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Ventilation regulations and occupant practices: undetectable pollution and invisible extraction

RESEARCH

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ABSTRACT

This sociotechnical investigation examines the use of ventilation systems in homes in London, UK. These homes were built with ventilation systems as described by guidance in the UK Building Regulations Approved Document F. These systems are assumed to provide adequate ventilation rates. However, previous measurements in these homes show that ventilation rates are inadequate. Using social practice theory as a framework to analyse the qualitative data, the intended use of the ventilation systems is compared to participants' actual practices of manipulating the indoor air, revealing discrepancies between the two. Occupants had limited knowledge of indoor pollutants but were highly motivated to control and interact with the smells and air in their homes. They primarily used technologies that were not part of the planned system, because the latter's functioning was opaque to occupants and not well connected to their other practices. The highlighted discrepancies in four case study homes between planned and actual ventilation system operation help to identify how future systems could be improved to ensure adequate ventilation rates and good indoor air quality in airtight homes.

POLICY RELEVANCE

This research investigates the extent to which the intended operation of domestic ventilation systems set out in Approved Document F to the UK Building Regulations is accomplished in practice. The findings show that ventilation equipment is not used as intended. The research suggests a need for future guidance to more actively consider routes by which occupants can learn how to use and maintain their ventilation systems, and how to identify and remove indoor air pollution. There is a risk of continuing underventilation in homes unless efforts are made to ensure the systems are easily interpretable and robust to a reasonable range of internal conditions and social contexts.

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1. INTRODUCTION

People spend a significant proportion of their lives indoors – in the US, over 90% of their time (Klepeis *et al.* 2001). Indoor air quality (IAQ) can have serious implications for their health (NICE 2020). This issue rose to prominence during the Covid-19 pandemic with the increased risk of transmission in poorly ventilated spaces (Bhagat *et al.* 2020). Increasing ventilation rates can improve IAQ but can also increase energy consumption in buildings (ASHRAE 2017). Reducing building energy consumption is crucial for meeting climate change mitigation goals, for example as noted by the Climate Change Committee (CCC 2020) in the UK. Ideal ventilation rates in must balance these considerations.

The Building Regulations for England and Wales require that new buildings have 'adequate means of ventilation provided for the people in the building' and that 'reasonable provision shall be made for the conservation of fuel and power in buildings' (HMG 2010a). The Building Regulations Approved Document F (ADF) gives guidance on meeting the ventilation requirement. It describes a ventilation strategy and ventilation systems that are assumed to meet the requirement for adequate ventilation. Homes have become increasingly airtight to improve energy efficiency so strategies for providing adequate ventilation increasingly rely on mechanical ventilation systems. ADF describes what is now the most common domestic ventilation system in new UK homes: trickle vents with mechanical extract ventilation (MEV). MEV extracts air from kitchens, bathrooms and utility rooms, causing a negative pressure difference between inside and outside. Trickle vents are closable vents, often located in window frames, which are intended to be left open to provide air inlets for the MEV.

There have been several revisions to ADF, the most recent version taking effect in 2022 (HMG 2021). These revisions were supported by research in homes with ventilation systems in accordance with the regulations of the time, for example Crump *et al.* (2005), DCLG (2010) and MHCLG (2019). This research has several common themes: first, measured ventilation rates were often below the level specified by the relevant version of ADF. Second, the researchers often opened trickle vents and switched on mechanical ventilation systems to measure ventilation rates. These key technologies in the planned system were often not used as intended by the occupants. However, there has been limited analysis of the differences between occupants' actual and ADF's intended use of the ventilation systems. Moreover, the ventilation rates were measured after the system had been switched into the intended mode of operation, suggesting that ventilation rates as found would have been even lower. Given that these ventilation systems have been installed in thousands of homes, aiming to ensure adequate ventilation rates, it is important to understand how these systems are being used compared to the design intentions, and what impact this is likely to have on the ventilation rates experienced.

There has been limited integration of physical results with insights into the actions of the occupants in domestic ventilation research. While energy research has been dominated by physical and technical research, there are growing calls for a greater emphasis on social research both in its own right and combined with technical research (Sovacool *et al.* 2015). Social practice theory (SPT) places an emphasis on the interactions between technical and social regimes, and has brought useful insights to research on various aspects of energy use in homes (e.g. Kuijer and Watson 2017; Moeller and Bauer 2022; Martin and Larsen 2024). This suggests that SPT is likely to be a useful lens through which to explore ventilation, first because SPT has been successfully applied to research regarding energy use in homes and ventilation is strongly related to this, and second because ventilation research has also been dominated by a physical approach to the phenomenon within the context of a home.

SPT has been described as a 'fragmented body of theories' (Gram-Hanssen 2010: 176) that analyses actions and expressions rather than signs and symbols. SPT research has drawn extensively on the various works of Schatzki (1996, 2002, 2010), who describes (2002) a practice as an organised nexus of doings and sayings. A practice can be thought of as a collection of things that people do, talk about and know about, and which have intended outcomes and are part of a common social understanding of what it is to do that practice. Empirical research that has used SPT in the context of energy use has emphasised the role of the material in shaping energy consuming practices and has often added the material as an element of a practice.

Previous works have explored domestic ventilation within an SPT framework (Gram-Hanssen 2010; Hauge 2013; Behar 2016), from which common themes emerge. First, the importance of fresh air for removing unwanted smells, where airing is associated with feelings of freshness, cleanliness and health. Second, airing is involved in common tasks or as part of the ordering of the day. Third, air and airing are interpreted with reference to qualities of the indoor environment, including smells, freshness, humidity, temperature and sounds. Moreover, qualities of outdoor air are important in airing homes: letting fresh air in through windows sometimes provides a pleasant connection to the outside world, through which sounds and smells of nature can be enjoyed, while sometimes outside air is shut out due to outdoor pollution or to create a cosy home environment in the winter. Hauge argues that 'we listen to our environment through air, by using our bodies and senses and by paying social attention to it' (Hauge 2013: 184). Finally, the ways in which people interact with and interpret air varies with the material arrangement and specific demands of their present and previous homes.

The literature above illuminates the richness of everyday experience at home in relation to air, but it can be challenging to relate these findings to the technical observation that ventilation systems are frequently not used as intended and may not deliver adequate ventilation rates. As noted by Love and Cooper (2015), conducting separate social and technical research on the same topic can cause a disconnected understanding of the phenomena.

The aim of the present research is to compare participants' practices related to ventilation with the actions assumed by common designs, taking ADF as an example. Areas of discrepancy between design intention and actual home ventilation strategies are identified.

2. METHOD

2.1. SOCIAL PRACTICE THEORY FRAMEWORK

This research draws on the frameworks of Gram-Hanssen (2010) and Madsen and Gram-Hanssen (2017), and considers practices to be made up of the following components:

- *Meanings, engagements:*

  what the practitioners want, or the goal they are pursuing.

- *Practical understanding, know-how:*

  the practical doings used to service meanings and engagements, knowing how to affect conditions in the desired way and how the body knows something needs to be done. This includes the action that is required and the recognition or perception that action is required.

- *Knowledge, rules:*

  knowledge is formal information; rules are requirements placed on the practitioners.

- *Products, things, technologies:*

  the physical things that the practitioners interact with.

The participants' practices related to air and its components included steps to actively control ventilation, but these were part of a wider picture that involved seeking to control many characteristics of the air in their homes. For this reason, it is helpful to consider the approach of Cass and Faulconbridge (2017), which draws on Schatzki's distinction between 'dispersed' and 'integrative' practices. Dispersed practices are small-scale actions, which are commonplace and take place in different contexts. Their meaning may be altered when performed in different circumstances. Integrative practices are wider practices that constitute and are part of particular domains of life.

A comparison of the intended operation of the ventilation system and aspects of the indoor environment set out in ADF with the ways the occupants actually used the ventilation system and considered the indoor environment reveals points of conflict and can illuminate areas for consideration in designing ventilation systems. To incorporate the full remit of the ADF system (both ventilation and pollutant concentrations), a dispersed practice of manipulating the air is studied – the ways the participants seek to affect, manage or influence different qualities of the air in their home. This allows ventilation to be considered alongside activities that impact the concentration of indoor air pollutants and to acknowledge the overlap with many integrative practices. For example, opening windows could be for removing cooking smells (part of an integrative practice of cooking) or it could be part of creating the right environment for sleeping (part of an integrative practice of getting ready for bed). There is an immediate tension in that ADF is narrowly focussed on ventilation with regard to IAQ, but it is not straightforward to separate IAQ and ventilation from other indoor environmental parameters when considering the participants' practices.

2.2. APPROACH TO INTEGRATING ADF AND SPT FRAMEWORKS

Approved Document F (ADF) to the building regulations sets out ventilation systems that are assumed to provide adequate ventilation in homes. This research refers to ADF 2010 (HMG 2013), which was in place when the building studied was converted to dwellings. Some aspects have been updated in the latest version (HMG 2021); however, the central strategy and design intention for the ventilation system remain the same. ADF sets out a ventilation strategy with three types of ventilation:

- *Purge ventilation* should be available 'throughout the building to aid removal of high concentrations of pollutants and water vapour released from occasional activities such as painting and decorating or accidental releases such as smoke from burnt food or spillage of water' (HMG 2013: 14).
- *Extract ventilation* should be provided in 'rooms where most water vapour and/or pollutants are released, e.g. due to activities such as cooking, bathing or photocopying' (HMG 2013: 14). This type of ventilation can be intermittent and vary spatially.
- *Whole-dwelling ventilation* is intended 'to provide fresh air to the building and to dilute and disperse residual water vapour and pollutants' (HMG 2013: 14). This type of ventilation should be constant while the building is occupied.

ADF's description of the ventilation system outlines the different types of pollutants in terms of their location and the time frame over which they are released. A technology is assigned to deal with each type of pollutant but the intended operation of the technology by the occupant is only implied.

The *design intention* of the ventilation strategy and functioning of the ventilation system were translated into an SPT framework for comparison with real-world practices. Taking purge ventilation through windows as an example, in the planned system a window needs to be opened if there is smoke from burnt food to remove pollutants. In an SPT framing, the goal or meaning is the removal of airborne pollutants and this goal is achieved via a technology (a window) and practical understanding of when and how to use the technology (open a window if there is smoke from burnt food). This comparison can reveal limitations of the ADF assumptions more clearly. Regarding the SPT framework, it can be difficult to separate the rules/knowledge element from the practical understanding element. Here we have considered rules/knowledge to be either information that participants know or things they know they are supposed to do. An example of knowledge/rules related to the above could be knowledge that smoke is harmful, and knowing that when harmful pollutants are released the windows are supposed to be opened. The Domestic Ventilation Compliance Guide states that end users should be given an 'operation and maintenance manual [that] should contain specific instructions for the end user on how and when to use the ventilation system' (HMG 2010b: 53). This appears to be the intended route for gaining formal knowledge regarding the operation of ventilation systems.

2.3. INTERVIEWS AND ANALYSIS

Five semi-structured interviews with six participants took place in winter 2019/2020, lasting 35–60 minutes. The interviews were combined with a walk-through where the participants showed the interviewer their home. Walk-throughs can help interviewees recall contextual habits or information, and help the interviewer understand the physical arrangements and context; they can be particularly helpful when the topic is related to everyday or routinised actions (Chiu *et al.* 2014). Additionally, interviewing in the home allows technologies and their use to be demonstrated within the interview (Pink *et al.* 2017). These interviews aimed to elicit insights into the ways the occupants interacted with their homes and influenced ventilation (intentional or not), to enable comparison of ADF's design intentions and assumed occupant actions with the participants' practices. Details of the content of the interviews are provided in the supplemental data online.

Interviews were recorded, transcribed verbatim and analysed using NVivo to manage the data. The interviews were coded by assigning codes related to the four elements of a practice outlined above to short sections of the transcript. Memos were used to note ideas emerging throughout the analysis process (Merriam and Tisdell 2015). After several rounds of in-depth reading of the transcripts, comparing the findings with the literature and considering the findings in the context of the wider research project, emerging themes were recorded with short extracts from the interviews, alongside links to ADF, to the literature and to the technical findings from the other parts of this research. The main outcomes of this analysis are presented in Section 3.

2.4. CASE STUDY

This research is based on four case study homes, so caution should be applied in generalising the results. The time and resources required to carry out both technical and qualitative data collection and analysis limited the total number of cases that could be recruited. Key details of the cases are given in Table 1. The homes were constructed in 2015 and the planned ventilation system was inferred from the installed ventilation equipment, technical drawings and communication with the building developer confirming that the ventilation systems had been designed in line with system 3 in ADF (HMG 2013) – continuous MEV and trickle vents. This allowed comparison of the ways the occupants used the system with the technical intention.

Monitoring equipment was installed so that ventilation measurements could be taken. Interviews coincided with the removal of monitoring equipment, so that they did not influence the use of the ventilation equipment.

Figure 1 shows a typical layout for these homes. The supplemental data online provides further context on the case study buildings.

The ventilation extract system was centralised with extract points in the kitchen, bathroom and utility room connected to a central fan and then ducted outdoors. Table 1 gives key information about the ventilation system and measured ventilation rates in each flat. The researchers did not change the ventilation system operation. The planned system assumes that trickle vents will be open and MEV switched on. According to the planning drawings, the MEV should have had a humidity sensor for automatic switching into boost-flow mode. No evidence of this was found and the ventilation system permanently operated in normal flow mode. The homes had recirculating cooker hoods, which do not contribute to the ventilation rate but could remove some pollutants depending on their filter.

Repeated measurements of ventilation rates were recorded, with continuous monitoring between June 2019 and January 2020. With the windows closed, the vast majority of measured ventilation rates were below the level specified in ADF (Table 1), and below 0.5 ach – a threshold commonly used to indicate adequate ventilation rates (Dimitroulopoulou 2012). The occupants were likely to frequently experience inadequate ventilation when their windows were closed and therefore may have experienced poor IAQ (whether or not this was consciously noted – see Section 3.1). Further details of the measured ventilation rates are provided by Few (2021) and the CO_2 decay method by Few and Elwell (2021).

