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When behaviour change is about hot air: home systems should change behaviour to fit practices

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Abstract: Existing residential housing has to become more sustainable to meet global CO2 reduction goals. Zero energy home refurbishment is one approach to achieve this. Rather than the currently common behaviour change approach, this study investigates residents' experiences and practices with regard to their home environment. The study consists of interviews in 11 residents' own homes. The residents live in homes in various levels of refurbishment, including zero energy. The study focuses particularly on ventilation. Ventilation is an issue that is understudied yet known to affect homes' energy performance as well as residents' comfort experience. The study reveals many issues with trust, understanding and unfavourable associations of ventilation systems. The study then presents a number of exemplary design directions that could address these issues. The implications are that practices should be studied more to reveal such issues, and that there is a need for better home systems design approaches.

Keywords: sustainability; practices; home systems; zero energy

1. Introduction

Existing residential housing has to become more sustainable to meet global energy goals (Silvester et al., 2017), yet the challenge is to integrate energy-reducing refurbishments with the way people already live in the homes. To establish zero energy consumption the energy demand for cooling and heating is minimized. The remaining energy demand is met from renewable sources generated with heat pumps, solar panels, wind turbines or solar water heaters (Li, Yang & Lam, 2013). Zero energy (ZE) homes are often air-tight to minimize heat loss through uncontrolled ventilation and are equipped with a balanced ventilation system with heat recovery. Good functioning of such systems is of increasing importance, considering that people typically spend 90% of their time indoors (Lohani & Acharya, 2016). Often, indoor air is five times more polluted than outdoor air (Kim, Paulos & Mankoff, 2013). Polluted air has negative effects on productivity, health, and comfort of residents and can cause allergies, inflammation, infections, and asthma (Dimitroulopoulou, 2012). Numerous materials and activities can pollute the air with gasses and particles such as fine dust, CO, CO2, odours and water vapor (Behar & Chiu, 2013). Some indoor activities can quickly increase the concentration of pollutants: for example, cooking, lighting a fireplace, laser printing or cleaning (Kim & Paulos, 2009). Besides, building materials and furnishings can be a source of pollution: for example, pressed wood furniture (Kim et al., 2013). People are often unaware of air quality and pollution sources, since identifying air quality is very difficult. Physically people cannot sense changes in air quality since pollutants are often invisible and odorless (Kim et al., 2013).

1.1 Balanced ventilation

Balanced ventilation systems use mechanical components like air handling units, ducts and valves to supply clean and extract polluted air. Generally, air is extracted in 'wet rooms' of the house: the kitchen and bathroom. Fresh air is supplied in 'dry rooms': the living room and bedroom. Some mechanical systems recover heat from used air to preheat fresh air before supply (Dimitroulopoulou, 2012). Furthermore, systems can be equipped with sensors like CO2 and humidity to regulate airflow.

1.2 The residents´ role

The residents' interaction with ventilation systems impacts indoor air quality and energy usage. Residents' activities have been shown to affect the success of ZE housing: the activities partly cause what is known as the performance gap, the difference in expected and actual energy usage of buildings (Behar & Chiu, 2013; Paone & Bacher, 2018). For example, residents sometimes use ventilation differently from how it was designed to be used: they open windows while heating is on, disable ventilation or block vents (Behar & Chiu, 2013). Furthermore, maintenance like replacing filters, which is crucial to maintain the capacity of a ventilation system, is often not performed (Soldaat & Itard, 2007). This impacts not only energy goals (Behar & Chiu, 2013) but can also result in decreased comfort and unhealthy situations.

1.3 This study

The work presented was carried out in connection with the 2nd Skin ZE refurbishment project (Silvester et al., 2017) and is based on the first author's graduation project that focused on ventilation practices of residents who experienced a ZE refurbishment of their homes. The graduation project was supervised by the other authors. Practices are particularly important in the context of ZE refurbishments of rented houses as residents stay in the same house while they are expected to adjust their practices. The aim is to support residents to transition their practices so that they can benefit from their ZE homes in terms of health and comfort but also financially. With a research through design approach (Stappers & Giaccardi, 2017) this study simultaneously generates new knowledge on ventilation practices and design directions to support a transition of practices. In this way, the study generates knowledge on designing home systems from a practice-oriented perspective. Through supporting a transition of practices, the generated design solutions contribute to decreasing the performance gap.

We first describe the practice of maintaining indoor air quality to identify points that hinder a transition of the practice. We show that the lack of feedback of the ventilation system makes residents insecure and makes it hard to understand. Besides, associations that mismatch the new material make residents reluctant to use the ventilation system. Residents struggle to integrate the new system into their practices. We then propose design directions that could address these issues. Research questions were:

- What practices do residents have in relation to indoor climate?
- What material, skills and meanings are attached to residents' practices (Kuijer, 2017)?
- To what extent do residents transition their practices after refurbishments?

