Summer post occupancy evaluation of a Passivhaus care home in the UK

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ABSTRACT: This study investigates summer comfort in the first Passivhaus care home in the UK. Passivhaus is a German standard which aims to save energy and provide a warm indoor environment in cold seasons, but concerns remain about overheating in summer. There are different types of occupants in a care home. They differ in the type of activities they perform and also in their clothing requirements. This study sought to determine thermal comfort levels for the different groups of occupants. Continuous monitoring of indoor and outdoor parameters was carried out for the summer period. Energy consumption for specific final use and heat delivered to radiators were also measured, as well as spot measurements of air speed. The POE also included structured interviews with the staff who answered questions about their comfort and the operation of the building. Residents were not interviewed due to their poor health. Predicted Mean Votes were calculated from the measurements and the information provided in the interviews. Calculations were carried out for both residents and staff in each of the spaces monitored including a selection of occupied bedrooms, lounge, dining room, nurse station and reception. The results were compared with data from the comfort survey of the staff and showed that most members of the staff are not comfortable and consider the building to be too warm in the summer. However, the PMV calculation showed that while indoor temperatures were too high for staff, they were acceptable to the residents because of their lower activity rate. Staff often accepted this discomfort because they were aware of the needs of the residents and acknowledged that higher temperatures are necessary for their comfort. This suggests complex relations are at work, which would normally be glossed over in conventional comfort studies. The paper concludes by considering the implications of this in the design of caring environments.
Keywords: Comfort, Post-occupancy monitoring, Passivhaus, Care home

INTRODUCTION

In the UK, there is an increased interest in the Passivhaus energy standard. The core focus of the standard is “to dramatically reduce the requirement for space heating and cooling, whilst also creating excellent air quality and comfort levels” [1]. Air tightness combined with mechanical ventilation with heat recovery (MVHR) are the basic Passivhaus elements. Due to the air tightness of the envelope, and large windows used to maximise solar gains in the winter, concerns remain about the potential for Passivhaus buildings to overheat during the summer. Summer overheating could increase the use of air conditioning, or electricity for fans, as well as discomfort to the occupants of the building. This study focuses on the initial post-occupancy evaluation of the first Passivhaus certified care home in the UK. The objective of the study is to determine the performance of the building during the summer in relation to thermal comfort and indoor air quality.

The case study consists of 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. The construction is timber frame, with very high insulation levels and triple glazing to achieve the required air tightness. 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 etc. MVHR units are used to recover heat from exhaust air and provide fresh air. The building was constructed under a design and build contract for the development company, which has let it to a care provider on a 35 year, long term lease. The development company has more than 15 years of experience building care homes, but this is their first Passivhaus project. The BSRIA soft landings initiative [2] was implemented to improve the operational use of the building. The care home providers specialise in dementia care, and the first floor of the building has been designated for residents with this condition. However, there are no design differences between the ground floor and the first floor. Due to the increasing number of people with dementia [3], the importance of providing the best environments for residents and carers has been noted and research has been conducted in recent years [4, 5, 6]. This research focuses only on thermal comfort and indoor air quality. Methods to evaluate other aspects of quality of life in residential care buildings have been identified elsewhere [4].

DATA AND METHODS

Indoor and outdoor parameters were recorded during the summer at 30 minute intervals. Temperature, relative humidity and CO_2 measurements were taken in selected spaces. The care home was not fully occupied at this time and so the selection of the spaces depended on the occupancy. These are: two bedrooms on the ground floor and six on the first floor, a nurse station, the lounge and dining room on the first floor, and the coffee shop in the ground floor. Bedrooms facing north and south were selected to compare the effect of solar gains. External weather conditions were also measured.

To evaluate comfort in the building, interviews with the occupants were conducted. The care home has different types of occupants, with very different activities and health condition. Therefore, the level of comfort of each group needs to be evaluated. Four groups were identified: 1) residents are the most sensitive group since they live in the building and usually suffer from poor health; 2) nurses and carers have 12-hour 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; and 4) administrative staff have a lower activity level (usually office type) and work 8-hour shifts. The groups also differ in that they occupy different parts of the building. Residents and care staff spend most of the day in bedrooms and common areas, housekeeping staff also use the laundry room, kitchen staff are mainly in the kitchen and dining areas, and administrative staff have offices on the ground floor. Thus, to evaluate comfort, we asked the occupants about their comfort levels in different areas of the building.

Occupant behaviour was investigated to determine its effect on comfort and energy efficiency. Heat meters were installed in the radiators of 12 bedrooms. Sensors were installed on a selection of windows in bedrooms, but data were not available at this stage of the study. Measurements of CO_2 concentration and temperature were also used as indicators on the use of windows and air conditioning. To corroborate the data from monitoring, the occupants were asked about the way they interact with the building.

Energy meters and sub-meters have been installed to determine the energy consumption per energy use. A customised 17-channel logger was installed to monitor energy use; the results are not reported in this paper.

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RESULTS

The results presented in this paper are from the first seasonal monitoring of the care home: from mid-June to end of August 2012. Interviews were conducted during two days at the end of August. Not all staff members could be interviewed because some were on annual leave and others did not have shifts on those days. Residents were not interviewed during this initial period due to lack of residents with good health condition. Not all monitored rooms were occupied, but we compared the data from unoccupied and occupied rooms where we believe occupancy has a large effect, for example, indoor air quality (CO_2 concentration).

	June Mean(SD)	July Mean(SD)	August Mean (SD)
Nurse	23.1(1.2)	26.4(2.0)	24.6(1.2)
Coffee	22.7(1.3)	25.8(2.3)	23.4(1.2)
Lounge	23.1(1.4)	26.6(2.2)	24.2(1.4)
Dining	23.5(1.4)	26.4(2.2)	24.7(1.4)
B18	21.8(1.7)	25.9(1.9)	22.5(1.8)
B20	23.0(1.3)	26.1(1.9)	22.9(1.5)
B48	21.2(2.0)	23.1(2.2)	22.2(1.7)
B55	26.4(1.2)	29.9(0.8)	27.9(3.1)
B56	27.4(1.2)	28.0(2.0)	24.5(4.2)
B49*	23.5(0.9)	23.6(1.6)	22.5(1.5)
B50*	23.3(0.9)	23.7(1.4)	23.1(1.1)
B54*	25.3(1.2)	25.2(1.6)	23.8(1.3)

(*) occupied bedrooms

Table 1 Descriptive statistics Temperature per room

Building conditions

Temperature, relative humidity and CO_2 sensors were set up in eight bedrooms and four common areas. Only three bedrooms out of the eight were occupied at this time. Table 1 shows the statistics of each month for monitored spaces. Analysis of the temperatures shows similarity across the occupied spaces most of the time. The temperatures in occupied bedrooms and common areas are more or less constant, usually with less than 3°C of difference in one month. There was an increase in temperature in common areas and unoccupied bedrooms in July, which was followed by starting using the air conditioning on a regular basis.

Thermal comfort

During the interviews, staff members were asked to rate their thermal comfort based on the seven-point thermal sensation scale, and to rate the temperature and air quality in the building also on a seven-point scale. Fourteen staff members were interviewed. The interviews showed that most of 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 is used in the summer. However, as some other studies have shown [4], staff reported feeling “comfortable” working at the care home due to other factors such as working conditions provided by the organisation. Some staff members, mostly care staff, stated that the building was too warm, but was “just right” for the residents. However, there are spaces not intended for residents that were considered too warm. Staff members reported the kitchen and laundry to be too hot and to have no control to change it, since on warm days opening windows does not cool these spaces. Table 2 shows the comfort ratings given by staff members for monitored areas. The lounge was rated between neutral and slightly uncomfortable, and mostly warm.

The coffee shop was rated mostly as comfortable. It is important to notice that in the coffee shop, the activity level of the staff members is lower than in other areas. The nurse station was the space reported to be most uncomfortable and between warm and hot. The dining room was reported as too warm and uncomfortable but the staff understands that it because of heat gains from the meals. Most staff members felt no difference in temperature between bedrooms and only few between the ground floor and the first floor. Differences between bedrooms were reported to be mostly dependent on the residents. The rating of bedrooms varies between comfortable and slightly uncomfortable. Although the staff acknowledge their discomfort ensures residents' comfort, some felt that their own comfort could be improved through more breathable uniforms and they expressed preferences for a polo shirt type of uniform. In subsequent interviews, the staff were asked about their opinion about residents' comfort. They reported that residents were comfortable in all spaces.

	<Comfortable					Uncomfortable>
	-3	-2	-1	0	+1	+2	+3
Lounge	0	14	7	**35**	**30**	7	7
Dining	0	14	7	7	**20**	**35**	14
Nurse	0	10	10	10	**20**	**50**	0
Coffee	0	**60**	7	20	7	0	%
Bedrooms	0	0	**50**	8	**33**	8	0

Table 2. Comfort ratings by staff (%, N=14)

Building operation

Data about the operation of the building were collected in several ways. First, the staff were asked about opening windows for ventilation and cooling, and about their use of air conditioning in the common areas. Second, the heat flow to radiators in bedrooms was constantly monitored for the period. Last, correlations between indoor parameters and outdoor conditions were used as an indicator of ventilation activity. CO_2 concentration and indoor temperatures for each monitored space were correlated (individually) with wind speed and external air temperature.

The results showed that the radiators of some unoccupied bedrooms were on during the summer, increasing the indoor temperature of such rooms and affecting other indoor temperatures because doors were left open. The radiator in one occupied bedroom was also in use during the summer, as shown in Figure 1. However, the temperature in this room was not higher than in the other occupied monitored rooms because of the use of natural ventilation. Staff reported opening windows in the bedrooms in the morning mainly to get rid of stale air and odours, but when the resident was in the bedroom, they would ask them about opening the window before doing so. Most of the staff members reported opening windows as part of the normal cleaning 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."

Visualisation of indoor conditions, analysis of energy usage, and reports from the facilities manager indicated that the air conditioning was 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^{o}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.

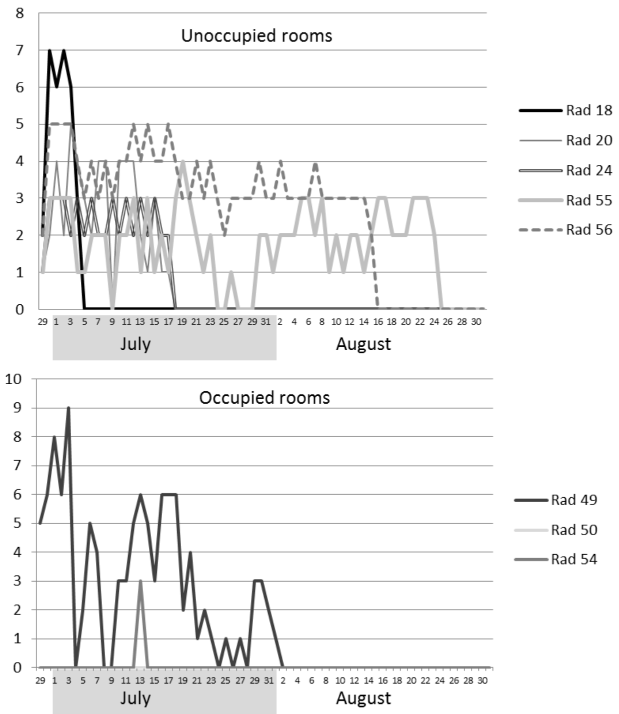

Figure 1. Heat to radiators in unoccupied and occupied bedrooms per day (kWh)

Analysis of the correlation between indoor and external conditions was carried out. Two assumptions were made: 1) a positive correlation between indoor and outdoor temperature suggests reduced use of air conditioning in common areas and greater use of natural ventilation; and 2) that a negative correlation between indoor air quality (CO_2) and wind speed indicates natural ventilation. These assumptions are made based on the high air tightness of the building. The results showed that in June, air conditioning was not extensively used in common as indicated by medium correlations between external air temperature and indoor temperature (Nurse .501, Coffee .397, Lounge .344 and Dining .503, $p<0.001$). In July, air conditioning was more frequently used, as indicated by very low or no correlation with external temperature (Nurse .098 and Dining .136, $p<0.001$). In August, air conditioning was less frequently used than in July; a smaller correlation was found in comparison to June but larger in comparison to July (Nurse .162, Coffee .435, Lounge .247, Dining .426, $p<.001$).

Small and medium negative correlations were found between CO_2 concentrations in common areas and wind speed, with exception of the Coffee Shop in August, suggesting some use of natural ventilation. All bedrooms showed medium to high correlations between external air temperature and indoor temperature; the only exception being two occupied rooms which showed no correlation in June. In addition, small and medium negative correlations were found between wind speed and CO_2 concentration in all rooms; the small correlations correspond to the same occupied bedrooms in June. These two findings suggest frequent use of natural ventilation in bedrooms, although occupied bedrooms appear to have been less well ventilated (via windows) in June.

Correlations between indoor temperature and solar radiation showed differences in the effect of radiation between rooms on the north and south facades. Rooms facing south (small to medium correlation) have larger correlations to radiation than rooms in the north (small or no correlations).

	PMV	PPD	CO2
Category 1	-0.2<PMV< 0.2	<6%	<350 ppm*[1]
Category 2	-.05<PMV< 0.5	<10%	350-500 ppm*[2]
Category 3	-0.7<PMV< 0.7	<15%	500-800 ppm

(*1) Since external CO_2 levels now reach 400 ppm, this category will not be considered further.
(*[2]) This category becomes <500 ppm
Table 2. Categories according to ASHRAE standard 55:2004-04.

Building performance: thermal comfort and indoor environment standards

In this study, building performance is assessed in two areas: thermal comfort and indoor environment, and energy efficiency; however this paper only reports on thermal comfort and indoor environment performance. To evaluate the thermal comfort and indoor environment performance of the building, we have used the ASHRAE standard 55:2004-04 [7] for thermal comfort. The Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfaction (PPD) were calculated for every monitored space and for each measured interval (30 minutes). For this calculation, it is necessary to take into account activity and clothing levels of the occupants. Since there are large differences in activity and clothing across the different types of occupants, two calculations were made for each space: one for residents and one for care and housekeeping staff. 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. Clothing insulation values were calculated from observations. A value of 0.95 was used for residents. For staff, a value was derived for each of two uniforms: 0.472 and 0.392. The PMV of staff was calculated for both uniforms. Activity level was assumed to be 1.0 met for residents (sedentary activity level), mostly sitting and resting; and 2.0 met for the staff (moderate activity). These were also based on observations. The activity level of the staff in the coffee shop was considered as 1.2 met.

The percentage of time of the spaces being in each category was calculated next. The ASHRAE standard 55:2004-04 introduces three categories of performance. These categories depend on the stringency of the building evaluation. The building can be evaluated based on the amount of time (%) that a given parameter (PMV, PPD, CO_2) falls within the requirements of each category. The categories are: 1) used when it is desired to adhere to higher than typical comfort standards; 2) new buildings and; 3) existing buildings. We have considered the building to belong to Category 1 since Passivhaus buildings should provide both energy efficiency and good indoor comfort. In addition, it is the category that should be used for occupants with serious health conditions. However, it is important to notice that it would be prohibitive for a building to be always within one category in terms of energy consumption. The ranges per category are shown in Table 2. The following figures show the performance of the building in the summer.

Figure 2 shows the results of the categories for CO_2. In this case, we use CO_2 as an indicator of indoor air quality. The figure shows that occupied bedrooms are most of the time within Category 3 (500-800ppm). Considering that this is during the summer, when windows can be opened, it indicates a potential problem during the colder seasons. Concentrations of CO_2 in common areas are around 50% within Category 2, indicating more ventilation than in bedrooms. The figure also shows the same categories for unoccupied rooms, which show better indoor air quality.

Figure 3 shows the percentage of time in each category (for PMV) per space and occupant group. The PMV of staff is based on the lighter uniform. The building is within Category 1 for residents between 40-50% of the time in the bedrooms and only 20-30% in common areas. Common areas are too hot for the residents. The building is in Category 1 for the staff less than 10% of the time in bedrooms and less than 20% of the time in common areas.

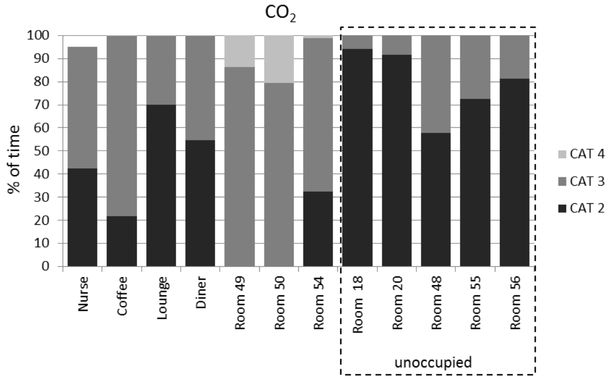

Figure 2 Percentage of time within categories: CO_2 concentration

DISCUSSION

According to the results of the PMV analysis, residents are not comfortable all the time. The building is within Category 1 20-60% of the time depending on the room. The reasons for discomfort are both low and high temperatures. However, the staff and residents (interviewed during the winter) reported that residents are comfortable and usually wear a jumper. Literature on people with dementia suggests that they might not always respond to external factors as healthy adults do [5]. Therefore, different indoor conditions in occupied rooms could be based in such differences in perception and also on differences in comfort preferences. Mean temperatures per month were different across rooms but constant within a room from month to month, indicating differences in residents' preferences. Since the residents and carers are free to open windows and even use the radiators in the summer, we suggest that both residents and carers try to keep the indoor conditions as the residents prefer. However, it could also suggest that it is difficult to manage the building to keep comfortable settings.

Staff members, according to the PMV calculations, are uncomfortable most of the time. This finding is in accordance with the results of the questionnaire survey applied during the interviews. Their discomfort is reduced when a lighter uniform is used, according to both the results of calculations and interviews. Even when they are uncomfortable, the staff are aware that keeping high temperatures is necessary for the residents to be comfortable.

The results of this study indicate there is some degree of discomfort for the residents and the staff are uncomfortable most of the time. However, the reasons for discomfort in both groups are for different reasons. Some spaces are too hot for the staff and some spaces are too cool for the residents because thermal comfort requirements of both groups of occupants are different. While in other settings, the best could be a compromise for both groups, in a care home for the older people with poor health, this would not be possible. Due to 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.). In addition, care staff understand that residents need to be warm and may be willing to accept warmer indoor conditions than occupants of other types of building.

We used the ASHRAE standard to evaluate building performance. Residents' PMV in the bedrooms was only around 50% of the time in Category 1, but 70 to 90% in Category 2. According to the calculations, two bedrooms are too cool and one is too warm. However, since the residents can freely open windows and even turn on the radiators, we can assume that their rooms are at their preferred temperatures, unless the system is incapable of providing the preferred warmth, which is unlikely. This would suggest that the narrow range of Category 1 is not needed, as residents are comfortable with the wider variations of Category 2. The categorisation of the standards have been criticised in previous research [8].

CONCLUSIONS

The results from monitoring show that temperatures in the common areas of the building are too high for both residents and staff, even when residents require higher temperatures due to their low activity levels and health conditions. The temperatures in bedrooms are too high for the staff, but seem to be right for the residents, who can freely open windows and make use of the radiators even in the summer. Evidence of this can be found in the indoor conditions in occupied bedrooms, which show different temperatures. Such differences are related to the ventilation preferences of the residents and the use of radiators.

The staff are uncomfortable but understand that the residents in their care require higher temperatures. Residents seem comfortable and have freedom to affect the indoor environment in their own bedrooms. Raising awareness among other members of the staff about this issue could increase the overall comfort.

