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Monitoring the performance of a Passivhaus care home: Lessons for user-centric design

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ABSTRACT

The paper presents the results of monitoring a Passivhaus care home regarding the effect of design intentions, occupancy practices and user preferences, on building energy and indoor environmental quality performance through a mixed methods approach.

The results of the thermal comfort assessment showed that the staff is uncomfortable, while the residents are comfortable. Warm temperatures are preferred by the residents. The staff understands the needs of the residents and acknowledge the fact that their discomfort assures the comfort of the residents.

Energy usage is higher than expected. None of the daily routines required in a care home were considered in the energy calculations. The calculations were made by a team of designers, who did not know well the activities carried out in the care home. As a result, the expected performance of the building was unrealistic in terms of energy use.

The results point at the importance of taking into account the user during the design process: even though the actual needs and preferences of the occupants were not considered in the energy calculations, they were considered in the design of the building's installations. This allowed the staff to air the rooms daily without compromising the comfort of the residents.

1. Introduction

Within the building sector, one of the major challenges nowadays is seen in housing and care facilities for the older population, and specifically for people with dementia. The number of people with dementia has increased in recent years [1]. In the UK 310.000 people with dementia live in care institutions. Due to an aging population, this number is expected to rise over the next twenty years to 640.000 [1,2]. Because of these rising numbers, new care institutions are being built. These institutions need to comply with energy-efficient building regulations, and at the same time, ensure the quality of life and health of the buildings' residents. The construction of very low energy buildings (such as Passivhaus) are considered primordial to achieve global targets on carbon emissions, however, there are still large uncertainties regarding the influence of the user on the building performance, and the effect of building technologies on users' comfort and quality of life [3,4]. The introduction of innovative energy-efficient technologies in buildings can pose challenges to the users, since the interfaces are often too complex, and buildings might need specific control strategies, which are unknown to the users [5–7]. This can lead to higher energy use than expected, as well as to suboptimal indoor environmental conditions.

This challenge is magnified in care facilities due to the different activities and comfort requirements of the building users, since people living with dementia have different needs than the working staff or visitors [8–10]. People with dementia are more sensitive to large temperature fluctuations and are comfortable in rooms with higher temperatures because of changes associated to old age [11,12] or their dementia condition [13,14], for example, change on judgment, cognition, and perceptual deficits alter the sensitivity of people with dementia, while changes on lifestyle affect their activity patterns [8,15]. Furthermore, there are also more and more indications that other indoor environmental factors, like CO2 levels and humidity, affect negatively older people with dementia and cause problem behaviour [16–18]. Although the effects of the indoor environment on people with dementia are not completely demystified, it is clear that their needs are different from people without cognitive impairments. Not well-adapted environment might lead to behavioural issues like wandering behaviour or aggression', which negatively influences quality of life [19], while good indoor cli-

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mate factors might reduce behavioural issues like agitation [20–22] and decrease pressure on the care professionals [17,18].

It is therefore important that the needs of the different user groups are included in the building design for example through user-centric and participatory design [23,24]. These design processes can be made more effective with the use of monitoring data on the actual performance of building [25]. Thus, evaluating the performance of this type of buildings to fine-tune indoor conditions, as well as to provide feedback to designers to improve future designs is imperative to ensure the health and wellbeing of ageing groups in low energy buildings. The objective of this research is to determine the influence of occupants' behaviour (also known as practices), occupants' needs and preferences, and design intentions, in the energy and indoor environmental quality of a Passivhaus care home in the UK. The research questions are: what is the actual performance of the building in relation to both typos on main users (residents and staff)? and what is the effect of design assumptions and decisions regarding building operation on the performance of the building?

Section 2 of this paper contains the methods for data collection and analysis and introduces the case study. Section 3 presents the results of the analysis in terms of indoor conditions and thermal comfort; occupancy practices; and energy performance. The discussion and conclusion are presented in section 4.

2. Materials & methods

In this section, the case study, methodology, and monitoring campaign are presented.

2.1. Case study

The case study includes a large care home (more than 3000 m^2) with 60 beds, distributed in four Care Suites, each containing 15 bedrooms, a lounge, a dining room, a nurse station, and an assisted bathroom (Fig. 1). The building has a timber frame structure with very high insulation levels and triple glazing to achieve the required airtightness of a Passivhaus building. The mechanical system consists of a gas-fired heating system supplying hot water to radiators in the bedrooms with air source heat pumps providing heating and cooling in the communal areas (circulation spaces, day rooms). Mechanical ventilation with heat recovery (MVHR) units are used to recover heat from exhaust air and provide fresh air. Outlets are located in the bathroom of every bedroom, while inlets are located in the bedrooms.

The building was constructed under a design and build contract and has been let to a care provider organisation for a 35 year, long term lease. The development company has more than 20 years of experience building care homes, but this was their first Passivhaus project. The BSRIA soft landings initiative [33] was implemented to improve the operational use of the building. The research study was initialised by the developing company (designers/builders) of the care home, being especially concerned about the suitability of Passivhaus for a care home and the performance of the building in the autumn and spring. Due to the airtightness of the envelope, and large windows used to maximise solar gains in the winter, the main concern of the developers was regarding the use of natural ventilation in the bedrooms during the winter, activity necessary in some rooms to get rid of stale air.

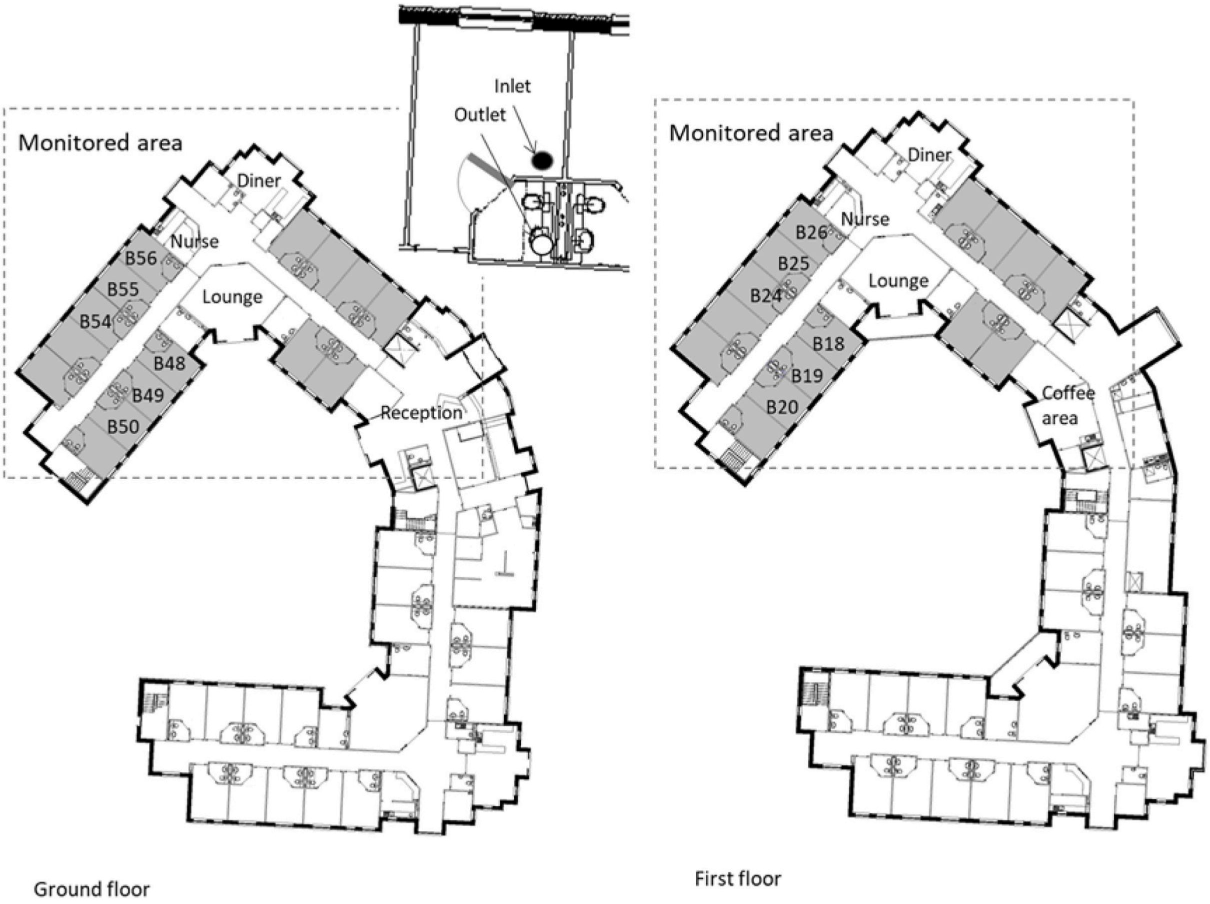

Fig. 1. Case study floor plan.

2.2. Mixed-methods methodology

A mixed-methods approach to data gathering and analysis was followed to determine the building energy and indoor environmental quality (IEQ) performance, as well as occupants' behaviour (practices). These performance and practices were analysed in relation to the initial project expectations (i.e. expected building performance) to determine how users were considered during the design process.

Mixed methods are used to capture pragmatically the technical and social aspects of occupancy practices. This approach integrates qualitative and quantitative methods to answer the research questions. The methods can be integrated at different stages in the research process: data collection, data analysis, or interpretation of results. The data can be integrated in three ways: connecting (one type of data building on the other), merging (compare or relate results), or embedding (explain one with another). In this research, we embed the results of the qualitative data to explain the results of the quantitative data.

Originally, Post Occupancy Evaluations focused on quantitative data collection and the use of surveys to determine the comfort and satisfaction of the building users. These techniques are useful to determine the performance of buildings but cannot be used solely to determine occupants' behaviours or practice. Thus, in this research we use a mix-methods analysis to understand the performance of the building in relation to 1) design intentions and 2) occupancy practices.

Fig. 2 shows the research framework used in this project. To determine the performance of buildings, we compare the expected [Fig. 2 - A] versus the actual [Fig. 2 - B] performance. The actual performance can be evaluated in terms of energy and indoor environmental quality. Expected energy performance can be determined based on a benchmark, energy calculations or simulations, national energy regulations or energy performance certificates or labels [26]. In this study, we use three sources of expected performance: the results of the Passivhaus Planning Package (PHPP) calculations made to obtain Passivhaus certification, the predicted energy consumption based on calculations made by the designers of the building, and benchmarking with other care homes. Actual energy use is based on measured energy data. In this study, it consisted of energy readings from gas and electricity meters and sub-meters taken by the facilities manager on a monthly basis, and from sub-meter monitors transmitting data in 30 min intervals.

