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Qualitative and Quantitative Investigation into the Indoor Built Environment of Modular Student Housing: A Multiple-Room Case Study

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Abstract

Studies on the indoor built environment (IBE) of modular student housing (or dormitory/hostel) are scant. This study aims to investigate the IBE of a Dutch modular student housing using a research approach that integrates both IBE performance data and occupants' perception for synthetic analysis. In the first stage, based on grounded theory, a focus group discussion (FGD) was conducted to capture occupants' perceptions of the IBE of the student housing. With thermal quality and indoor air quality (IAQ) revealed from the FGD as the most critical IBE factors, a field study was carried out to measure the temperature, relative humidity, and CO_2 concentration in the apartments of the FGD participants; meanwhile, the participants' ventilation control behaviours were logged. Statistical analysis was carried out and the results suggested significant differences between the five sampled apartments in temperature and CO_2 concentration. Furthermore, the logged behaviour data revealed that both room orientation and occupant behaviour have significant impacts on the thermal quality and IAQ. This study unveiled the correlation between the IBE and the occupant behaviour, and the methodology developed can be applied to investigate more modular student housing in future, for enhancing their design and management.

Keywords: Indoor environment quality, grounded theory, focus group, modular building, on-site measurement, student housing

Abbreviations

ANOVA	analysis of variance
FGD	focus group discussion
IAQ	indoor air quality
IBE	indoor built environment
IEQ	indoor environmental quality
RH	relative humidity
T	temperature

1. Introduction

A prime function of student housing is to provide students with an environment to live and study during their boarding period (Fields, 2011; Simpeh and Shakantu, 2019). Comfortable and healthy student housing environment could benefit the development of a sound charter and improve education performance (Hassanain, 2008). Previous studies indicated that the characteristics of student housing could affect students' acculturation (Paine, 2008), overall

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college experience (Chickering and Reisser, 1993), and health (Sanni-Anibire and Hassanain, 2016). Since the outbreak of COVID-19, most universities around the world have transitioned from face-to-face teaching to online teaching, requiring students to study from home. This has put university students' life under difficulties and they are confined to their residence or student housing (E. Wilson et al., 2020). Therefore, it is crucial to provide a quality living environment for all university students.

In the Netherlands, students' accommodations are not provided by universities but by student housing associations (Fang & van Liempt, 2020). In the recent decade, because of the rapid increase in Dutch university student numbers - from 266,000 in year 2016 to 329,000 in year 2020 (Onderwijs in Cijfers, 2021), the demand for student housing increased sharply (NL#TIMES, 2021). To quickly tackle this problem, modular construction systems, which consist of repeated prefabricated sections and can be constructed within a short time, have been widely used in Dutch student housing (Lawson et al., 2014; Lomholt, 2009). However, there are hardly any studies on the indoor built environment (IBE) of modular housing in the Netherlands or in other countries. IBE has been defined to include three main components – space management (i.e., building design and layout), building services (including but not limited to lighting, ventilation, and temperature), and support facilities (including but not limited to fixtures and furniture) (Leung et al., 2019). IEQ, commonly assessed by indoor air quality (IAQ), thermal quality, visual quality and acoustic quality (Bluyssen, 2009), is regarded as one of the components of IBE, according to Leung et al., (2019)'s definition of IBE. This study concerns building design features, IEQ and management practice of student housing and thus, IBE is considered as the suitable definition as it includes the above-mentioned building performance aspects.

This study aims to develop a novel IBE performance evaluation methodology that considers both building conditions and occupants' living experience. The methodology developed for this study integrates both quantitative data (onsite physical parameters measurement) and qualitative data (occupant perceptions solicited via focus group meetings) to devise a synthetic evaluation framework. The methodology provides not only a scientific investigation approach for IBE performance evaluation but also an in-dept understanding of the relationships between the building and occupants through the investigation process (e.g., focus group discussion).

Built environment design and management practice have to address the needs of occupants with diverse backgrounds. Furthermore, the occupants should be given the opportunities to have a comprehensive understanding of different performance aspects of the building they reside in. A student housing with a high percentage of international students is considered to be a suitable investigation target to verify the methodology. A modular student housing was selected in this study for the following reasons: 1) building performance evaluation studies on modular building are scant; 2) the study findings based on a modular building can be used for future comparison with those from traditional student housing investigation; and 3) the study results can help to enhance the design and management for future student housing.

2. Literature review

Normally, people spend 90% of their time indoors, with 60% of their time staying at home (Ortiz et al., 2020). The time people spend at home has increased significantly during the COVID-19 pandemic because of the "work-from-home" policy (Davis et al., 2021; Galanti et al., 2021). According to a web-based questionnaire survey conducted in the U.S, people spend an average of 21 hours per day at home during the pandemic (Weerakoon et al., 2020). Even though student housing associations have been working hard to keep the virus out of student housing during this period, infection cases among university students have been reported across the world (Aristovnik, 2020). As most infections happened indoors (Borrud and Dillon, 2021), the IBE should be given more attention and fully investigated, by which evidence-based support could be provided for developing effective IBE control measures and facilitating virus-proof student housing design.

In the context of student housing, IBE has not been clearly defined. Previous studies had attempted to investigate different building performance aspects and yet, no universal evaluation framework has been developed to support the IBE performance evaluation. Hassanain (2008) evaluated the physical performance of student housing from two dimensions: technical and functional performance. Elements in the technical performance dimension are thermal comfort, acoustic comfort, visual comfort, IAQ, and fire safety. In the functional performance dimension, the assessment parameters reflect the architectural design aspects of the student housing performance, including interior and exterior finish systems, room layout, furniture quality, support services, systems, efficiency of circulation, and proximity to other facilities on campus. In another investigation on student housing facilities, Sanni-Anibire and Hassanain (2016) selected six assessment parameters, namely, building layout, interior and exterior appearance, access to facilities on campus, thermal comfort, IAQ, acoustic comfort, and visual comfort. These first three parameters describe the architectural design aspects while the rest are the same set of parameters used to measure IEQ.

In the studies of Lai (2013a, 2013b) and Hou et al. (2020), six parameters were used to evaluate the occupants' perceived importance, expectation, and satisfaction level of the student dormitory performance. Determined based on a focus group discussion (FGD) with the dormitory residents, the six parameters are: visual comfort, thermal comfort, aural comfort (or acoustic comfort), fire safety, hygiene, and communication. In recent years, "social dimension" and "sustainable dimension" have been emphasised in student housing performance evaluation. The assessment parameters used by Kim and Kim (2016) are categorised into three groups: "habitability", "sustainability" and "affordability". Their assessment framework was developed based on a wider social context, rather than taking an occupant's perspective to understand the occupant's comfort level. Nazarpour and Norouzian-Maleki (2021) also added "social contact and interaction" as one of the assessment parameters while the rest are physical environment, hygiene and health, safety and security, facilities, and equipment. Even though the previous studies on student housing performance evaluation framework varied, they all tended to include building design parameters (Hassanain, 2008; Sanni-Anibire and Hassanain, 2016); IEQ parameters: thermal comfort, acoustic comfort, visual comfort, and IAQ (Hassanain, 2018; Sanni-Anibire and Hassanain, 2016; Lai, 2013a, 2013b and Hou et al., 2020); and management service parameters: safety, and hygiene (Hassanain, 2008; Lai, 2013a, 2013b; Hou et al., 2020). The present study includes three building performance aspects to evaluate the student housing IBE.

IEQ, which is an important parameter for building performance evaluation, has been proved to be crucial to occupants' health, comfort, and work/study efficiency (Bluyssen, 2013; Turunen et al., 2014; Wong et al., 2009). All the factors of IEQ, including IAQ, could cause negative effects (Mendell and Heath, 2005; Tsang et al., 2021; Zhang et al., 2021). After the airborne transmission of COVID-19 has been confirmed (Morawska and Cao, 2020; N. Wilson et al., 2020), year 2020 witnessed an unprecedented attention to IAQ from the human society. Even without COVID-19, poor IAQ could be harmful to occupants' health (Cincinelli and Martellini, 2017; US EPA, 2016), comfort (Korsavi et al., 2021), and their academic or working performance (Haverinen-Shaughnessy et al., 2011; Johnson et al., 2018; Wargocki, 2008). According to a self-reported investigation conducted on 682 university students from different countries/regions, the smoking rate among Dutch university students was the highest (39%) (Bluyssen et al., 2021). This habit could undermine the IAQ in student housing, especially during the COVID-19 pandemic when students spend most of their time in the housing. To improve IAQ, increasing ventilation is one of the most effective approaches, which also has been considered by governments as an important measure to prevent the spread of SARS-CoV-2. Besides, ventilation was perceived by university students as one of the extremely important factors in housing facilities (Simpeh and Shakantu, 2019). Even though measures against the coronavirus have been lifted in many places, greater emphasis still should be placed on IAQ and ventilation when evaluating the IBE of student housing, even in a post-pandemic period. Effective and simple measures for improving ventilation rate should be introduced to and popularized among students.

To date, no universal IBE assessment framework has been developed. The selection of parameters and approaches might be influenced by different climates and cultures. To obtain a comprehensive understanding of student housing performance, a combination of qualitative (e.g., interview and focus group) and quantitative (e.g., on-site measurement) methods was suggested (Taylor, 2005). For qualitative investigation, to generate a full understanding of participants' experiences and beliefs, focus groups - "a good way to gather together people from similar backgrounds or experiences to discuss a specific topic of interest"- are commonly used (Mishra, 2016). Given this merit, focus group is widely adopted in studies about the built environment (Grey et al., 2017; Omar, 2018). As regards quantitative methods, on-site measurement is commonly used to investigate the IBE of buildings, especially about the IEQ including IAQ, thermal quality, visual quality, and acoustic quality (Aguilar and Tilano, 2019; De Giuli et al., 2014; Mahyuddin and Awbi, 2012).

3. Methodology

A flow map depicting the research framework and activities is illustrated in Figure 1. The study includes five stages, starting with student housing selection and recruiting volunteer student residents from the selected student housing as stage 1. In stage 2, the student residents were invited to participate in an FGD for obtaining a preliminary understanding about the IBE of modular student housing. In stage 3, the qualitative data collected through the FGD was analysed to find out students' most concerned IBE factors. After that, focusing on these factors, a field study combined with both qualitative and quantitative data collection methods was organised to investigate the empirical conditions of the IBE of the modular student housing. In this stage (stage 4), the student residents' behaviours related to their most concerned IBE factors were recorded by themselves and on-site measurements were conducted in their apartments in the student housing. In the last stage, the qualitative (behaviour) and quantitative (measurement) data were analysed to reveal the conditions of the IBE and provide suggestions for improving the IBE. Details of each step are explained in the ensuing sections.

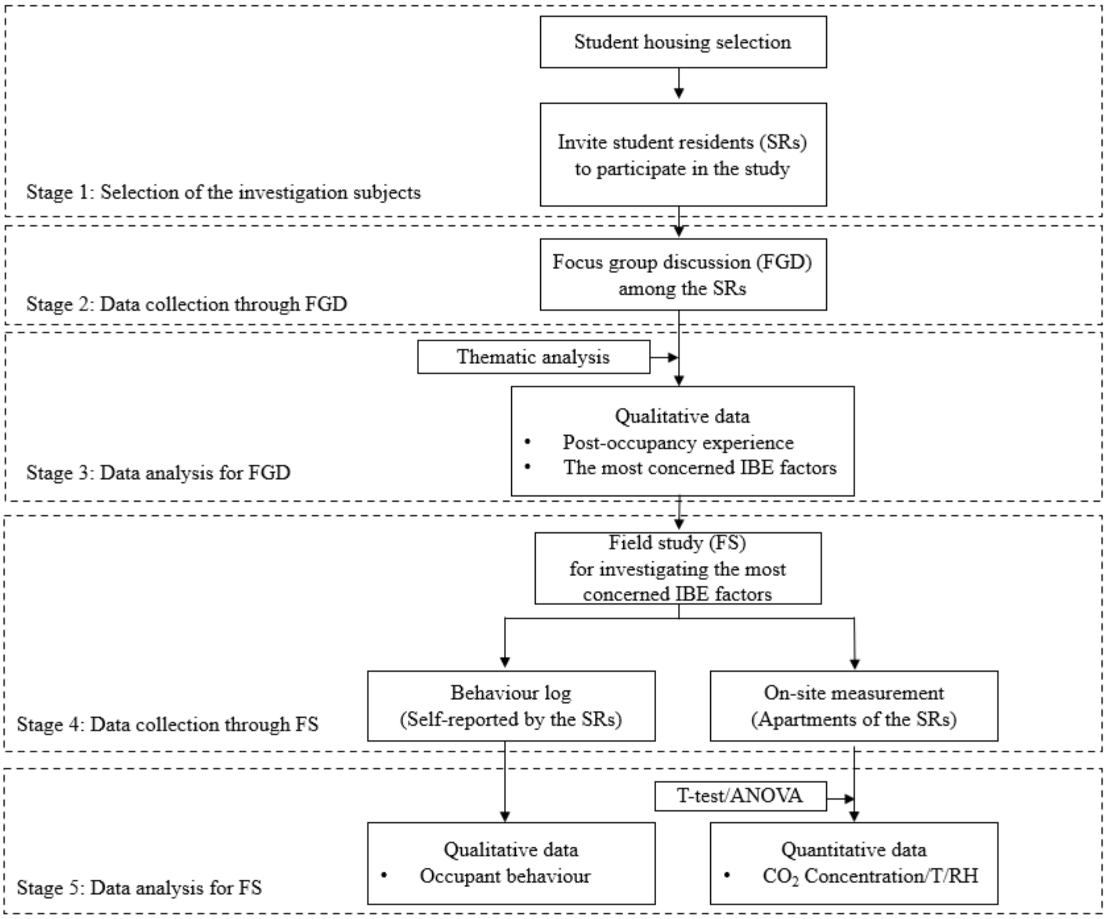


Figure 1. Research flow map

3.1 Selection of student housing and FGD participants sampling

To get an in-depth understanding of residents' perceptions of the indoor environment in their accommodations, to collect a reliable and representative sample (with representative number of participants who are cooperative and dedicated) and to enhance the feasibility of the investigation, the following criteria were applied when selecting the student housing and the participants: (i) long-term stay (over one year), (ii) a large building (or community) containing more than 100 the same type of student accommodations, and (iii) on campus. In this study, a modular student housing located on the campus of a Dutch university was selected. Aside from the above-mentioned criteria, the selected modular student housing is considered as a representative case due to first, it is the largest modular student housing in the investigated Dutch province (the province of South Holland), second, it is managed by the largest and most reputable student housing management agency in the Netherlands, which means its management is in line with other student housing in the Netherlands. As shown in Figure 2, the selected student housing contains 525 apartments spread over 22 floors, which is largest student housing in the campus.

Figure 2. Selected student housing for case study (Source: authors)

As building occupants/users' perception of IBE significantly affects the built environment management practice, grounded theory, a rigorous methodology extensively adopted in various disciplines, has been increasingly applied in built environment research (Allen and Davey, 2018). It provides a constructivist approach for understanding the dynamic interactions between human and built environment. Rather different from traditional residential buildings, the residents of student housing change from time to time: for example, a student would leave the student housing after a semester or upon graduation. Additionally, occupants' behavior could affect IBE performance in student housing considerably (Yan et al., 2017). Thus, student housing performance evaluation should consider student residents' opinions and living experiences. Grounded theory allows researchers to focus on the context, processes, and interpretations of key players in stances (Charmaz, 2000). Based on grounded theory, FGD was adopted in this study to obtain student occupants' perception of the student housing IBE.

The announcement for recruiting volunteer student residents to participate in the FGD and the field study was made through the student housing's online community webpage. Affected by the COVID-19 pandemic, most of the students were taking courses at home while the number of student residents living in the student housing during the research period was limited. Furthermore, some student residents living in the student housing were concerned about the spread of COVID-19 and thus were hesitant to allow the researchers to implement the on-site measurement in their apartments. Despite these constraints, five students (aged 29-34; female vs. male: 4 vs.1) who lived in the student housing volunteered to participate in the FGD. These students can be seen as representative samples of the whole building occupants because (i) the research object is modular student housing, and all the apartments share the same building characteristics; (ii) there are only two different apartment types in the investigated building and they are covered by the investigated samples; (iii) the apartments of these students covered three different orientations.

While the sample size of five participants is not large, it is a right fit for FGD as an FGD should allow each participant to have sufficient time to share their opinions and interact with each other. A larger sample of participants may undermine the discussion quality. Furthermore, according to grounded theory, the appropriateness of sample units can be people, words, texts, observation, events, incidents, experience, social process, or other objects of study (Onwuegbuzie & Leach, 2007). Therefore, information extracted from the FGD is the essence of the qualitative investigation and the discussion results of an FGD are sufficient to extract important information about the resident-building relationship.

All of the participants had spent more than three years living in the student housing and thus, their understanding of the building performance and interaction level with the student housing were sufficient. Before the FGD, a consent form was presented to each participant, where they were assured that all the data would only be used for this study. Additionally, they were informed that they have the right to withdraw from participation at any time.

3.2 Focus group discussion (FGD)

The FGD was organised to understand the students' overall perception of living in the student housing and identify the IBE factors that they are most concerned about. The FGD was held online (due to COVID-related measures) and moderated by a researcher with prior experience in organising focus group discussions. A brief introduction of the study background and aim were given at the beginning of the FGD. After that, two main questions were brought up for discussion: 1) What is your living experience in this student housing? 2) What IBE factors of the student housing are the ones you are most concerned about? The first question served as an opening question that guides the participants to focus on building-human relationship experience. The participants were encouraged to talk openly, share their personal experiences and opinions, and interact with the other participants, while the researcher, as a facilitator, stayed neutral towards their responses (Escalada and Heong, 2011). Meanwhile, the facilitator was also responsible for probing based on the discussion contents, time controlling, and notes taking. The second question was designed to probe more information from the participants upon their sharing of opinions on specific building performance factors. This question served to guide the participants to shift their sharing of personal feelings towards description of the building performance. The FGD lasted approximately one hour.

3.3 Field study

3.3.1 On-site measurement

From the FGD, the two most concerned factors identified were: IAQ and thermal quality. Considering the students' concerns and the COVID-19 pandemic, the real conditions of thermal quality and IAQ of the student housing were further investigated. To record data in the normal situation of a complete day, measurements over 24 hours are needed. To cater for any measurement interruption, the normal measurement period was doubled, i.e., a 48-hour continuous monitoring of CO_2 concentration (indicator for IAQ) together with T and RH (indicators for thermal quality) was carried out in the apartments of four FGD participants. The measurement was carried out on June 17-19, 2021, which is in the middle of a semester, neither exam nor special events happened to the students during the monitoring period. Therefore, the select dates can be seen as two typical days. Measurements were not taken in the apartment of the fifth participant, who moved out not long after the FGD.

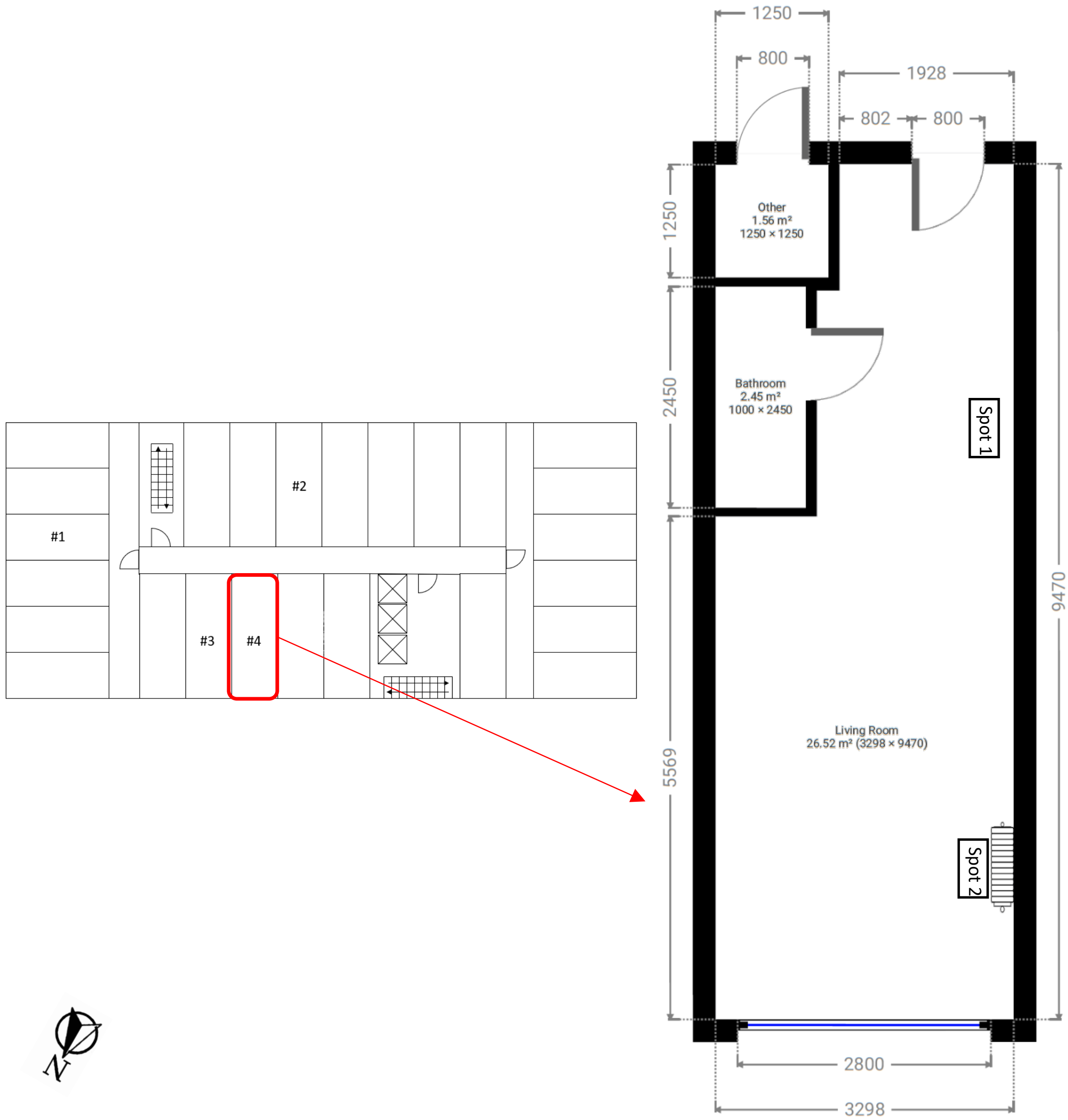
The monitoring was performed with a time interval of one minute using a HOBO MX1102 data logger, which has the following characteristics:

- T-sensor with an accuracy of ±0.2℃ in the range of 0-50 ℃
- RH-sensor with an accuracy of ±2% in the range of 20-70% (when the CO_2-sensor is enabled)
- CO_2-sensor with an accuracy of ±50 ppm in the range of 0-5000 ppm

All the devices were carefully calibrated by the researcher before the measurement.

3.3.2 Investigated student housing

Figure 3 illustrates the floor layout of the student housing (left) and the details of the apartment layout (right). The four apartments (marked #1, #2, #3, and #4) share the same layout but are located on different floors with different orientations. #2, #3 and #4 are of the same size (3.29m × 9.47m) and located on 17th floor while #1, with a slightly shorter depth (7.98m), is located on 9th floor. Detailed information of the apartments is summarised in Table 1. Furthermore, the dimensions of a typical apartment and the locations of the double-glazing window, the radiator, and bathroom are indicated in Figure 3.



Note: all dimensions without units are in mm.

Figure 3. Typical floor/apartment layout and measurement locations

Table 1. Information about the four apartments

Apartment	Orientation	Net size	Floor	Gender of the occupant
#1	East	24 m^2	9	Male

#2	South	29 m^2	17	Female
#3	North	29 m^2	17	Female
#4	North	29 m^2	17	Female

More detailed interior design can be found in Figure 4. As shown in Figure 4 a) and b), the apartment is undecorated when the students moved in. It only has the basic devices, including a radiator (Figure 4 c)), two lighting sockets (Figure 4 d)), a manually controlled ventilation grille (Figure 4 e)), two faucets and a toilet. It worth noting that although the window width is marked as 2.8 m in Figure 3, only a part of it (1 m (w) × 1.1 m (h)) can be open (as shown in Figure 4 a)).

Figure 4. Interior of a typical apartment in the Dutch modular student housing. a) full view of the apartment; b) conducting furnishment in the apartment; c) radiator in the apartment; d) lightings in the apartment; e) ventilation grille in the apartment.

Regarding the on-site measurement, two spots were selected in each apartment to place the HOBO data loggers (see "Spot 1" and "Spot 2" in Figure 3): one near the window, the other near the door. Both loggers were placed at 1.3 meters above the floor, which is approximately the average mouth height of people when sitting (First in Architecture, 2022). All the measurement devices were set to automatically operate from the 17th of June, 8:00 a.m. until the 19th of June, 8:00 a.m.

3.3.3 Behaviour log

To understand the impact of student residents' behaviour on their most concerned IBE factors, which are IAQ and thermal quality, in their apartments, all four students were requested to fill out a paper form to record their ventilation-related and thermal quality-related behaviours during the measurement period. They made a log entry every time they opened or closed the window/ventilation grille and when they entered or left their apartment. Both the type and timing of such activities were recorded by the participants on the form, and a few notices were sent to the participants through a social media tool on a daily basis to ensure them to fill in the forms.

3.4 Data analysis

3.4.1 Qualitative analysis

Based on grounded theory, coding technique, including sifting, sorting, and synthesizing (Thornberg & Charmaz, 2014), was adopted to categorise the qualitative findings. Two levels of categories were created: first, the qualitative data was categorised based on the questions asked in the FGD; second, after examining the qualitative data, three types of attitudes from the participants were identified based on their tone in the discussion towards each IBE factor; participants' feedback regarding each IBE were categorised into three groups: positive (+), negative (-) and neutral (/).

To further interpret participants' concern on each IBE factor and to find out their most concerned IBE factor, a concern index was introduced and calculated based on the time participants spent on discussing a specific factor. Since the maximum duration the students spent on discussing an IBE factor was 20 minutes, 10 minutes (i.e. mid-point of the maximum duration) was taken as the threshold in determining the value of the concern index. The index is defined as the number of students who spent more than 10 minutes talking about their concerns on the same factor. Therefore, the range of the concern index is 0-5.

3.4.2 Quantitative analysis

Measurement data obtained from the field study were imported to the SPSS software (version 26.0) and analysed with the following steps: First, a data screening process was performed based on Z-factors; data with a Z-factor (absolute value) higher than 3 were regarded as outliers and thus eliminated (Frost, 2019; Shiffler, 1988). Second, basic information (e.g., mean and standard deviation of the parameters) was analysed using descriptive analysis. Third, a series of paired samples t-tests were conducted to check any statistical difference in the CO_2 concentration/ T/ RH between the two measurement locations within the same apartment. At last, one-way ANOVA (analysis of variance) tests were applied to check any differences in CO_2 concentration/ T/ RH between the apartments. For the frequencies of ventilation-related behaviours, they were also imported to the SPSS software and processed using descriptive analysis.

Additionally, the ventilation rate was calculated based on the CO_2 concentration collected during the field study. Two methods were applied for the calculation according to different conditions in these apartments (with or without occupants). If there was one person in the apartment and the status of the window/grille (open or closed) remained unchanged, and if the CO_2 concentration reached a relative steady-state after a certain period of time, then this steady-state CO_2 concentration was used to calculate the ventilation rate in the apartment using Equation (1) (ASTM International, 2007; Batterman, 2017; Shaughnessy et al., 2006):

$$V = \frac{10^6 \cdot n \cdot G_p}{C_{steady} - C_{out}} \tag{1}$$

where V is the ventilation rate (l/s); n is the number of persons in the apartment; G_p is the average CO_2 generation rate per person, which is estimated as 0.0040 l/s (daytime) or 0.0036 l/s (sleeping) (Persily & de Jonge, 2017); C_{steady} is the average measured indoor CO_2 concentration (ppm); and C_{out} is the outdoor CO_2 concentration (ppm).

If there was no occupant in the apartment and the CO_2 concentration kept decreasing during a time period, the decay method, which is commonly used when a space is vacant, was applied (Batterman, 2017). Under this condition, the ventilation rate (l/s) can be calculated based on Equation (2).

$$V = \frac{1}{\Delta t} ln(\frac{C_1 - C_{out}}{C_0 - C_{out}}) \tag{2}$$

where Δt is the time period between the occupant leaving the apartment and the CO_2 concentration reached a steady state; and C_0 and C_1 are the CO_2 concentrations (ppm) measured respectively at the start and the end of the observation.

4. Results

4.1 Focus group discussion results

Based on the student residents' discussion on the second question – "What IBE factors of the student housing are the ones you are most concerned about", 10 most mentioned factors were identified using the coding technique.

Table 2. Coding results regarding question 2 (What performance factors of the student housing are the ones you are most concerned about?)

Factors	Participant A	Participant B	Participant C	Participant D	Participant E
1. Building layout	"shape of the room, floor plan, space"	"Room configuration"	"room and floor configuration"	"Room configuration"	"Shape of the floor area, not just the room, but also the whole floor area"
2. Interior design	"Interior design"	"The design"	"Interior design"	"Space and design"	"Interior design"
3. Access to facilities on campus	"Location; convenient to access internal (campus) and external facilities"	"Convenient location"	"The location of the building"	"The location of the building"	"Easy access to other parts of the campus"
4. Public facilities and equipment	"Public infrastructure and facilities"	N/A	"Compatible facilities, such as bike racks, canteens, supermarket, etc."	"Public facilities"	N/A
5. Thermal comfort	"In-room temperature"	"Temperature control system"	"Insulation and ventilation"	"Thermal comfort"	"The indoor temperature control"
6. