Ventilation in energy efficient UK homes: A user experience of innovative technologies

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Abstract

A widely adopted mechanism for reducing the amount of energy consumed in dwellings is to increase airtightness and reduce ventilative heat losses through the building envelope. As building regulations get more stringent, we are having to change the way we ventilate our homes, to address the challenge of providing adequate ventilation while maximising energy efficiency. The construction industry has responded through the use of whole-house ventilation systems. Although these innovative technologies may have great potential, our increasing awareness of the role of people's actions on domestic energy consumption prompts us to question how the residents' experiences of these ventilation technologies relate to those anticipated by the designers of the system. Consequently, we cannot be certain that the expected energy savings will actually be achieved. This paper presents the findings of an exploratory study to investigate the processes by which residents in the UK embed energy efficient ventilation systems into their lives. This information is required if we are to ensure that the diffusion of continuous whole-house ventilation in UK housing results in the predicted and required energy savings, without compromising occupants' health and comfort. This paper presents the findings of the first stage of a case study in which we examine how people engage with new ventilation technologies. A qualitative methodology was adopted, with data analysed using the domestication of technology theory, in order to explore the interactions between ventilation systems and their users. From this perspective we investigate to what extent the four stage model of domestication (appropriation, objectification, incorporation and conversion) proposed by Silverstone et al. (1992) can be used to interpret the findings of a case study exploring residents' experience living in low energy homes which contain one of three ventilation systems: passive stack ventilation, mechanical extract ventilation and mechanical ventilation with heat recovery. Fieldwork is being conducted at three recently completed social housing developments in the UK, using in-depth interviews, photography and a walk-through of the dwelling with the resident, supported by analysis of design and construction documentation. The paper argues that seen through the theoretical lens of domestication theory, the phenomenon of adaptation to ventilation technology is complex and the findings challenge some of the assumptions of the four stage domestication model. We suggest that the users' adaptation experiences could be better viewed within a conceptual two-dimensional 'adaptation space', where the two major axes are defined by the varying degrees of access to and utilisation of help and the different individual understandings of the system.

The way we ventilate our homes is changing

The UK's housing stock is responsible for 25 % of total UK CO_2 emissions, which must be reduced by 80 % to fulfil the obligations of the legally binding Climate Change Act 2008 (Palmer and Cooper, 2011, 2008). As we improve the energy efficiency and thermal performance of buildings it is important to also consider the effects of these changes on our comfort and well-being so that energy is saved without harming health (Bone et al., 2010). In particular, we spend a large portion of our time at home (Eurostat, 2004), an environment which should be kept

thermally comfortable and free of pollutants.[1] Space heating is thought to account for 65 % of a typical dwelling's energy use, while ventilation heat loss accounts for about 20 % of a dwelling's heat loss (Utley and Shorrock, 2008). Improvements to the building envelope reduce space heating loads by increasing thermal insulation, and by replacing uncontrolled air infiltration with an airtight envelope and controlled ventilation (Johnston et al., 2005). Ventilation is required in all dwellings to disperse internal pollutants such as odours, water vapour, CO and $CO_{2,}$ to provide healthy and comfortable conditions, and to prevent condensation and mould which can damage the building (NHBC and BRE, 2009). The movement of air also contributes to occupants' thermal comfort or discomfort at home (Nicol and Roaf, 2005, Fanger, 1970).

Most existing UK homes are sufficiently leaky to require purpose provided ventilation only in the kitchen and bathroom. However, modern homes are being built increasing tightly with a maximum permeability of 10 m^3/m^2 at 50 pa. As buildings become more airtight, we can no longer assume that sufficient fresh air to keep the building fabric and its occupants comfortable and healthy will be available automatically (CLG, 2008). Consequently, all new dwellings in the UK *must* be provided with some kind of controlled ventilation. Building Regulation Approved Document F (ADF) is concerned with ventilation, and specifies mandatory ventilation rates for new dwellings (Government, 2010a), while Approved Document L1 (ADL1) sets increasingly stringent domestic energy performance targets within its remit of 'Conservation of Fuel and Power' (Government, 2010b).

It is expected that regulations will continue to become more demanding as we move towards the 2016 zero carbon homes target. If this is the case then it is likely that most new homes built in the not so distant future will incorporate 'whole-house' ventilation systems (Edwards, 2005). Although these innovative technologies have great potential, the existence of a performance gap between predicted and actual building energy consumption prompts us to question whether relying on technological solutions alone will solve the problem of decarbonising the UK's housing stock. Cole et al. (2008) call for a more integrated approach to understanding the interactions between building inhabitants and new technologies. Based on their study of inhabitant comfort in commercial buildings, the authors argue that the target carbon savings will not materialise through 'technological solutions that do not challenge currently accepted design norms or inhabitant engagement (p. 335)'.

In this research a case study approach is adopted to explore the processes by which inhabitants of new low energy UK homes incorporate whole-house ventilation installations into their lives. Two key research questions are being investigated:

1. When and how do the inhabitants of low energy homes interact with their ventilation technologies and are they able to use the ventilation to maintain a healthy and comfortable internal environment?
2. How well do the inhabitants of low energy homes comprehend their ventilation systems and does this level of knowledge affect ventilation behaviour?

Diffusing innovative ventilation technologies into the home context poses new challenges

OCCUPANT BEHAVIOUR AND DOMESTIC VENTILATION PRACTICES

Since the now seminal Twin Rivers Project, conducted during the 1970s, found that difference between the energy consumption in 28 nominally identical houses varied by more than a factor of two between the highest and lowest consumer, there has been a growing recognition amongst academics and policymakers that people play an important role in determining the energy consumption of a building, and therefore that research concerned with maximising energy savings must consider the factors that drive humans to act or 'behave' in a certain way (Sonderegger, 1978) (Socolow, 1978).