IEQ was evaluated in terms of thermal comfort and indoor air quality based on the standards EN 16798–1:2019 [27] and ASHRAE standard 55:2017 [28], which indicate the acceptable ranges for each indoor parameter to be met most of the time in buildings (see Table 1). To evaluate the comfort in the building, two methods were used: a) the Predicted Mean Vote (PMV) method developed by Fanger [28]; and b) structured interviews and surveys with the occupants. The results from the comfort survey were compared against the results from the PMV calculation. The comfort of the different occupants' groups in the building was evaluated. Occupants' comfort was assessed in different areas of the building according to the occupants' daily activities.

The PMV method was based on measured indoor conditions, and observation of activity level and clothing of the staff and residents. The PMV method was used because of the impossibility to interview the residents with dementia, and due to the effect of the large differences on activity types and clothing between the occupants in the building (staff and residents). Furthermore, given the systems' control in the building, the PMV seemed to be the most suitable method, since during the winter the windows should, in theory, not be opened.

During the interviews and the survey, the participants were asked to rate the temperature of different rooms (thermal perception) in the building on a seven-level thermal evaluation scale from too cold to hot, and to rate their own comfort (thermal evaluation) in the same spaces on the seven-level perceptual scale from very comfortable to very uncomfortable. This approach was used to determine the specific preferences of the users for thermal comfort, since people might feel comfortable at different indoor temperatures (i.e. preference for warmer or colder temperatures).

We go beyond a performance evaluation by determining the occupancy practices [Fig. 2 - C] followed in the building, and the needs and preferences of the building' users [Fig. 2 - D]. Practices and preferences determine the ways in which the users control and interact with the building (HVAC's and windows). To understand the performance of the building and its relation with the occupants' practices, and the needs and preferences of the users, we also need to determine the design intentions [Fig. 2 - E] during the design process, since these will affect the definition of the 'expected performance' (e.g. assumptions made during the energy calculations, including occupants' behaviour, use of systems and needs of preferences of the users). The design intentions could also affect the occupancy practices because these can determine the type of control and instructions received by the users from HVACs installers or Facilities Manager.

Fig. 2 also shows the type of data used in this research (see data collection in Section 2.3). Qualitative data (such as user's interviews), quantitative subjective data (thermal evaluation), and quantitative objective data (opening windows, meters, and indoor parameters) were

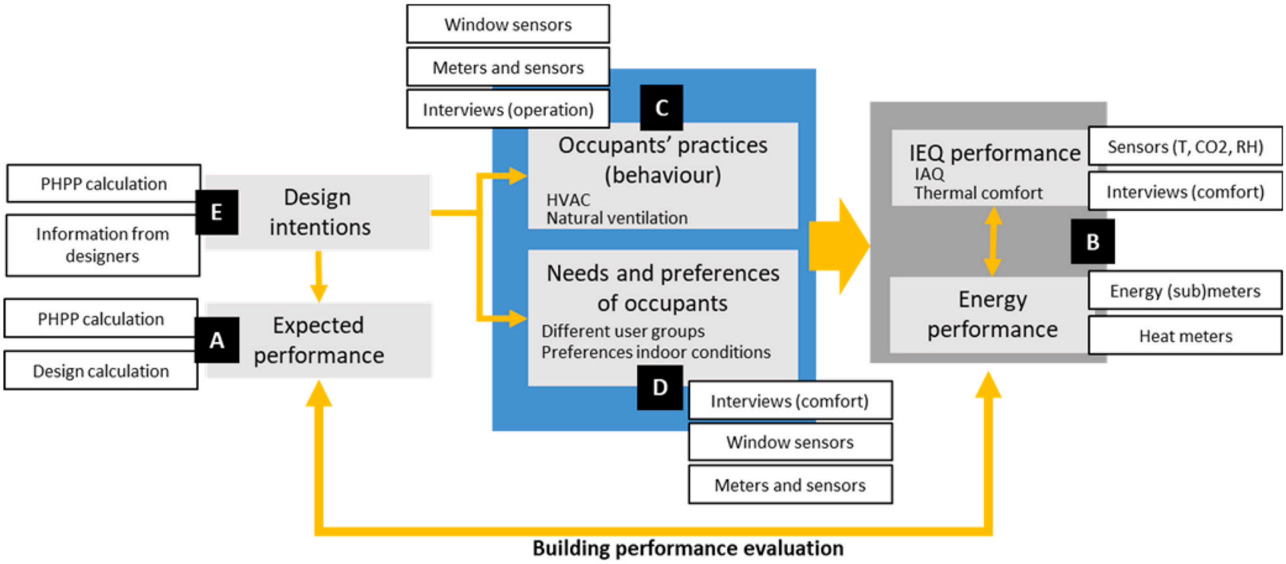

Fig. 2. Research framework and data collection methods.

Table 1
Categories according to ASHRAE standard 55 and EN 16798–1:2019, and "Category 4" - outside of established categories.

	PMV	PPD	CO2
Category 1	$-0.2 < \text{PMV} < 0.2$	$<6\%$	<350 ppm above external values
Category 2	$-.05 < \text{PMV} < 0.5$	$<10\%$	350–500 ppm above external values
Category 3	$-0.7 < \text{PMV} < 0.7$	$<15\%$	500–800 ppm above external values
Category 4	$\text{PMV} > 0.7$	$>15\%$	>800 ppm above external values

collected during the monitoring campaign. The different types of data were analysed using triangulation methods.

The quantitative data give us a clear idea of the actual conditions in the building, as well as the performance of the systems, while the qualitative data allows us to understand the actions taken by the occupants that have an influence on the performance of the building. Furthermore, we chose to evaluate thermal comfort following established models, as well as using self-reported thermal evaluation and thermal perception. The self-reported data allow us to determine the actual experiences and preferences of the users of the buildings, while the models allows us to determine the performance of the building based on standardised thermal preferences. This methodology is particularly important in care homes, where not all residents might be able express their own comfort feelings (i.e. people with dementia). The following section present the methods to collect the data.

2.3. *Data collection*

The monitoring campaign was conducted in the years 2012–2013. Information on indoor and outdoor environmental conditions, energy usage, and building operations were collected for the first year of occupancy. In the following sections, the details of the campaign are presented.

2.3.1. *Sensors*

Indoor temperature, relative humidity, and CO_2 measurements were taken in selected spaces, since monitoring all spaces in the building would have been prohibitive. The care home was not fully occupied and so the selection of the spaces depended on the occupancy. Bedrooms facing north and south were selected to compare the effect of solar gains. Table 2 shows the spaces and monitoring period for each space.

The selected indoor environment monitoring transmitter incorporates a combined relative humidity and temperature and NDIR (infrared) CO_2 sensor. The CO2 sensor included a daily auto-calibration feature to ensure fast and accurate measurement. All the indoor environmental transmitters were able to send readings at 30 min interval to the logger at a central location.

External weather conditions were also measured with a weather station installed at the open area behind the building. Air temperature, solar radiation, humidity, wind speed, and wind direction were recorded at 30 min intervals.

In addition, contact sensors were installed in the windows of four rooms from June to November. The window sensor are contact switches, magnetic based. Each sensor consist of two parts, one has spring loaded metal switch sealed in a glass tube, and the other part is a magnet. Once they become too close the switch closes and creates a '1' signal, which represents a state of being closed. The Eltek data logger recorded at what time a state changes at a channel. The monitored rooms can be seen in Table 2. Only a small selection was made to avoid damage to the walls, to avoid high costs and due to the uncertainty on the usability of the data. The specifications of the monitoring devices are shown in Table 3.

Table 2
Variables measured in monitored spaces from June 2012 to June 2013.

	Orientation	Temp & RH	CO_2	Radiators	Windows
Coffee shop (GF)	W	June–June	June–June	NA	Not installed
Nurse station (1F)	N	June–June	June–June	NA	Not installed
Lounge (1F)	S	June–June*1	June–June*1	NA	Not installed
Dining room (1F)	NE	June–June	June–June	NA	Not installed
Bedroom 18 (GF)	S	June–June	June–June	June–June	Not installed
Bedroom 20 (GF)	S	June–June	June–June	June–June	Not installed
Bedroom 48 (1F)	S	June–June	June–June	June–June	Nov–June
Bedroom 49 (1F)	S	June–June	June–June	June–June	Nov–June
Bedroom 50 (1F)	S	June–June	June–June	June–June	Nov–June
Bedroom 54 (1F)	N	June–June	June–June	June–June	Nov–June
Bedroom 55 (1F)	N	June–June	June–June	June–June	Not installed
Bedroom 56 (1F)	N	June–June	June–June	June–June	Not installed

(GF) Ground floor; (1F) First floor.
(*1) Missing data in November (transmitter was unplugged) and March (transmitter was broken).

Table 3
Sensors specifications.

Sensor type	Range	Accuracy
Indoor environmental parameters		
CO2	0–5000 ppm	+50 ppm at 25 °C. 1013 mbar
Air Temperature	–20 °C to 65°	+0.4 °C (–5 °C to 40 °C)
Relative humidity	0–100% RH	0.1%
External weather conditions		
Air Temperature	+0.3 °C	–20 to 70 °C
Relative humidity	0–100% RH	+2% RH, 5–95% +2.5% RH, <5% or >95% RH
Rainfall	160 mm funnel diameter	0.2 mm/tip
Solar Radiation	0–1.1 kW.m-2	+1% at 45° +4% at 75°, at zenith angle.
Wind Speed	0–75 m s^{-1}	+0.1 up to 10 +1.1% of reading over 10
Wind direction	Mechanical 0 to 360° Electrical 0 to 356°	+4°

2.3.2. *Interviews and survey*

The care home has different types of occupants, with very different activity patterns, health conditions and building areas they occupy. Thus, each group needs to be investigated. The building's occupants are:

1) Residents are the most sensitive group since they are fulltime in the building and usually have poor health. They are very passive and have less control over the building systems;
2) Nurses and carers have 12-h shifts (day or night) and a moderate activity level;
3) Housekeeping staff have an activity level higher than nurses and carers but only work the day shift;
4) Administrative staff have a lower activity level (usually office type) and work 8-h day shifts.

