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Data encounters in renovated homes: Sense-making beyond displays

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Abstract. There is an increasing acknowledgement of the role of residents in the success of low- or zero-energy renovations. One of the approaches to improve this factor is by influencing resident behaviour by means of devices for feedback on consumption. The goal of these systems is to help residents make sense of the relation between their actions and choices, and their energy consumption, indoor environmental conditions and comfort. In this paper we describe interactions with these devices as one form of data encounter. We then suggest that there are other forms of data encounters already happening in renovated homes by which residents make sense. These data encounters are useful to understand if we want to understand the interactions between residents and buildings. We introduce the concepts of sense-making and interactive adaptation to better understand these data encounters. In this study we show data encounters in various forms as they happen in four renovated homes in the same building in the Netherlands. We use interviews and video-recorded walkthroughs to identify data encounters related to indoor climate and energy consumption within these homes. We find data encounters that involve more than displays and technical devices. Residents use bodily senses, information from other people, and complex contextual information to understand indoor climate and energy consumption. We also find that data encounters relate to, and are embedded in everyday practices and routines. Finally, we find that data encounters involve active sense-making rather than passive consumption of information. We discuss these findings and conclude by suggesting that existing data encounters could serve as a starting point for the improved design of buildings, renovation processes, and the selection, design and implementation of new data encounters.

Keywords. Occupant behaviour, data, feedback, renovation, sense-making, design, home energy management systems
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1. Introduction

There are a lot of unknowns concerning the interactions between residents and buildings, including about how resident behaviours change in response to feedback.

Although measures to improve the efficiency of buildings (e.g., renovations with heat pumps and improved insulation) have made great progress, a performance gap remains between expected and actual energy performance. Increasingly there has been an acknowledgement of the role of residents themselves in the performance of buildings and achieving actual energy savings [1]. The impact of occupant behaviour is significant, with potential energy savings of 62-86% in residential buildings [2].

This realization of the role of residents has spurred a wide variety of approaches to better understand this behaviour, including profiling of households, and the recording and modelling of this factor [3,4].

In addition, attempts are made to influence resident behaviour. This includes instruction of residents after the renovation by means of a manual, energy advise by professional energy advisors, and behavioural change programs [5].

1.1 Feedback on consumption

An increasingly popular way of influencing resident behaviour is by means of feedback on consumption within the home. This includes various forms and guises of eco-feedback: smart meters, smart thermostats, home energy management systems (HEMS), and in-home displays (IHD's), feedback

communicated to the user, e.g., by SMS or email, or made available on website. Sometimes these eco-feedback solutions go under the name of energy monitors, dashboards, or are embedded in smartphone applications. This eco-feedback is sometimes enriched with various forms of visualization, enables the setting of goals, or employs gamification approaches to achieve energy saving goals [6,7]. Finally, they sometimes include a component of social interaction, by e.g., ranking and comparing consumption within a neighbourhood [8].

The goal of these systems that are introduced is to help residents *make sense* of what is going on. This sense-making is expected to *relate energy consumption, indoor environmental conditions and comfort* to *choices or actions*. The expectation is that residents use some form of data or feedback, visualized or presented, to 'gain insight into, and control over, a household's energy consumption'[6]. Underlying assumptions are that households as end consumers of energy, make informed choices in everyday life, ultimately with the goal of reducing energy consumption. These systems often envisage householders as managers of resources [9] who, with the right information might be persuaded towards sustainable behaviour [10].

These interventions have reached varying degrees of success [11]. In particular in the long term, sustained energy savings are not guaranteed, and users may react in unexpected ways, generating undesired consequences such as cold homes or increasing levels of consumption[12]. The disappointing results of in-home displays even led researchers to urge the UK government to reconsider introduction of in-home displays [12].

Several reasons have been given for this lack of consistent success. Authors point to a lack of understanding, and design for, user engagement with these systems [12], and a lack of understanding why people would be interested in the feedback in the first place [13].

Despite the lack of consistent results, authors agree that, if well designed and implemented, there is a high potential in feedback on consumption to lead to changes in resident building interaction which improves comfort and energy savings in homes. This potential stems from observations that energy end-users are able to and willing to change behaviour (such as operating windows) if it is convenient and makes sense to them in everyday life [14].

1.2 Feedback as data encounters

Interactions with feedback systems are an encounter between residents and one very specific type of data: numbers or graphs indicating consumption of resources. However, in everyday life, residents encounter a lot of different forms and types of data or information. Some of these encounters have an impact on everyday practices: Looking out of the window to see the weather might influence one's decision to bike to work. And, less consciously, one might encounter the smell of a nearby restaurant, have increased appetite, and have lunch earlier. Some of these encounters do not give feedback on consumption of resources, yet have a significant influence on the consumption of resources and on indoor climate. One can think of opening windows as a response to smell, changing clothes in response to weather forecasts. We will call these moments of feedback related to indoor climate and energy consumption: *data encounters.*

The research question of the study reported here is: What data encounters related to indoor climate and energy consumption are currently happening? The aim of the study is to show data encounters in various forms as they happen in renovated homes, without the intervention of newly introduced interventions such as HEMS. This contributes to a better understanding of interactions between buildings and residents, which is a crucial aspect of the energy performance of the built environment.

A better knowledge of data encounters could impact the design of renovated homes by finetuning our expectations of resident behaviour in response to various design decisions (e.g., making the state of a ventilation system audible). In addition, this knowledge allows us to better select, design and implement new data encounters; both by designing essential ones (e.g., on thermostats or maintenance) and by introducing additional systems such as HEMS, smart meters or otherwise.

To answer the research question, we select some concepts pertinent to interactions between buildings and residents. We use these concepts to analyse interview data from four zero-energy renovated households. The results will show that data encounters are diverse, are embedded in everyday life and routines, and are active

1.3 Sense-making and interactive adaptation

Sense-making and interactive adaptation are two concepts that are presented and have been used in the past to understand interactions between residents and buildings, in particular data encounters.

The concept of sense-making has been used to understand how residents respond to information such as energy use feedback on HEMS [15]. Sense-making concerns how meaning and understanding is gained in action and interpretation, while also incorporating existing knowledge gained in the course of everyday life [16]. Three interrelated processes have been identified in literature, that together constitute sense-making. *Noticing:* something that interrupts ongoing activities and habits and triggers the need for further interpretation. *Interpreting:* The active process of drawing on different sources to form a more

complete sense of the situation. And *enacting*: acting on this more complete understanding. In this study, we use this framework to identify sense and categorize sense-making activities.

Interactive adaptation is a concept that has been used to understand occupants behaviour and perceptions regarding comfort and control [17,18]. The framework sees comfort as something that residents *achieve* in interplay with heating and cooling systems, and as part of other household practices such as cooking, washing and cleaning [19,20]. For this study, this means that we will look beyond system control actions of residents (e.g. turning up the thermostat), and pay attention to other daily practices that relate to and have an impact on indoor climate (e.g., cleaning or letting pets out).

2. Research methods

In this study we take a qualitative and ethnographic research approach to answer our research question: What data encounters related to indoor climate and energy consumption are currently happening within renovated homes?

2.1 Building and participating households

The building is located in the South-West of the Netherlands. The post-war industrialised housing is renovated around 5 years prior to this study, according to a zero-energy scheme, with solar panels powering electric heating. The building is social rented housing, and contains 12 apartments. This study includes four of the households within this building. Three of these households are single person households of age between 22 and 65, and one four-person household, all living in similar apartments of approximately 55 sqm.

The building is outfitted with a geothermal heat pump in a cascade-setup. Heating is delivered using a low temperature scheme, manageable by a simple thermostat, without clock-functionality. A generic ventilation control panel controls the mechanical heat recovery ventilation system. The building is highly insulated using triple glazing.

Some problems of the building are known: it tends to overheat on hot days, some of the households were unsatisfied with the heating performance of the low temperature heating, the installed climate management systems had small and bigger technical issues, and some households experienced general problems after the renovation such as leakage.

2.2 Data collection

We conducted semi-structured interviews (with the initial goal to explore occupant experiences and practices, and in relation to a larger study that monitors building performances). The interview included a walkthrough. A walkthrough is a method where residents guide the researcher through their house and provide descriptions and re-enactments of actions and practices related to indoor climate management and consumption. This technique has been introduced as a situated and embodied activity that enables users to participate in understanding and communicating their daily practices [14,21]. All interviews and walkthroughs were digitally recorded and transcribed for analysis.

2.3 Data analysis

Transcripts and video recordings were analysed by the authors, with the aid of Atlas.TI software. We identified data encounters by verbal mention of, and photographic evidence of sources of information that played a role in *noticing, interpreting* and *enacting*. We paid special attention to information related to indoor climate and energy use, commonly found in HEMS (like electricity usage, temperature and indoor climate) but were also attentive to secondary factors that might directly influence these (e.g., air flows). This would also include aspects like maintenance (of filters, e.g.,) as these aspects influence energy consumption, and might be concluded from HEMS as well. The authors listed, and clustered the data encounters using a bottom-up clustering approach. This resulted in 103 data points, with some overlap. The results section describes the most illustrative data encounters, after which we illustrate key findings with participants quotes and pictures.

3. Results

We have introduced the concepts of sense-making and interactive adaptation. In line with these concepts, we analysed the data and present it below. Sense-making includes processes of *noticing, interpreting* and *enacting* [15,16], which we identify in the data. In line with interactive adaptation [19], we look at how these data encounters relate to *daily practices*. This relation to daily practices is particularly present as a consequence of sense-making, and thus found in the process of *enacting.*

Below we present a selection of illustrative data encounters. We also identify possible effects of changes in daily practices in terms of their effects on indoor climate, comfort and energy consumption.

Tab. 1 – Data encounters involving technical devices.

Noticing	Data involved	Interpreting	Enacting	Effects
Turning the thermostat up to 21, each time before the grandchildren arrive for their weekly visit.	Temperature displayed on thermostat in the day that follows the action.	The heating system isn't able to heat the apartment to 21 degrees.	Leave the thermostat to 20 degrees	No change in energy consumption (if it does not reach 21 degrees), dissatisfaction with renovation
Opening cupboard door to view energy meter. Temporarily disabling Christmas lights	Energy consumption numbers on smart meter	Christmas lights consume more energy than expected	Turn off Christmas lights when resident is not present in living room	Reduction in energy consumption

3.1 Technical devices

Data encounters involving technical devices, like displays and thermostats, played a significant role in sense-making processes. (Table 1) shows some examples and their effects. One of the residents explained how she wasn't able to provide her grandchildren with the indoor climate she thought they needed. *'The thermostat just doesn't get to 21'.* In this case, the thermostat was particularly present as a display that shows current temperature in relation to set temperature. For this household, the data encounter was *noticed* as it was part of her preparation for the arrival of her grandchildren. It was particularly meaningful as it related to her frustration of not being able to have variable indoor temperatures (lower when she is alone, higher when her grandchildren are present).

Another data encounter was between a resident and the numbers on the energy meter. She explained how she went actively investigating to reduce the consumption of her Christmas lights. In this case her *noticing* followed from her own investigations. *"And then I thought "what the hell?" and then I'll go and see what's going on that I don't need. You know what I mean? Then I'll go and investigate."*

The insight from these data encounters with technical devices is that they enabled sense-making if people actively engaged with them (by opening a cupboard door and turning lights temporarily off), or if they disturbed *practices* related to values important to the resident (caring for her relatives).

3.2 Bodily senses

Data encounters that involved bodily senses featured prominently in the data (Table 2). Sometimes residents directly sensed the state of the indoor climate, such as temperature. Other data encounters that we found included *noticed* sound. One of the residents explained why he *interpreted* the mechanical ventilation system to be not working properly, and why he thought this led to his occasional shortness of breath. He referred to the sound it makes at different locations in his home. *"It is set to only properly extract in the bathroom. You hear nothing in here [the living room]"*.

Another resident noticed how she couldn't sleep with the traffic sound from a neighbouring street and therefore *enacted* her sense-making by closing the windows at night: *"It's quite a busy street, so that's something I hear".*

When asked about how she deals with hot days, one resident explained how she moved her hands across

Tab. 2 – Data encounters involving bodily senses.

Noticing	Data involved	Interpreting	Enacting	Effects
Sound from outside disturbs sleep with windows that are open for fresh air	Sound from outside (traffic)	Sound level is too high to fall asleep	Closing the window at night	Reduced thermal comfort (less 'fresh air')
There is a difference between sound levels in bathroom and living room	Sound levels emitted from air valves	The mechanical ventilation system only properly works in the bathroom	None	Reduced resident satisfaction
Dry throat	Waking up with a dry throat	The air is dry	Opening more windows during the day	Possibly increased in consumption because of heat loss through window
Felt airflows	Airflow on hands when put above convector	Convector fans are cooling	Turn the convector fans on when feeling hot	Slight increase in thermal comfort, negligible energy consumption of fans

Tab. 3 – Data encounters involving extended periods of time

Noticing	Data involved	Interpreting	Enacting	Effects
Clothes dry quicker than expected	Drying clothes feel dry to the touch	The air in this apartment has low humidity	None	None
Temperature does not increase while thermostat is set to 24 degrees for multiple days or weeks	Bodily sensed temperature and reading on thermostat over extended periods	This apartment is not heating as expected, it cannot reach the set temperature	Thermostat set to 24 degrees permanently, managing climate by electric heater & operating windows	Increased energy consumption, lack of thermal comfort

the convector panel and thereby *interpreted* the convector fans to bring some cooling (Figure 1).