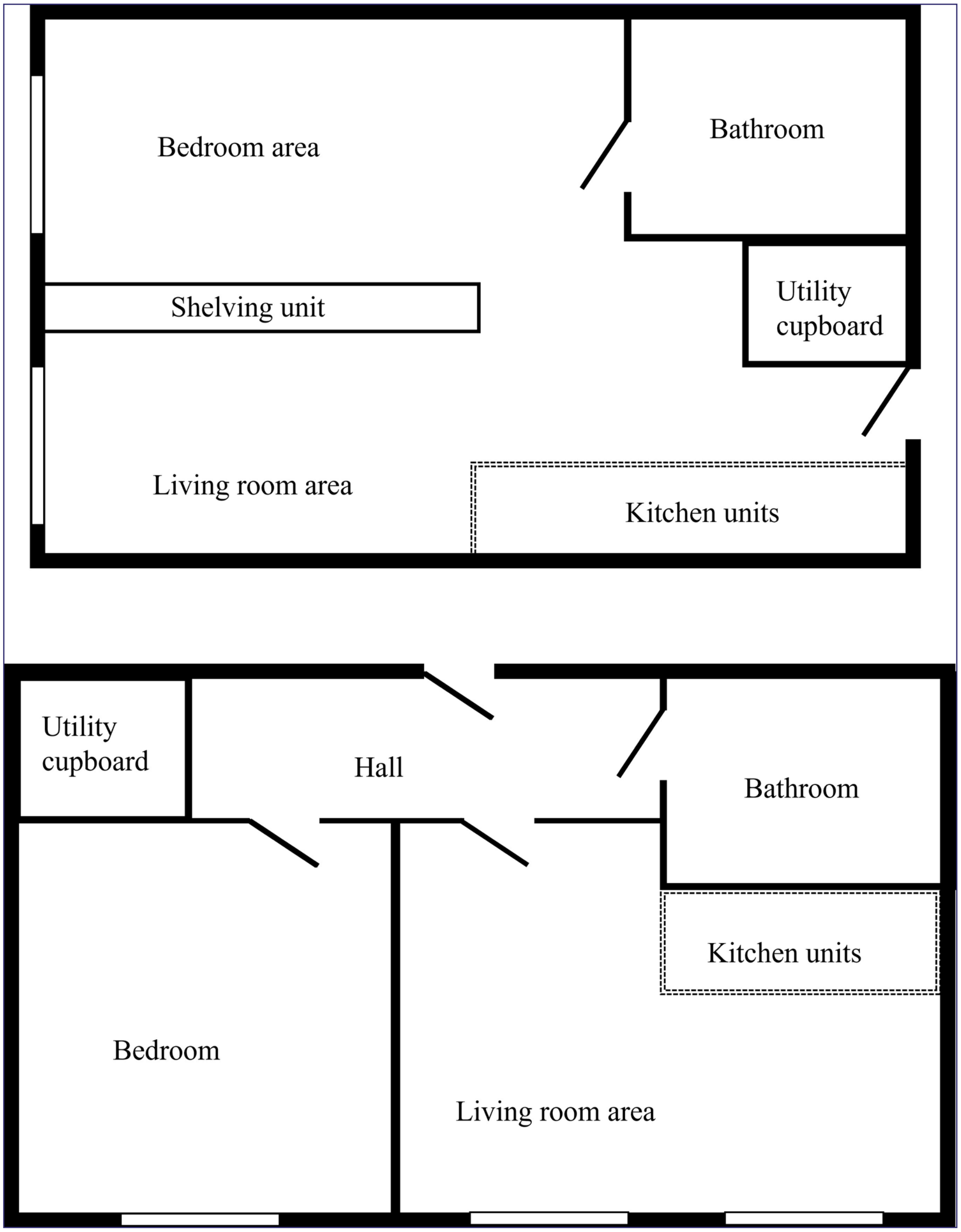

Figure 1: Floor plan for studio flats (upper) and 1-bedroom flats (lower).

FLAT	A	B	C	D
Occupants	Aaron and Alice*	Brandon and Bridget*	Cal	Darren
Dwelling type	1-bedroom	Studio	Studio	1-bedroom
Floor	First	Ground	Ground	Ground
Trickle vents as found (and measured)	Closed	Closed	Closed	Closed
MEV system as found (and measured)	On	Off	On	On
Median (25th and 75th percentile) measured ventilation rate with windows closed (ach)	**	0.25 (0.19, 0.37)	0.42 (0.27, 0.57)	0.41 (0.33, 0.53)
ADF ventilation rate	0.44	0.56	0.56	0.45

Table 1: Occupants, case study homes, status of the ventilation system as found and measured, and the ventilation rates measured and expected according to ADF

Notes: * Aaron and Alice (Flat A) were a couple, they lived in the flat together and were interviewed together. Brandon rented Flat B to Bridget, they did not live in the flat at the same time and their interviews were conducted separately.

** It was not possible to measure ventilation rates with windows closed in Flat A as the windows were rarely closed while the dwelling was unoccupied.

3. RESULTS AND DISCUSSION

The ventilation strategy set out in ADF (which sets out ventilation systems that are assumed to provide adequate ventilation) is contrasted with the ways that participants manipulated the air in their homes. First, the meanings associated with indoor air are compared (Section 3.1), then the technologies and know-how for removing indoor air pollution, which is the key focus of ADF (Section 3.2). Finally, the question of how ventilation is connected to the whole indoor environment from an occupant viewpoint is considered (Section 3.3).

3.1. MEANINGS OF INDOOR AIR POLLUTION AND SMELLS IN THE HOME

According to ADF, 'ventilation is simply the removal of "stale" indoor air from a building and its replacement with "fresh" outside air' (HMG 2013: 13). ADF also intends that 'odours' will be removed by ventilation. 'Odours' are not explicitly defined within the document but it can be inferred that this refers to unpleasant smells as the only examples given are bio-effluents (also called body odours), and odour as the main pollutant in the context of WCs.

The range of factors affecting whether the occupants felt they needed to do something to affect the air in their home is different to those in ADF. Participants only used the terms 'pollution' or 'pollutant' to refer to *outdoor* air pollution. To enable a comparison between the planned system and the participants' practices, 'unwanted air elements' from the participants' perspective can be considered like pollutants in the planned system – these are the components that should be removed. Throughout the rest of the discussion, important discrepancies between these two concepts will be apparent.

Freshness and circulation of air were noted as desirable, similar to the ADF notion of fresh air:

> I like it when it's fresh, [...] it's been circulated, [...] it's not a bit stuffy.
>
> (Cal)

Fresh air could also be used to counteract a sense of uncleanliness:

> [My sister] has a bunch of room-mates who are just like really lazy about cleaning up anything, so the whole place always smells. [...] [S]he's like, 'I want to open the windows so I don't feel like I'm suffocating'.
>
> (Darren)

The smells are associated with an assessment of the character of the people Darren's sister lived with. Wakefield-Rann *et al.* (2018) discuss modern home cleaning practices and sensitivity to specific smells, sights and sensations as indicators of 'uncleanliness' and 'germs'. Shove (2003) writes comprehensively about the social significance of cleanliness, including how this is related to notions of propriety and morality. Pink's (2007) work on the sensory experience of the home environment is also highly relevant to the ways the participants described the air in their home.

For these participants, different smells held different significances, for example the boosting of the scent of freshly laundered clothes, and the taboo of smells associated with the toilet. A striking example was discussed by Alice, who opened the window and turned an air freshener on while she was out because of her social concern about her flat smelling like their dog:

> I find [the air freshener] quite strong smelling and I don't really like it. But as I said, I'm conscious of having a dog, so especially if other people are coming here I would put the plug-in on so that hopefully it doesn't smell awful.
>
> (Alice)

Hauge (2013) discusses the social judgements related to smells in the home and the importance of conveying the 'correct' image to others through smells in the home. The participants show the judgement associated with smells. Alice perceived the introduction of the air freshener as a way to remove the unwanted smell of the dog and provide more socially acceptable air, whereas from a technical perspective additional pollutants had been introduced (Steinemann 2017), albeit in this case alongside increased ventilation through the window.

While Alice used air freshener to cover unwanted smells, Brandon found their addition unpleasant:

> I don't like the smell of those fake air fresheners, like the Christmas tree things, they don't add to the air quality, they make you a bit coughy, don't they?
>
> (Brandon)

And, while Alice used air fresheners intermittently, Brandon burnt scented candles almost every time he arrives at home:

> It's the ambience, the relaxation of them, the smell of them.
>
> (Brandon)

Like Alice's use of the air freshener, Brandon's use of candles would have introduced various pollutants into the home. However, unlike the air freshener, they did not induce a direct physical reaction (coughing). Instead, they constituted part of his home-making practice: what he did to feel comfortable and at ease at home.

