Local Environment
The International Journal of Justice and Sustainability

ISSN: 1354-9839 (Print) 1469-6711 (Online) Journal homepage: http://www.tandfonline.com/loi/cloe20

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To cite this article: Alice Owen , Gordon Mitchell & Rachael Unsworth (2013) Reducing carbon, tackling fuel poverty: adoption and performance of air-source heat pumps in East Yorkshire, UK, Local Environment, 18:7, 817-833, DOI: 10.1080/13549839.2012.732050

To link to this article: http://dx.doi.org/10.1080/13549839.2012.732050

Published online: 08 Nov 2012.

Local Environment, 2013
Vol. 18, No. 7, 817–833, http://dx.doi.org/10.1080/13549839.2012.732050

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Reducing carbon, tackling fuel poverty: adoption and performance of air-source heat pumps in East Yorkshire, UK

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Deploying heating technologies, such as air-source heat pumps (ASHPs), can respond to the dual challenges of tackling fuel poverty and reducing carbon emissions from domestic energy consumption. In the UK, ASHP performance has been found to be below design levels. Elements of three strands of literature – innovation diffusion, environmental psychology and neighbourhood effects – are combined to gain insights into why the adoption and performance of ASHPs are lagging policy targets and design potential. Evidence from users, installers and area-based scheme facilitators suggests that the perceived complexity of the technology is a barrier. The level of technology maturity and the typical profile of the elderly fuel poor do not match; the target group might prefer to be late adopters or laggards in adopting technology. The role of installers is critical as the disruption from installation is a barrier to adoption and ASHPs place demands on users to change existing practices.

Keywords: heat pumps; fuel poverty; carbon reduction; innovation diffusion; place effects; installation

Introduction

A major element in mitigating climate change is to reduce emissions from domestic energy use. Homes accounted for 25% of UK emissions and 40% of energy use in 2009, and space heating and water heating account for over three-quarters of domestic energy use (DECC 2011a). Action must focus on reducing fuel consumption, changing the fuel mix to reduce emissions and enabling households to switch to alternative, lower emission heating technologies. As fuel prices rise, there is an allied agenda to mitigate the effects of the costs of energy on poorer households: to relieve "fuel poverty". Taking action needs to be delivered at a fine spatial scale if it is to be appropriate for specific contexts. This paper focuses on air-source heat pumps (ASHPs) being introduced to reduce emissions and energy costs. Heat pumps are relatively new to the UK domestic heating market and have been installed mostly in areas where mains gas is not available. Researchers working with the Energy Savings Trust have undertaken some evaluation of heat-pump technology adoption, both ground source and air source (Caird and Roy 2010, Caird *et al*. 2012), as part of a UK field trial assessing technical performance of heat pumps (EST 2010). This paper aims to add further depth and detail to that analysis by exploring a specific case of adopters of ASHPs in a rural area. All of the data collected for this study are original, so there is no overlap with the data obtained in the UK field trial.

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From 2008 to 2011, not-for-profit organisation Community Energy Solutions ran a partnership programme with East Riding of Yorkshire Council (ERYC) to install ASHPs in order to tackle fuel poverty and reduce carbon emissions. The investment of ERYC in the scheme was £150,000 over 3 years, matched by capital funding from other sources, notable the regional development agency. At the start of the programme, an ASHP installation typically cost £5000 per property, making the system comparable with installing an oil-fired system but more expensive than installing mains gas central heating or electrical storage heaters. Able-to-pay households were offered grant aid of up to £3000. Some cost reductions were achieved through learning effects over the scheme duration.

"Fuel poverty" is a condition defined as a household being unable to have sufficient energy services for 10% of the household income (Boardman 1991). Energy services include warmth, lighting and cooking, although heat or warmth is the major component and most discussed. However, a review of fuel poverty in the UK has recently suggested that a better measure would assess the number of households and individuals who had required fuel costs above the median level and, were they to spend that amount, would be left with a residual income below the official poverty line, reflecting that the poorest households may reduce their fuel bills to below 10% of their income by reducing their comfort and not using the amount of fuel required to maintain warmth (Hills 2012). While both definitions use the need for energy services as their starting point, the proposed new definition focuses on where low incomes and high costs overlap. A local authority's interest in alleviating fuel poverty can be traced to data which show that households in cold, energy-inefficient properties are more likely to be in worse health and require more social care support than warm households (Boardman 2010, p. 169). Cold, energy-inefficient households are more likely to be amongst the fuel poor. The data for this study come from the ERY, except for one surveyor in West Yorkshire with experience of ASHPs. ERY is a rural county in the east of England with substantial areas not served by mains gas.

For households not connected to the gas grid, space heating options typically include solid fuel fires, oil or propane central heating, electric storage heaters or, occasionally, electric boilers. Water heating is provided by a back boiler on a solid fuel fire, the central heating system or an electric immersion heater. Both oil and propane are carbon-intensive fuels and costs are rising. While it is possible to make monthly payments for these fuels through a merchant, users often pay for a tank full when delivered, meaning that these fuels have cash flow implications, especially for households on fixed incomes such as pensions or benefits. While the first step to take in tackling fuel poverty is to reduce demand through better home insulation, the issue of how to provide the remaining heat demand in a less carbon-intensive and more affordable way must still be addressed.