1.4 Practice-oriented approach

We take a practice-oriented approach in this research. Practices are routinized ways of doing (Shove & Watson, 2006). The advantage of this approach is that it broadens the analysis away from specific product-user interactions (Kuijer, 2017). By understanding the residents' routine actions, we can identify points for intervention to support a desirable reconfiguration of practices in their refurbished house. Practices are things people do and regard as normal. Cooking is a practice. However, cooking on a camping trip is quite different from cooking at home. This demonstrates the distinction between 'practices as an entity' and 'practices as a performance'. Cooking is the overarching entity; the different observable ways of cooking are the performances (Kuijer, 2017). Practices are described as a configuration of the following elements: skills, material, and images (Kuijer, 2017). In the cooking example, material are pans and knives, but also the air, experienced as fresh or not. The skill is knowledge and routinized actions required for cooking, for example ability to boil an egg. Images are the meanings people attach to cooking, for example on what is healthy or sustainable food and what is a pleasant kitchen environment. In the context of home systems, a practice-oriented approach facilitates designing for what people do in their homes, rather than designing for a fictional user who is primarily interested in the technical performance of their home, also referred to as "Resource Man" (Strengers, 2014).

Transitioning practices

Practices are not fixed; they are dynamic and can transition over time. In the process some materials, skills, and meanings become useless and new ones are added. The practice of maintaining warmth is used to illustrate this. With the introduction of gas, coal sheds and the skill of creating a fire became obsolete. Meanwhile, pipes and skill to regulate temperature using knobs became needed. At the same time, the related image changed as the amount of work involved decreased (Kuijer & De Jong, 2012). Transitioning practices has been a matter of attention in the design field, especially in the context of sustainability (Jégou, Liberman &

Wallenborn, 2009; Kuijer & Jong, 2009). Whereas the goal is often to transition practices to become less resource intensive (e.g. using less water), this study has a different primary aim: it aims to support residents in the integration of new elements, the new technologies, the new materials that enter their ZE houses.

2. Method

The first author conducted interviews with residents in their own dwelling. The interviews were semi-structured and consisted of open-ended questions. The set-up of the interviews was inspired by the path of expression: sharing current experiences, recalling memories and concluding by defining possibilities for the future (Sanders & Stappers, 2012) as well as by method insights by Boess, Silvester, de Wal & de Wal (2018) who employed a listening-first approach in ZE refurbishment. This framework was used for the set up because it would support residents to not only share current practices but also explore and express desirable futures. The following method and analysis part is the first author's description.

2.1 Approach to the interviews

The interviews took approximately an hour and took place in residents' homes. Some were preceded by residents filling in reflection booklets ahead of the interview in order to become aware of the topic, which made experiences and practices relating to air easier to discuss (Sleeswijk Visser, Stappers, Van der Lugt & Sanders, 2005). During the interview, I asked residents to explain what they filled in and I then asked questions about it. The structure of the workbook followed the path of expression and also alternated between Make, Say and Do. The interview concluded with a Dolls' house toolkit which the residents used in order to create and express desirable futures. The other, more exploratory interviews started off by covering past and present experiences using stimuli like a timeline, ambiguous pictures and prepared questions to induce stories and memories. Future scenario statements were presented to uncover what residents consider important or desirable for the future. A statement was for example "with a heat pump it is efficient if the temperature is constant and not too high, for example, 21 degrees". These interviews concluded with a home tour, where residents often shared anecdotes about how they manage indoor comfort. In the interviews with residents living in ZE houses, I used statements on current life rather than future scenarios to find out what the residents regard as normal. Information that addresses or challenges people's beliefs can support them in critically reflecting on practices and revealing thoughts (Scott, 2008). A statement was for example: "I always open the window, because it makes me feel more connected to outside".

2.2 Participants

Eleven residents took part in the study. Interviewees differed in age, gender, living situation and type of property (Table 1). Having a diversity of residents participate supports observing a variety of configurations of a practice (Kuijer, 2017). The visited properties were equipped with different ventilation technologies (Table 2). By visiting residents living with different material, I could study to what extent the material influences the practices.

Table 1 Overview of 11 residents interviewed and their housing, gender and living situation

Nr	Set	Age	Gender	Living situation	Sort of property
1&2	Explorative	± 35	Male&Female	Couple	Two story house
3	Explorative	± 40	Female	Alone	Zero energy ready apartment
4	Explorative	± 55	Female	Alone	Zero energy ready apartment
5	Explorative	± 45	Female	With adult son	Zero energy apartment
6	Explorative	± 67	Male	Alone	Zero energy apartment
7	Explorative	± 40	Male	Partly together	Zero energy apartment
8	In-Depth	22	Male	Alone	Student studio
9	In-Depth	27	Male	Alone	Student studio
10	In-Depth	23	Female	Alone	Student studio
11	In-Depth	19	Female	Alone	Student studio

Table 2 The visited houses and their different material for ventilation

Zero energy	Zero energy ready	Student Studio	Two story house
Well insulated	Well insulated	Well Insulated	Poor insulation
Apartment	Apartment	Studio	Two story house
Balanced ventilation with heat recovery	Mechanical exhaust natural supply	Balanced ventilation with CO2 and humidity sensors	Minimal mechanical extract, natural supply

2.3 Analysis

The analysis combined qualitative data of both the explorative and the in-depth interviews and used visual thematic clustering (Figure 1). The sense-making moved along the DIKW dimensions (Ackoff, 1989): from data to information to knowledge. The qualitative data set, gathered in interviews, included pictures, reflection booklets and transcripts. To turn this into information, I read through the transcripts, marked interesting quotes and wrote their interpretation on post-its. Thereby, I gave it an interpretation and attached meaning to it. Thereafter, I moved towards the level of knowledge and clustered and sought for patterns. In clustering, I kept in mind practice theory and grouped insights into the different elements: images, material and skill. Intermittent with this individual analysis, I organised team sessions in which all the authors reviewed the results. From the analysis and these sessions, key guiding ideas were derived that served as input for design directions.

Figure 1 Visual thematic clustering of insights

3. Results

Residents of ZE (ready) housing struggled to incorporate the balanced ventilation system in their practices, because it is difficult to understand what the system does and hard to develop trust in the system. This disintegration in practices is a key finding, considering that ventilation becomes increasingly important with houses that become more airtight. The ventilation system is of great importance for comfort, health, and energy.

3.1 Associated practices

The practice of maintaining indoor air quality is interconnected with many other practices (Figure 2). Showering, cooking, drying laundry and cleaning are polluting and causing an increased need for air. Sleeping and cleaning are associated with the need for fresh air. Furthermore, images are linked to the following practices: maintaining a comfortable indoor climate, managing energy loss through windows, managing energy bills and keeping the house safe. The insights are clustered into material, image and skills to maintain indoor air quality.

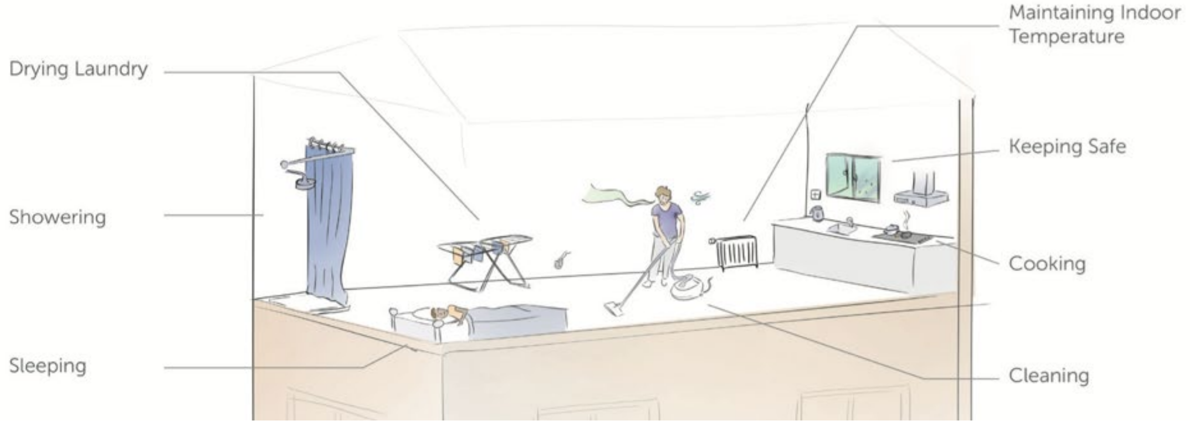

Figure 2 The practice of maintaining indoor air quality is connected to many other practices

3.2 Insights related to the material to maintain indoor air quality

In non-refurbished housing, the following material supports maintaining indoor air quality: windows, doors, the extractor hood, cracks, trickle vents, ventilators, air fresheners, and plants (Figure 3).

1. Windows, trickle vents and doors are regarded as the most obvious and important materials to ventilate.

In non-refurbished housing, cracks create uncontrolled ventilation with the outside, which is often unnoticed by residents. With refurbishments, material changes. Improved insulation makes uncontrolled infiltration impossible. Furthermore, new material like supply and exhaust channels, a ventilation control panel and sensors are installed (Figure 3).

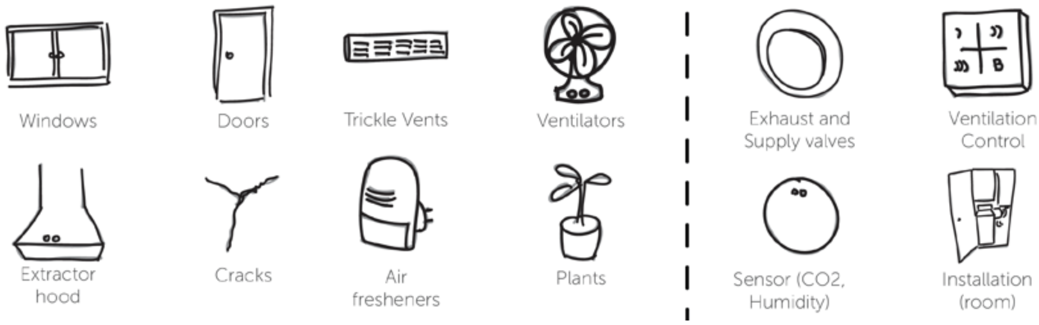

Figure 3 *First columns: ventilation material in pre-refurbishment housing. Last two columns: ventilation practice material in ZE (ready) housing.*

The interviews with the residents showed that those living in refurbished, ZE housing felt that the system's feedback and feedforward poorly communicated system functioning and its functions (Figure 4).

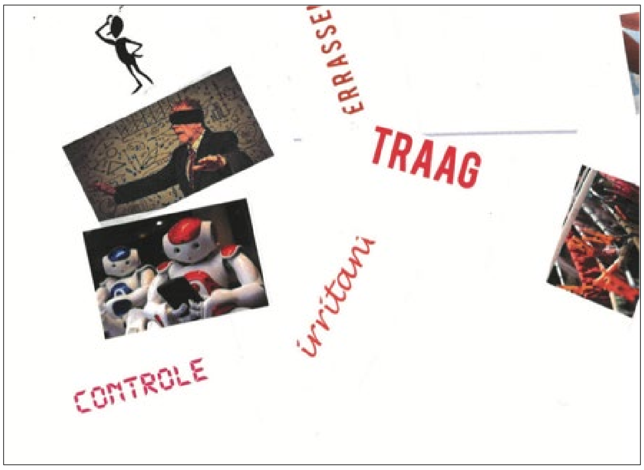

Figure 4 *A collage from a reflection booklet showing annoyance and insecurity about the ventilation system, described as slow, unexpected, irritating and lacking control.*

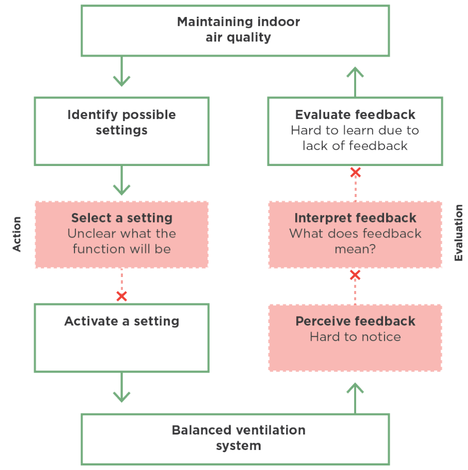

Figure 5 *Seven-stage action cycle to operate a balanced ventilation system*

To analyse the operation of the ventilation system in a ZE home, I applied the model of Norman (2013) (Figure 5) describing the use of products in action cycles. On the action side, residents struggle to select a setting. In the ZE homes visited, residents have to choose from 1,2,3 and boost (Figure 7). Residents have to learn the settings and when to use them. In interviews, they often recalled the instructor who had explained the system to them. Residents that had automatic ventilation combined with a boost control were insecure about what the control did. This also had to do with the system's feedback, because it is difficult to perceive what the system does and therefore hard to evaluate the performed action. Overall residents feel insecure and frustrated when selecting a setting (Figure 4). Due to lack of feedback residents lack trust in the system's functioning.

> "As Sue [the instructor of the system] said of course, I have to keep it on level two; she mailed what the impacts are on air quality. So now I put it on three when cooking."

> "But it is unclear what it is doing, really. They say that it will turn on if you press the control once and increase intensity if you press twice. Maybe you can also turn it off using the control, but I don't know about that."

Figure 6 The installation room in a ZE house. It houses the equipment, but is a black box to residents.

Figure 7 Selecting the function suitable for the situation: no indication of the setting the control is currently on.

2. Residents often rely on natural ventilation, because they perceive the effect better

It is difficult to sense an effect with balanced ventilation. Linking back to the seven stages of action (Figure 5) (Norman, 2013), natural ventilation allows for an evaluation phase by feeling the airflow and lower temperature of incoming air. With balanced ventilation evaluating the effect of the action is difficult because no temperature difference or airflow is felt. The system does not compensate for the lack of natural feedback.

> "But if it is warm and a bit stuffy I would rather open a window, because it feels like it has a quicker effect. I would not press the button."

3. The new installation room is a technical black-box to residents

To fit all equipment belonging to ventilation and heat pump an installation room is made on the balcony of ZE houses (Figure 6). Although the room is part of their house, it is not designed for resident interaction – yet they are expected to clean the filters.

> "Where that technical stuff is, no girl. That door remains closed... I don't have anything to do with that".

4. Residents do not realize the impact an air-tight house has on ventilation

With refurbishments houses become air-tight, therefore ventilation becomes increasingly important. However, some residents did not seem to be aware of this change. One resident of a ZE home mentioned rarely opening a window and had the ventilation on a low setting. This is not healthy due to the increased air-tightness of the house.

3.3 Insights into images related to maintaining indoor air quality

Indoor air quality is something most residents are hardly mindful of: air is always there. Only at the moment of entrance, people are briefly sensitive to it. Also when signals like damp, smell and warmth are felt, residents become aware for a short period. Sometimes they take action to improve indoor air quality. In the absence of signals, people generally quickly adapt and forget about it.

1. Quality of indoor air felt to be important for health

Residents mentioned sufficient oxygen and the right level of humidity as important for their health.

> "Yes air is important for my health, for example, sufficient oxygen is necessary to live."

> "Since I have skin problems it is very important for me to have fresh air. Not too damp, not too dry air. Well, just nice and fresh."

2. Good indoor air quality is felt to bring comfort

Mainly unpleasant smells were mentioned to decrease comfort. Residents also recognize that pollen and a lack of oxygen can make them feel less fit (Figure 8).

> "That window is open all day, because it will get damp and smelly if I don't. And well, I don't like that of course"

Figure 8 This collage expressed discomfort from indoor air quality as feeling tired and sneezing from pollen

Figure 9 This collage from a resident shows she wants to be able to feel the air like with an open car window

3. Maintaining quality of air is connected to energy consciousness

By ventilating through windows, heat is lost. Therefore, for residents it is associated with energy consciousness.

> "And if it then gets really cold actually, I close the open windows on both sides. Because you would be heating the outside air if you didn't."

4. Air quality is important during sleeping

During sleep residents find ventilation important, not only to have healthy air but also to have comfortable cool temperatures.

> "If I go to sleep, I always find it pleasant to open a window. To notice a bit that there is fresh air coming in"

> "Yes, I indeed always have my bedroom window open. Yes, I find it.. I like it better if it is nice and cold than when it is hot in the bedroom."

5. The practice of maintaining indoor air quality is part of a tradition

Residents perform practices as part of a tradition.

> "My mother told me open the window and exchange air. I was told."

6. Air from outside is considered as healthy and feels pleasant

> "Well, I do really enjoy the air from outside. The smell and the freshness of the air. And usually I don't like the airco. Maybe they could fake air at the window, but I can't imagine that would work."

> "I find it pleasant that even when the window is closed semi-fresh air is coming in with the ventilation system. But well, I do notice that it is a different experience in my room, when the window is open. "

7. Increased insulation and balanced ventilation restrict the feeling of being connected to outside

Sounds, air, and smell make residents feel connected to outside. Due to the mechanical supply of air and insulation, this changes: residents hear fewer sounds, smell less and feel less of the airflow.

> "At (X's) parents they have insulated the place so incredibly that it seems like you live in a vacuum. I think ...you do have to hear something from outside. To have a bit the idea, at least I find it pleasant to have the idea that things are happening around me..."

8. Air from balanced ventilation feels less clean because it is indirect

> "Well, with ventilation it is like there is old air circulated in the room. While with an air grill, you know it is air from outside. So maybe an air grill would give me a fresher feeling."

9. The ventilation system is sometimes regarded as a waste of energy

Residents with automatic ventilation mentioned they find it unnecessary that the ventilation is always on. They regard it as a waste of energy when they have their windows open or when they are not at home.

> "I think it is wasteful that it is always on and that you can't control it the moment you want to, that is a waste of energy. On those moments when I am not here, the air here does not have to be ventilated."

10. In one moment a breeze is experienced as pleasant, while it is unpleasant at another moment

In some moments residents enjoy the feeling of incoming air: the movement and its temperature. However, at other moments residents experience the same breeze as an uncomfortable draught.

11. Outside air has more positive associations compared to balanced ventilation

> "They say that you can leave the windows closed in summer, in theory, that sufficient air is coming in. But personally, for my own feeling it is in some way nicer to have the window open. Not needed, but well..." (Figure 9).

3.4. Insights into the skills needed to maintain indoor air quality

Typically, residents act upon indicators of pollution. Pollution motivates residents to do something about indoor air quality. Pollution is often hard to sense, only if there is a direct comparison (e.g. when entering a room). Residents with natural ventilation make use of the following skills: creating airflow, balancing noise pollution and the need for fresh air, and balancing fresh air and a comfortable indoor climate. When equipped with balanced ventilation after a refurbishment, residents need to develop new skills to select settings, manage energy usage of the system, clean the filters and limit heat loss through windows.