Qualitative data on occupants' satisfaction and daily practices were collected seasonally. Not all staff members could be interviewed because some were on annual leave and others did not have shifts on those days. Staff members were interviewed in summer and autumn 2012, and spring 2014. Due to the busy schedule of the care staff, a questionnaire survey was applied during the winter; however, it showed a low response rate. During the interviews, and on the questionnaire survey, staff members were asked to rate their thermal comfort (thermal evaluation) based on the seven-point thermal evaluation scale from very comfortable to very uncomfortable, and to rate the temperature (thermal perception) in the building on the seven-point perceptual scale from cold to very warm.

Residents were only interviewed one time during the monitoring campaign in the winter season. The residents were asked about their own comfort (thermal evaluation) and their opinions and feelings about living at the care home. Only four residents were interviewed because only residents without dementia and in good health could be considered. Although research has shown the advantages of self-reporting of older people with dementia [29], for this research, residents with dementia were excluded because the care staff did not consider them to be able to participate in the research. As an extra indicator of the thermal comfort of residents, the staff was asked about their opinion about the thermal comfort of the residents. Table 4 shows the qualitative data collected per season.

Furthermore, the care and cleaning staff responded questions about their use of the air conditioning (in common areas), heating system (radiators knobs in bedrooms), and window opening schedules. Seasonal talks were conducted with the facilities manager, who also informed us of the status of the building and the installations.

All participants (interviews and survey) were informed about the purpose of the study and signed a consent form. Sensitive data was not collected in this study. Private data only concerned the first names of the participants in interviews and the survey, which were recorded to keep track of the participants during the interview days. All data was automatically anonymised. No photography or video of participants were taken during this research.

Table 4
Methods of qualitative data collection per season.

Season	Summer	Autumn	Winter	Spring
Period	June 2012 to August 2012	September 2012 to November 2012	December 2012 to February 2013(*1)	March 2013 to June 2013
Structured interviews with staff	13 staff member	14 staff member	(*2) 7 staff members	
Structured interviews with residents			4 healthy residents	

(*1) The winter period was extended until March 2013 due to very cold days during most of the month.
(*2) A questionnaire survey was applied instead of interviews.

Table 5
Energy meters.

Channel number	Connected to	Data type/description
Ch. 1–12	12 Heat Meters on radiators in bedrooms	Heat energy emitted into each bedroom, kWh equivalent, 1 pulse = 1 kWh
Ch. 13	Laundry Gas Sub Meter	Gas consumption at Laundry room, 1 pulse = 0.01m3 gas
Ch. 14	Kitchen Gas Sub Meter	Gas consumption at Kitchen for cooking purpose, 1 pulse = 0.01m3 gas
Ch. 15	Plant room Gas Sub Meter	Total Gas consumption, 1 pulse = 0.1m3
Ch. 16	Total Domestic Hot Water Pipeline – Heat Meter	Heat energy consumed by hot water circuit, kWh equivalent
Ch. 17	Total Heating Pipeline – Heat Meter	Heat energy consumed by space heating circuit, kWh equivalent

2.3.3. *Energy meter and submeters*

Three types of sub-meters were used to measure electricity, gas, and heat meters. Apart from the read-only electricity meters, all the sub-meters transferred pulse output via wired and wireless connections to the data loggers. Pulse resolution for gas meters was 0.01m3 per pulse, while the resolution for hot water meter was 1 kWh per pulse. A customised 17-channel logger was used to monitor energy use. Five gas sub-meters were installed and connected to the logger to monitor energy use for laundry, kitchen, plant room boiler, domestic hot water, and heat to radiators (Table 5). To monitor the use of the heating system, 12 heat meters were installed in the radiators of 12 selected bedrooms (the same bedrooms in which indoor conditions were monitored). However, three heat meters did not work, due to faulty flow meters sending only void volume pulse count feed into heater meters. Each heat meter measured the hot water temperature difference between the inlet and outlet together with the corresponding volume for the total radiator circuit and hot water tap circuit. Fig. 3 shows an overview of the meters and sub-meters.

The following sections present the results of this analysis.

3. Results

3.1. *Indoor environmental quality performance*

3.1.1. *Measured indoor conditions: temperature and air quality*

The ASHRAE standard 55:2017 introduces three categories of performance. These categories depend on the stringency of the building evaluation. The building can be evaluated based on the percentage of time that a given parameter (PMV, relative humidity, temperature, and CO2) falls within the requirements of each category. The categories are: 1) used when it is desired to adhere to higher than typical comfort standards, for example for vulnerable people; 2) new buildings and; 3) ex-

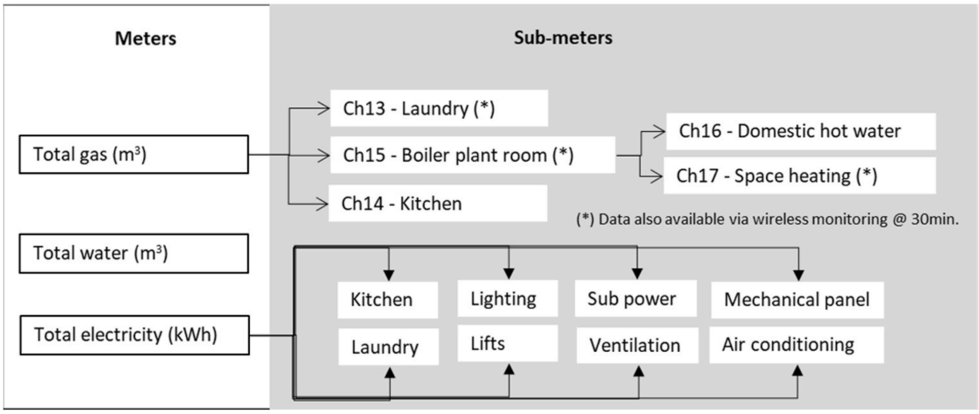

Fig. 3. Overview of meters.

isting buildings. The ranges per category are shown in Table 1. The percentage of time that the building is within each category was calculated next. For the analysis, we consider that the building should be within category 1 for the residents, and within category 2 for the staff.

The temperature was analysed through statistics and visualizations of external and internal temperatures. Fig. 4 shows boxplots per room for one month corresponding to each season. The shadowed areas in the centre represent the acceptable range (21–24 °C) according to the EN 16798–1:2019 standard [27]. The figure shows that in July, all common areas are too warm (around 75% of the time above 25 °C), while in the other seasons, they tend to be at least 75% of the time within the accepted range. The exception is the nurse station, which tends to be warmer than other common areas because there are no windows and the air conditioning control is not easily accessible. In February and April, the dining room shows many instances with very low temperatures (under 10 °C), caused by use of air conditioning because the room tends to overheat at dinner time (food is kept warm in place). The coffee shop is the coolest common area because both air conditioning and crossed ventilation are used.

Occupied bedrooms tend to keep mostly within an acceptable range in all months. However, cooler temperatures are seen in autumn and spring, and significant overheating (up to 25% of the time in some rooms) is seen in bedrooms in April. This over and underheating can be caused both by the greater variation in temperature in these months, as well as the heating system or cooling strategies not fully implemented (due to the greater weather variations).

Fig. 5 shows the results of the categories for CO_2 concentration levels. CO_2 is used as an indicator of indoor air quality. Fig. 5a shows that in the summer, occupied bedrooms (49, 50) are only 50% of the time within Category 1 (below 750 ppm), the rest of the time being in Category 2 (below 900 ppm) and 5%–9% in Category 3 (below 1200 ppm). CO_2 concentrations in common areas are mostly within Category 1, only the nurse station (which has no windows) is 15% of the time within category 2. Fig. 5b shows a worsening on indoor conditions in the autumn in comparison to summer, due to less frequent natural ventilation, and, in the case of the common areas, also to an increase in the number of residents. Bedroom 49 and 50 are a significant amount of time (35 and 25% of time respectively) within category 3, and room 49 is 10% of the time within Category 4 (above 1200 ppm), while rooms 48 and 54 show better air quality. Fig. 5c shows that in winter, the percentage of time within Category 3 is considerably higher, especially in rooms 48, 49, 50, and 55. In common areas, the CO_2 concentration is within Category 3 for more than 50% of the time. Fig. 5d shows that in spring, the results are very similar than in autumn if individual areas are compared, the only exception is bedroom 48 which shows higher CO_2 concentration in the spring, and the coffee area, which shows better air quality in the autumn. These figures raise concerns about the efficiency of the mechanical ventilation to maintain by itself a good indoor air quality in the bedrooms. The outlet of the mechanical ventilation is in the bathrooms, which doors are usually closed due to the layout of the rooms (see Fig. 1).

3.1.2. *Self-reported thermal comfort*

Interviews with staff and survey. Summer interviews showed that all the staff members consider the building to be too warm and reported to be (thermally) uncomfortable most of the time. The only space considered comfortable was the coffee shop, where air conditioning and natural ventilation are most often used. Fig. 6a shows the **comfort**