People's ventilation behaviour at home can have an impact on both energy use and indoor air quality (IAQ). Consequently, it is possible that differences in the way inhabitants interact with ventilation technologies may be responsible for part of the 'performance gap' that has been observed between predicted and actual building energy use (Bordass et al., 2004) (Janda, 2011). However, residents are often unaware of the potential energy implications of their actions, nor of the benefits that correctly functioning domestic ventilation systems may bring in terms of health and comfort (Soldaat and Itard, 2007).

Research indicates that dwelling occupants regularly use windows and ventilation technologies in different ways to those intended by the designer. For example, opening windows while the heating is on, use of boost switches and even disabling of ventilation technologies, such as for example blocking trickle vents, have all been found to affect energy consumption (Macintosh and Steemers, 2005). Routine domestic activities such as cooking and cleaning will influence air quality, and most ventilation systems require some kind of maintenance, usually the periodic replacement of filters, which many users are failing to carry out properly (Soldaat and Itard, 2007).

With the focus on users' behaviour, the current handover requirements in the UK building regulations go some way towards addressing these concerns through the minimum recommended requirement to provide the end user with an 'Operation and Maintenance Manual' (Government, 2010c, p. 53). This manual should comprise the following information: a design statement, manufacturer's contact details, information detailing the location and setting of automatic controls and the location and use of boost settings for mechanical ventilation, details of air inlets for background ventilation, instructions for cleaning and maintenance including the location of filters and information on how to access ducts and recalibrate sensors. A description of warning lights and acceptance tests are not included in this list.

Other research has also raised the importance of studying the interactions between people and ventilation technology. For example, Meyringer and Trepte (1986) discuss the critical importance of considering *user compatibility* in terms of comfort requirements and user habits when planning an effective

1. According to the Eurostat study European men spend 60–69 % of their time at home and European women between 68 and 75 %. Individual data for the UK were not available as in these datasets location was not coded for sleep, study and work activities ONS 2003. The United Kingdom 2000 Time Use Survey, Technical Report. *In:* STATISTICS, O. F. N. (ed.). Norwich: Her Majesty's Stationery Office (HMSO).

ventilation strategy. They argue that these concerns have been neglected, with detrimental consequences, quoting a German study which found 'a high probability of inhabitants rejecting or counteracting ventilation systems which do not comply with user expectations' (Meyringer et al., 1987, p. 1.4).[2] They identify a number of requirements for a ventilation system which would meet user expectations of ventilation. These include avoiding draughts and noise from the system, specifying a system that is robust to different user behaviours and interference by occupants and requires minimum maintenance, and providing a means for users to become familiar with the system. These requirements point to the importance of an appropriately-designed ventilation system as well as a designated handover procedure. Recommendations proposed by Meyringer et al. include an acceptance test for every installation, a warning light when filters need cleaning and a 'filter cleaning procedure to accommodate [the] user' (p. 1.8).

THE DOMESTICATION OF HOUSEHOLD VENTILATION TECHNOLOGY; A SOCIO-TECHNICAL PERSPECTIVE

Diffusing and embedding a technology in a new context requires changes in the socio-technical system (Shove, 1998), which comprises various human 'actors' and technological 'artefacts' (Bijker, 1993). Science, Technology and Society (STS) is an interdisciplinary research area concerned with interactions between people, society, and technologies. It rejects technological determinism in favour of a more reciprocal relationship between technologies and humans (Smith and Marx, 1994). STS draws on a variety of theories and methodologies (see Williams and Edge, 1996) , including ideas concerning the 'domestication of technology' (Sorensen, 2006, p. 40).

Lie and Sorensen (1996) argue that it is useful to investigate the concept of domestication of technology from the users' perspective as their interactions and *manipulation* of technical artefacts may result in the shaping of routines and practices. Routine domestic practices are not fixed; instead, they are continually evolving in response to new technologies entering the home. Gram-Hanssen (2008) describes two historical examples of this process. Firstly, the introduction of washing machines in the 1920s prompted an increase in the frequency and volume of laundry carried out by women (see also Cowan, 1983), and secondly, the transition from communal to individual refrigerators had implications for the way families bought food and arguably facilitated the move towards suburban living, where there is often a greater distance between homes and shops.

Silverstone et al., (1992) suggest that there are four stages for a technology to be widely adopted by individuals and society. These are: Appropriation, Objectification, Incorporation and Conversion. Domestication carries an implication of individual and household choice. The dynamic of domestication is associated with the private use of technoculture in the home. This concept was initially proposed as a way of understanding how people integrate information and communication technologies (ICT), such as televisions, personal computers and mobile phones into everyday life by looking at the roles and meanings that people ascribe to them (Haddon, 2006).

2. This reference is for a book published in German, which is currently out of print and not held in a UK library. The abstract is available at http://www.baufachinformation.de/literatur.jsp?bu=1987089040472.

To date, no studies have been carried out to examine how energy efficient whole-house ventilation technologies are diffused and appropriated within the context of UK housing. It is the authors' view that the understanding of the extent to which users adapt to this new technology is important to its eventual diffusion into the UK housing stock. In applying the theory to explore our case study data, we have raised the following issues at each stage as follows:

Appropriation concerns the extent to which the individual or the household chooses to bring a 'technology' into the home. It involves an imaginative projection of the household by its members and the adoption of the technology from outside the domestic sphere into the private space. Questions which need to be considered include: What are the running costs for all occupants and including capital costs for private homeowners (affordability)? Who in the household makes the decision to have the system installed? Who is seen as using, or consuming, the new system and under what circumstances?

Objectification refers to locating the object in the home spatially. Often, the accommodation of the new technology involves a change of the home environment, such as finding a desk for the new computer. In this case, the installation of the ventilation system may have altered or impacted the configuration of space in the home in quite a substantial way. This objectification process may also have altered the dynamic of the social space in the home considerably.