1. Using ventilation control is bothersome and confusing

Once ventilation controls are installed during refurbishment, they should be discoverable and learnable for residents and they should be able to develop practices incorporating them. In the visited ZE homes residents had to decide whether setting 1,2,3, or boost is proper for the situation (Figure 6). Setting '1' is intended for situations where residents are not at home, however, residents tend to select this setting because they assume that it is more silent and energy-efficient. The control demands of residents to recognize situations with an increased need for air. When there is a party, for example, residents should increase ventilation. Residents have to learn these situations by themselves. This knowledge is not required for residents with automatic ventilation. However, it is unclear for those residents what the boost does and how long it is active. They also doubt how manual control and automatic function together. They are insecure about whether they should take action.

> "Here, it has apparently, an orange light could come on and that should mean that air quality is poor I believe. But I am not sure whether I have to turn the ventilation on myself, or whether that happens automatically."

2. Residents doubt systems functioning because they are unable to perceive it

Feeling the decrease of temperature and airflow are means to observe ventilation through windows. Both means of feedback are absent in the balanced ventilation system. As nothing makes up for this feedback, residents doubt the systems' functioning.

> "yes, then I put it to level three, but you don't feel anything from that"

> "Here is the ventilation control. There, I pressed it. I hope it works, but I do not know, really"

3. Residents lose interest because they experience a lack of control

Residents experiment with the controls at the start, but if they do not perceive changes or the system does not meet their wishes they lose interest (Figure 10). The ventilation system will continue to work, but residents only incorporate natural ventilation in their practices.

> "and you get used to the way it is. At one point you just accept the way it is. I have researched the system and tried what I can do. It ends at one point and then you make time for other things."

Figure 10 In the interviews this resident showed the control. She had lost interest and placed a clothes rack in front of the ventilation control

Figure 11 Residents are expected to clean the valves. But cleaning them without adjusting configuration or mixing up valves is a challenge

4. Residents are not as careful with the configuration of the valve as the design demands

The configuration of the valves is very delicate and specific for the room where it is installed because it determines the amount of air being added. Residents are unaware of this. Besides, they are expected to clean them. By cleaning the configuration can accidentally be adjusted and during cleaning, valves from different rooms can also be swapped as valves of all rooms look similar (Figure 11).

In the interview, one resident said that he sometimes completely closes the valves of the ventilation to decrease noise pollution.

> "For example, when my mother comes to stay for the night. She is annoyed by the noise of the system, so then I sometimes rotate it to close it off."

3.5 Synthesis

A lack of system feedback, unfavourable associations and unmet needs currently lead to the fact that residents are unable to integrate balanced ventilation sufficiently into their daily practices. Due to the lack of feedback that the new material provides, the ventilation system is experienced as a black box. Residents become insecure about the systems functioning and as a result of the poor feedback residents lose interest (Figure 10). Besides, residents hold associations which make transitioning practices more difficult. For example, they regard air from ventilation as less fresh, because it is indirect. Also, ventilation is associated with high energy consumption, rather than saving energy. Furthermore, the new system does not meet the desire to feel airflow and the need to feel connected with outside. The experience of balanced ventilation should match residents' needs. As long as it does not, they are likely to use the windows. To summarise: the lack of trust in the new systems and of understanding of the system's functioning is caused by a lack of system feedback (Figure 12)

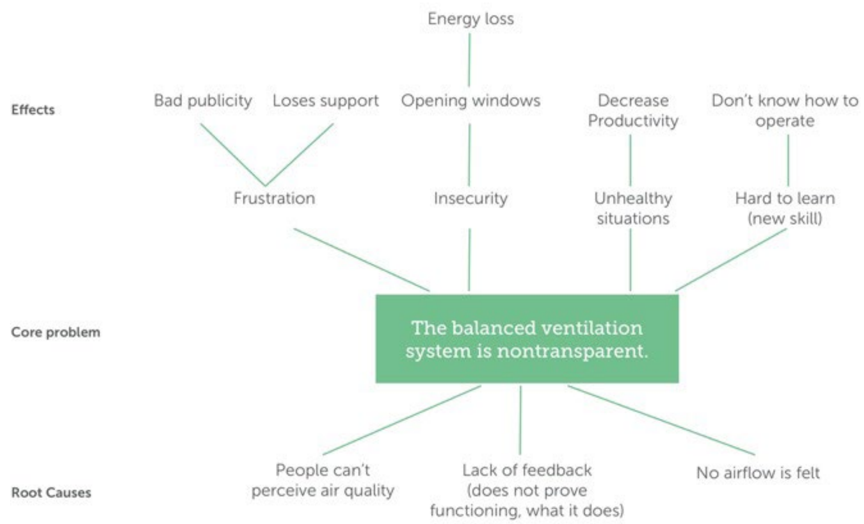

Figure 12 Problems summarised: a lack of feedback is a root cause of the system's non-transparency.

3.6 Design directions

In order to target the key issues of trust and understanding, particular images and skills are targeted that could be evoked when the overall goal is to support residents to integrate the new ventilation system (material) in their practices (Figure 13).

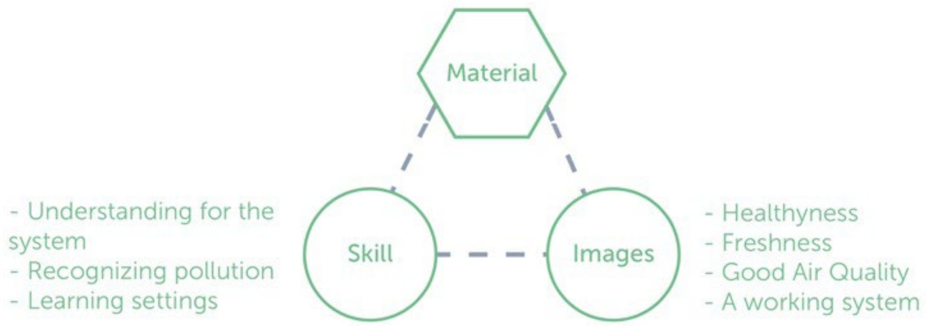

Figure 13 Targeting trust and understanding: images and skills that could be evoked. The overall goal is to support residents to integrate the new ventilation system (material) in their practices. Image adapted from Shove and Pantzar (2005).

Feedback is not only considered as feedback on action, but also a general proof of functioning and air quality.

In the following, a number of examples illustrate design directions how ventilation feedback and transparency could be embodied in the home context to improve trust and understanding.

Audio Feedback

This example welcomes the resident with a breeze to foster associations that the system is present and healthy. Audio feedback is used to communicate what the system is doing (Figure 14).

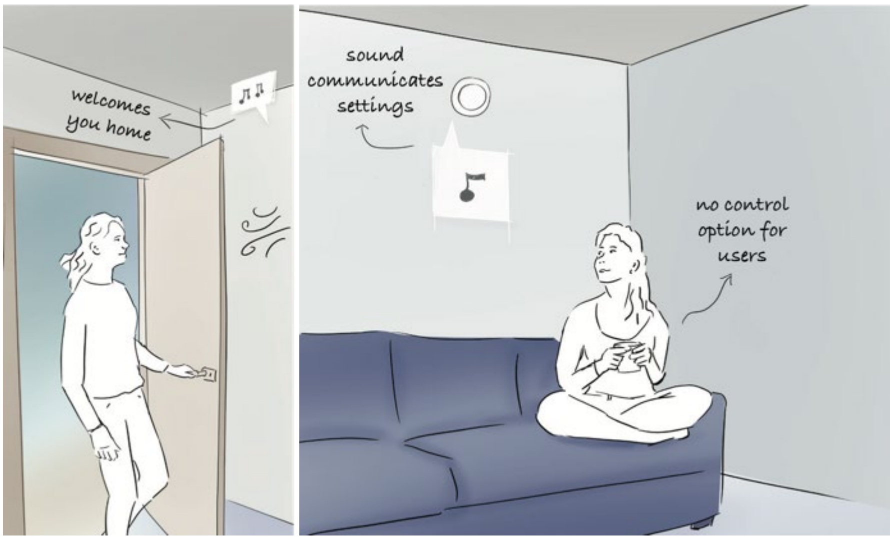

Figure 14 Welcoming the resident with a breeze to foster associations that the system is present and healthy.

Smart Doors

This example uses the doors to provide information on indoor air quality. Residents can access more information in a second layer of information. Information on air quality proves the quality of air and supports learning about pollution (Figure 15).

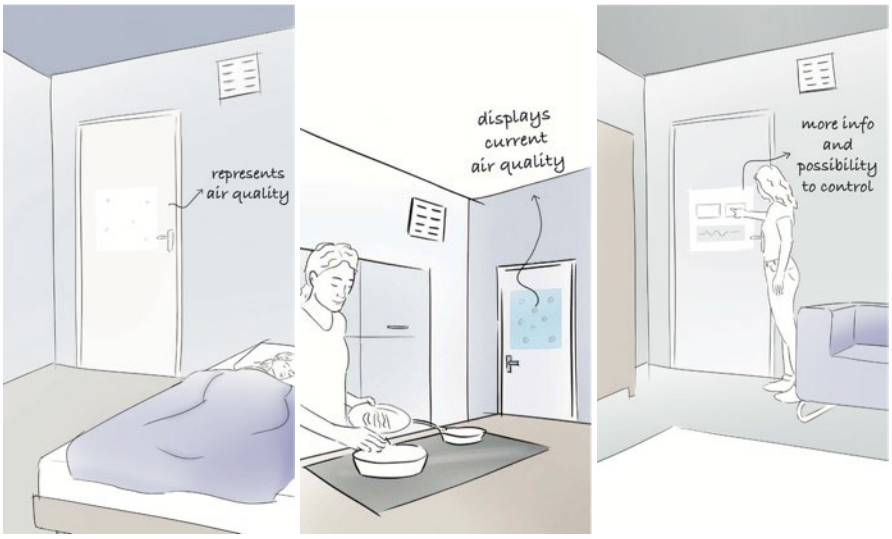

Figure 15 Smart doors to provide information on indoor air quality.

Visual Supply

This example uses the supply valves to prove the system is working and show what it is doing. Through increased trust and understanding for the system it supports integration in practices (Figure 16).

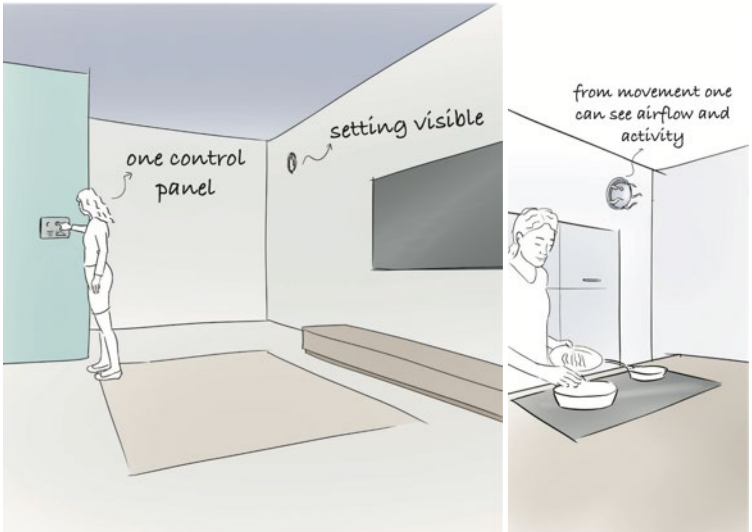

Figure 16 Using the supply valves to prove the system is working and show what it is doing.

Feedback Valve

This example shows that the need to clean valves could be indicated right at the place of the valve itself. Additionally, the valve could be designed in such a way that it can only be re-mounted after cleaning in the way that provides the right amount of air. Showing the need to clean can help residents develop a practice around it like cleaning curtains or windows (Figure 17).

Figure 17 Indicating the need to clean valves right at the place of the valve itself.

4. Discussion

This study investigated residents' ventilation practices to identify starting points for supporting residents to transition their practices in ZE homes. We have shown an example of how a practice-oriented research approach (Shove & Pantzar, 2005) reveals a lack of system feedback, unfavourable associations and unmet needs. An added detail analysis of system operation (Norman, 2013) adds understanding to the practices perspective of where the breakdowns occur that impede integration of new systems in residents' lives. Lastly, we provide exemplary design directions to better support resident practices. Based on these findings, future research may need to start by engaging with residents' existing and potential practices and then designing system behaviour change to correspond with that, rather than the more common approach in this domain of designing home systems and then resident behaviour change.

Studying practices in field research revealed that residents struggle to develop new practices that incorporate the balanced ventilation system. We described the associated practice of maintaining indoor air quality in order to identify points that hinder a transition of the practice. We found the lack of feedback makes residents insecure and makes it hard to understand the system. Besides, associations that are mismatched with the new material make residents reluctant to use balanced ventilation systems.

In addition to the analysis, we proposed design directions to illustrate how feedback could be improve and desirable associations with the ventilation system fostered. This could help residents trust that the system is working, understand what the system does and develop appreciation for it. The design directions could serve as input for the design of new product-service-systems and the design of touch points for them. Ideally a ventilation system should be self-explaining, because owners and residents change and there is often no introduction or manual available.

We have seen that the design directions involve modifications to installation components such as valves, which also has implications for the system balance as a whole. It is important to get stakeholders like general contractors and installation components manufacturers excited about the potential of solutions in this domain. The design directions developed in this project so far only address understanding and trust of the system, but even more links could be made between the technical functioning of systems and practices and positive experiences at home.

In conclusion, both the design directions and the insights generated can contribute to a transition of residents' ventilation practices in ZE homes. Overall, the study shows that studying practices helps design better home systems. The generated insights about ventilation practices could be used by general contractors to design the touchpoints and communication in the ZE refurbishment process. Besides, ventilation component manufacturers could use design directions as input for the design of future ventilation systems. In this way, the study supports residents to transition practices in both current and future systems.

Hence, it can contribute to decreasing the performance gap (Behar & Chiu, 2013; Paone & Bacher, 2018) and increase residents' comfort after a refurbishment.

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