In some cases, whether a smell was considered desirable or not had spatial or temporal aspects:

> If I fry [...] garlic and onion and then it's like ok, it's a nice smell but I don't want to have it all night!
>
> (Cal)

Where Cal highlighted the *temporal* appropriateness of specific smells, Brandon was sufficiently concerned about *spatial* appropriateness that he would have much preferred living in a home with a door between the kitchen/living room and bedroom than his open-plan studio-flat:

> I guess just the smells of the cooking [...] to keep that a bit more separate.
>
> (Brandon)

The above quotes reveal that the participants had a consistent desire for appropriate smells in appropriate locations over appropriate time frames; meaning matters and the meaning varies according to the social context. The ADF approach does not consider the social significance of different smells in different spatio-temporal contexts highlighted by our participants: naturalness, cleanliness, laziness, social judgement, taboos and ambience.

The participants were keenly aware of the air and smells in their homes and were motivated to manage them to obtain the right conditions. However, they were unlikely to recognise unscented or pleasantly scented pollutants, so were unlikely to take action to remove them. At times, sources of pollution were also identified visually – by seeing black mould, smoke or steam. This highlights the importance of the sensory experience of the home (Pink 2007) in considering ventilation. None of the participants had formal knowledge or rules relating to pollution from indoor sources. This is important because there are a variety of sources of air pollutants in homes, such as candles and air fresheners, cleaning products, personal hygiene products, dust, and volatile organic compounds (VOCs) released by furnishing and fittings (Shrubsole *et al.* 2019); these do not all have unpleasant smells or visual appearance. The risk that occupants might not detect harmful pollution and thus might not act take action to combat it underlines the importance of the ventilation system working effectively.

Figure 2 summarises the similarities and differences between how participants and ADF interpreted elements of indoor air along the axes of harm and pleasantness. Note that an activity might release multiple pollutants (e.g. cooking smells concurrent with particulate matter and NO_x) and the harmful ones (particulate matter and NO_x) might not be easily detected by occupants.

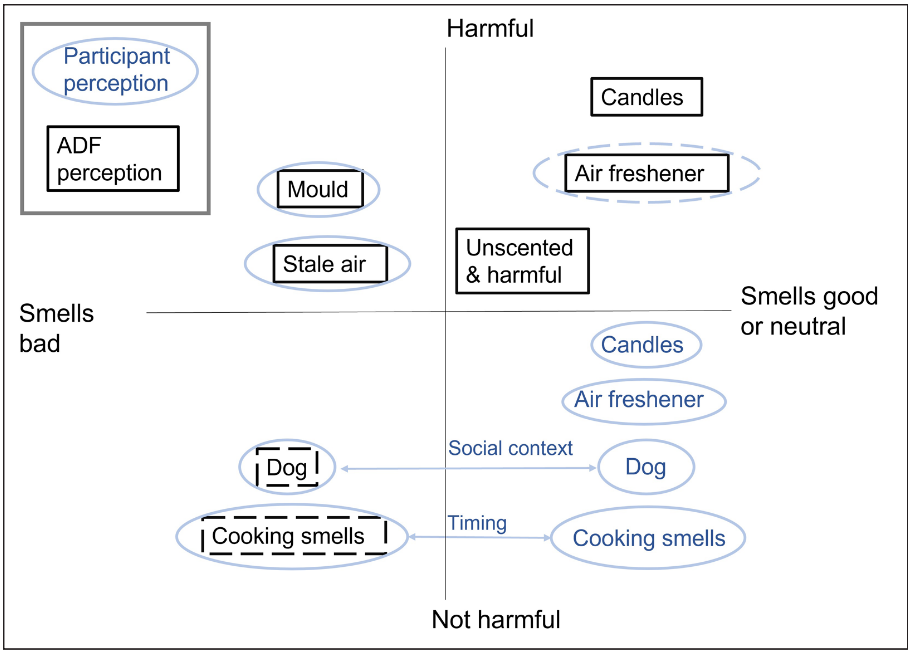

Figure 2: How different pollutants could be classified according to their harmfulness and smell by participants and ADF.

Note: Whether something smells good or bad is largely subjective, so dashed lines for the participant perception indicates differences of opinion between occupants; dashed lines for ADF indicates dependence on how the participants perceive the smell.

3.2. TECHNOLOGIES AND KNOW-HOW FOR REMOVING INDOOR AIR POLLUTION

The ADF system couples the type of ventilation (whole-dwelling, extract or purge) with the technology and actions intended to achieve this. For these flats, the design intention was:

- *Whole-dwelling ventilation* should be provided by the MEV system operating in low-flow mode, drawing air through open trickle vents and out through ventilation terminals in the kitchen, bathroom and utility.
- *Extract ventilation* should be provided by the MEV system automatically switching into boost-flow mode if high humidity is detected. In practice the automatic switch did not exist. The system should have had a manual boost-flow switch, but this was also absent.
- *Purge ventilation* should be provided by windows with a minimum opening area. The windows were 'tilt and turn' type (see Figure 3), which only provide purge ventilation in 'turn' mode. Internal rooms, such as the bathrooms, should have purge ventilation provided by the MEV operating in boost-flow mode, but as noted above this was not provided so these rooms lacked purge ventilation as well as extract ventilation.

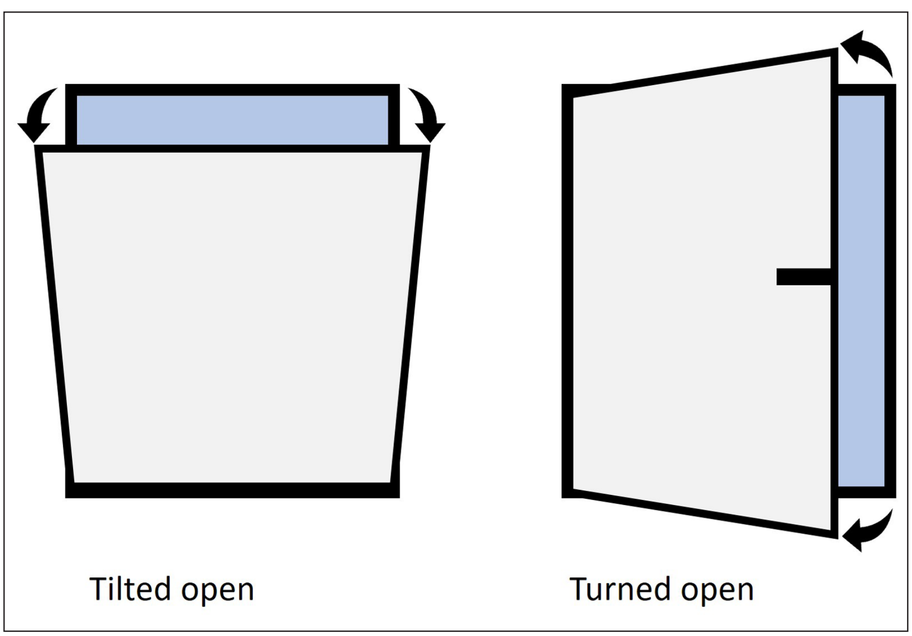

Figure 3: Schematic of the windows tilted and turned open.

Note: In the 'tilt' mode the opening was restricted to approximately 10 cm at the top of the window. There was no restriction when 'turned' open.

