Monitoring the indoor environment for older people with dementia: a lesson learned

Chuan Ma [a,*], Olivia Guerra-Santin [a], Anne Grave [a], Masi Mohammadi [a]

[a] Smart Architectural Technologies, Department of the Built Environment, Eindhoven University of Technology, the Netherlands.

Email address: c.ma@tue.nl (C. Ma), o.guerra.santin@tue.nl (O. Guerra-Santin), a.j.j.grave@tue.nl (A. Grave), m.mohammadi@tue.nl (M. Mohammadi)

Abstract. Dementia is a syndrome that progressively affects cognitive, behavioural and psychological functions. People with dementia may have difficulties in sensing and expressing indoor environmental changes. Sensor technologies, such as environmental sensors, can be used to evaluate indoor environmental quality by accurately detecting the indicators, including air temperature, relative humidity, illuminance, noise level, CO_2, TVOC, and particulate matter. Monitoring these indicators for older people with dementia helps maintain their health and comfort. Moreover, some clues of behaviours and symptoms of older people with dementia could also be shown in the sensor data. This study used a mixed-method approach to find the links between indoor parameter variations and residents' activities. In a care home in the Netherlands, we collected quantitative environmental data through a sensor network deployed in bedrooms and central living rooms, and the care professionals filled qualitative data by diaries. Ten residents and two care professionals were recruited to take part in observation and diary recording. During two months monitoring campaign, care professionals selected one week that recorded five-category information on residents' daily lives: 1) building facility operation; 2) external factors; 3) details in daily lives; 4) problem behaviours or symptoms; 5) indoor comforts. By comparing the two types of data obtained, residents' wandering and sleeping problems have been found that coincide with the data fluctuations to some extent. The timing and process of these behaviours can be presented through data analysis. But more underlying factors in behavioural changes of people with dementia still require long-term observation and validation of future research.

Keywords. people with dementia, care home, indoor environmental quality, sensor, problem behaviour.
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1. Introduction

In 2019, over 50 million people lived with dementia globally, and this number is steadily increasing [1]. In the Netherlands, the population diagnosed with dementia was 270,000 in 2017, and the number will rise to 520,000 in 2040 [2]. Dementia is a progressive syndrome that leads to a change in cognitive, behavioural and psychological functions [3]. Appropriate indoor environmental conditions could have positive impacts on helping delay the dementia progression and reducing problem behaviours [4]. Some studies have explored the effects of indoor environmental indicators on people with dementia. For instance, controlling the indoor air temperature in an appropriate range can alleviate agitation; long-term exposure to a dark environment could disrupt biological rhythms; overexposure to noise can cause confusion, illusions, and sleep disorders; and poor indoor air quality can accelerate the spreading of airborne diseases in care facilities [5-8]. However, the suitable ranges of these indicators and the thresholds that could trigger symptoms and problem behaviours still need to be validated.

The development of smart technologies could support older people's daily activities and monitor their safety, health, and living environment [9,10]. As the data gathering part of smart systems, sensors have a broad range of potential applications in dementia care [11]. Although indoor environmental quality is important, the majority of sensor applications are focused on monitoring the health indicators, locations, and activities of people with dementia. Moreover, the devices with cameras are not welcomed, so gathering data on older people with dementia's daily lives normally requires a relatively sophisticated sensor network, including passive infrared sensors (PIR), contact sensors, power usage sensors, pressure sensors, wearable

sensors, environmental sensors, etc. [12].

In a review study on the research that used IoT devices and sensor technologies for elderly care in the last decade, Stavropoulos et al. found that only five of them used environmental sensors in a total of fifty-three studies [13]. Directly detecting people with dementia's physical conditions, positions, and activities is essential to maintaining their health and safety. However, the impacts of indoor environmental quality cannot be ignored, which could be precipitating factors of problem behaviours and symptoms. For instance, Cremers's research showed that the restless behaviour of people with dementia coincided with peaks in the bedroom CO_2 level above 800 ppm. And this behaviour will disappear after the room has been ventilated for thirty to forty-five minutes [14]. In most cases, sensor data is only used to evaluate indoor environmental quality in a given space, and a few studies have explored the extent of indoor environmental parameter variations influencing occupants' health and well-being.

This paper describes a preliminary method to gain more insight into people with dementia's actual living conditions. We collect quantitative and qualitative data from the participants' daily lives and living environments. The study aims to find underlying factors behind these data that link indoor environmental parameters with residents' circumstances. Section 2 introduces the research methods of the case study, including data collection and analysis. Section 3 shows the findings by elaborating on two samples. Section 4 contains the discussion and conclusion.

2. Research Methods

The case study was conducted in a small-scale care facility in the Netherlands for older people with dementia. Each floor of this two-storey building consists of sixteen bedrooms, two lounges, a central living room, and a nurse station. A spacious green courtyard locates on the ground floor, and a semi-opened terrace is on the first floor. Each bedroom is equipped with a private bathroom, and the ventilation outlet is inside. The mechanical ventilation inlet is on the top of the bedroom entrance. The floor heating system supplies hot water in heating seasons or cold water in summer to cool down the indoor temperature.

Residents can furnish the interior according to personal preference, and with their own belongings, so the layouts of bedrooms were slightly different. Sensors were placed on the top of wardrobes or shelves and away from heat and light sources (Figure 1). The receiver side of sensors was toward beds, where some residents with severe dementia spend most time every day. This study collected indoor environmental data from the main activity areas of residents.

Fig. 1 - Sensors in bedrooms.

The monitoring campaign was continuously in June and July that measured indoor environmental data in ten bedrooms and two central living rooms. Table 1 shows the sensor specifications of light intensity, relative humidity, air temperature, particle matter (PM), CO_2, and total volatile organic compound (TVOC). 10 of 32 residents living in the care home participated in this study. Two care professionals were invited to record participants' information by using a designed checklist template (see Appendix), including: 1) building facility operation (curtain, light, ventilation system, window, floor-heating, and electronic devices); 2) external factors (weather and visitor number); 3) details in daily lives (mood, status, vitality, clothes, and activities); 4) problem behaviours or symptoms (agitation, depression, wandering, aggression, restless sleep, screaming, hallucinations, dry eyes, cough, chest tightness, etc.); 5) indoor comforts (thermal comfort, visual comfort, and air quality). For simplifying the tasks, icons were used instead of long texts for describing the scenarios. Care professionals could tick the proper selection or make a cross if the description was not correct. They also can write down comments or remarks if they have other findings.

Tab. 1 – Sensor specifications.

Parameter	Range	Accuracy	Resolution
Humidity	0 – 100 %	± 3 %	0.01 %
Temperature	0 - 60 °C	± 0.4 °C	0.01 °C
CO_2	400 – 2000 ppm		
TVOC	0– 600 μg/m^3		
Light	0.01 - 83k Lux		
$PM_{2.5}$	0 – 500 μg/m^3		1 μg/m^3

The diary recording started from the 19th to the 25th of June, 2021, for one week and followed the ward round schedule three times a day (8:00 to 10:00 in the morning, 14:00 to 16:00 in the afternoon, and 20:00 to 22:00 at night). Each time care professionals asked participants about their indoor comforts and observed the other required information by the checklist. The diary records were analysed by SPSS Statistics associated with environmental sensor data and local weather data (from The Royal Netherlands

Meteorological Institute) to find the links between data deviations and participants' circumstances.

3. Results

We received 184 valid records that involved ten bedrooms for approximately six days and selected one-day data of two residents living in adjacent bedrooms to show the analysis method and results. We use Resident A, B and Room A, B to refer to these two participants and their bedrooms.

By comparing the sensor data with ASHRAE Standard 55, CIBSE Guide A, and WHO air quality guidelines [15-17], the indoor environmental parameters in the care home were in the suggested ranges most of the time. The indoor air temperature was between 22 to 27 degrees Celsius, and the relative humidity was in the range of 40 to 70%. $PM_{2.5}$ was kept at a low level, and the mean value was less than 3 μg/m³. The CO_2 and TVOC concentrations and the indoor illuminance varied significantly among rooms and changing followed the time. Furthermore, the weather had obvious influences on the indoor light environment. The maximum illuminance in bedrooms was between 150 to 300 lux and matched the moderate light intensity level [18,19]. But the mean indoor illuminance value of a windy day (June 20th) was 43.2 lux, and the mean value of a rainy day was only 18.5 lux (June 21st).

Figures 2 and 3 show the data of Residents A and B and their bedrooms on the 20th of June. Both sensor and diary data were integrated into these figures. According to the diary records, Resident A had no sleeping problems but had other symptoms such as depression, cough, and bad mood since the 19th. The main activities were sitting on the sofa and watching TV in the following days. Resident A felt cold at night due to the outdoor temperature dropping from 23 to 16 degrees Celsius since the 20th. Care professionals opened the curtain and window at the first ward round in the morning for natural ventilation and light. The bedroom started getting brighter and fresher around 9 am (Figure 2). Because the window in Room A kept open from 19th to 20th, the data clearly shows the air quality parameters were low while the relative humidity and temperature had fluctuations. After the window closed on the 20th night, both CO_2 and TVOC concentrations increased significantly, but relative humidity and temperature fluctuations tended to be a straight line. This figure shows regular indoor environmental parameter changes of a room from ventilated to confined.

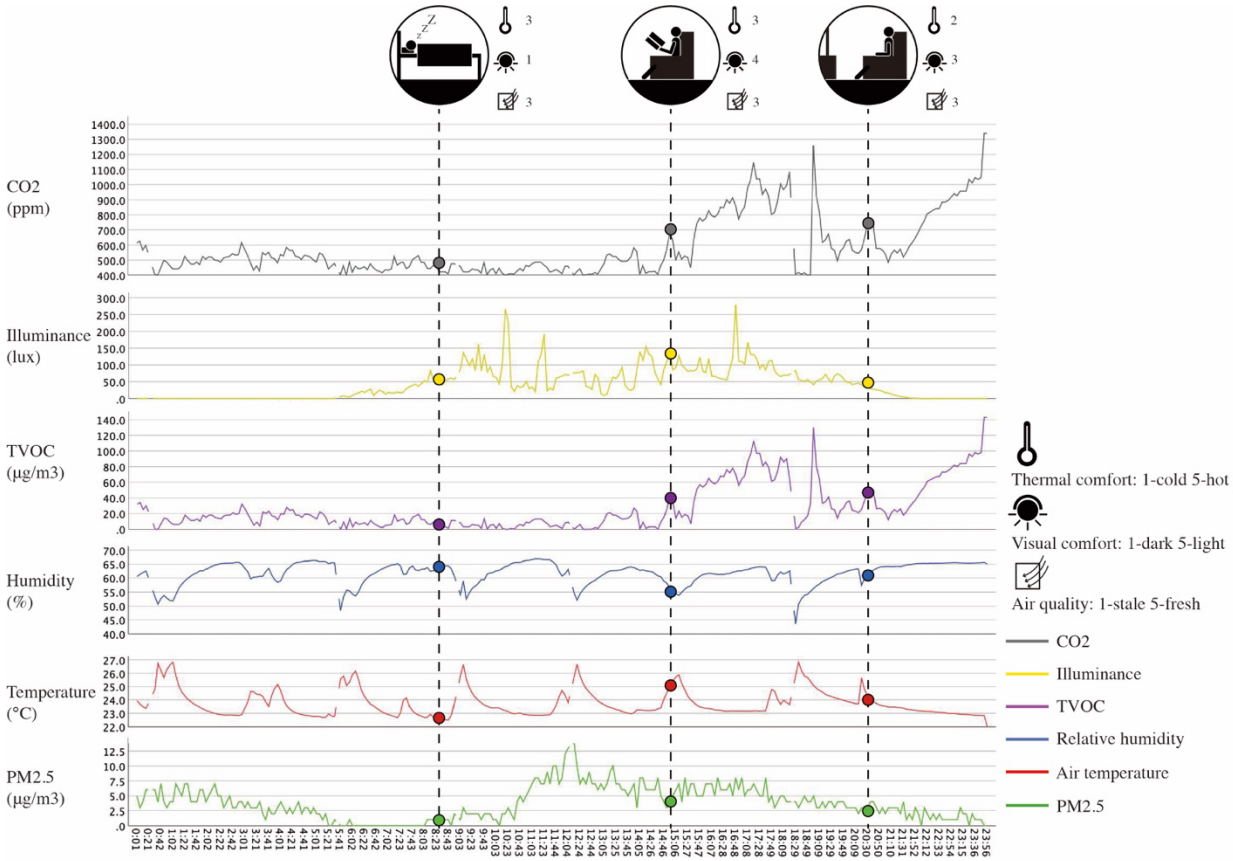


Fig. 2 - Room A and Resident A data on the 20th of June.

Resident B had sleeping problems, wandering behaviour, and joint pain. During the diary logging period, Resident B was found wandering in the care home several times when care professionals checked the room. Figure 3 shows the data of Room B on the 20th of June when the wandering behaviour of Resident B was reported. The first air quality parameter fluctuations were captured around 1:00 to 3:00 am. The CO_2 and TVOC concentration significantly increased to 2000 ppm and 280 μg/m³. Then the data decreased to 750 ppm and 50 μg/m³ from 3:00 to 6:00, while the rest parameters were stable. The second air quality parameter fluctuations

were between 7:00 to 9:00 am. The CO_2 and TVOC variation ranges were from 850 to 2350 ppm and 70 to 230 μg/m³. Resident B was found in the corridor at 8:30 and brought back to the bedroom. Then the care professional opened window and curtain that the illuminance data increased to 150 lux, and the CO_2 and TVOC concentrations dropped from 1900 ppm and 230 μg/m³ to 450 ppm and 10 μg/m³. Because the door was not closed after the last ward round on the 20th, Room B was continuously ventilated via the corridor. Air quality parameters were at low levels, and the rest parameters were stable at night. This figure shows a very different indoor variation trend than Room A.

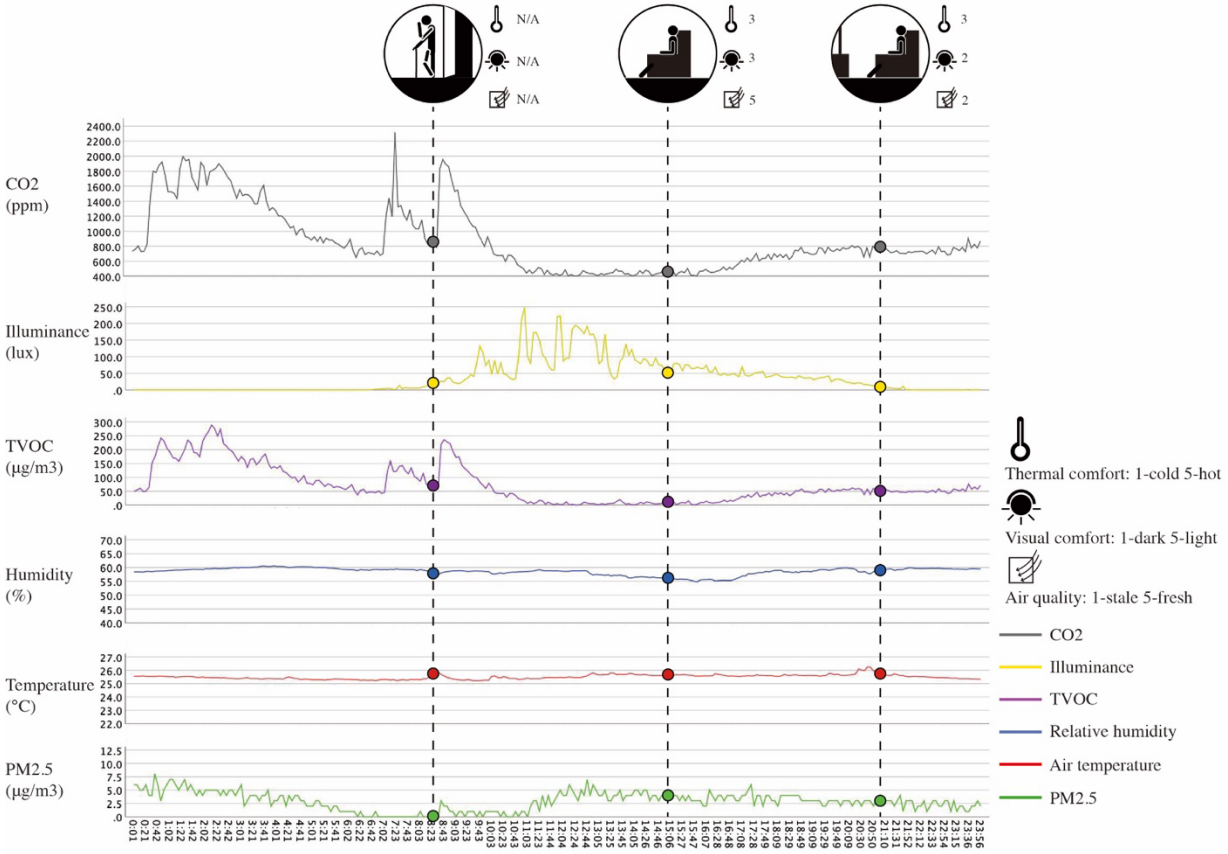


Fig. 3 - Room B and Resident B data on the 20th of June.

4. Discussion and Conclusion

Using environmental sensors to monitor people with dementia's living environments could contribute to dementia care. The proposition explored in this study was the method used to find the relationship between the circumstances of people with dementia with indoor environmental parameter changes. We assumed that the environmental data could reveal some health impacts, problem behaviours, or living details that could improve the quality and efficiency of dementia care. Therefore, this study used a mixed-method approach to continuously collect the indoor air temperature, relative humidity, illuminance, CO_2, TVOC, and particulate matter data in different rooms and capture the details of residents' living conditions at specific moments to verify the hypothesis.

Data and diary logging were recorded simultaneously to capture the real-life conditions of the participants and to determine the actual living scenarios. All participants living in similar indoor environments and having similar daily routines was an advantage since we could find similarities and differences by comprehensive analysis and comparison. For example, we could find different ventilation habits by comparing the data of the central living room on the same floor. We can speculate the time when Resident B was wandering into the corridor on the early morning of June 20th. The sensor data show the CO_2 level decreased significantly from 2000 ppm to 750 ppm since 2:30, and this value was close to the data (700 ppm) monitored in the central living room at that time. Room B was ventilated via the corridor. The temperature, humidity, and illuminance had tiny fluctuations because these data were similar in the care home. Of the 16 reported sleeping problems and wandering behaviours of all participants, 11 cases happened in poorly ventilated spaces as a similar trend in Figure 3. Moreover, collecting outdoor environmental data could also benefit the study. For example, natural ventilation plays an essential role in indoor air quality. We assume that Room A kept the window open all day until the night of June 20th because its CO_2 concentration was around 450 ppm (near the outdoor level [20]). We still need to confirm our assumption by comparing indoor and outdoor data. From the diary records, we found that residents prefer to close curtains or window shades for protecting their privacy and prevent glare. If a bedroom was kept less than 50 lux on a sunny day, it could more likely indicate the resident was staying in

the room with the curtains closed. Thus, outdoor lighting data could help identify residents' occupancy.

Many limitations remained in this study due to the heavy workload of the care professionals, limited access to the residents, and the small research sample. Data from more participants filling in the diary logging, as well as a monitoring campaign across different seasons, could provide more insightful results. Evaluating residents' indoor comfort only by asking them might not be accurate if they were impatient with answering repeated questions. The diary recording frequency of each room is also open to debate. The air quality in bedrooms was usually getting worse during the night. One ward round during midnight could have improved the quality of the data. In addition, we found that many of the diaries filled in by the care professionals were not completely filled in. In 45% of them (83/184), the information regarding the dementia problem behaviours or symptoms was not completed. Most of the mood selections were neutral and happy, which seems less relevant to the indoor environmental quality. These lead us to conclude that either the care professionals did not have enough time to fill in this part due to their busy schedules or the right questions were not included in the diary. Further research is suggested to use less time-consuming data collection methods that reduce participants' workload.

Sensor placement was also a challenge for measuring the living environment of people with dementia. Data loss due to devices offline was a limitation in this study. Older people with dementia might fiddle with sensors if they are placed reachable, such as on bedside tables. The sensors used in this study were Wi-Fi-based and connected with the local Wi-Fi network. Because the routers were in central living rooms located in the middle of the building, signals in bedrooms at the end of corridors were too weak for data transmission. In this case, adding routers or using other protocol sensors, such as Zigbee, could improve the sensor network. Sensor selection and installation are suggested to consider the building layouts.

Objectively understanding the living conditions of people with dementia requires taking into account all the possibilities of data variations. For example, indoor air temperature fluctuations could be caused by heating, cooling, building insulation, or weather changes. If the temperature deviation is shown to be minor for a long time, it could mean the excellent building insulation but could also indicate the lack of natural ventilation in the room. Normally, air temperature fluctuates with air quality parameters and relative humidity in a reasonable range in a ventilated room. The behavioural habits of residents living in familiar environments usually show regular variations in environmental data. Occasional fluctuations in data are likely linked to behavioural changes. However, the connections from the diary records, such as cough, dizziness, and shivering to indoor environmental parameters still require more data and long-term observation.

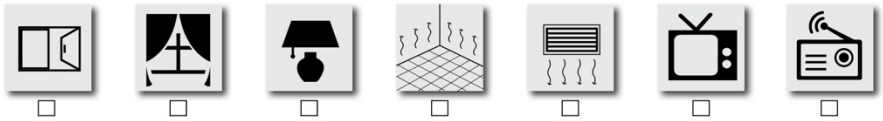
Overall, the care home provided good living conditions for residents since indoor environmental parameters were basically within suggested ranges. This study provides a preliminary method to collect data from older people with dementia. By comparing and verifying the environmental sensor data with the diary records, the occurrence of some problem behaviours, such as wandering, can be revealed. With more solid evidence linking sensor data with health indicators and building environments, using sensors to monitor people with dementia's living environments could be more efficient and non-intrusive to maintain their comfort and well-being.

5. Appendices

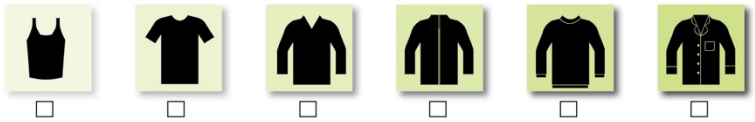
Date and time: _____ Weather:

Room number: _____ Visitor number: _____

Building facilities and electronic devices (✓: open/on; X: closed/off)



What is he/she wearing?



What is he/she doing?

What is his/her mood?

Any symptoms?

Any problem behaviours?

Agitation ☐ Aggression ☐ Restless ☐ Screaming ☐ Depression ☐ Wondering ☐ Hallucinations ☐

Additional remarks

What is his/her thermal comfort?

Hot ☐ ☐ ☐ ☐ ☐ Cold

Neutral

What is his/her preference of the light environment?

Dark ☐ ☐ ☐ ☐ ☐ Light

Neutral

How is the indoor air quality?

Bad ☐ ☐ ☐ ☐ ☐ Good

Neutral

Other comments

Appendix - Diary recording template.

6. References

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