Incorporation suggests that the technology (ventilation system) is integrated into the everyday life of the household and of members of the household. It seeks to describe the process by which the household incorporates themselves into the wider society by establishing routines around how and when the technology is used and interacted with.

Conversion dynamics refers to the reverse process to appropriation. It defines the relationship between the household and the outside world. It looks at how individual occupants or the household use the technology to enhance their social status, or convert the by-product (in the case of electronic technology e.g. computer) into tokens (newsletters) of exchange with the outside world.

Within our context of UK social housing, this paper presents the findings of users' experience of their energy efficient ventilation technologies.

A case study investigation of three energy efficient ventilation installations

Fieldwork was conducted at three residential sites in the south-east of England, each incorporating a different ventilation strategy. Cases were sampled purposively, a technique which according to Mabry (2008), may be effective in uncovering the most revealing insights about the research topic. One site was chosen to investigate each of the three technically innovative systems specified in the Building Regulations, namely Passive stack ventilation (PSV), Mechanical extract ventilation (MEV) and Mechanical ventilation with heat recovery (MVHR). The strategy of choosing three different ventilation systems installed in three different dwellings, each with different demographic characteristics is intended to explore both social and technical dimensions of adaptability. The three types of ventilation systems are likely to provide different patterns of air-flows

in different rooms, over the year. These physical differences will have direct consequences for the thermal environment, which may lead to different styles of engagement from users. The diversity of users (e.g. age and sex) should minimise inadvertent gender and age bias. Although the sample is small, we believe that the insights gained with this sampling frame will help us to explore the interaction processes fruitfully using the domestication theory as interpreted above.

In each of the dwellings there are a number of ways in which the residents can interact with ventilation technologies. A schematic diagram explaining the theoretical functioning of each of the systems, alongside an explanation of the opportunities for residents to engage with the technology is presented in Figure 1[3].

A qualitative mixed-method approach was planned; the value of research designs which combine different techniques to gather data is advocated by Morgan (2007). An in-depth interview was conducted with one resident at each site, followed by a walkthrough, observation and photo survey of the dwelling. Interviewees were selected and approached by the relevant housing officer; An interview schedule was developed using semi-structured and open-ended questions, broadly covering the themes of 'ventilation histories', 'current context', 'attitudes and beliefs', 'sense-making' and understanding', in relation to the following more specific topics which were identified through the literature review: household demographics, ventilation practices, energy consumption, use of windows and doors, interaction with ventilation technology, condensation and mould, daily routines, health and IAQ, cost of utility bills and sustainability and climate change. The interview guide was pre-tested during three practice interviews, to resolve the mechanics of the research instrument.

During the walkthrough, occupants were asked to point out and demonstrate how they use each of the ventilation system components, (e.g. windows, vents, boosters). At the same time the dwelling was inspected by the researcher to check for evidence of mould or condensation, which would suggest that the provision of ventilation in the home was insufficient, and also to observe whether windows were opened and closed and whether the heating was on or off. An important aspect of the walkthrough was the use of photography as documentary evidence. This enabled thermostat settings and the exact position of windows at the time of the visit to be recoded quickly and accurately. Each interview lasted 1–1.5 hours and was recorded and transcribed verbatim. The large quantity of data generated were then condensed, grouped and reconstructed into a narrative using an inductive approach. The next section presents some findings of the empirical fieldwork.

Users' experience of a new ventilation technology

CASE A: ACTIVE ADAPTATION AND NEED FOR CONTROL (MEV)

Ali[4] is a 39 year old father of three who lives with his wife and school age children. He has a formal education in design but has not worked for several years due to health reasons, and therefore spends much of his time at home. *Ali* is active in the local Muslim community and is involved in voluntary projects when he is able to work. His willingness to engage on the subject of climate change, social justice and environment was notable. He has a strong sense of community but at the same time seemed to separate himself from his immediate neighbours and made several references that suggest that he sees himself as a bit of an outsider in social housing.

Ali makes several remarks which hint at the disjunction 'between the type of people who need social housing and the dream of people building their houses'. For example, he believes that his neighbours 'won't care about where the windows came from; they are more concerned that they've got a house to live in', and seems to feel strongly that people who live in social housing are not the ones who should be targeted to change consumption behaviours, because 'you need to be able to earn a living and feed your family properly before you can start looking at how you can help other people' and because they have other more pressing problems: 'drug addicts (…) family breakdown (…) other issues (…) they don't care where the ventilation's coming from'.

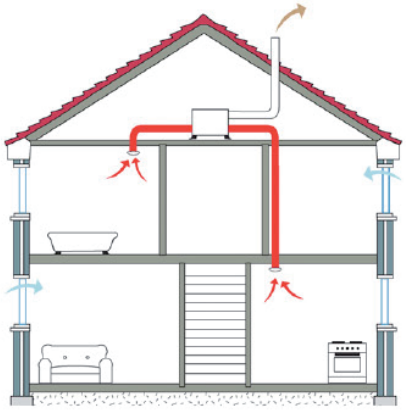
On the other hand, *Ali* has a positive impression of his new home and seems proud of the fact that it is 'unique', listing some of the features such as recycled newspaper in the walls and the use of 'natural' materials. For him, the sense of the 'openness of the place' and the fact that there is 'lots of light' was a critical factor in his choice of home. He mentions further positive features of the house; its 'warmth' and 'welcomingness' both seem to contribute to the feeling that 'mentally, psychologically it was a relief to come in somewhere like here, compared to where we were and compared to what I'd seen'. *Ali* suffers from a combination of physical and psychological symptoms which he believes are 'helped by the house', by the 'sense of nature' and because 'you can see the trees'.