Air-source heat pumps

A heat pump transfers heat from one location to another, even if the location it is moving heat from is colder than the destination. An ASHP transfers heat from the ambient air outside a building to inside that building. Heat cannot flow from a colder area to a warmer area on its own, so an outside source of energy (electricity) must be used to compress the air and transfer the heat. "A heat pump works along exactly the same lines as a refrigerator or air-conditioning system (Indeed, a heat pump is basically an air conditioner running in reverse.)" (Rhodes 2011).

ASHPs are considered a "green" form of energy supply because although the required mains electricity is still carbon intensive in the UK, they use that electricity very efficiently, with a (hotly debated) heuristic of supplying about three times more heat than what direct electric heating, for example, an electric bar fire, would do (Cantor 2011). A comparison between carbon emissions from heat pump installations and those from electric or gas heating (taking into account the UK government's predictions for electricity grid decarbonisation) shows that a well-installed heat pump can lead to carbon savings compared with solid fuel or electric heating systems delivering the same level of comfort (EST 2010). ASHPs are part of the UK carbon plan: By 2030, government ambition, based on modelling of the interventions required to achieve the UK's carbon budgets, is to have between 1.6 and 8.6 million low-carbon heat installations in buildings, providing between 83 and 165 TWh of heat (Rhodes 2011), although the central estimate for what is achievable by 2020 in light of current deployment costs and non-financial barriers is much lower at 16–22 TWh for ASHPs and ground-source heat pumps combined (DECC 2011b). However, empirical investigation has shown that ASHPs rarely achieve their design efficiencies, particularly when introduced to existing properties rather than designed from the start of a build (EST 2010). Reasons for this are touched on in the discussion below of factors that affect the use and impact of ASHPs. ASHPs are effective at providing low levels of heat over extended periods, but are not efficient when asked to provide intense heat rapidly. Their efficient operation is therefore well suited to space heating for households with the elderly or less active at home much of the time. Other analysis has considered the barriers to heat pump adoption in the UK, identifying the technical characteristics of heat pumps and the links to UK housing stock, climate, electricity supply and distribution socio-technical systems and other institutional actors (Singh *et al*. 2010).

Innovation diffusion theory

What, then, are the important influences on the adoption of ASHPs? Innovation diffusion theory suggests that five attributes of the innovation itself account for approximately half the variance in the rate of innovation diffusion: relative advantage conferred by the innovation on the user, compatibility with existing practice, complexity, trialability and observability. Other factors which have been found to influence the rate of innovation diffusion are the type of innovation decision (optional, collective or imposed), the communication channels used, the norms and interconnectedness of the social system and change agents in the population (Rogers 2003, Chapter 6). Innovation diffusion theory also suggests that the characteristics of the users differ as the innovation diffuses more widely: a small number of "venturesome" innovators are followed by early adopters who may be opinion leaders and then an early majority to make up approximately half of the population. The late majority are followed, eventually, by "laggards" (Rogers 2003, Chapter 7).

Technology adoption as a form of pro-environmental behaviour

The theory of planned behaviour (TPB) (Ajzen 1991) provides a model of rational decision-making which, by suggesting potential determinants of behaviour, enables the relative importance of factors at different stages to be assessed. The TPB suggests that behaviour can be separated into the "intention to act" and the action itself. The intention to act is co-determined by the attitude that individuals hold towards that specific behaviour, their subjective norm (what they believe to be appropriate behaviour) and their "perceived behavioural control" (PBC), which encompasses both the individuals' perception of their capability and the individuals' actual impact when carrying out a behaviour. PBC and intention to act then influence how the individuals move from intention to action (in this case, technology adoption).

A behaviour then leads to some kind of impact. Combining this analysis of behaviour with the main elements of innovation diffusion theory, the authors developed a conceptual framework, illustrated in Figure 1, describing the factors affecting the adoption and use of domestic green technology, in which four sets of attributes, technology, user, place and installation process, can all play a role at the three stages of developing an intention to adopt a technology, adopting that technology and then using it. Each of the sets of attributes can be subdivided, and our research explored which factors hold most influence under what conditions at different stages of the decision-making process for these households. We do not mean to suggest that the process is a simple linear one, but using a simplified framework allows us to identify different points of emphasis.

The impact of "place characteristics" is worth further consideration for the insights it offers into designing and implementing an effective area-based scheme. The focus by scheme facilitators on technology attributes and, to a lesser degree, users means that issues of place can be overlooked. The "neighbourhood effects" literature offers useful ways of considering how place affects behaviour and (policy) outcomes. This literature is largely concerned with understanding social problems and what drives different types of deprivation in different areas, leading to the different policy and support needed to unpick these problems. A review identified 15 mechanisms (Galster 2010) for neighbourhood characteristics to affect social outcomes, several of which might be considered pertinent to green technology adoption including the quality of a neighbourhood's physical environment, the strength of local social norms, the strength and quality of social networks, and the impact of stereotyping and stigmatisation on a neighbourhood's perceived capacity to act. Social policy offers three distinct groups of "characteristics of place", each moderating the "neighbourhood effects" in different ways (Lupton and Power 2002). These three sets of characteristics are as follows:

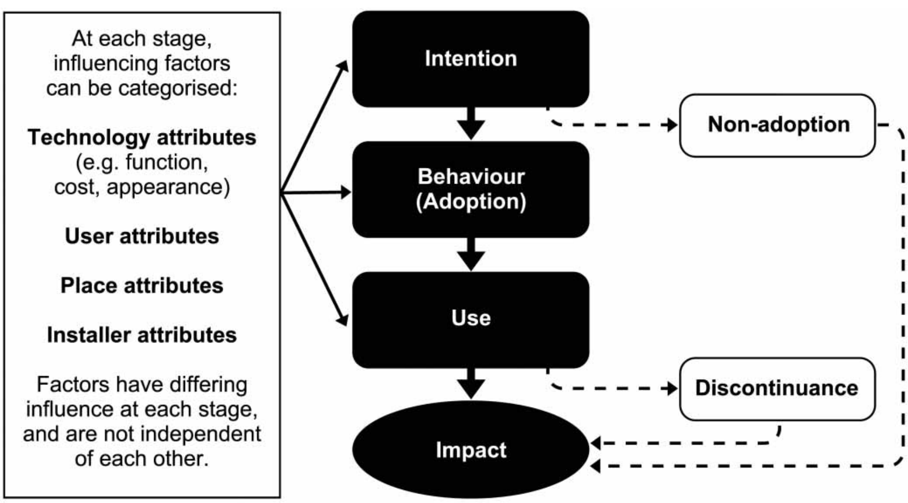

Figure 1. Conceptual framework for the factors that affect the adoption, use and impact of domestic green technology (ASHPs in this case).

- Intrinsic characteristics. These might be the physical attributes of a place such as topography, climate and existing building stock, which are very difficult to change.
- Population composition and dynamics and the socio-demographic factors.
- Acquired characteristics, such as local authority policy, community cohesion and transport networks.

These categories are not independent or mutually exclusive. This is a useful way of distinguishing between the different place factors that affect green technology adoption. These three sets of characteristics overlay reasonably well onto three sets of variables used by researchers in Canada seeking to understand whether place played a role in a community's propensity to take environmental action (Wakefield *et al*. 2006) where the three dimensions were contextual (the neighbourhood environment, which could be either intrinsic or acquired), local compositional (individuals' characteristics, taken in aggregate) and collective (the strength of social networks).

Method

Data were collected through 12 interviews, typically 1 h in length, carried out by the same interviewer with six households that had adopted ASHPs, the two programme managers who designed area-based programmes, and four surveyors and installers who specified and installed the ASHP systems. Households were contacted directly, focusing on smaller subsets of the total ERY area, using information provided by ERYC that had previously checked that households were willing to participate. All households were in private ownership and were representative of the older or more vulnerable households at risk of fuel poverty that the scheme has been designed to target. The other six interviews represent nearly all the individuals professionally involved in scheme design and delivery, apart from the contractors who carried out the installation.

Despite the relatively small number of interviews, data saturation was apparently reached: no new information emerged from the final interview with an adopter. Because the ERYC scheme focused on using ASHPs to tackle fuel poverty, the majority of the users interviewed (five of seven) were retired, and of these householders, three had significant health problems. All of the ERY adopters lived in relatively small (one- or two-bedroom) properties. This makes the sample different from the general profile of early adopters of microgeneration heat in the UK who are "environmentally concerned, older [25% retired], middle-class householders who tend to live in larger rural properties off the gas grid" (Roy *et al*. 2008) or the innovation-receptive "early adopter" profile associated with microgeneration more widely (Guagnano *et al*. 1986). The interviews were recorded digitally and fully transcribed. Analysis was undertaken using Nvivo, computer-assisted qualitative data analysis software. The analytical approach is based on "template analysis" (King 2004), using the conceptual model as the template starting point.

Results and discussion

The findings from this study are presented and discussed below, using the framework emergent from the integration of the TPB and innovation diffusion described above. We consider what user, technology (including cost), place and installation factors influence the intention to adopt, adoption, use and the impacts, both direct and indirect, of ASHPs.

Intention to adopt

The service provided by the technology was, for all users, the main factor that shaped their intention to adopt an ASHP, specifically the promise of cheaper or more comfortable heating:

> I suppose all we were interested in is getting a bit more warmth on a night-time. (ERYC adopter)

None of the ASHP users interviewed expressed a strong interest in low-carbon technology more generally; their interest was in effective space heating. This reflects the target of the ERYC scheme, in particular, to provide affordable warmth to homes off the gas network. Users in ERY framed their interest in ASHPs as dissatisfaction with their previous systems, rather than as a particular appeal of the new technology. Specifically, three users described how the timing of heat from electric storage heaters did not meet their needs. The heat generated during the day was not as useful as heat available in the evening when the interviewees were typically more sedentary. ASHPs were perceived to have a high degree of complexity, with users describing them as "baffling" and a scheme facilitator describing the technology as "not intuitive". The same facilitator suggested creating greater observability to overcome this barrier; he believed that showing people how the ASHP worked was essential for adoption and positive impact. Part of the scheme design in ERY tried to make it possible for people to go and see an ASHP in action. An ASHP has also been installed, with separate funding, in a village hall in one of the target villages. It has been found in community renewable energy studies elsewhere in the UK that a lack of visible success or a project not being clearly rooted in local concerns, issues and knowledge may inhibit further participation (Walker and Cass 2007, Rogers *et al*. 2008, Allen *et al*. 2012). ERYC facilitators and users alike expressed a view/agreed that both visibility (seeing the technology) and observability (seeing or experiencing the effect of the technology) helped with ASHP acceptance. User comments suggested that seeing an operational unit helped them decide to adopt an unfamiliar technology, but did not necessarily help with understanding how the unit worked.