In the planned system, forms of pollution not associated with the automatic humidity sensor implicitly require an occupant to detect the pollution and intervene to increase the ventilation rate. For example, pollutants from candles or cleaning products might not occur concurrently with high humidity. These homes did not have either automatic or manual boost-flow for their MEV systems, so extract ventilation did not happen and purge ventilation only happened when the occupants turned open the windows.

The operation of the ventilation system is meant to be explained in a manual giving 'specific instructions for the end user on how and when to use the ventilation system' (HMG 2010b: 53) according to the Domestic Ventilation Compliance Guide (DVCG). However, none of the participants in this study recalled receiving such information.

3.2.1. Key occupant know-how and technologies for removing indoor air pollution

Apart from windows and scented products, the only other significant technology for manipulating the air in the participants' practices was the cooker hood. The cooker hood recirculated air rather than extracting it, and therefore did not contribute to the ventilation. Nonetheless, Alice, Aaron, Brandon and Cal shared the practical understanding that the cooker hood is usually used when cooking to remove cooking smells. Bridget and Darren, meanwhile, did not use the cooker hood in these flats:

> [I've used them] everywhere before. Here, just very easily fall into a habit of just not doing it, because it doesn't seem to have any negative consequences.
>
> (Darren)

This illustrates that the way the participants managed the air was informed by their observation of conditions. Darren and Bridget found that cooking smells dispersed quickly enough whether or not they used the cooker hood, so they stopped using them.

3.2.2. Know-how related to the main technologies in the planned system

The participants had limited practical understanding, few rules and little knowledge associated with the main components of the planned system. The MEV isolation switch was off at the time of interviewing Bridget, and it was unclear how long it had been off. The system was on in the other flats, although in Alice and Aaron's flat the MEV isolation switch was mistaken for the utility cupboard extract only, rather than for the whole system. Darren explained that he had paid little attention to the system because it formed part of the invisible foundation of his home:

> It's one of those things, like, you never look at how your plumbing system works until your taps don't work.
>
> (Darren)

In a previous hot and stuffy flat, Darren had been much more conscious of needing to take actions to obtain and maintain air with appropriate qualities. However, in his present flat nothing indicated that he needed to take steps to manipulate the air – he did not find the flat stuffy, that smells lingered, or that the flat was overly hot, all of which would have indicated to Darren that more ventilation was needed.

Cal was disappointed that the MEV system did not seem to eliminate stuffiness, leading him to doubt its efficacy:

> I can sometimes feel like when I come home that maybe it's a bit stuffy […] I was wondering if the [MEV] works properly
>
> (Cal)

Alice was likewise uncertain that the MEV was functioning; she mentioned that condensation cleared quickly in the bathroom but remained unsure whether the MEV was working. In contrast, Aaron took the clearing of condensation as evidence that the MEV worked well:

> I don't know what it's doing, if it's doing anything.
>
> (Alice)

> It's probably doing, ah, I don't know what it's doing but whatever it is it's pretty good. Tiny little fan, doesn't make any noise.
>
> (Aaron)

Like Alice, Darren found the MEV difficult to interpret:

> There's not fans, there's these [points to the kitchen terminal], which I presume are taking some of the smells away and stuff like that, there's another one in the bathroom which doesn't have a fan, although I haven't really checked... Maybe there'll be a noise when I switch that on. [Switches the light on and pauses to listen] Yeah so there is that but it doesn't seem to do anything.
>
> (Darren)

Participants stated the function of the continuous MEV tentatively, highlighting the limited know-how and meanings associated with it. Under the intended operation of the MEV the occupants do not need to interact with it except to keep the system switched on. Significantly, participants lack a means of verifying that the MEV is functioning correctly. Moreover, from a user perspective, the MEV is not strongly connected to the other elements of a dispersed practice of manipulating the air in the home; keeping it on could be considered a 'stranded action' – something that is intended in the designed system but not connected to any of the elements in a dispersed practice of manipulating the air.

Alongside the MEV, the system is designed to have trickle vents open. Closing trickle vents prevents the ventilation system as a whole operating properly, since they are meant to provide an air inlet for the MEV. All trickle vents were closed on all research visits to all the participants' flats. Participants had varied interpretations of trickle vents, as demonstrated by this interaction:

> Oh! You can do stuff to them?
>
> (Alice)

> Yeah... you just flick them open.
>
> (Aaron)

> Oh! Well, I didn't know that. What does that do?
>
> (Alice)

> Lets a small amount of air in.
>
> (Aaron)

Bridget was unaware of the presence of the trickle vents, and Darren had never noticed them in Flat D but had kept them open all the time in his previous flat:

> My previous place I had [the trickle vents] open the whole time because letting heat out just passively and just any sort of airflow at all was quite important. Because it was only facing one way and also the door was, like to the rest of the block of flats, was super airtight and things like that, so there was no airflow at all.
>
> (Darren)

Although Darren understood that trickle vents can provide airflow, he did not want it in Flat D. Cal and Aaron occasionally used the trickle vents in their flats, but only when they were not at home and did not want to leave windows open, for example:

> [It] drives me up the wall when you leave the window open when we go away because I'm always convinced someone's going to break in and steal everything. So [after you went] I closed the windows and I opened the air vents.
>
> (Aaron to Alice)

Although some participants understood their potential for providing outdoor air, open vents were not the default, and they were not considered in conjunction with the MEV. The trickle vents hardly featured in participants' practices, and keeping them open could be considered another 'stranded action'.

Finally, although windows featured significantly in the participants' practices and they 'knew-how' to turn windows open (see Figure 3) to provide high ventilation rates, they rarely did this for a variety of practical reasons.

3.2.3. Comparison of approaches to removing indoor air pollution

Figure 4 illustrates the divergence between ADF and the occupants in terms of the technologies used for ventilation for different reasons. The continuous MEV and trickle vents were core to the ADF system but featured minimally in the participants' practices and were not operated as intended. Windows were used extensively but were not always used as intended. Air fresheners and scented products were an important part of some participants' practices, but from the planned system's perspective they added pollutants rather than removing them.

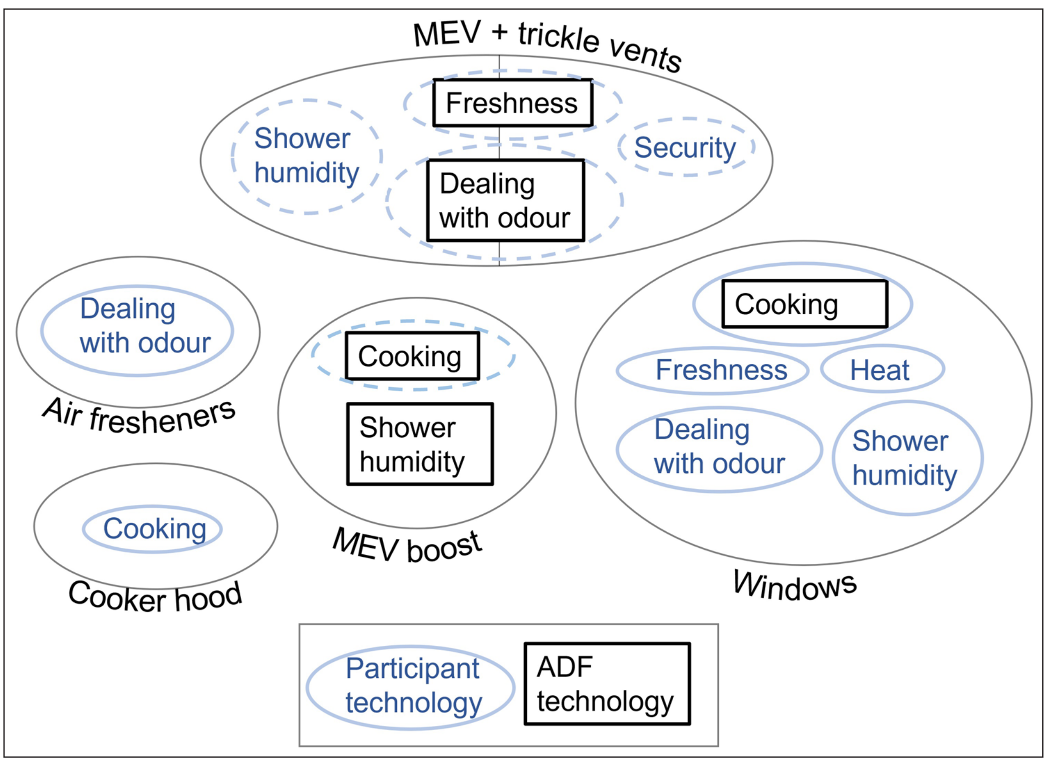

Figure 4: Comparison of ADF and occupant use of technology for different kinds of pollutants.

Note: Dashed lines for the participant use of technology indicate use in some scenarios or some differences of opinion between participants.

Whole-dwelling ventilation rates in these homes were inadequate, as noted in Section 2.4, but participants had no means of detecting this inadequacy. Moreover, none could recall receiving advice on how to operate their ventilation systems, which may have contributed to the systems not being used as intended. The findings highlight that there is no planned route for identification and rectification when ventilation systems are not working as planned and not delivering adequate ventilation rates. It is challenging to design a system that is robust to the range of domestic settings but it is increasingly important to ensure good IAQ in homes.

3.3. MANAGEMENT OF THE INDOOR ENVIRONMENT NOT COVERED BY THE PLANNED SYSTEM

Some aspects of indoor environmental quality beyond indoor air pollution are acknowledged in ADF, for example: 'ventilation may also provide a means to control thermal comfort' (HMG 2013: 13), and it is noted that a noisy external environment may prevent occupants from opening windows. However, thermal comfort 'is not controlled under the Building Regulations' (HMG 2013: 13) and 'expert advice' is recommended in the case of a noisy environment. While ADF acknowledges that there could be factors other than indoor pollution that affect ventilation, the default system is not designed to consider these parameters alongside pollutants. In this section we discuss how other indoor environmental parameters interacted with the ways that the participants ventilated their homes.

The participants described a range of techniques for managing heat flows around their home, similar to Royston's (2014) concept of heat-out-of-place and heat-out-of-time: occupants manipulated heat flows using a range of skilful interactions to obtain the right temperature in the right space at the right time. The windows and doors were involved in the ways the participants controlled the location and flow of heat around the building to obtain and maintain conditions they found comfortable. Darren described having open windows and a closed bedroom door as a habit picked up in childhood to maintain a comfortable temperature in his room while facilitating the thermal preferences of the rest of the family. Although he no longer opened the windows, his closure of the bedroom door had persisted into adulthood; this is relevant to Hansen's (2018) discussion of 'sticky' practices.

In other instances, use of windows interacted with noise and thermal comfort concerns, for example regarding sleeping conditions:

> [I]f the window is closed there's no noise and it's pleasant, but then also it feels, you know it gets a bit too hot and you know, in a way, stuffy.
>
> (Cal)

This demonstrates how considerations of noise, thermal comfort and air quality influence the extent to which ventilating using the window is an appropriate solution.

Windows were also used to navigate the boundary between the home and the outside world. Sometimes elements from the outside were desirable. Darren noted that in previous homes he had enjoyed sounds through open windows:

> in previous places it's been a park, it's been middle of suburban nowhere and farmland with loads of birds, so [the sounds are] one thing that I have missed [here].
>
> (Darren)

Alice also appreciated feeling connected to the outdoors through letting outdoor air into the home:

> rather than having like the smog of London coming in the window [...] it's like having a bit of nature [...] I like the outside being in. And I feel, perhaps irrationally even, claustrophobic if windows are closed for too long.
>
> (Alice)

Hauge (2013) discusses the role of ventilation in feeling connected with the outdoors. She frames air as an intermediary between home and nature, whereby allowing outdoor air into the home blurs the boundary between the home and the world outside. Hauge's study took place in Denmark but the quotes above suggest that these participants share similar meanings associated with bringing outdoor air into the home.

Internal doors have no role in the planned ventilation system; however, closure of internal doors can have significant impacts on ventilation rates (Few *et al.* 2019). Aaron and Alice discussed circumstances in which they would close the living room door:

> Blazing row! [All laugh]
>
> (Aaron)

> I don't really like the feeling of being in a room with the doors closed. [...] Yeah I suppose in my life, I've only really closed doors for privacy.
>
> (Alice)

Doors were closed for privacy, to confine cooking smells, and to control the flow of heat around the building.

Windows were intended to provide purge ventilation by 'turning' them open, but there were a variety of practical reasons that they were not used in this way. Brandon's windows were incapable of being turned open, unlike the windows in the rest of the homes. Brandon explained that he would not have turned the windows open even if it had been possible:

> Because I'm on the ground floor people could have just walked in.
>
> (Brandon)

Brandon only tilted the windows open because this felt secure. While Brandon, Bridget and Cal all frequently tilted the windows open, including while their homes were unoccupied, Darren was concerned about security with any amount of window opening. The same technology in very similar locations (ground-floor or first-floor flats in the same building) was interpreted in different ways, and this had considerable consequences for the way the flats were ventilated.

The participants noted that tilting the windows meant wind and rain had little impact inside and there were other practical considerations:

> We open them fully [turned open] in the summer [...] not so much the bedroom one because like, you get those shitty little fly things don't you, so we just [tip] that one most of the year, but [one or both of the living room windows] we'll always open fully.
>
> (Aaron)

> So when you open them fully, because I just notice that the desk is there as well, would you have to move stuff around to be able to open them?
>
> (interviewer)

> They are massively inconvenient windows. And also, when you open it fully that is an enormous space. I am quite conscious of the dog like climbing up and potentially jumping out of the window.
>
> (Alice)

The degree of window opening was related to the extent to which a boundary between indoors and outdoors was wanted and required. Both keeping unwanted things (people, flies, weather) out and things that belonged indoors (dogs, possessions) inside the flat were easier to achieve with the windows tilted rather than turned. This demonstrates how the design intention of using turned-open windows for purge ventilation is not always practical given wider consideration of the significance of the boundary between indoors and outdoors.

Throughout the discussion of the dispersed practice of manipulating the air, a broad range of considerations beyond indoor pollution have been explored. This includes a nuanced consideration of smells, noise, privacy, thermal comfort, and their spatial and temporal aspects, as well as security and connections with the outside world. Madsen and Gram-Hanssen (2017) explore the notion of 'comfort' at home, arguing that previous research has largely focussed on thermal comfort, to the exclusion of other senses. They find that being comfortable at home is related to a wide range of senses, including aspects related to air (e.g. pleasant smells and fresh air), as well as softness and lighting. They argue that the narrow framing of thermal comfort also narrows the realm of ways to improve comfort to those that increase temperatures, potentially ignoring many avenues that may improve comfort if understood as a wider concept. This is like the way that ADF has a narrow remit related to indoor air pollution but neglects the wider whole-body experience of obtaining a satisfactory environment. Figure 5 illustrates the variety of factors that influence the way the participants manipulate the air, and the factors that the designed system considers.

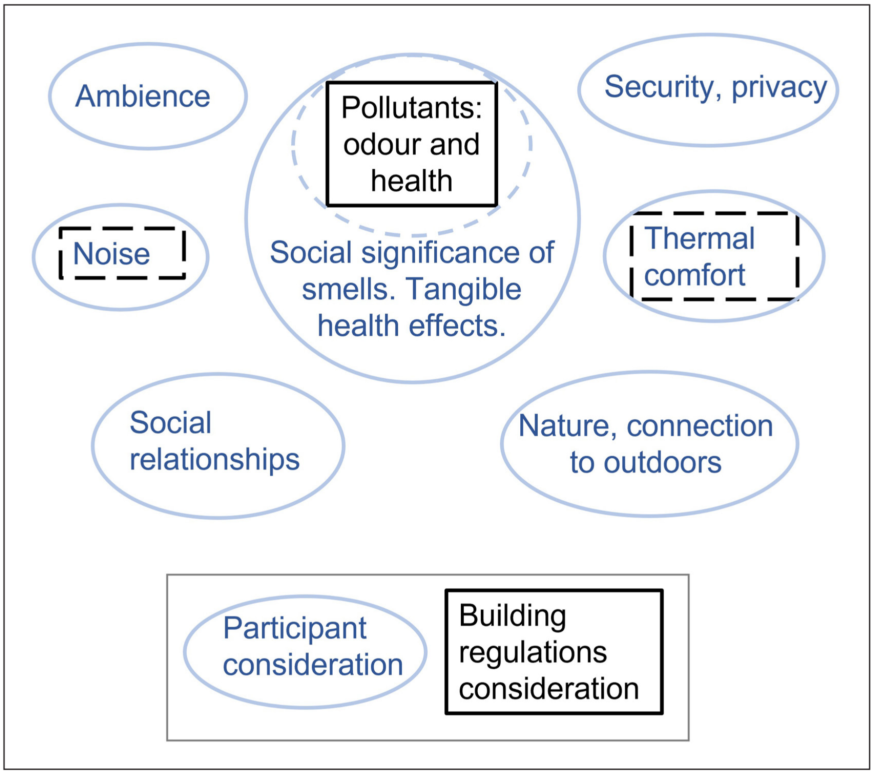

Figure 5: Factors affecting the need for ventilation, or incidentally associated with ventilation.

4. CONCLUSIONS

This research has compared the ways that occupants ventilate their homes with the strategy set out in ADF (HMG 2013). Several key differences have been identified.

First, occupants and ADF did not always consider the same things to be pollutants. ADF assumes occupants will ventilate in the event of high concentrations of pollutants, but the participants had almost no formal knowledge, rules or practical understanding regarding indoor pollutants and their removal. Indeed, participants did not use the word 'pollutant' at all in relation to the air in their homes. Nonetheless, air in the home was shown to hold social significance for the participants, and they took actions to obtain 'fresh' air in the home, keep the air moving and limit the spread of undesirable air. Various organisations have advice for the public regarding indoor air pollution, but this had not clearly impacted the practices of the participants in this study. However, the participants were keen to have the 'right' kind of air in their home, suggesting that there may be social cues that advice could be aligned with, thus tapping into existing aims, goals and meanings that occupants have for their homes.

Second, ways of detecting pollution differed between the occupants and the planned system. The design intention was that a boost-flow rate would be triggered by humidity sensors alongside manual control of the boost (implicitly for occupant-detected pollution), although in these homes there was no boost flow. Purge ventilation via windows is also implicitly associated with occupant detection of pollution, while background ventilation is intended to be continuous. Despite this implicit reliance on occupant detection in the planned system, not all harmful pollutants are perceived by occupants. Although the participants were motivated to maintain appropriate air in their homes, the ventilation rates were inadequate with the windows closed. In the case of pollution caused by unscented or pleasantly scented products (for example, candles or air fresheners releasing VOCs), it is likely that formal rules or knowledge is important because the direct perception of harms is unlikely to be possible. The lack of formal knowledge and practical understanding suggests there is a need for effective strategies to communicate practical steps to reduce exposure to indoor pollutants at home.

Third, the participants did not use the ventilation equipment as intended. The participants had no formal knowledge, no rules and limited practical understanding of the ventilation equipment (except the windows). The participants lacked a direct verification of what the MEV system was for, whether it worked properly, and whether they were using it as it was intended to be used (e.g. the trickle vents were closed but the participants had no way to interpret that this was not the intention). The participants were not aware of having received manuals regarding the intended use or maintenance of the system as required (HMG 2010b). Moreover, research suggests that only a very small proportion of people alter their actions after the simple provision of information (Baddeley 2011; Southerton *et al.* 2011).

It is possible that changes to the design of ventilation technologies could encourage practical understanding regarding their use, without necessarily influencing the formal rules or knowledge dimension of the practice. However, further research using appropriate methods and disciplines would be required to assess any revisions to the planned ventilation system since it is challenging to balance the combined issues of energy use, adequate ventilation provision and occupant requirements.

Finally, the participants' practices were related to many aspects of the indoor environment. Some were reflected in the remit of ADF, e.g. they took opportunities to control the strength, timing and location of different smells within the home. However, many other factors are involved, including thermal comfort, noise, communication in the home, pleasant feelings of freshness and cleanliness (see the discussion of comfort by Madsen & Gram-Hanssen 2017). The participants paid attention to the *whole* environment inside their home and manipulated airflows to obtain their best combination of conditions. In contrast, ADF almost exclusively focusses on the presence of pollutants and odours. As a result, although there is some acknowledgement of a wider set of environmental conditions within ADF, the designed ventilation system is not robust to the foreseeable ranges of wider environmental conditions expected within homes.

It is challenging to design ventilation systems that are robust to a range of internal conditions and are consistently used by occupants in ways that achieve appropriate ventilation rates. Nonetheless, this is increasingly urgent as more homes are built and retrofitted to be more airtight and more reliant on ventilation systems to provide good IAQ. The present research highlights important fault-lines between planned ventilation systems and the way they are used in practice. The findings suggest that ventilation system designers and ventilation regulations should more deeply consider how occupants use ventilation technologies when designing future systems, so that they can be better integrated into existing occupant practices and used more intuitively and effectively to ultimately provide better IAQ for occupants. Further sociotechnical research could usefully explore technologies and communication strategies that reduce the distance between intended and in-use operation of ventilation systems in homes and provide adequate ventilation.

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COMPETING INTERESTS

The authors have no competing interests to declare.

DATA ACCESSIBILITY

Full transcripts of the interviews analysed for this research are openly available at: https://doi.org/10.5522/04/24851355.v1

ETHICAL APPROVAL

Participants gave their informed consent and the research was approved by the UCL Research Ethics Committee, project number 10917/001.

Each of the participants was given a pseudonym with the first letter matching the letter used to identify their flat.

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SUPPLEMENTAL DATA

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REFERENCES

ASHRAE. (2017). Ventilation and infiltration. In American Society of Heating, Refrigeration and Air-Conditioning Engineers (Eds.), *Handbook of fundamentals (SI edition)*.

Baddeley, M. (2011). Energy, the environment and behaviour change: A survey of insights from behavioural economics (Cambridge Working Papers in Economics, October). http://www.econ.cam.ac.uk/research/repec/cam/pdf/cwpe1162.pdf

Behar, C. (2016). *A socio-technical perspective of ventilation practices in UK social housing with whole house ventilation systems; design, everyday life and change*. University College London.