Ali demonstrated some understanding of passive design features when he used rather technical vocabulary to describe his home as having 'very low airtightness'. However, the fact that on the day of the visit three bedroom windows were open while the thermostat was set at 22 °C suggests that knowledge of the fact that his home has an airtight building envelope does not influence his ventilation and comfort-seeking behaviour. *Ali* is aware of the MEV system, although he demonstrates some confusion about how it actually works. He explains that air is being fed to the trickle vents via the central fan unit and then pushed around the house, thus confusing the direction of the airflow and misinterpreting the purpose of the trickle vents. So far he has not carried out any maintenance on the system (4 years). He seems reassured that things are working because the fans occasionally make some noise, although he is not satisfied by the kitchen extractor as 'it's not really fit for removing a lot of the smells in the kitchen (…) it can be pretty nasty', and opens the window instead. They use the windows to remove odours as well as 'just to freshen the room up'. Despite the apparent lack of understanding, *Ali* appears to be able to operate his ventilation to provide satisfactory indoor conditions, although this is mainly through the use of windows which may have negative energy implications.

When they first moved into the house the family experienced a problem with overheating. *Ali* recalls how during their first summer at the house 'it was oppressively hot'. In

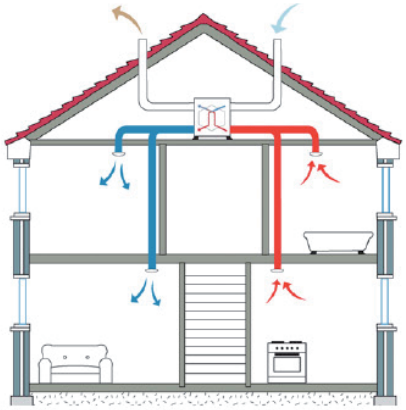
3.Images from http://www.homeventilation.co.uk/self-builders-home-improvers-guide.php (accessed 26.11.12).

4. Real names have been replaced with pseudonyms throughout the paper, and are shown in italics.



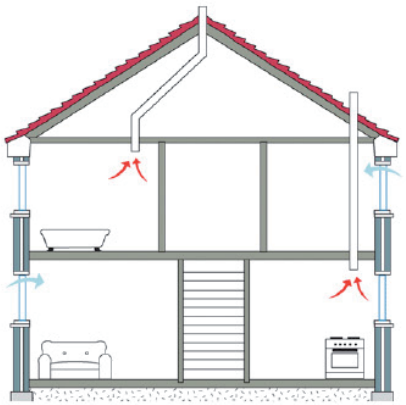
Case A: Continuous mechanical extract ventilation (MEV)

- Extract vents in wet areas remove pollutants via central fan unit in loft
- Purpose-provided ventilation via humidity controlled trickle vents
- Passive infra red (PIR) sensors activate fans in bathrooms
- Manually operated boost switch for kitchen extractor, no separate cooker hood
- During summer windows and doors can be opened to reduce overheating
- Night ventilation using open windows can be used to precool spaces on hot days
- No way for resident to turn off system without tampering with electrics
- It is recommended that vents at the base of ducts are cleanined regularly to remove dust and dirt



Case B: Mechanical ventilation with heat recovery (MVHR)

- Supply and extract air pass through central fan unit
- Extracts in wet areas and inlets in other habitable spaces
- Incoming air filtered to remove pollutants
- Incoming air preheated using heat extracted from outgoing stale air
- Manually operated boost switch for kitchen extractor, no separate cooker hood
- Tilt and turn windows require key to be opened and safety catch prevents
- wide opening
- During summer windows and balcony doors can be opened to reduce
- overheating
- Night ventilation using open windows can precool spaces on hot days
- No way for resident to turn off system without tampering with electrics
- It is recommended that regular maintenance is done to ensure the system is still in balance and that vents and the heat exchanger are clean
- Filters must be cleaned or changed regularly



Case C: Passive stack ventilation (PSV)

- Pollutants passively removed using natural ventilation via ducting from wet areas
- Purpose-provided ventilation via openable trickle vents
- Mechanical extract hood above cooker in kitchen
- 'Tilt and turn' windows throughout
- During summer windows and doors can be opened to reduce overheating
- Night ventilation using open windows can be used to precool spaces on hot days
- It is recommended that vents at the base of ducts are cleaned occasionaly to removedust and dirt

Figure 1. Diagrams explaining the function and operation of the three energy efficient ventilation systems installed in the case study dwellings.

fact, the tendency of one of the bedrooms, which he uses as his study, to overheat, has prompted him to purchase a laptop so that he can work downstairs. The family suspected that the cause of overheating was the fact that they were unable to open either of the skylights in the house, one of which was in the hallway and the other in a child's bedroom. On asking their registered social landlord (RSL) for help a pole was provided to open and close the skylights, allowing the family to regain control over their internal environment and reduce the overheating problem. This narrative highlights the importance of user control of ventilation as the resident describes how 'once we were able to control all of the ventilation things started improving'.

Ali and his family have adapted to living with the new ventilation technology and are satisfied with conditions. However, they seem to be relying on the use of windows to provide fresh air and the skylight to prevent overheating. Having control appears to be important to *Ali* as his frustration was resolved once he was given the means to control his thermal environment. He demonstrates an engaged and active approach to their use of new technology, stating that 'we have had to adapt our daily routine to fit with the idea of the house […] because I think it is a learning process when you're living in a house that requires [a] slightly different way of approaching it'. However, his actions do not necessarily align with this statement as his ventilation behaviour appear to be based on a window-opening regime

developed in his previous home. This is evidence that window opening behaviour in the home can change in response to indoor conditions.

CASE B: FOLLOW RULES AND SEEKS HELP TO MINIMISE EFFORT (MVHR)

Betty is an elderly, retired widow who lives alone. She moved into her two-bedroom first floor flat six months before the interview was conducted and is the flat's first occupant. She has two children, a son who lives relatively locally and a daughter who lives further away and who comes to stay from time to time. Although *Betty* felt that she had no choice in the choosing of her home, she seems satisfied. She likes the views out onto the park, although she misses the daily contact with her neighbours that she had at her previous home.