Analysis of heat flows to radiators showed that the radiators of some unoccupied bedrooms were on during part of the summer, raising the temperature in these bedrooms and potentially contributing to higher indoor temperatures in common areas when the doors are kept open. In addition, the radiator in one occupied bedroom was in use during July and part of August, but the temperature in this room was not higher than the temperature in the bedrooms with the radiators off, suggesting the use of natural ventilation. This was corroborated by the interviews.

The CO_2 level seems high, especially in the bedrooms, indicating the need to greater ventilation. More ventilation via windows could also help to decrease the indoor temperatures of the lounge and dining room.

The staff were able to open windows and use air conditioning in common areas. Air conditioning was reported to be overused during the summer, with the staff adjusting the temperature in the lounge and dining area. The temperature in the nurse station is more restricted and therefore shows less variance. The staff reported opening some windows when necessary but there is a lack of a systematic natural ventilation strategy to cool the building as it would be necessary in a Passivhaus building.

Higher ventilation rates could increase comfort and air quality in common areas, which overheat in the season. Overnight ventilation in common areas could also help to address this problem. More natural ventilation is needed in common areas if there is a desire to restrict the use of air conditioning. By looking at the temperature in bedrooms, and coffee shop, it seems that with the right interaction between people and building, better indoor conditions could be reached. A follow up in the summer would help to determine the adaptation of the users to the building.

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. However, 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.

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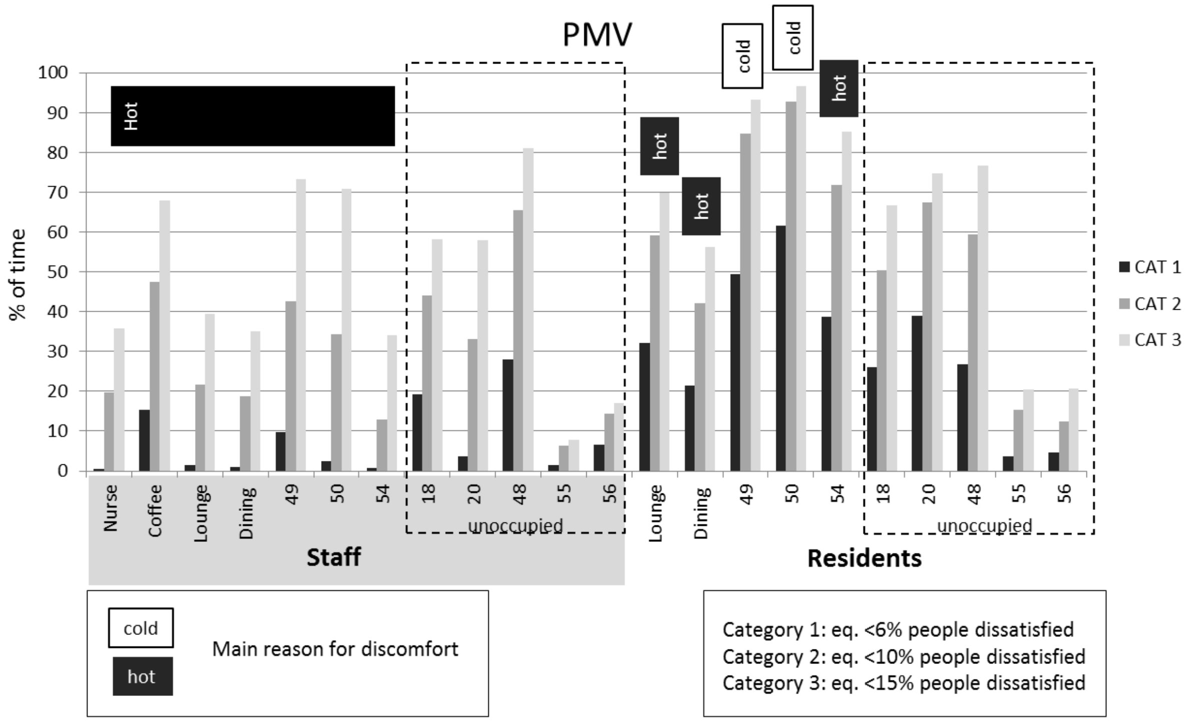

Figure 3. Percentage of time within categories: Predicted Mean Vote for residents and staff