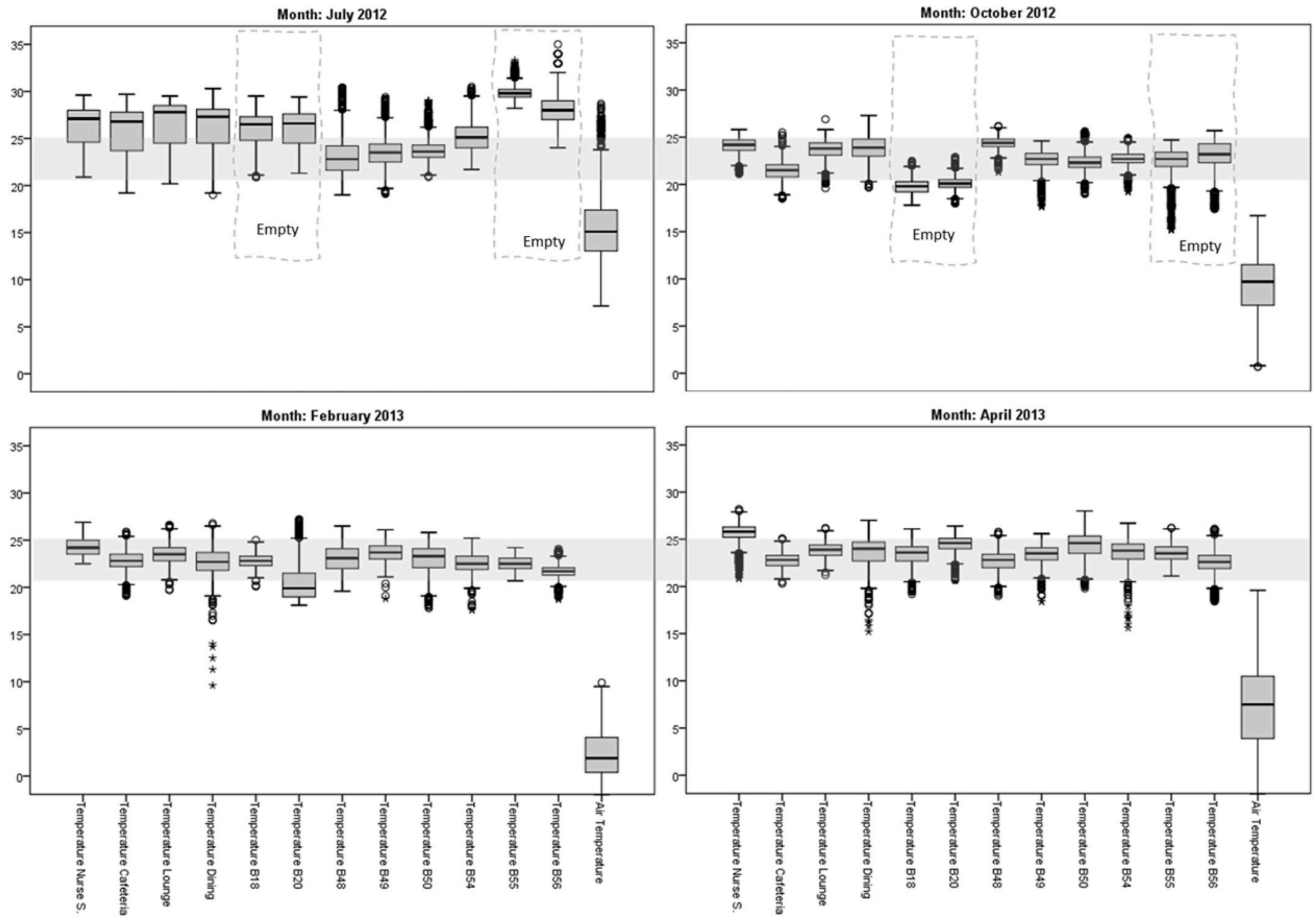

Fig. 4. Boxplots: temperature per room per season.

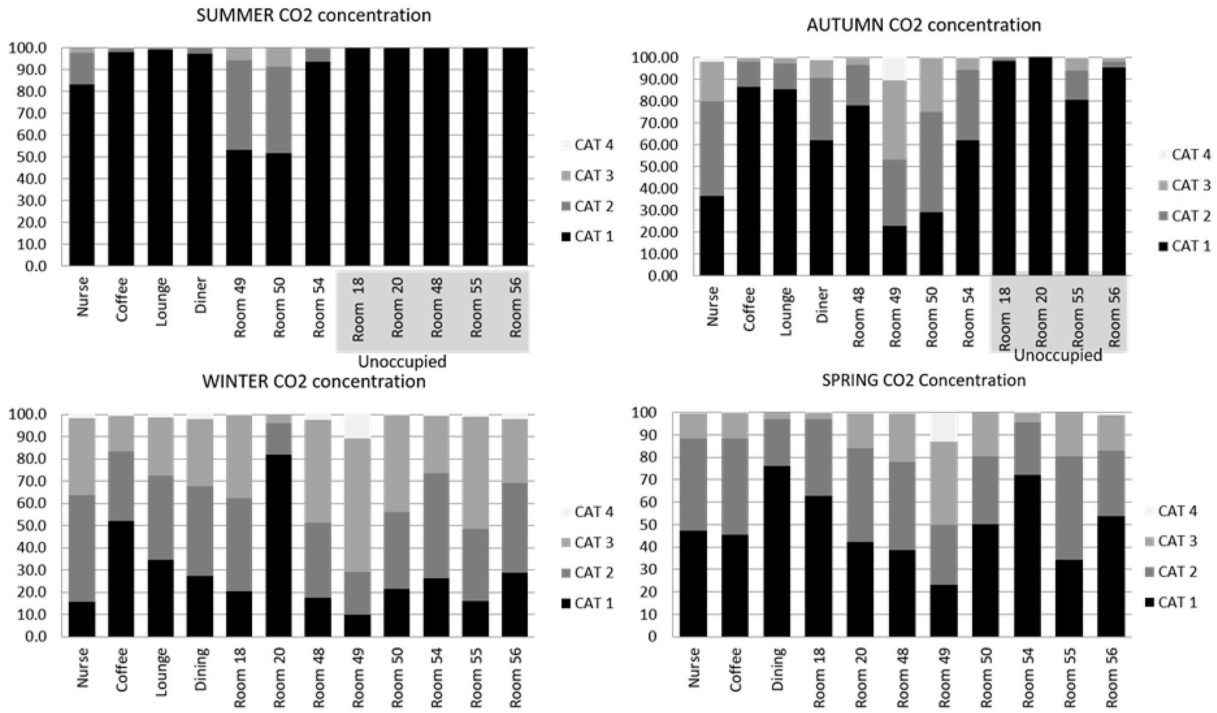

Fig. 5. CO2 concentration per category, per season.

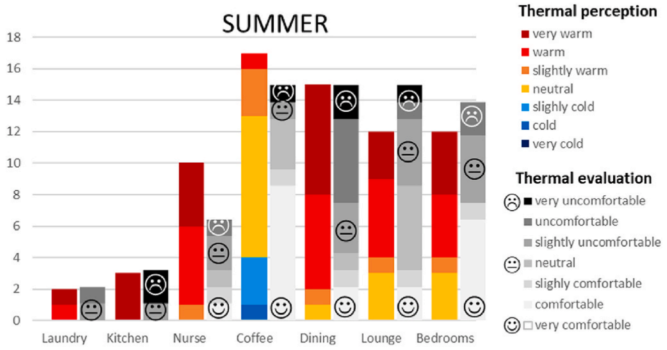

Fig. 6a. Thermal evaluation and thermal perception: summer (a), winter (b) and spring (c).

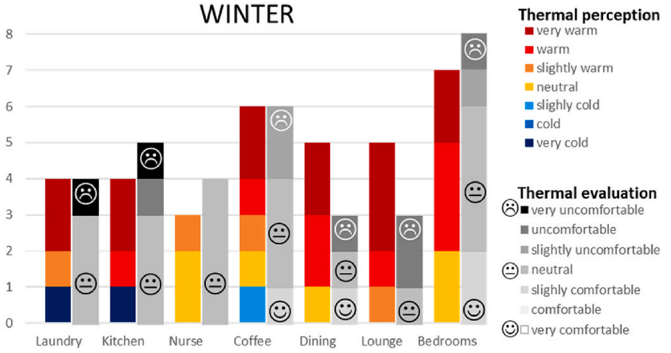

Fig. 6b. Thermal evaluation and thermal perception: summer (a), winter (b) and spring (c).

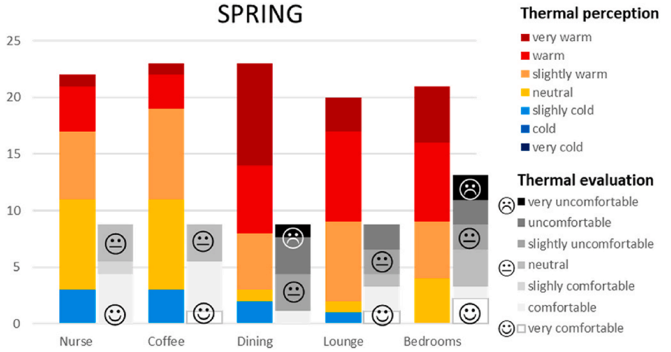

Fig. 6c. Thermal evaluation and thermal perception: summer (a), winter (b) and spring (c).

and **temperature** ratings given by staff members for monitored areas in the **summer**. The staff seem to be more forgiving of high temperatures in the bedroom and lounge, places were the residents spent most of the time. These spaces were rated by around 80% the respondents between neutrally comfortable and comfortable, while the temperatures were rated mostly as (slightly) warm and very warm (65% of respondents). On the other hand, the dining room is rated mostly as (slightly) warm and too warm (90%), while 50% of the respondents feel some level of discomfort. The figure shows a large variation in comfort rating in the nurse station while the temperature is rated as warm and very warm.

During the **winter**, most spaces were also rated as warm and very warm, but as seen in the summer, the bedrooms were rated as neutral or comfortable (Fig. 6b) by 75% of the respondents. The dining room was rated as uncomfortable and very warm and the coffee area as neutral in comfort but varied in temperature rating. The largest difference in comparison to the summer was seen in the lounge, which was rated as very warm and uncomfortable.

In spring (Fig. 6c), neutral or around neutral ratings were given to the nurse station and reception, while the dining room was rated as warm to very warm and the lounge as slightly warm to warm. The bedrooms were considered warm but showed more variation on the thermal evaluation.

As some other studies have shown [30], staff reported feeling “comfortable” working at the care home due to other factors such as the working conditions provided by the organisation. Some staff members, mostly care staff, stated that the building was too warm for them, but "just right" for the residents. However, there are spaces not intended for residents that were also rated too warm. Although the staff acknowledge that their discomfort ensures residents' comfort, they reported the **kitchen and laundry** to be too warm and to have no control to change it, since on warm days opening windows does not cool down these rooms and no other ways to cool down the rooms are provided (see Fig. 6b).

Interviews with residents. The residents were asked to rate different areas in the building based on the same thermal evaluation scale (−3 to 3) given to the staff. In all areas, residents seem to feel warm and comfortable. Only one resident of those interviewed thought that the lounge was too warm for her but in her opinion, all other residents, especially those with dementia, felt comfortable and were usually wearing jumpers.

3.1.3. Modelled thermal comfort: PMV differences between groups

The comfort survey and interviews are of limited statistical value because of the low number of data points. Even with full response rate from the staff, the number of questionnaires would not be more than 20. Therefore, we have also assessed the thermal comfort of users of the building by calculating the Predicted Mean Vote (PMV) based on the ASHRAE standard 55:2017 [28] for thermal comfort. The comfort survey allows us to compare the results from the calculation with actual perceived thermal comfort. This is described in further sections.

The Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfaction (PPD) were calculated for every monitored space and each measured interval (30 min). To calculate the PMV, we estimated the metabolic rate (MET) and clothing level (CLO) of the two main types of occupants in the building due to their differences in activity level, clothing, and health condition: 1) housekeeping and care staff, and 2) residents. Three PMV calculations were made for each space, one for the residents and two for the staff according to their clothing level. Clothing insulation values were calculated from observations. A value of 0.95 was used for residents. The PMV of staff was calculated for both uniforms: a value of 0.472 was derived from the winter uniform and a value of 0.392 from the summer uniform. Activity level was assumed, also based on observations, to be 1.0 met for residents (sedentary activity level), mostly sitting and resting; and 2.0 met for the staff (moderate activity). Because administrative staff stay mainly in their offices and have more freedom to open windows and adjust their clothing, calculations were not made for them.

Fig. 7shows the percentage of time that each monitored room is within each category per season (residents results shown to the left and staff to the right). For both groups, the green bars indicate the percentage of time within their allocated category (category 1 for residents and category 2 for staff). In other words, the bars in green indicate the percentage of time in which the occupants are comfortable. In addition, for the residents, category 2 is shown in light green, indicating a broader range of comfort. This is because in previous research category 1 range has shown to be too strict. The bars in orange (category 3) and red (category 4) indicate the amount of time in which the occupants' discomfort is due to temperatures being too high, while the bars in blue (category 3) and dark blue (category 4) indicate the amount of time in which the occupants' discomfort is due to temperatures being too low.

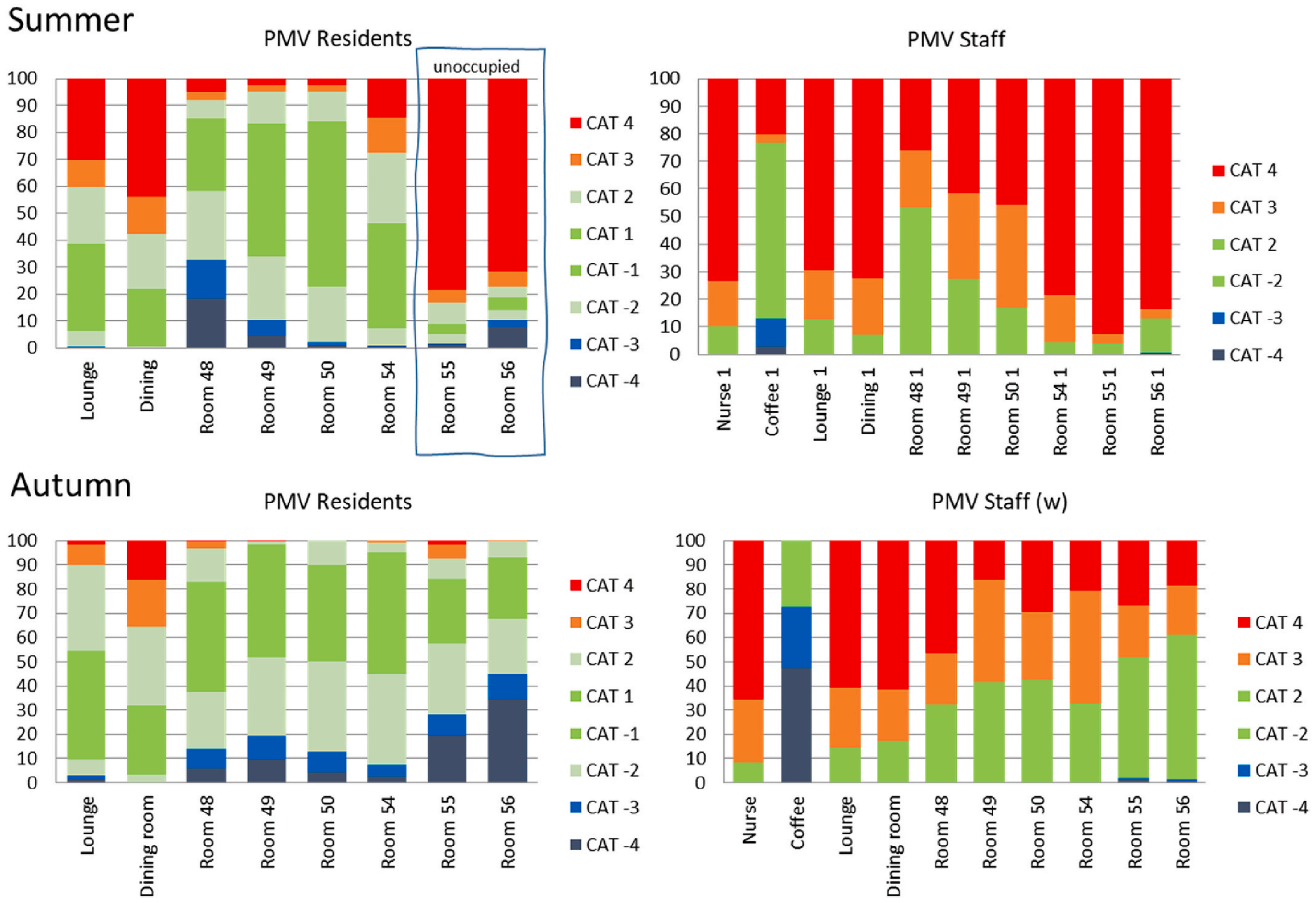

Fig. 7a. PMV categories per season per user type.

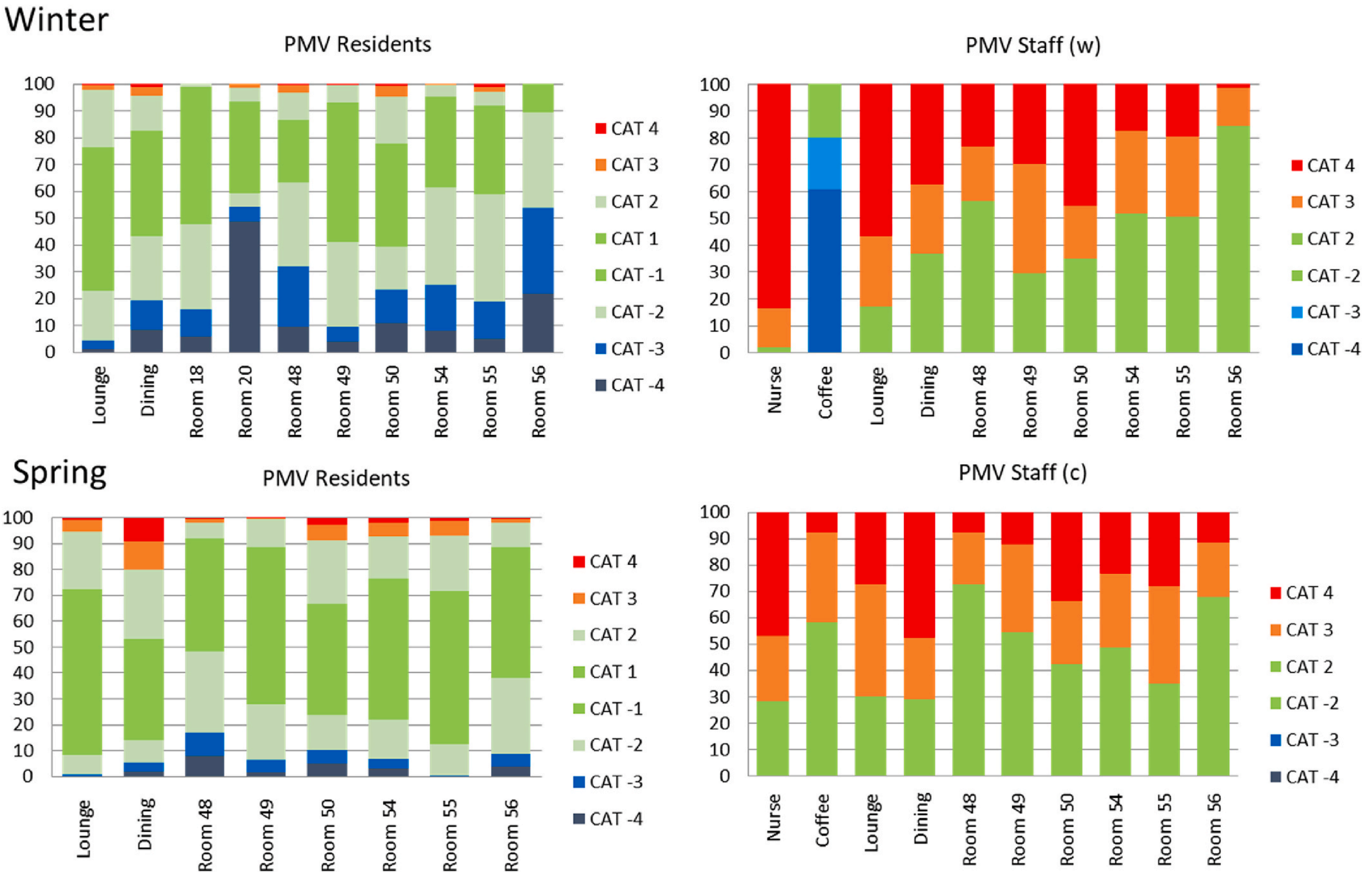

Fig. 7b. PMV categories per season per user type.

The analysis showed that in general, all rooms (except the coffee shop) were a significant amount of time, too warm for the staff, especially in the summer and in common areas along the year. On the other hand, residents comfort is around 50% of the time within category 1, and if the less strict category 2 is considered, their comfort increases significantly. However, some rooms (20, 48, 55, 56) are in some seasons below comfort levels for up to 50% of the time. Residents' discomfort is caused by both too low and too high temperatures in all spaces, according to the season (too low in winter, too warm in summer) (see Fig. 7b).

3.2. Result from the occupancy practices analysis

In this section, the results on energy-related practices for heating, ventilation, and air conditioning are presented, as well as the implications in relation to user preferences for comfort.

3.2.1. Heating practices

The monitoring of selected bedrooms showed that radiators in some occupied bedrooms were in use during summer and spring. However, the temperature in the monitored rooms was not much higher than the temperature in the other occupied monitored rooms because of the use of natural ventilation. Fig. 8 shows the heat to radiators in the selected monitored bedrooms. It shows that radiators were on in some bedrooms during the summer and in the spring. It is also visible that some rooms are heated more than others. Room 49 and 50 utilising most of the heat in the monitored bedrooms. This shows the large differences in energy requirements between bedrooms, linked to thermal comfort and ventilation preferences.