Betty is not very familiar with modern technologies; referring to technology as 'fidlies' her thermostat as the 'old whotsit', ceiling vents as 'thingys' and sensors as 'eco-gadgets'. It is the first time she has lived in a home with central heating, and the MVHR is also completely new to her. She doesn't appear to have much confidence in her ability to use these technologies, but generally seems to be coping well with the new systems. A recurring theme is how she acquires knowledge about her new home and learns how to use it, through interactions with different groups of people, who include her electrician son, her handyman, the community centre where the RSL have an office which she visits more or less weekly and the interaction with members of the design and procurement team who visit the flat regularly as it is part of an in-depth post-occupancy evaluation project. *Betty* seems to benefit a lot from these interactions.

For example, while discussing heating control, it transpired that *Betty* had used one of the TRVs to turn down the radiator but had since stopped adjusting it because the person who had conducted her handover interview 'said 'no need for that' and he put it back on four'. During the same interview she found out that her flat has 'double insulation in this flat because it's an eco-flat'. She was also shown how to unhook the safety latch on the windows so that she could open the window wider: 'the lad that was here the other day (…) he showed me how the windows worked (…) he took me over there and he showed me how to unhook it so I can open it.'

Betty reveals her misconception that the air is being recirculated between the flats in the block, based on the fact that she is noticing smells from the floor below. In fact what is more likely to be the case is that the inlet for her system is positioned downwind or too close to the extract from her neighbours flat, thus causing cross-contamination of air. Although she has no formal understanding of how the MVHR works, she is able to use the boost functions correctly and is satisfied with the internal air. *Betty* also relies on sounds to inform her whether a system is operating. This seems to apply to both the heating which 'clicks' on and ventilation booster which she knows is working because 'you can hear it'. It is unclear who will do the maintenance such as changing the filters as she has been told not to touch the central fan unit and has no other interactions with the technology.

Betty seems satisfied to allow the MVHR system to do the job of providing ventilation and only very rarely opens the windows, although she doesn't like to do so 'when the wind's blowing' because she's a 'chilly mortal'. She cannot reach the window in the kitchen as it is behind the sink but is not overly concerned as she doesn't need to open the windows: 'I opened a window if necessary but other than that I don't bother. (…) and with these extractor fans you don't need it anyway.'

Betty is not particularly concerned about reducing her bills and doesn't believe that climate change has anything to do with her; instead, convenience is her priority. She seems happy to abide by the rules set by the RSL, as well as following her son's instructions not to touch the boiler. Her motivations seem to relate to minimising effort and making her life simple and convenient, feelings which are perhaps indicative of her age. *Betty* appears to use alternative strategies for adapting to the ventilation and other new technologies in her home. She relies on other people, such as her son to help her with domestic appliances, explaining how she doesn't understand how the ventilation and heating work, but that 'as long as it works I'm all right'.

CASE C: CONFUSION AND FRUSTRATION LEAD TO REJECTION OF SYSTEM (PSV)

Carla is a middle aged, working mother of four teenage children, one of whom has a physical disability and uses a wheelchair. She lives with her husband who works nights and three of her children, while her eldest son is away at university. During the interview, *Carla* almost immediately launches into a list of complaints about the property, mentioning peeling paint, poor quality materials compared to their previous home and serious problems with maintenance. She seems happy with certain aspects of the house, such as the 'eco-friendly' design, the fact that it is spacious and peaceful and allows her to cut off from the stresses of the outside world. Although she states that 'it's a beautiful house, beautiful concept', the overarching impression is one of disappointment that after four years they have still not settled in and that the house has not delivered on its promise of a new beginning for them all.

Her major concern with the property is the fact that it is extremely dusty, with dust rapidly and visibly collecting on surfaces, to the point where she spends all of Saturday cleaning, yet does not feel able to keep on top of it. *Carla* suggests that the reason for all the dust is that the ventilation hasn't been switched on by the designers: 'my hunch is that maybe there is something that they didn't switch on'. She struggles to make sense of the PSV technology and is not able to explain how it is supposed to work, lamenting that 'these are the vents I was talking about, what they were doing – what work it does I have no clue'. Instead, her ventilation strategy involves using windows to provide fresh air and reduce overheating, even when the heating is on. She is also aware of and occasionally uses the trickle vents which are a 'push pop' design; several windows and vents were open at the time of the walk-through.

Carla is experiencing serious problems with IAQ, with condensation forming on many windows and mould growing in the bathroom with only a vent and no openable windows. She explains the fact that other bathroom has no mould by pointing at the skylight, demonstrating her own interpretation of the role of windows in preventing mould growth. The household are also struggling to maintain thermally comfortable indoor conditions. Furthermore, she believes that serious overheating at the top of the three storey house is exacerbating health problems for one of her children and that simultaneous underheating downstairs is causing some discord between her and her husband about the heating settings. *Carla* describes

a situation which caused a conflict between staying warm and providing sufficient air to remove pollutants: while doing some painting to correct peeling paintwork she opened all the doors and windows to air the house, but found that it was too cold for her daughter to stay at home. In the end 'she had to go to the library, because (…) I had to open the kitchen window and this door too, so that the air can circulate but it was cold for her'. Temperatures in the house seem to vary so that 'it's either it's too cold or it's too hot'; *Carla* is struggling 'to get the balance' and consequently has resorted to leaving the heating on all the time, and using windows to cope with overheating. The south-west facing kitchen is particularly prone to overheating, especially when cooking. This has changed the family's behaviour, so that they now open the window whenever they are cooking and tend to cook less often. In these subtle ways, *Carla* has rejected the integrated ventilation system which she does not believe is working properly or able to meet her needs.