In the ERY scheme, ASHPs were not promoted as a renewable energy technology, rather their equivalence to a gas boiler in space heating function and cost was emphasised. Carbon reduction was not the primary concern, but an added benefit from the local authority's viewpoint. No adopter stated an interest in carbon reduction. The users therefore had the functionality of a gas or an oil boiler in mind, despite the different operating mode, and lower running temperature, of ASHPs. ASHPs are typical of all retrofitted heat systems, in that they are "usually a distress purchase" (Rhodes 2011). Thus, reliability is a technology attribute likely to be highly valued. One of the fears expressed by potential adopters to the surveyor was the impact of power cuts.

In the ERYC scheme, deciding on a preferred technology reflected the scheme objectives of tackling fuel poverty and carbon emissions together; that is, the primary considerations were the technology attributes and performance which led to a focus on heat pumps, rather than to a focus on user capabilities which might have ruled out unfamiliar technologies. Water heat pumps were ruled out because of the lack of consistency in their performance, leaving ASHPs and ground-source heat pumps. The scheme facilitators also reported that practical considerations such as supply chains and availability were applied as filters to technology selection.

Place influenced the intention to adopt through the area-based scheme objectives and funder's requirements. The facilitators focused on areas with a high index of multiple deprivation, a measure which ranks neighbourhoods on the basis of social and material disadvantage. ERY overall has high levels of fuel poverty (27% was reported) and an older population. Social housing comprises approximately 11,000 households in a total of 140,000. Being off the gas grid also drives higher fuel costs (Hills 2012). Given this clear focus, the scheme facilitators were frustrated by the lack of available data to identify target areas. One of the scheme facilitators stated that the most important improvement that could be made was to make a map of the gas grid publicly available.

The scheme facilitators now get enquiries about low-carbon domestic energy from all over the north of England. There are not many enquiries about ASHPs specifically, but when there are enquiries about ASHPs, they are often from the East Riding. The facilitator thinks that this is likely to have been influenced by ERYC publicity, including information in council publications, increasing the awareness that the council is supportive. Other case studies concur that having a visible and locally knowledgeable agent leading a scheme is important to the success of implementing green technology on an area basis (Walker 2008, Saunders *et al*. 2012). The scheme managers believed that it was helpful to have councillors involved and to use the council brand. Two councillors in particular were involved in promoting the scheme because their electors had concerns about rising fuel prices. Letters about the scheme to potential participants were sent from councillors and councillors featured in photos for local papers and in leaflets. However, the ERY adopters interviewed did not mention any role that the councillors had played, while two of them explicitly praised the care and interest of council officers, rather than elected representatives.

A smaller scale place factor was the property types in a location and how the technology attributes might interact with property design:

> One of our first concerns when we'd seen the units and explored [Brand A], was the noise. And I thought, it's going to be a bit of a situation with the noise. Knowing the type of properties we have ... social housing usually, either semi-detached or ... and in blocks, aren't they? Or terraced. And we saw that the problem would be if we were putting an air source heat pump at the back of number one, and number two weren't having one, they would possibly complain about the noise. (Surveyor/installer)

Property tenure is linked to the likelihood of fuel poverty as a large proportion of people on low incomes and at risk of fuel poverty are not homeowners (Walker 2008). However, social housing, the occupiers of which characteristically have lower household incomes, is, overall, more energy efficient than private housing stock (Hills 2012). The ERYC scheme funded ASHP installation in social housing and in privately owned housing. However, of the ASHP adopters interviewed, none were social housing tenants; one household was a private rented tenant, another home was owned by the interviewee's daughter and the rest were owner-occupiers. Also linked to tenure, all those interviewed said that they intended to stay in their homes indefinitely and had no intention of moving. This might make them more amenable to adopting a system where installation was potentially disruptive as they would have a long period of benefits following installation.

Health conditions might also constrain feasible technologies. One invalid used oxygen cylinders to breathe and therefore could not have an open fire; a heat pump was safer. Health and age, separately or in combination, shaped the frailty of the decision-maker, which was important in shaping the intention to adopt:

> ... in a lot of cases we might have been dealing with an old person that had maybe got to the time of life where they didn't want to be humping coal about and cleaning fires out and that sort of thing. (Surveyor/installer)

The role of the surveyors who specified the technology was very important in shaping the intention to adopt. One of the surveyors emphasised that it was vital not to oversell the information shared before installation. The installation needed to meet people's expectations. The same council team had been installing storage heaters and other heating solutions before the ASHP scheme started and challenged the facilitators as to how they were going to ensure that this "new-fangled" thing worked and whether it would actually be cheaper to run. Part of the project was therefore persuading the technical team that they needed to try the new technology. The scheme facilitators reported that these initially sceptical installers became champions for the technology as they learnt more about it through experience. Analysis of the development of the domestic microgeneration market in the UK suggests that there are skill synergies between some microgeneration technologies (Bergman and Jardine 2009), but the installers involved in these schemes were still in the early stages of extending from more conventional plumbing, heating or solar thermal businesses.