3.2.2. Natural ventilation practices

During the summer, staff reported opening windows in the bedrooms in the morning mainly to get rid of stale air and odours, but if the resident was in the bedroom, they would ask them first about opening the window before doing so. Most of the cleaning staff reported opening windows as part of the normal routine. Staff also reported opening some windows in common areas to cool the spaces. However, few staff members reported to having been instructed "not to open windows" during the winter, as it is usually recommended in Passivhaus buildings. During the autumn, staff reported to open windows less frequently than in the summer in common areas, but about the same in the bedrooms. During all seasons the same natural ventilation operation routine was used in the bedrooms: windows being open to cool down spaces and to get rid of odour and stale air. In the winter, windows are open with less frequency in common areas, but bedrooms are still ventilated in the mornings.

To investigate further window opening behaviour, analysis of the data from windows sensors in 4 bedrooms were used as indicators of natural ventilation in the building. We wanted to know whether windows were opened at all during the winter (as opposed to the requirements of a Passivhaus building). Fig. 9 shows the hours with windows open from November 2012 to April 2013. Although according to the design of the building, windows should not be open during the cold weather period (mechanical ventilation should keep good air quality), the figure shows that in all four monitored bedrooms, windows are used for ventilation. Long hours of ventilation in rooms 49 and 50 correspond to the higher heating requirement seen in Fig. 8.

3.2.3. Air conditioning

Visualisation of indoor conditions, analysis of energy usage, and reports from the facilities manager indicated that the air conditioning was

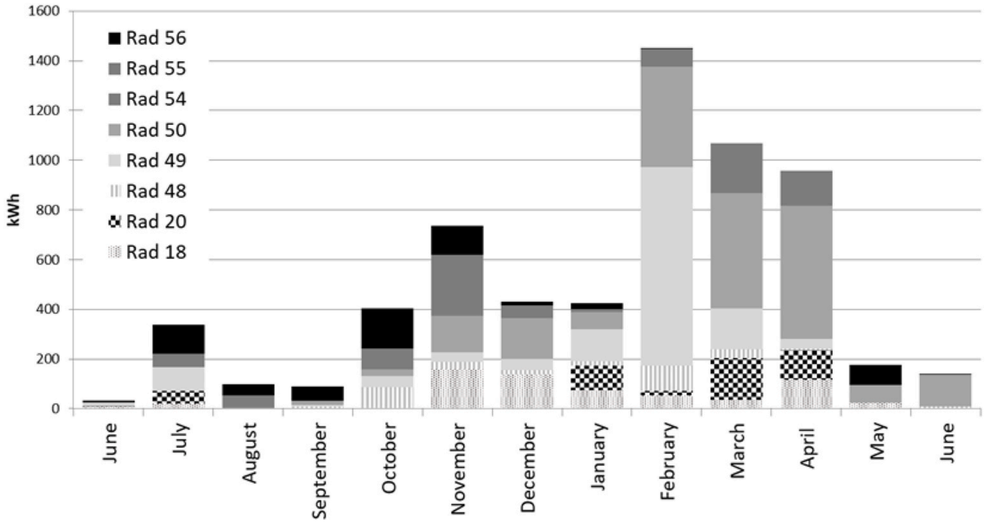

Fig. 8. Heat to radiators in a selection of bedrooms.

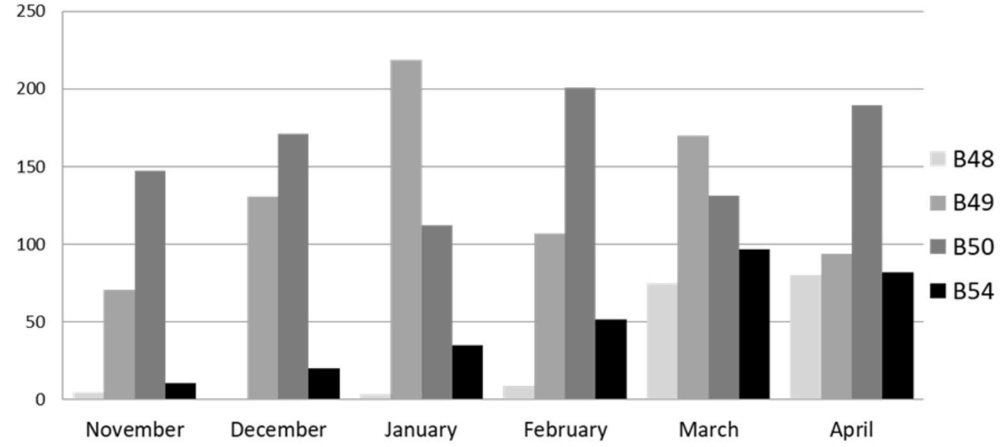

Fig. 9. Windows opened per room (in hours).

overused during the summer. The staff started using the air conditioning after some warmer days in July. After this period, even in not very warm days, the air conditioning was functioning. Some spaces became too cold in the summer, and the staff reported large swings in temperatures between day and night and from day to day. In early August, staff attended a system induction meeting to advise them not to set the temperature too low to cool the building faster. They were told to keep the thermostats at 22 °C. During the interviews, most staff reported rarely using the air conditioning because they had been told not to. Further analysis showed a reduction in the use of air conditioning in August in comparison to July. However, data visualizations and talks with the Facilities Manager showed that the air conditioning was used to cool down the spaces during the winter when common areas became too warm (see also Fig. 4 boxplot February) (Fig. 10).

3.3. Results: energy performance

For better seasonal comparison we have calculated the monthly energy consumption per day. Some sub-meters were not working at the beginning; therefore we show the disaggregated data only from August. However, the total energy consumption consists of all the energy used from the June 18, 2012 to 1st June 2013.

Fig. 11 shows the electricity consumption per end-use in kWh per day. The energy consumption for the mechanical panel, kitchen, laundry, and ventilation remained constant during the year only increasing with the number of residents. Lighting and sub-power socket showed an increase in December, the month in which the residents' population also increased. The air conditioning, which provides cooling and heating to common areas shows the largest variation. The lowest energy consumption for air conditioning is shown from September to November, increasing in December due to a higher number of residents and lower external temperatures. However, energy consumption in April and May is higher than in summer and autumn 2012. The large energy consumption for air conditioning indicated that the system might have been misused or overused and required further investigation. By observing daily temperature fluctuations in the common areas, and interviews with the facilities manager and walkthroughs in the building, it was found that the staff was using the air conditioning to cool down spaces down to 16 °C during the winter with the intention to cool down the room faster.

Fig. 12 shows the gas consumption in m^3/day obtained from energy sub-meters. The figure shows an increase on gas for all final uses from December, linked to the increase in the number of residents. Gas usage for space heating also increases in December due to colder external temperature. However, gas for space heating was used during the summer 2012 and the spring of 2013, which equals roughly a third of the winter consumption. In the summer some radiators were left on in unoccupied bedrooms, but in both seasons, radiators were used also in occupied bedrooms. Energy for DHW, kitchen, and laundry increased with the increase in the number of residents.

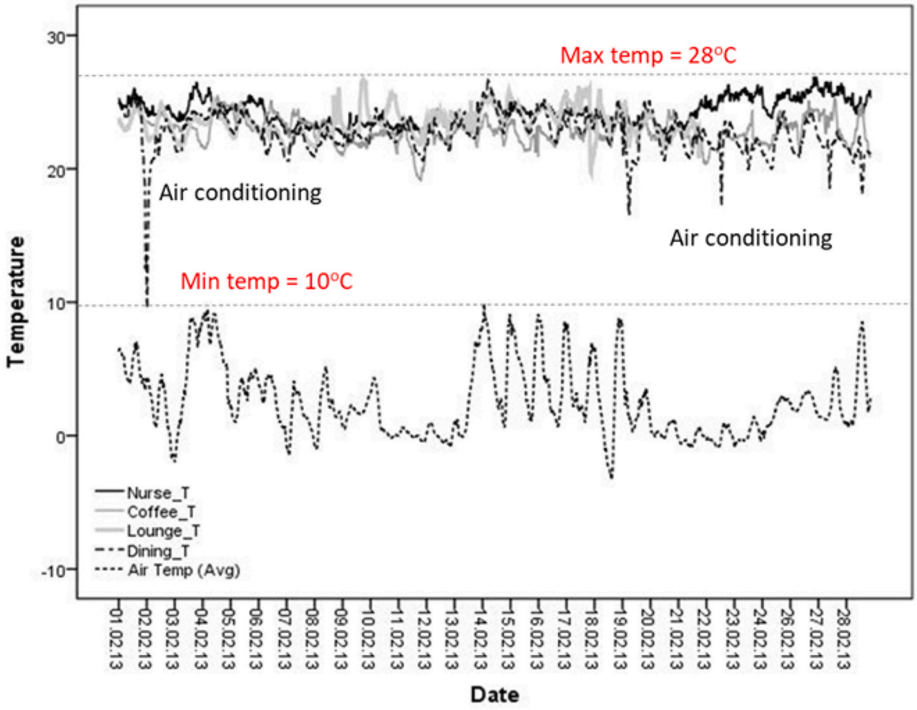

Fig. 10. Temperature in common areas in February 2013.

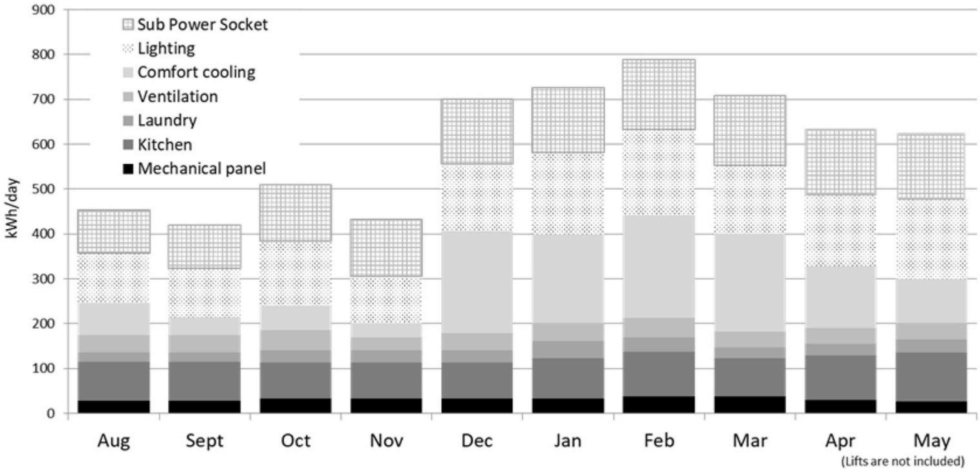

Fig. 11. Measured energy consumption: total electricity per end use.