For *Carla* saving money on bills is a priority and something she was particularly looking forward to in her new home. She explains that 'I am one person that is really conscious of – we don't waste water and you don't waste electricity and you don't waste food. If you want to use it, yes, use it – but don't waste it' She also demonstrated a strong tendency towards reducing waste and saving resources in all areas of her life, practices connected to her desire to protect nature and the environment: 'oh I love nature. I try to recycle things as much as I'm able to do (…) when I see them leaving water about [laughs] I turn it into – there is the container there – I use it to water my plants.'

Perhaps as a consequence of relying on the windows, her heating bills are higher than in her previous 1970s home. She has repeatedly asked for help from the RSL to fix the ventilation and other maintenance problems she is experiencing at home, but after receiving none is left feeling frustrated and helpless. Overall, the poor ventilation, which is connected to a range of IAQ and thermal comfort issues, does seem to be having a negative impact on her quality of life. She appears isolated socially as she doesn't know her neighbours well enough to find out if they are experiencing similar problems and the RSL has not provided support. In fact, she states that the reason she agreed to take part in the interview was because she felt she had no one else to turn to for help.

Discussion: The domestication of energy efficient ventilation technologies in UK social housing

BARRIERS TO APPROPRIATION

According to the domestication theory (Silverstone et al, 1992), the first stage of domestication is the process of appropriation. *Appropriation* occurs at the moment the technology is sold and becomes 'owned' by the individual or household. At this point meanings begin to be formed, as the object crosses the boundary between the public and private domains and enters the home. However, this conceptualisation presumes that the technology is purposefully chosen by the end user, and that this user is already in the home before the arrival of the new technology. Neither of these assumptions apply to our cases where there were several intermediary 'owners' of the technology, such as the architect or engineer who chose and specified a particular system, the contractor who placed the order and took delivery of the components, the installer who assembled these components into a useable form and the building owner, here an RSL, who then leased the dwelling to its tenants. These tenants are the ultimate users of the technology, yet had no choice as to which ventilation system was installed. This separation of the end user from the purchase and installation of the ventilation technology may hinder its appropriation and consequent domestication. This idea is supported by a study of domestic MVHR systems in Austria, where Rohracher (2001) suggests that communication between users and producers of a domestic ventilation installation is critical to facilitate the successful incorporation of these innovative systems into homes, stating that 'mismatches in the way the technology is handled by suppliers (designers, building professionals) and how the technology is adapted to the preferences of specific user groups may result in low rates of user acceptance and satisfaction' (p. 294). Furthermore, as implied by *Ali,* social housing tenants may have more pressing concerns than ventilation type, when choosing a home from a limited selection and with a constrained budget.

It could be said that here the RSLs have carried out the appropriation on behalf of the tenants. However, this does not appear to have been effective for all of the residents; for example, *Carla* is deeply dissatisfied with her supposedly energy efficient ventilation, despite the fact that she appears to have a strong desire to protect nature. Thus, environmental motivation alone appears to not be enough for a resident who has not chosen the technology and who has had limited support with its operation and maintenance. This prompts us to question whether some additional support mechanism might be required to make up for the lack of choice in the social tenant context?

OBJECTIFICATION OF VENTILATION SYSTEMS

Objectification relates to the spatial aspects of how the technology is used and displayed. Ventilation systems comprise a large number of components that are positioned all around the dwelling, some of which are hidden in the walls and floors and are therefore not visible to the casual observer (see Figure 1). Silverstone et al. (1992) describe how 'the arrangement and decoration of rooms … is a central component of the process of objectification'. However, in our cases the way the technology is displayed is largely predetermined by a range of temporary users who will never actually live in the dwelling; instead, it seems that the residents may have been pushed to *arrange themselves* around the technologies. If they are not able to do so then this lack of input with regard to the final appearance and location of the technology may be yet another barrier to its domestication by the household.

We see evidence of this in the cases of *Carla* and *Ali* who were both prompted to change their use of certain spaces in the home due to the experience of overheating and inadequate ventilation. While *Carla* says that she is reluctant to cook as much as she had hoped to because it gets so hot in the kitchen, *Ali* has found a way of adapting to the problem of overheating in his study by purchasing a laptop, enabling him to work in a cooler room. While *Ali* seems largely satisfied with his home, *Carla's* inability to move the location of food preparation to a different space may be contributing to her feeling of dissatisfaction.

There are also some signs that ventilation inlets and outlets are being obstructed by household items (Figure 2, Figure 3).



Figure 2. Partly obstructed trickle vent in child's bedroom [C1].



Figure 3. Partly obstructed extract vent in kitchen [C2].

The placing of objects in the way of the vents may be a sign of a lack of a sense of how the ventilation is designed to work; alternatively, it could relate to routine behaviours or other social functions, which may take priority over considerations of building service technologies. These behaviours are important to note, as they can have an effect on the system performance and may lead to increased energy consumption or problems with IAQ.

In our view, the concept of objectification with respect to ventilation technology may take on a different form. Instead of moving or displaying the object, it involves the purposeful manipulation of systems components such as trickle vents and booster switches. In order to do this, users will need to have a functional understanding of how the system works. Recognising this, the Building Regulations therefore require that operation manuals be provided to users. However, each resident in our case study demonstrates an individual and partial understanding of how the ventilation operates, which differs widely from the purely 'technical' definition of how these installations function that was presented in Figure 1. Despite the lack of technical knowledge *Betty* is very satisfied with her system and has happily delegated the function of ventilating to the technology, and has also found a way to use the boost switch to meet any additional fresh air requirements. In turns out that instead of acquiring knowledge, *Betty's* strategy for controlling the system is to seek support from her social network which includes family, professional experts and members of the local community. It is also important to note that *Betty's* system is an MVHR system, which if installed and maintained correctly, will provide constant fresh-air without the need for occupants to intervene through the adjustment of trickle-vents (though windows may still need to be opened to avoid overheating in summer).

From the presentation of the three residents' stories, it appears that lack of technical comprehension may become an issue when things go wrong, as it did for *Ali* (MEV) and *Carla* (PSV). However, while *Ali* was able to resolve his problem with overheating satisfactorily, *Carla* did not get the help she required and became dissatisfied, ultimately rejecting the technology. A notable difference between the experiences of *Ali* and *Carla* was their ability to access support. While *Ali's* request for help from the RSL was soon answered with the provision of a device for opening and closing the previously unreachable skylight, *Carla* has not received the help she has asked for on multiple occasions and has even resorted to doing some maintenance painting work herself.

Unfortunately *Carla* does not appear to have anywhere else to turn for help. She does not know the neighbours, has had no contact with those responsible for the design and construction of her home and, unlike *Betty*, she doesn't have a friendly handyman or an electrician son in her close social network. On the other hand, *Ali* does seem to have more social resources at his disposal, which may have contributed to his ability to resolve the overheating problem. In addition, the frequent use of his home as an exemplar project has put him in contact with the design and management team on several occasions. He even refers to the architect by his first name. *Ali* attributes his knowledge about some of the design features to the fact that 'there were architects coming in – and people normally come and have a look at our house and we talk to people and stuff'. Overall, *Ali* exhibits a greater engagement with the process of domestication than *Carla*.

Control can also be associated with the psychological concept of '*forgiveness*' which was introduced by Bordass and Leaman (1997). It was found that where occupants have a greater degree of control over internal conditions, they could forgive other negative aspects of the systems. It is interesting that despite the fact that *Carla* praises the concept of the house and speaks of her desire to protect the environment, she gives the overall impression of being dissatisfied with her home. Overall, the negatives seem to outweigh the positives and she is not able to forgive the home its faults.

The notion of feedback could also play a role in the objectification stage as a tool for residents to learn how to determine if the system is working as they believe it should be. Unlike *Betty* who relies on sound to tell when the ventilation boost is operating and whether the heating is switched on, *Carla* questions whether her ventilation is working correctly because her system is completely silent and offers no other feedback. The presence of mould in one of her bathrooms but not in the other one that has a window may act as a visual feedback that reinforces *Carla's* belief that windows provide effective ventilation while the hidden ducts do not.

The experiences of all the users highlight the complex psycho-socio-technical processes that are involved in the process of adaptation. In adapting to the ventilation technology, users appear to try to make sense of the system as best they can, looking for visual or aural cues to detect whether the system is functioning, and mobilising social resources to control their ventilation systems.

INCORPORATION INTO DAILY LIFE

Incorporation addresses the temporal use of the technology. In order for a technology 'to become functional' it must be incorporated into the daily routines of the household (Silverstone et

al., 1992). In our cases it is interesting to examine how users incorporate a new ventilation system into their everyday life when parts of it are embedded into the existing fenestration. *Ali* is the only resident who explicitly talks about how his family have had to adapt their daily routines to live in a new type of house. On the other hand, *Betty* demonstrates some resistance to changing her habits; despite mentioning that window opening is no longer necessary with her new ventilation system, she seems pleased that she has been shown how to open the windows.

Incorporation also brings to mind the way that interactions with the new object(s) may become characteristic of changes in a wider ventilation culture that reaches beyond the individual household. In this case we could ask how might a more conscious ventilation behaviour using the boost switches and operating trickle vents be incorporated into existing patters of opening windows for fresh air? A potential barrier to this process is that windows remain an important feature of all new homes, despite no longer being required for ventilation. The provision of might and their use in summertime temperature control are notable example of this. It is not difficult to imagine how confusing it must for residents to be to be told that you no longer need to open the window to 'air' the house, yet still be presented with openable windows in most rooms. Therefore it is perhaps unsurprising that on the day of their interview all three dwellings had the heating on and at least one window open. This suggests that the habit of manual window-opening may deeply rooted and slow to change.

Whole-house ventilation systems are designed for two temporal frames of operation – *summer mode* and *winter mode*, with the implied assumption that *winter* is any time when the heating is being used and that *summer* is any time when heating is not being used. This prompts the questions of whether the time of year that the dwelling is occupied by new residents has some bearing on how the ventilation is domesticated? For example, it may be that in a home first occupied during the summer, ventilation routines are formed around the use of windows, which may then become habits that continue during the winter.

Incorporation may also relate to the development of maintenance routines for the ventilation. As illustrated in Figure 1, the three systems all require slightly different maintenance procedures; however, none of the residents who were interviewed had carried out any maintenance to date, despite having lived in their home for between six months and four years, nor were they aware of any having been done by their landlords. Although it is not clear why this is the case, or whether the RSL or resident are ultimately responsible for the maintenance of service technologies, an explanation might lie with the observation that the early stages of domestication were bypassed by the residents, with both appropriation and part of the objectification stages carried out by other, non-resident actors.

CONVERSION AND SYMBOLIC MEANINGS

Finally, *conversion* describes the relationship between the technology in use and the outside world. New technologies may be associated with a certain status, or imply membership of a particular group who have shared interests or aspirations. According to Aune (2001) the symbolic aspect is less apparent in energy technologies than in ICTs. While from the point of view of an energy researcher these technologies evoke meanings of energy efficient innovation and environmentally sustainable design, it is unclear how relevant, if at all, these ideas are to the non-specialist users of these systems and whether they in fact attach other symbolic meanings to the ventilation technology.

The residents who took part in this study did not explicitly choose to live with this type of ventilation and they were not involved in the spatial arrangement of the system components. Therefore, it cannot be said that they are actively involved in the conversion of their technology in terms of its visual display to outsiders. However, conversion may occur in discourse, as well as in action (Juntunen, 2012). There is a difference in the way *Ali* and *Betty* described their homes to the researcher during their interview. While *Ali* seems to welcome innovation into his home and appears proud of the light and open feel of the house, its uniqueness and the use of natural materials, *Betty* refers to new features in her home as 'fidlies' and 'that old whotsit', suggesting a sense of distance between herself and these technologies which she is encountering for the first time.