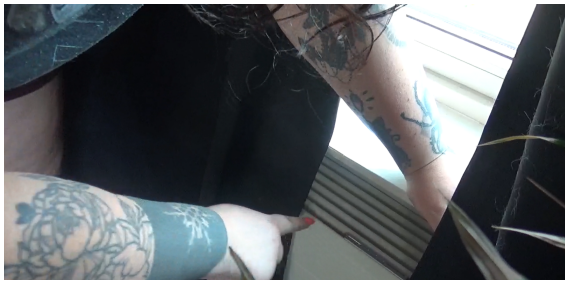

Fig. 1 – Residents notices air flow with hands.

In addition, some residents *interpreted* dry throats and headaches as results of bad indoor air quality. Multiple residents explained how they opened windows to counter these effects.

The insight these data encounters bring, is that bodily senses were found by residents to result in highly trustworthy data, both to evaluate indoor climate, and to actively investigate the working of systems.

3.3 Extended periods of time

Sense-making doesn't just happen at one point in time. Often residents *noticed* data for extended periods of time (Table 3).

Residents were involved in data encounters that required repeated checking (of e.g., how dry clothes feel) and thereby *interpreted* the air quality in the apartment. This data encounter was significant to household practices as it reconfigured existing routines of clothes drying (drying for shorter periods).

Other times, the sense-making started with *enacting* change (setting the thermostat to 24) and not getting the expected response. *"When I sit down it's cold. When I work it's also cold."*. This required the family to keep an eye on the thermostat for longer periods of time and repeatedly *enact* their sense-making by turning the thermostat wheel to *notice* the set point.

The resulting insight from these observations is that sense-making can be intensive in terms of cognitive requirements. Residents rely on their memory of data encounters over extended periods of time to make sense of the state of their home. Another insight concerns the *effects* of sense-making over extended periods of time. With longer periods of *enacting* change (e.g., keeping the thermostat to 24), the effects on aggregate energy consumption increases. Additionally, when resorting to managing indoor climate by windows, the thermostat as a control device might well be forgotten and remain on a high setting, even when no heat is required.

3.4 Social situations

Interviews with the residents reveal that sense-making often involves other people and social dynamics (Table 4). The parents within the four-person household were increasingly worried about the health of their kids, when they *noticed* their coughing, and *interpreted* this as underheating of the apartment. *"I always think: are they cold or not? So they don't get sick."*.

Another resident knew about herself that she preferred lower temperatures, but *noticed* her guests mentioning they were cold. The small size of her apartment, and the slow cooling due to the high insulation values, motivated her to not immediately change her *practice* of keeping windows open. She

Tab. 4 – Data encounters involving social situations.

Noticing	Data involved	Interpreting	Enacting	Effects
Kids cough	Coughing repeatedly	The apartment is too cold for the health of the children	Getting and using an electric heater	Increased energy consumption
Visitors mention they're cold	What visitors say, thermostat setting and temperature.	The apartment is cold for others	Offer a blanket, and close windows if repeated	None, thermostat set point is not raised.

Tab. 5 – Data encounters involving complex contextual sense-making

Noticing	Data involved	Interpreting	Enacting	Effects
Cat sits on convector when convector fans are on	Position of cat	The convector fans are providing some cooling	Keeping the fans on hot days	Slight increase in thermal comfort, negligible increase of consumption by fans
Discolouration of interior	Colour of interior items	Keeping the sun out keeps things looking nice	Keeping curtains closed when away during the day	Reduces chance of overheating
Mechanical ventilation valves have changed colour	Colour of valves when inspected	The ventilation system is working, and the air is unclean	Cleaning the valves at regular moments	Possibly a slight increase in ventilation performance

would first act on guests' discontent by offering them a blanket.

Social sense-making reveals that sense-making, and in particular *enacting* change in *practices* is situated within social situations. Something might not be noticed if other people don't point it out. In addition, this category reveals that divergence from social norms and expectations ('having a cold apartment') triggers *noticing* and further sense-making.