3.3.1. *Comparison with PHPP calculation*

Table 6 shows the yearly calculated electricity consumption (in PHPP) and the measured electricity for the period of June 2012 to June 2013. The table shows data from lighting, air conditioning, ventilation, and total electricity requirement from the PHPP calculation. Even without full occupation of the building, actual electricity consumption for lighting is in reality 25 times more than calculated, four times more for air conditioning, and more than double for ventilation.

Table 6 also shows the yearly calculated on PHPP gas demand and the measured gas usage for the period June 2012 to June 2013. The figures show that the actual energy consumption for domestic hot water roughly doubles the calculated consumption, while gas for space heating is roughly four times more than calculated in PHPP. Again, this is even without full occupancy of the building.

These tables show that for the PHPP calculations, the assumptions made about building operation and occupancy were unrealistic. Some of the differences could have been caused by using the systems less efficiently during the first year, as well as due to faulty installations and lack of commissioning, however, in other instances (e.g. energy use for kitchen activities, laundry, DHW), the differences are caused by the lack of consideration during the design calculations of the actual the user needs, preferences, and practices.

3.3.2. *Comparison with expected energy consumption by the design team*

Table 7 shows the actual total energy consumption compared against 1) the predicted energy consumption calculated by the designers, 2) an average of 10 care homes run by the same services provider, and 3) a typical care home according to the current building regulations. The table shows a much closer relationship between actual and predicted energy consumption. However, the actual electricity consumption is more than double the expected electricity consumption, while gas is roughly the same even with half occupancy. In comparison to the average care home of the same care provider, the building con-

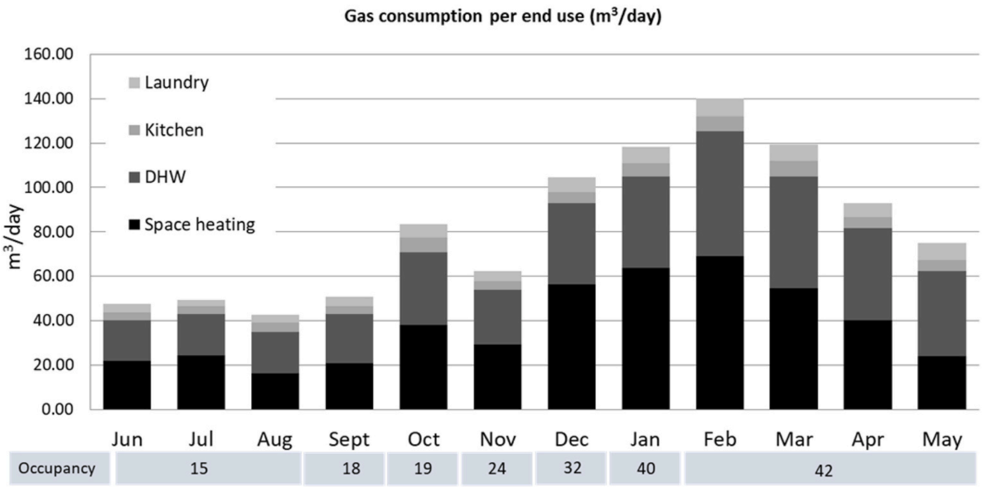

Fig. 12. Gas consumption per end use (m^3/day) and building occupancy.

Table 6
Measured and calculated gas and electricity consumption.

	Measured (kWh)	Calculated PhPP (kWh)
Electricity ($\sum$*)	159,961	72,051
Lighting*	51,407	1914
Air conditioning*	44,997	9732
Ventilation*	13,337	5350
Power*^	39,785	N/a
Mechanical panel*	9809	N/a
Lifts*	601	N/a
Gas (excl. Laundry and kitchen)	267,446	98,804
Domestic hot water	124,858	70,544
Space heating	143,188	28,260

(^) Missing data from last two months.
Gas: June 2012–April 2013; Electricity: June 2012–June 2013.

Table 7
Measured, predicted, average and typical energy consumption.

	Beds	Surface (m^2)	Electricity (kWh)	Gas (kWh)	Total (kWh)
Measured*	60	3065	216,494	267,446	483,940
Predicted	60	3065	101,657	248,886	350,543
Average	62	3089	133,394	559,130	732,524
Typical	60	3000	205,821	749,286	955,107

(*) Not full occupancy.

sumes less than half the gas and 60% more electricity. In comparison to a typical care home, the case study consumes 5% more electricity and one-third of gas for heating.

Table 8 shows the predicted (typical and PHPP) and measured electricity and gas consumption for laundry and kitchen. In comparison to a typical care home, the building consumed five times less electricity for laundry and 3 times less for the kitchen. The care home consumed almost half the gas used in the laundry and a fifth in the kitchen. The comparison with PHPP calculations shows that the care home used five times more electricity in the laundry than calculated by PHPP but almost half of the electricity for the kitchen. The table also shows that the building used five times more gas than calculated by PHPP in the laundry and more than the double of the gas calculated for the kitchen. The table also shows that there is a very large difference between PHPP calculation and the energy use of a typical care home.

Table 8
Predicted, calculated and measured energy consumption for laundry and kitchen in kWh.

	Beds	Surface (m^2)	Typical care home	Measured*	Calculated PHPP
Laundry electricity	60	3000	52,342	9284	2069
Kitchen electricity	60	3000	63,437	26,594	40,644
Laundry gas	62	3000	34,944	21,589	3814
Kitchen gas	60	3000	94,170	18,731	7500

(*) Not full occupancy.

The calculated energy consumption in PHPP was deemed so low because the building was considered as fully domestic, and therefore the assumptions made in PHPP about occupancy affected the calculations. However, the care home cannot also be fully considered as a non-domestic building. Thus the Passivhaus calculation cannot reflect the actual electricity consumption of a care home. The major differences were in the use of gas and electricity in the laundry and gas for cooking. Thus, the practices specifically followed in care homes were not known by the PHPP consultants (i.e. amount of laundry and cooked food).

Taking into account the calculations made by the design team (typical care home), the energy performance of the care home with respect to gas consumption seems just as predicted. However, the gas measured for domestic hot water was actually based on half occupancy; energy consumption for DHW would, therefore, increase significantly with full occupancy. The energy performance with respect to electricity is much higher than expected. Electricity consumption doubles the prediction and is even higher than a care home based on the building regulations, because of the use of air conditioning for both heating and cooling. Since electricity was used for heating, we would expect an increase in electricity usage.

Table 8 also shows the total (gas and electricity) energy consumption, predicted energy use of the average and typical care home (according to regulations). The results show that more energy (40%) was used than predicted, but a 50% reduction can be seen in comparison to an average care home and (70%) in comparison with a typical care home.

4. Discussion and conclusions

The research presented in this paper focused on the lessons learned from monitoring the performance of a Passivhaus care home in the UK in regard to design intentions, occupancy practices and user preferences, and their effects on building performance. The main conclusions are presented in this section according to the main aspects related to occupants' preferences and occupancy practices, both regarding thermal comfort, indoor air quality, and energy consumption.

4.1. Thermal comfort and indoor air quality

The results of the thermal comfort assessment (with monitoring data and using a questionnaire) show that the staff is uncomfortable (too warm) in the building, while the residents are comfortable, although some spaces tend to overheat at specific times in the day. The staff seems to understand the needs of the residents and acknowledge the fact that their discomfort assures the comfort of the residents. While in other settings, the best could be a compromise for both groups, in a care home, this would not be possible. Due to their age and health conditions, the residents are less able to actively control their surroundings to achieve comfortable conditions (such as opening windows, turning radiators on/off, changing clothing, etc.).

Warm temperatures are preferred throughout the year by the residents. The heating system was also used during the summer, spring, and autumn. This is in line with other research indicating that older adults need higher temperatures to achieve comfort. This finding show a contrast with findings by Fisher [31], who found that when the heating was on in the summer, the building became unbearable and too warm. However, in the study by Fisher [31], actual temperatures were not measured.

According to the calculations for Category 1, some bedrooms are too cool and others are too warm. However, since the occupants can open freely windows and even turn on the radiators throughout the year, we can assume that their rooms are at their preferred temperatures unless the system is incapable of providing the preferred warmth, which is unlikely. Furthermore, the staff and healthy residents (interviewed during the winter) reported that residents with dementia seem comfortable and usually wear a jumper. This would suggest that the narrow range of Category 1 might not be needed, as residents are comfortable with the wider variations of Category 2. The narrow range of ideal comfort in Category 1 in the standards has been criticised in previous research [32].

Literature on people with dementia suggests that they might not always respond to external factors as healthy adults do [33]. Therefore, the variations in temperature (2–3 °C) within some of the bedrooms on different seasons could be caused by such differences in perception, while the differences among bedrooms could be caused by differences in comfort preferences. Further research is needed on the preferences of older adults with dementia and their capacity to control their environment.

4.2. Occupancy practices related to comfort and indoor air quality

It is evident that the staff aims at maintaining the right indoor conditions (in terms of temperature and air quality) for the residents, often asking them for their preferences. The staff makes use of the heating system, air conditioning system and natural ventilation to achieve it. The heating system is used during the summer, while the air conditioning (providing cooling and heating) is used throughout the year. Both systems are used to maintain acceptable ranges of comfort for both residents and staff.

Natural ventilation is used throughout the year to keep a healthy indoor environment for the residents, even though a heat recovery ventilation system is provided. The care home seems to be ventilated as a normal care home would be ventilated: windows in bedrooms are opened to remove stale air, and windows are opened in common areas to cool them down. However, there is a lack of a natural ventilation strategy during the warmer months. Since Passivhaus buildings depend on natural ventilation during the summer to avoid overheating, the development of a strategy for systematic natural ventilation by care staff and housekeeping staff is needed.

4.3. Energy performance and energy-related occupancy practices

Energy usage is higher than expected because the heating is used throughout the year, windows are opened when needed and the air conditioning is also used to keep a comfortable temperature in the summer. None of these practices was considered in the PHPP calculation of the expected energy demand.

Furthermore, while gas consumption was significantly reduced and in accordance to designer's expectations, the reduction was not enough to reach the Passivhaus target. Due to the high airtightness, the building required air conditioning for the summer, but it is used most of the year due to temporal overheating. The use of air conditioning significantly increased electricity consumption. The reduction in energy requirements for heating was significant in comparison to an average or typical care home, but might not be significant in comparison to a low energy building (i.e. non-Passivhaus).

The Passivhaus calculations were made by a team of designers, who did not know well the activities carried out in the care home. As a result, the expected performance of the building was unrealistic in terms of energy use. If the actual activities in the care home would have been taken into account, the building could not be considered as Passivhaus due to the minimum requirements for this type of buildings. The baselines for energy consumption defined by the care home provider were much more realistic and in line with the actual consumption of the building since these were based on other existing care homes.he results highlight that setting a target is not enough to reduce electricity consumption. Knowing that a strategy for reducing electricity consumption for other uses than air conditioning was not planned, electricity reduction was bound to be not much lower in comparison to a typical care home built according to building regulations.

4.4. Lessons learned: user-centric design

The results pointed at the importance of taking into account the user during the design process. The importance of daily activities in the care home, such as airing rooms were taken into account during the design, because if the experience of the designers in the care sector. The building was provided with radiators in the bedrooms and openable windows all year round. This allowed the caregivers and cleaning staff to air the rooms daily without compromising the comfort of the residents.

In this case study, the user was well taken into account because the building was designed and built by care home developers, who know well their target group. Even when the Passivhaus concept energy targets were not met, and are unlikely to be met in the long term, the energy consumption for heating decreased due to the passive measures used in the building, while maintaining the thermal comfort conditions needed by the residents.

In this case, the concept of Passivhaus was experimental by the developers, since they had doubts from the beginning whether this concept was suitable for care homes given the usual activities. For this reason, they “proof” the building in a way to ensure the comfort of the residents.

Nevertheless, other types of users in the building were not taken into account. Air conditioning and openable windows were not provided in nurse stations or the kitchen and laundry, making working conditions for the staff in these areas very uncomfortable in the summer. In this building, the main objective of everybody is the comfort of the residents, so the staff understands that their discomfort is necessary in the areas for the residents, but not in areas never accessed by them.

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Author contributions

Prof. Tweed secured the funding and initial supervision of the project. Dr. Guerra-Santin carried out the data analysis, as well as drafting the document. Dr. Jiang contributed to the monitoring campaign and data collection. Prof. Mohammadi and MSc. Grave contributed to the investigation on people with dementia and review the document.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Alzheimer's research Uk, Alzheimer's research UK, 2020. www.alzheimers.org.uk.

[2] Dementia Statistics Hub. Retrieved March 5, 2020, from https://www.dementiastatistics.org/statistics/care-services/.

[3] O. Guerra-Santin, in: D. Keyson, O. Guerra-Santin, D. Lockton (Eds.), Living Labs: Design and Assessment of Sustainable Living, Springer, Cham, 2017, pp. 333–344 12.

[4] A. Franco, Balacing user comfort and energy efficiency in public buildings through social interaction by ICT systems, Systems 8 (29) (2020) 1–16, https://doi.org/10.3390/systems8030029.

[5] O. Guerra Santin, A.C. Tweed, In-use monitoring of buildings: an overview of data collection methods, Energy Build. 93 (2015) 189–207.

[6] R.J. Cole, J. Robinson, Z. Brown, M. O'shea, Re-contextualizing the notion of comfort, Build. Res. Inf. 36 (4) (2008) 323–336.

[7] K.E. Thomsen, J.M. Schultz, B. Poel, Measured performance of 12 demonstration projects—IEA Task 13 "advanced solar low energy buildings", Energy Build. 37 (2005) 111–119.

[8] S.E. Weaverdyck, Assessment as a basis for intervention, in: D.H. Coons (Ed.), Specialized Dementia Care Units, The John Hopkins University Press, Baltimore, 1991, pp. 205–523.

[9] J. van Hoof, H.S.M. Kort, J.L.M. Hensen, M.S.H. Duijnstee, P.G.S. Rutten, Thermal comfort and the integrated design of homes for older people with dementia, Build. Environ. 45 (2) (2010) 358–370, https://doi.org/10.1016/j.buildenv.2009.06.013.

[10] C. Craig, Imagined futures: designing future environments for the care of older people, Des. J. 20–1 (2017) S2336–S2347, https://doi.org/10.1080/14606925.2017.1352749.

[11] V. Soebarto, T. Williamson, A. Carre, L.A. Martins, Understanding indoor environmental conditions and occupant's responses in houses of older people, IOP Conf. Ser. Mater. Sci. Eng. (2019) 609 042096.

[12] Y. Jin, F. Wang, M. Carpenter, R.B. Weller, D. Tabor, S.R. Payne, The effect of indoor thermal and humidity condition on the oldest-old people's comfort and skin condition in winter, Build. Environ. 174 (2020) 106790.

[13] R. Fleming, B. Goodenough, L.F. Low, L. Chenoweth, H. Brodaty, The relationship between the quality of the built environment and the quality of life of people with dementia in residential care, Dementia 15 (4) (2016) 1–18, https://doi.org/10.1177/1471301214532460.

[14] C. Childs, J. Elliott, K. Khatab, S. Hampshaw, S. Fowler-Davis, J.R. Willmott, A. Ali, Thermal sensation in older people with and without dementia living in residential care: new assessment approaches to thermal comfort using infrared thermography, Int. J. Environ. Res. Publ. Health (2020) 6932 17,.

[15] M. Brown, D. Tolson, L. Ritchie, Changing needs in advanced dementia, Nurs. Older People (2020), https://doi.org/10.7748/nop.2020.e1204.

[16] J. van Hoof, H.S.M. Kort, M.S.H. Duijnstee, A.M.C. Schoutens, J.L.M. Hensen, S.H.A. Begemann, The indoor environment in relation to people with dementia, in: P. Strom-Tejsen (Ed.), Conference on Indoor Air Quality and Climate, Indoor Air, Copenhagen, 2008 Retrieved from www.tue.nl/taverne.

[17] M. Leung, C. Wang, X. Wei, Structural model for the relationships between indoor built environment and behaviors of residents with dementia in care and attention homes, Build. Environ. 169 (2020), https://doi.org/10.1016/j.buildenv.2019.106532.

[18] P. Cooper, F. Tartarini, R. Fleming, Getting the temperature just right helps people with dementia stay cool, Online: Faculty of Engineering and Information Sciences - Papers: Part B. 1795, 2018 https://ro.uow.edu.au/eispapers1/1795.

[19] J. Garre-Olmo, S. López-Pousa, A. Turon-Estrada, D. Juvinyà, D. Ballester, J. Vilalta-Franch, Environmental determinants of quality of life in nursing home residents with severe dementia, J. Am. Geriatr. Soc. 60 (7) (2012) 1230–1236, https://doi.org/10.1111/j.1532-5415.2012.04040.x.

[20] F. Tartarini, Impact of Temperature and Indoor Environmental Quality in Nursing Homes on Thermal Comfort of Occupants and Agitation of Residents with Dementia Doctor of philosophy thesis faculty of Engineering and Information Sciences, University of Wollongong, Australia, 2017 https://ro.uow.edu.au/theses1/128.

[21] F. Tartarini, P. Cooper, R. Fleming, M. Batterham, Indoor air temperature and agitiation of nursing home residents with dementia, Am. J. Alzheimer's Dis. Other Dementias 32 (5) (2017) 272–281, https://doi.org/10.1177/1533317517704898.

[22] F. Tartarini, P. Cooper, R. Fleming, M. Batterham, Indoor air temperature and agitation of nursing home residents with dementia, Am. J. Alzheimer's Dis. Other Dementias 32 (5) (2017) 272–281, https://doi.org/10.1177/1533317517704898.

[23] I. McHugh, D4FC Factsheet 9: British Trimmings Extra Care Home, Leek,, Technology Strategy Board, Staffordshire, 2014.

[24] A. Botti, M. Ramos, Adapting the design of a new care home development for a changing climate, International Journal of Building Pathology and Adaptation 35–4 (2017) 417–433, https://doi.org/10.1108/IJBPA-11-2016-0028.

[25] O. Guerra-Santin, N. Romero Herrera, E. Cuerda, D. Keyson, Mixed methods approach to determine occupants' behaviour–Analysis of two case studies, Energy Build. 130 (2016) 546–566.

[26] O. Guerra-Santin, A.C. Tweed, M.G. Zapata-Lancaster, Learning from design reviews in low energy buildings, Struct. Surv. 32 (3) (2014) 246–264.

[27] Cen. EN 16798-1, - Energy Performance of Buildings - Ventilation for Buildings - Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustic, European Standard, Bruxelles, Belgium, 2019.

[28] American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Thermal Environmental Conditions for Human Occupancy, Washington, DC, 2017 ASHRAE 55:2017.

[29] D. Perfect, A.W. Griffiths, M. Vasconcelos Da Silva, N.L. Dekker, J. McDermid, C.A. Surr, Collecting self-report research data with people with dementia within care home clinical trials: benefits, challenges and best practice, Dementia 1–13 (2019) 10.1177/1471301219871168journals.sagepub.com/home/dem.

[30] J. van Hoof, H.S.M. Kort, H. van Waarde, Housing and care for older adults with dementia. A European perspective, J. Hous. Built Environ. 24 (3) (2009) 369–390.

[31] L.H. Fisher, D.J. Edwards, E.A. Pärn, C.O. Aigbavboa, Building design for people with dementia: a case study of a UK care home, Facilities 36 (7/8) (2018) 349–368, https://doi.org/10.1108/F-06-2017-0062.

[32] E. Arens, M. Humphreys, R. de Dear, H. Zhang, Are 'Class A' temperaturerequirements realistic or desirable?, Build. Environ. 45:1 (2010) 4–10.

[33] J. van Hoof, H.S.M. Kort, J.L.M. Hensen, M.S.H. Duijnstee, P.G.S. Rutten, Thermal comfort and the integrated design of homes for older people with dementia, Build. Environ. 45 (2010) 358–370.