THE ADAPTATION SPACE

In this paper we are looking at very different types of technologies than those typically associated with theories of domestication. With the case of energy efficient ventilation systems it may be more appropriate to present the domestication experience of each of the residents in a conceptual space defined by the axes of 'access to help' and 'making sense of technology' (Figure 4). This demonstrates how technical understanding may not be a prerequisite for a successful adaptation to take place and that the ability to ask for and receive help to resolve a problem with the ventilation may be an equally valuable resource. It appears that negative experience of a new technology may lead residents to reject the system outright.

There is also a possibility that an engaged user would take an active approach to adapting to the new ventilation technology. For example, *Ali* generally relies on the background system to provide sufficient ventilation, although he uses windows to remove smells and opens the skylight to prevent overheating during summer. Having control is important to the engaged user and his initial frustration was resolved once he was given the means to control the internal thermal environment. In contrast, the connected user appears to have successfully adapted to living in a dwelling with a completely new ventilation technology despite having little understanding of how the technology functions. Instead, she is happy to follow the instructions she was given and abide by the rules. She is socially well connected and relies on this access to social resources to receive help whenever she encounters a new technology. The disenchanted resident has rejected the passive stack ventilation system, as she does not believe it is working properly. Instead she leaves the windows open all the time, to provide ventilation and reduce overheating. She has asked for help several times and after not receiving any, she is left feeling helpless and disappointed that her expectation of a comfortable new home has not been met. Potentially there is also space for a 'technophile' user who has little access to help but is very interested in technology and is able to make sense of the systems without much support from outside groups, although this kind of user remains to be found.

Each of our cases illustrates how successful adaptation does not occur in isolation and solely within the boundaries of the

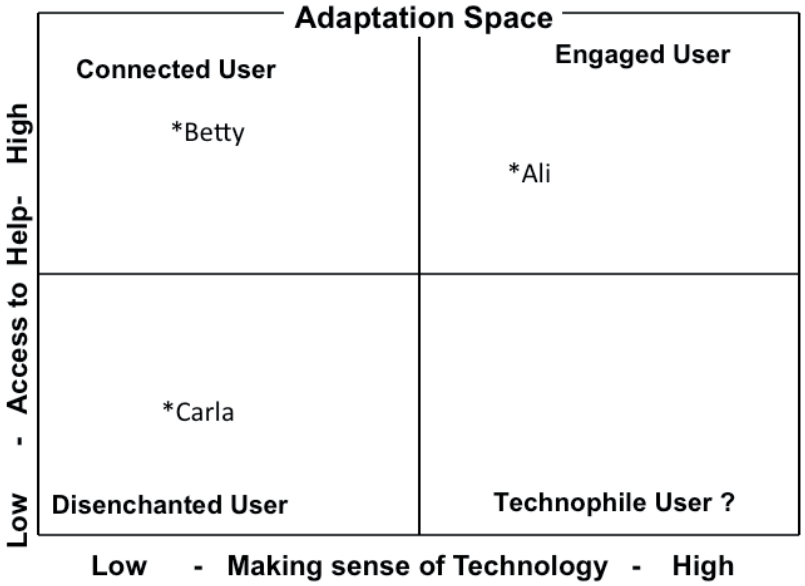


Figure 4. Adaptation space conceptual diagram.

private sphere as proposed by the domestication theory; instead it takes place in a space defined by both physical constraints of the "system" (to the extent that it offers control and feedback) and the opportunities for support and learning offered by the wider social world.

Conclusions

This paper presents the findings of the first stage of a case study in which we examine how people engage with new ventilation technologies at a time when increasing environmental concerns and energy efficiency measures are changing the way we ventilate our homes. A qualitative methodology was adopted, with data analysed through the lens of the domestication of technology theory, in order to explore the interactions between the ventilation systems and their users.

Analysis of the three sample cases revealed interesting insights into the processes of adaptation. It is not enough to simply design, specify and install an innovative technology and expect the residents to use it correctly. People may need a careful and more engaged handover process to make sense of the new technologies that they have to live with. They may also need continuing support to ensure that they can develop new ventilation practices in order to make most efficient use of and reap maximum benefits from these ventilation systems, particularly with respect to optimum performance through effective maintenance. While those from a technical background may be tempted to conclude that people require only technical knowledge to operate a new ventilation system, the personal experiences of the residents presented herein indicate that knowledge may not be the only contributing factor. What is also important is how people 'make sense' of a particular technology when they encounter it for the first time and how they mobilise their resources to control and adapt to it.

A more complex picture of the technology, people and context has been revealed from analysis of data from the appropriation stage. Users of the ventilation systems in our sample cases are social housing tenants who do not typically have any say in the technologies that are specified in their homes. This suggests that the assumed trajectory of appropriation of technology from the non-domestic sphere into the private space is insufficient. Attention has to be paid to the social positions of users and the social context in which technology is appropriated. This analysis highlights the difficulty of objectifying a technology that one has not chosen to live with and that, in the case of PSV, may not actually be visible to the residents. Furthermore, we might question how easy it is for people to incorporate a new ventilation technology into their daily routines when existing and often deeply rooted patterns of use are still possible within the constraints of the new configuration. Perhaps it is no wonder that this analysis has not revealed a strong symbolic relationship between residents and their ventilation technology.

Finally it is worth noting that the reason one resident, Carla, agreed to take part in the interview is because she was so dissatisfied with her home that she wanted someone to talk to about it and to ask for help. This leads us to question how we might enable these people's voices to be heard, in the hope that technological innovation is not pursued at the expense of human wellbeing?

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