Bhagat, R. K. *et al.* (2020). Effects of ventilation on the indoor spread of COVID-19. *Journal of Fluid Mechanics*, 903. DOI: https://doi.org/10.1017/jfm.2020.720

Cass, N., & **Faulconbridge, J.** (2017). Satisfying everyday mobility. *Mobilities*, 12(1), 97–115. DOI: https://doi.org/10.1080/17450101.2015.1096083

CCC. (2020). *Reducing UK emissions – Progress report to Parliament*. https://www.theccc.org.uk/publications

Chiu, L. F. *et al.* (2014). 'A socio-technical approach to post-occupancy evaluation: interactive adaptability in domestic retrofit'. *Building Research & Information*, 42(5), 574–590. DOI: https://doi.org/10.1080/09613218.2014.912539

Crump, D. *et al.* (2005). *Ventilation and indoor air quality in new homes*. Building Research Establishment.

DCLG. (2010). *Ventilation and indoor air quality in Part F 2006 homes*. Department for Communities and Local Government.

Dimitroulopoulou, C. (2012). Ventilation in European dwellings: A review. *Building and Environment*, 47(1), 109–125. DOI: https://doi.org/10.1016/j.buildenv.2011.07.016

Few, J. (2021). Ventilation in occupied homes: Measurement, performance and sociotechnical perspectives (Doctoral dissertation, University College London, London).

Few, J., Allinson, D., & **Elwell, C.** (2019). Airtightness and non-uniformity of ventilation rates in a naturally ventilated building with trickle vents, in *40th AIVC Conference, 8th TightVent Conference, 6th Venticool Conference*, pp. 527–536.

Few, J., & **Elwell, C. A.** (2021). Applying the CO2 concentration decay tracer gas method in long-term monitoring campaigns in occupied homes: Identifying appropriate unoccupied periods and decay periods. *International Journal of Building Pathology and Adaptation*, 41(1). DOI: https://doi.org/10.1108/IJBPA-05-2021-0077

Gram-Hanssen, K. (2010). Residential heat comfort practices: understanding users. *Building Research & Information*, 38(2), 175–186. DOI: https://doi.org/10.1080/09613210903541527

Hansen, A. R. (2018). 'Sticky' energy practices: The impact of childhood and early adulthood experience on later energy consumption practices. *Energy Research and Social Science*, 46(June), 125–139. DOI: https://doi.org/10.1016/j.erss.2018.06.013

Hauge, B. (2013). The air from outside: Getting to know the world through air practices. *Journal of Material Culture*, 18(2), 171–187. DOI: https://doi.org/10.1177/1359183513483908

HMG. (2010a). *Building and buildings, England and Wales – The Building Regulations*. Her Majesty's Government. https://www.legislation.gov.uk/uksi/2010/2214/schedule/1/made

HMG. (2010b). *Domestic ventilation compliance guide 2010 edition (with 2011 amendments)*. Her Majesty's Government. https://www.gov.uk/government/publications/ventilation-approved-document-f

HMG. (2013). *Approved Document F1: Means of ventilation. 2010 edition incorporating 2010 and 2013 amendments*. Her Majesty's Government.

HMG. (2021). *Approved Document F. Volume 1: Dwellings*. Her Majesty's Government. https://www.gov.uk/government/publications/ventilation-approved-document-f

Klepeis, N. E. *et al.* (2001). The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. *Journal of Exposure Analysis and Environmental Epidemiology*, 11(3), 231–252. DOI: https://doi.org/10.1038/sj.jea.7500165

Kuijer, L., & **Watson, M.** (2017). 'That's when we started using the living room': Lessons from a local history of domestic heating in the United Kingdom. *Energy Research and Social Science*, 28(December 2016), 77–85. DOI: https://doi.org/10.1016/j.erss.2017.04.010

Love, J., & **Cooper, A. C.** (2015). From social and technical to socio-technical: Designing integrated research on domestic energy use. *Indoor and Built Environment*, 24(7), 986–998. DOI: https://doi.org/10.1177/1420326X15601722

Madsen, L. V., & **Gram-Hanssen, K.** (2017). Understanding comfort and senses in social practice theory: Insights from a Danish field study. *Energy Research & Social Science*, 29(May), 86–94. DOI: https://doi.org/10.1016/j.erss.2017.05.013

Martin, R., and **Larsen, S. P. A. K.** (2024). 'I never look at a temperature device, I just feel it': Practical knowledge, smart technologies, and heating and cooling practices between Denmark and Australia. *Energy Research & Social Science*, 108(December 2023), 103389. DOI: https://doi.org/10.1016/j.erss.2023.103389

Merriam, S., & **Tisdell, E.** (2015). Qualitative data analysis, in *Qualitative research: A guide to Design and Implementation*, 4th edn (pp. 195–236). John Wiley & Sons.

MHCLG. (2019). *Ventilation and indoor air quality in new homes*. Ministry of Housing, Communities and Local Government.

Moeller, S., & **Bauer, A.** (2022). Energy (in)efficient comfort practices: How building retrofits influence energy behaviours in multi-apartment buildings. *Energy Policy*, 168(April), 113123. DOI: https://doi.org/10.1016/j.enpol.2022.113123

NICE. (2020). *Indoor air quality at home. NICE guideline*. National Institute for Health and Care Excellence. https://www.nice.org.uk/guidance/ng149

Pink, S. (2007). The sensory home as a site of consumption: Everyday laundry practices and the production of gender, in E. Casey & L. Martens (Eds.), *Gender and consumption: Material culture and the commercialisation of everyday life* (pp. 163–180). Routledge.

Pink, S. *et al.* (2017). *Making homes: Ethnography and design*. Bloomsbury Academic.

Royston, S. (2014). Dragon-breath and snow-melt: Know-how, experience and heat flows in the home. *Energy Research and Social Science*, 2, 148–158. DOI: https://doi.org/10.1016/j.erss.2014.04.016

Schatzki, T. (2002). Practices, in *The site of the social: A philosophical account of the constitution of social life and change* (pp. 59–122). Pennsylvania State University Press. DOI: https://doi.org/10.1515/9780271023717-004

Schatzki, T. (2010). Materiality and social life. *Nature and Culture*, 5(2), 123–149. DOI: https://doi.org/10.3167/nc.2010.050202

Schatzki, T. R. (1996). The emergence of practice, in *Social practices: A Wittgensteinian approach to human activity and the social* (pp. 1–18). Cambridge University Press. DOI: https://doi.org/10.1017/CBO9780511527470.002

Shove, E. (2003). Introducing cleanliness: Morality, technology and practice, in *Comfort, cleanliness and convenience: The social organization of normality* (pp. 79–92). Bloomsbury Academic.

Shrubsole, C. *et al.* (2019). IAQ guidelines for selected volatile organic compounds (VOCs) in the UK. *Building and Environment*, 165(June), 106382. DOI: https://doi.org/10.1016/j.buildenv.2019.106382

Southerton, D., McMeekin, A., & **Evans, D.** (2011). International review of behaviour change initiatives. https://webarchive.nrscotland.gov.uk/3000/https://www.gov.scot/Resource/Doc/340440/0112767.pdf

Sovacool, B. K. *et al.* (2015). Integrating social science in energy research. *Energy Research & Social Science*, 6, 95–99. DOI: https://doi.org/10.1016/j.erss.2014.12.005

Steinemann, A. (2017). Ten questions concerning air fresheners and indoor built environments. *Building and Environment*, 111, 279–284. DOI: https://doi.org/10.1016/j.buildenv.2016.11.009

Wakefield-Rann, R., Fam, D., & **Stewart, S.** (2018). 'It's just a never-ending battle': The role of modern hygiene ideals and the dynamics of everyday life in constructing indoor ecologies. *Human Ecology Review*, 24(2), 61–80. DOI: https://doi.org/10.22459/HER.24.02.2018.04

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