK Air Conditioning Trends	http://www.quantechenv.co.uk/uk-air-conditioning-trends/	Yes	Contains HVAC and heat pump market figures

52	DEVELOPMENT OF THE GHG REFRIGERATION AND AIR CONDITIONING MODEL	_	Yes	Existing installation and growth figures of UK HVAC market
53	RTOC (2010) "2010 Report of the Refrigeration, Air Conditioning, and Heat Pump Technical Options Committee."	http://ozone.unep.org/Assessment_Panels/TEAP/Reports/RTOC/RTOC-Assessment-report-2010.pdf	No	Not relevant to research questions
54	BSRIA (2011). World air conditioning: UK 2011. A multi-client study.	_	No	Cannot access sold report (due to cost)
55	Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases	http://ec.europa.eu/clima/policies/f-gas/docs/2011_study_en.pdf	No	Not relevant to research questions
56	Preparatory study for a review of Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases - Annexes to the Final Report	http://ec.europa.eu/clima/policies/f-gas/docs/2011_study_annex_en.pdf	Yes	HVAC and HP market estimates
57	Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation)	http://ec.europa.eu/enterprise/policies/sustainable-business/ecodesign/product-groups/airco-vent/files/residential_ventilation_en.pdf	No	No relevant data found (although data is cited by 52)
58	IEA Heat Pump Centre 2010: NEWSLETTER NEWSLETTER VOL. 28 NO. 4/2010. Supermarket refrigeration. IEA Heat Pump Centre (Volume 28 - No. 4/2010, No. 4).	http://www.heatpumpcentre.org/en/newsletter/previous/Documents/HPC-news_4_2010.htm	Yes	Market figures
59	Trends in the European Air Source Heat Pump Market	http://www.heatpumpcentre.org/en/newsletter/previous/D	Yes	Comparison of EER (performance) for

	IEA Heat Pump Centre Newsletter Volume 26 - No. 1/2008	ocuments/HPC-news_1_2008.htm		Europe and Japan
60	Efficiency of heat pump systems under real operating conditions	http://www.heatpumpcentre.org/en/newsletter/previous/Documents/HPC-news_2_2013.htm	No	Data not split by ASHP type
61	Heat Pump Efficiency - Analysis and Evaluation of Heat Pump Efficiency in Real-life Conditions Abbreviated version	http://wp-effizienz.ise.fraunhofer.de/download/final_report_wp_effizienz_en.pdf	No	No ATAs

Department of Energy & Climate Change
3 Whitehall Place
London SW1A 2AW
www.gov.uk/decc
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