3.5 Complex contextual sense-making

As already noted in some examples above, sense-making is often not a one-stop data encounter. It can involve drawing on multiple types of data and active investigations. We have clustered these data encounters as complex contextual sense-making (Table 5).

Fig. 2 – The cat on its way to jump on the convector.

One participant told a surprising story about how she was able to *interpret* the status and effect of convector fans from *noticing* the position of her cats on hot days (Figure 2). They would jump on the convector when the fans were displacing air. Not only did this require empathy with, and understanding of her pets, she was also able to corroborate this interpretation with her own senses as described above (3.2).

This participant also explained how she gained multiple *interpretations* from one data encounter with the colour of valves. *"It's been a while. So they are not really dirty. But when I moved in, they were pitch black."* She explained that they informed her of the unclean state of the air, and of the status of the mechanical ventilation system (Figure 3).

Fig. 3 – A slightly visible change in colour of valves.

The insight from these two examples of data encounters is that sense-making can happen by drawing on multiple complex data encounters, and result in multiple interpretations with possibly diverse effects on consumption and resident satisfaction.

4. Discussion

This research has shown data encounters in renovated homes and how sense-making happens. We have used the concepts of sense-making and interactive adaptation to analyse these data encounters. We have shown how data encounters are already happening in renovated homes, even when no newly introduced systems for feedback on consumption are present.

The data encounters we discovered *involve more than displays*: Although technical devices and displays (e.g., thermostats) were certainly present, other types of data were also encountered and sometimes found to be more trustworthy. Existing literature has described the goal of HEMS and other feedback devices as contributing to resident insight into, and control over, indoor climate and energy consumption [6]. The results show that there is a wide range of other data already present residents use to gain this insight. Residents use their bodily senses, information from other people, and complex contextual information such as the changing colour of ventilation valves to gain insight.

The data encounters we have shown are not solitary moments of insight. Instead, they *relate to, and are embedded in everyday practices and routines*. Sometimes these routines are disturbed, e.g., when traffic noise forces residents to close windows they had open during nights. Sense-making is not separate from, but embedded within practices of heating: When the apartment does not get to the set temperature, residents gain insight into the limited power of the heat pump. This research also confirms insights from studies of heating practices [22] by showing how practices are altered by sense-making and are interlocked with one another: The solution of using an electric heater daily will reduce the frequency of looking at the thermostat.

This research has also shown that data encounters involve *active sense-making*, rather than just a passive consumption of information. Residents *enact* a change of thermostat set point and gain insight from that, or engage in an experiment to ascertain the energy consumption of Christmas lights. This confirms the action-oriented dimension of sense-making found in literature [15].

Future analysis would be needed to further investigate and quantify the effects on energy consumption of the described data encounters. Future research also needs to collect more insights to develop a coherent framework for the development and evaluation of effective data encounters that contribute to energy efficiency.

4.1 Implications for design

The findings from this paper can be used to advance the field of indoor climate management by informing requirements and guidelines for the design of buildings and renovations, and guidelines for the design and implementation of data encounters, as part of a renovation or introduced later.

This improved understanding of the interactions between building and residents has several implications for the design of buildings, and the design of new data encounters such as HEMS.

In order to improve the design of housing and renovations, we can design for and build on existing data encounters and forms of sense-making. This could include e.g., enhancing rather than hiding the dirty state of ventilation valves.

In addition, the disturbance in daily practices introduced by renovations might be used as an opportunity to change everyday practices towards less resource intensive ones. This can be done using consumption feedback and efforts in communication in tandem, addressing e.g., window opening practices.

Finally, we have sought to bring attention to the active dimension of sense-making. Designing encounters with data could develop this active dimension more by making insights actionable for residents (e.g., suggesting to check the status of windows when lowering the thermostat for the night).

5. Conclusions

Currently, interventions that give feedback on consumption such as HEMS are focussed on one specific form of data on a display. In this paper, we have explored how other types of heterogenous data are encountered in the home. This has provided novel insights into how data is encountered and how these encounters relate to sense-making processes. We have shown how data encounters are diverse, are embedded in everyday life and routines, and are active. This paper has also suggested that existing data encounters could serve as a starting point for the improved design of buildings, renovation processes, and the design of new data encounters. Future research is needed to analyse the effects of these encounters and develop a framework for development and evaluation.

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Data access statement

The datasets generated and analysed during the current study are not publicly available because of the time and effort required for anonymization of video recordings that include personal details and faces, but requested portions of the data will be made available upon request to the corresponding author.

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