Adoption

The scheme facilitators believed that council branding was essential to the scheme's success in technology uptake, but in three cases the ASHP adopter particularly valued the advice and input of other (younger) family members, one even going so far as to say that she would not take any decision without consulting her adult daughter. Another adopter said

> I'm not very good at making decisions on my own. (ERYC adopter)

The same individual had also asked advice from a builder in her social circle, although he professed no knowledge. In most cases, the friends and family did not have positive knowledge but did not have bad experiences to report either, so the effect may have been neutral. The unknown nature of ASHPs meant that the opportunity to see the equipment installed was helpful, ideally elsewhere in the same village so that the context was comparable.

In all cases, the intrinsic properties of place (off the gas grid) together with the acquired property of place (the existence of an area-based financial incentive) led to adopting an ASHP rather than another technology. For ERY installations, ASHPs were only considered off the gas grid. This reflects the economic objectives of the scheme because where mains gas is available a gas boiler offers lower capital and operating costs than an ASHP. Local policy underpinning the area-based approach played a role. In the sole case where the potential adopter householder was not retired, the selection of an ASHP over other heating technologies was determined by the grant or loan availability, financing which was not available for fossil fuel systems.

ASHP technology attributes also interact with place characteristics in the capacity of the mains electricity distribution system. Heat pumps draw a significant quantity of power, around 3 kW for a standard-sized ASHP for a domestic dwelling (Rhodes 2011). The local electricity distribution networks may need reinforcement in rural areas with a lot of heat pumps installed. There is also an issue with the peak load for which a local network is configured. This issue was mentioned by the scheme facilitators and installers in ERY where additional costs for network upgrades had been incurred in some cases. The scheme facilitators developed links with the distribution network operator (DNO) that led to that DNO receiving special funding to lead on smart grids nationally. Having said that, the facilitator still described the relationship with the DNO as "they hate us and we hate them", suggesting that the inertia in the current distribution socio-technical system should not be underestimated.

The proximity of others who were considering adopting an ASHP was a place factor that appeared to have an influence on adoption by indicating a changing social norm in that location:

> . . . in [Street A] now I could probably give everybody in the street one, because everybody wants it now because they've all seen [an ASHP], because there've been so many done in [Street A]. (Facilitator)

Even when houses were in the same location and of a similar design, if they were more than a few years old, then the interior and exterior modifications would be sufficient to require a bespoke solution. In this sense, place factors at a very fine scale provided some barriers to adoption because there was never a standard installation solution.

Technology attributes and location also interplay in siting the pump's fan. The fan sits outside the property, typically on a concrete plinth. Installers preferred to place the fans on a south-facing wall to get as warm a situation as possible. ASHPs are not yet as familiar a domestic technology as, say, photovoltaic cells, and planning authorities' views on whether ASHPs are permitted development are mixed. In ERY, ASHPs are permitted development unless on an elevation facing a highway. This means that planning policy and the property configuration might compromise the optimal positioning of the ASHP:

> We had one property that . . . there was a step in the front of the building and when I went in to survey that I thought if . . . if I get that unit sat in there, in that corner, in that alcove, it's going to be in full sun all day long, you know, and they wouldn't let us do it there. It couldn't go on the end elevation [because of planning policy] and it ended up at the back of the house and it faced north. And when our first severe winter, it didn't work. (Surveyor/installer)

Requiring planning permission also led to other frustrations where potential users were unfamiliar with the planning system requirements. One household that had struggled with the planning process complained that its initial submission had been rejected because it had used the wrong colour pen and submitted the wrong type of map (Google rather than Ordnance Survey). The idiosyncratic nature of land associated with older houses can also be an issue in siting the installation and therefore in how well the ASHP functions. One adopter described how the location of the ASHP fan was sited suboptimally because a neighbour's boundary came right up to the preferred outside wall, making it impossible to build a plinth for the fan.

The installers' developing experience of the technology, coupled with their detailed knowledge of place characteristics, led to innovation in the way in which the ASHPs were installed in ERY:

> I was looking at where we were going to site this unit, and I said to the old chap who lived there, I said, "Do you have a problem with your garden?" And he said, "Oh, it floods". . . . You could tell by the lay of the land, you know, that . . . so I said, "I think we'll purchase a wall bracket." (Surveyor/installer)

The scheme facilitators recognised that the unknown nature of the technology might be a barrier to adoption. They took action to improve the visibility of the technology, but observed that the ASHPs needed to be seen in context. The managers and surveyors interviewed, who also had experience of gas and oil systems, stated that ASHPs are currently more challenging to install than a conventional boiler. National field trials confirm this (EST 2010). Electricity microgeneration now receives financial incentives for UK adopters through the Feed-in Tariff, and a Renewable Heat Incentive (RHI) is planned to provide similar incentives for heat. ASHPs may be included in the RHI although they are not within the definition of renewable technology under the EU Renewable Energy Directive. Even before the RHI is implemented, the UK has examples of using tariffs on an area basis to promote these green technologies for the fuel poor (Saunders *et al*. 2012).

Cost and perceived complexity, or simply unfamiliarity, were barriers to adoption that local policy or incentives might overcome. ASHPs are not unique in this regard. One of the purposes of the UK's Low-Carbon Buildings Programme, which ran from 2006 to 2009, was widespread demonstration of emerging microgeneration including solar thermal, photovoltaics, micro-wind, ground-source heat pumps and biomass boilers, facilitated through grant support and supply chain development (Bergman and Jardine 2009). Providing financial support countered a potential adopter's preference to select a familiar technology:

> Whether if the oil heating was going to be the same price or whatever, whether I would have gone for it then, I wouldn't like to say . . . I might have gone with what I already knew. (ERYC adopter)

A technology attribute which proved critical to achieving the low-carbon warmth intended, and which was a recurring theme from installers, was the antifreeze system required. In the ERYC scheme, two different manufacturers had two quite different approaches to the antifreeze circulation systems. The earliest systems installed were external water systems and the later ones were "split systems" where the circuit outside the property was a refrigerant and the water circuit was inside the property and therefore less likely to need an antifreeze. Installers expressed a strong preference for the split system for reasons including easier commissioning (not having to check antifreeze levels) and less likelihood of the system being compromised by home 'do it yourself' (DIY) activities where radiators were taken off, drained down and refilled without a replacement antifreeze being added.

While the lack of attention that an ASHP requires to function might have been attractive to users and might shape a positive intention to adopt, the disruption involved in implementing the ASHP may prevent intention developing into adoption and was cited many times in this sample. The inconvenience was not perceived as technology specific; putting in a new heating system of any type was felt to be too disruptive for many users. The level of disruption and the difficulty of installation depended primarily on the type of heating that had been installed previously. Moving from open fires to an ASHP was the most disruptive as radiator sites needed to be identified as well as tanks and pipework installed inside in addition to the fan unit outside. Moving from electric storage heaters to ASHPs promised most benefits in terms of comfort and warmth and did entail some redesign as not all radiators would be placed where the storage heaters had been. Changing from oil or bottled gas to ASHPs entailed the least change internally, usually just increasing the size of radiators. For ASHPs, this potential disruption figured more in the decision-making process than any financial benefits. The cost benefits were often difficult to forecast with certainty because of the way in which the ASHP would change heat use in the home. Even when cost benefits were clear, the potential user might not be persuaded. One facilitator reported his experience with a household spending more than £2000 a year on electricity:

> An air source heat pump could easily cut electricity bills in half, and you can't normally say that to people, because you can't tell how people are using their electricity. We could have saved her £1000 a year and she still said no because she'd just had the disruption in the house of redecorating. (Facilitator)

While technology attributes such as the level of disruption caused by installation will typically remain fixed over time, user attributes may change, altering the thresholds of acceptability and the relative advantage offered by a technology:

> She didn't take it up originally, Mrs A, because she had a parquet floor in. And that was a big turnoff. And then, subsequently her husband died out of the blue and she had a stroke, and she had a coal fire and so then, she did. (Facilitator)

Use

ASHPs deliver lower temperature circulating fluids to the radiators than conventional gas or oil boilers; therefore, radiators can feel cooler than the user expects. The ubiquity of gas, oil or electric boilers with rapid response times and high running temperatures has established expected standards of performance from heating systems, around which user habits and routines have developed. Thus, ASHP technology cannot deliver the desired outcomes without being integrated into lifestyles and practices (Shove 2003). To be effective, either technology design must reflect users' established practices, which is not feasible with heat pump technology, or users must be informed and supported to alter their expectations and practices. For example, the use of a timer which limits gas boiler operation to the period when heat is needed is not appropriate for the lower running temperatures of heat pumps. Two interviewees stated that they noticed this. To get the benefit of maintaining a lower temperature, the system needs to be allowed to run consistently for long periods. ASHPs do not function efficiently when put on short-duration timers or switched on and off frequently. However, a user who was used to an oil system expected a rapid response, conceptualising the heat pump as a boiler. She did not allow the ASHP to run for long periods, partly due to concern about the cost of electricity if the system was on throughout the day.

While noise was reported as the primary negative impact of ASHPs by the scheme facilitators, only one household interviewed expressed any concern about noise levels, and that was a worry about impact on neighbours rather than that on the adopter herself. One other installation had been upgraded to a different fan to reduce noise following neighbour complaints. Four said that noise was not noticeable or not an issue. Another user positively stated that she liked the noise of the ASHP, and the silence when it froze in winter was very disconcerting:

> I find it quite comforting. I love the noise. I do. And I can't explain it but I feel that I am enveloped in like a warm blanket. (ERYC adopter)

Another feature of the ASHPs during operation is that the fan units drip condensate. One installer noted that this causes problems in cold temperatures where the unit is floor-mounted because in cold weather the condensate can freeze around the base of the unit.

All the adopters stated that they did not really understand how the ASHP worked, and three of these ascribed their lack of understanding directly to their age, suggesting that age profile is an important user attribute, particularly in relation to the PBC that potential users have. Translating the idea of PBC from psychology to design, PBC has some parallels with the measures that users take to control the system, such as opening windows or turning the system on and off, which have been termed the "adaptive opportunity" presented by a system (Baker and Standeven 1996) The lack of understanding of how a system works, leading to issues of suboptimal control, is described in very similar terms for ground-source heat pumps installed in social housing for the elderly in another part of Yorkshire (Boait *et al*. 2011).

As mentioned above, installation and maintenance issues play some part in the intention to adopt, adoption and use. The variety and number of aspects mentioned by interviewees suggest that installation and maintenance merit further exploration. One factor, both a technology attribute and an installation issue, mentioned by three of the adopters was the space required for the ASHP tank. One interviewee lamented the loss of her airing cupboard and remembered it as the first thing that the surveyor had looked for in her property, whether there was space for the tank. A surveyor commented that in his experience, the loss of an airing cupboard was often the principal concern of the woman in the house. The ERYC surveyor/installer also listed the need for indoor space as a critical factor in selecting which of the different types of ASHPs available would be used in a particular property. This issue can be overcome by siting the hot water tank outside the thermal envelope of the dwelling, for example, in an outhouse if available, but this then leads to other issues of reducing efficiency through standing heat losses (Stafford 2011).

Because ASHPs are unfamiliar systems, commissioning and helping the users understand their new systems were very important factors identified in the UK field trials (EST 2010). These factors were reinforced in interview data when adopters were asked what would have improved their experience of the ASHP. The installation process typically took a team of up to three people 2 or 3 days. In the East Riding, the installation process and the teams who undertook the work were generally reported favourably. There was some evidence that, in light of a lack of understanding of the technicalities of what was being done, the cleanliness and care of property exhibited during installation were used as proxies to make a judgement on the quality of workmanship, rather than evaluating the performance of the ASHP. If an installation experience was positive, then ERYC quickly used these positive adopters to promote the opportunity to comparable households, recognising that the fear of complex or messy installation would prevent adoption. However, if the installation was not a good experience, that seemed to echo in the adopter's view on the efficacy of the ASHP. One household had a long list of reasons why it was unhappy with the installation: radiator silt leaking out of removed radiators, vinyl flooring raggedly cut, removal of a thermostat including cutting a door architrave, and a flood overnight during installation. This household saw the performance of the ASHP as no different from that of its previous (oil) system.

The UK national field trials found that the design and installation of the systems were problematic, with many installations being incorrectly installed. Poor design and sizing of the heat pumps to meet the property's heat demand were also observed. This could be due to contractors' relative inexperience in working with heat pumps (EST 2010). Part of the objectives of the ERYC scheme included building some capacity in the regional supply chain for installing heat pumps. Nearly all the ERYC installations were undertaken by the same firm, based in West Yorkshire. The distance that the crews had to travel was seen as a problem by adopters and was particularly a barrier to adopters in seeking advice or extra information about using their heating systems after installation. When a system broke down, as several did in the very cold winter of 2010/2011, adopters felt unable to afford calling out a contractor based 50 miles (approximately 1 h drive) away.

This remains an issue, with one interviewee who had recently had an ASHP breakdown being helped by the scheme facilitator to find an alternative maintenance contractor, based approximately 30 miles away. The immaturity of the heat-pump installation sector was reinforced by comments from the ERYC surveyors, who found that they had to put extra effort into explaining the technology to potential adopters. The extension from technical skill sets to communication was not particularly welcome, "almost off-putting, really". Installers identified that there are aspects of heat-pump installation that require a level of detailed attention that gas installation does not, for example, insulating the system to ensure efficient running at low temperatures. As well as skill development, the scheme facilitators found additional costs associated with heat-pump installation compared with more conventional heating systems, particularly the Microgeneration Certification Scheme (MCS) accreditation that installers are required to have. The facilitators reported that generally installers who have MCS accreditation require a larger margin to cover their larger overhead costs. In the tendering process to recruit installers for the ERY scheme, the facilitators found a considerable cost difference between MCS- and non-MCS-accredited installers, with the former being several hundreds of pounds more expensive and tending to be small companies with no social housing experience. The cheaper tender responses were from larger companies with social housing experience but no MCS accreditation.

Impact of installed ASHPs

In this sample, only one household, which had switched from bottled gas, reported a reduction in its fuel bills (of 50%). In all the other cases, households took their benefit in terms of increased comfort and increased resilience or confidence of warmth:

> I think the only thing that I would say is that I don't feel as if it's any cheaper to run. But, the quality of life is so much better. (Adopter)

In one case, an interviewee reported that bills had increased, but she thought that the increase might be caused by unit price rises. In another case, the interviewee reported that bills had stayed about the same, but as she was sure unit prices had risen, she felt that she must be using less electricity. Overall, the adopters were happy with their new heating systems. One interviewee emphasised how delighted she was, another said that there was no difference in performance compared with that of the oil-fired system, and a third, while content, did describe the concern and ambivalence that she had felt after taking the decision to adopt, wondering "Have I done right?".

Another household was surprised that its first electricity bill after ASHP installation had been approximately three times more than the equivalent quarter in the last year without the ASHP, but this triggered further conversations with the installer, increased information for the users and a change in operating procedures, specifically lowering the set temperature and allowing the unit to run for a longer time, which should reduce the bill for future quarters. This homeowner felt that he had to increase his understanding of the ASHP considerably. The importance of ongoing conversations with the installer emerged as a strong theme for households that had commissioning or cold weather problems.

The achievement of any carbon saving is strongly reliant on, but not determined by, the efficiency of the technology. Heat-pump performance is sensitive to installation and commissioning practices. As planning policies are concerned with visual impact and noise, there is the risk that complying with planning policy will reduce heat-pump efficiency and militate against achieving carbon or cost targets.

In addition to comfort, reduced bills and possibly carbon savings, other user benefits were reported. Typically, these benefits related to the lifestyle and practices of the household:

> One lady in particular springs to mind. She had an open fired, coal-fired heating system, partial heating system, and we took it out and I've asked her about the running costs and she was quite happy that it was cheaper. But said even if it had been dearer, she wouldn't have gone back to coal fires. Because when she had the coal fire, she had to dust every day with a damp cloth. And now she dusts once a week with a dry cloth. (Surveyor/installer)

In only one case, the interviewee reported dissatisfaction with the appearance of the ASHP outside her home. Interestingly, this was also the case where the installation process had been messy and disruptive.

Mediating impact: lifecycle, rebound and spillover effects

The likelihood of rebound effects in terms of total energy consumed, particularly amongst those in fuel poverty, the main target group for the ERYC scheme, is high. In a fuel-poor household, carbon emissions are limited by the amount of energy that the household can afford to purchase. When the energy service (heat) becomes cheaper, because of energy efficiency or a different technology, the household can afford more energy in order to reach comfort levels. Evaluation of the impact of energy efficiency schemes on the fuel poor has found that this "comfort taking" in lieu of cost saving is limited (Green and Gilbertson 2008). Achieving the improved warmth through more efficient supply may mean that that taking more comfort will not necessarily lead to increased carbon emissions. Responses to increases in energy prices will vary depending on household income. Middle-income households are likely to invest in measures that increase the energy efficiency of their homes or that allow more energy-efficient behaviours. Low-income households are likely to curtail energy use because these consumers do not have the financial resources to invest in efficiency (Ritchie and McDougall 1985).

Also, the impact on emissions from the rebound effect in fuel-poor households will be different and probably less than the impact from the rebound effect in non-fuel-poor households:

> In cold homes, the savings that are taken up as additional warmth reduce the opportunity for a rebound effect into other energy expenditures. For households who are already warm, the energy-efficiency improvement releases money that could be spent on other energy-using activities, such as additional flights. Therefore, a focus on the coldest homes will limit the growth in discretionary energy consumption. (Boardman 2010, p. 179)

The ERY ASHP funding scheme was designed to ensure that the participant household energy use was as efficient as possible before ASHP installation in order to reduce rebound effects. Funding, whole or partial, for an ASHP system was contingent on the house already having loft and cavity wall insulation, where it was feasible. Six of the seven properties where ASHPs had been installed had cavity walls and were insulated, and the seventh was solid walled but did have loft insulation.

Conclusion

Our data in this case study suggest that it is technology attributes, and specifically the technology function of providing affordable, timely warmth, that shape the intention to adopt an

ASHP for a potential user. A significant place attribute, in this case that a location is not on the mains gas grid, shapes technology selection within the policy requirements of the area-based scheme. These findings help refine the long list of possible influences in the conceptual framework presented in Figure 1 and suggest that bringing consideration of place and technology together could help increase the success of schemes that aim to use technology to achieve social policy goals.

The evidence collected in this study confirms that an area-based approach is vital in tackling an issue such as fuel poverty. Without the "acquired place characteristics" of a policy, a programme and local knowledge and networks, this technology, offering the opportunity to make a step change in both the carbon efficiency and economic efficiency of heat services, would not be adopted. The carbon reduction targets of the UK require deployment of renewable energy and energy efficiency to millions of homes. This research suggests that such ambition can only be realised if programmes are sensitive to how these factors vary from location to location and, if programme implementers are allowed, the flexibility to alter schemes using their knowledge of places and networks. There are parallels to this finding in the number of context-specific factors which have been found to shape the development impact of urban area-based energy schemes (CLUES 2012). The potential "transition pathways" identified for such urban schemes are numerous, with each pathway reflecting a combination of governance, social, economic and technological factors that apply to that particular scheme in that particular location. Taking a distanced view in order to examine a total of 182 case studies (CLUES 2011), researchers conclude that there is no single "obvious" route to achieving the objectives of an area-based energy scheme. Accepting this, the study described in this paper focuses selectively on one particular case in order to examine the detail within these different categories that support a specific "transition pathway". Even this focus on a single case illustrates how every household, apparently with similar demographic, locational and economic characteristics, required a unique approach in terms of the detail of installation and commissioning. There is no single package which will work across an area, and learning across the system appears to reduce per-installation costs by tailoring solutions more efficiently rather than by standardisation.

However, the potential to tackle fuel poverty and reduce carbon emissions is not yet being fully realised, and we suggest that the reasons for this become clearer when, using another of the models introduced in this paper, an innovation diffusion perspective is applied. Domestic ASHP technology is still developing; attributes such as price, performance and even technical configuration are still changing. Users for technology at this stage of development would usually be innovators interested in the technology itself or early adopters willing to take risks. But fuel-poor users here are likely to be late adopters or even laggards by preference. The technology design, installation and maintenance processes are not yet developed with these users in mind. Unfortunately, there are no other obvious low-carbon technologies which would be preferable to heat pumps in areas off grid for mains gas.

Thus, in developing an area-based approach with a clear focus on vulnerable users, technology design needs to recognise the user profile and installation and commissioning procedures need careful attention to ensure that desired outcomes are achieved.

Acknowledgements

The authors thank the ERYC, particularly Jane Mears, and the Environment Unit at Kirklees Council that supported the field work, Sharon Joyce and Amanda Woodhouse of the Engineering Design Centre at Newcastle University who also provided valuable support, Anne Stafford at Leeds

Metropolitan University and colleagues Chris Clegg and Martin Clarke for their helpful comments. Comments from two anonymous reviewers have significantly improved this paper. The study was supported by a grant from the EPSRC Sustainable Urban Environment Programme.

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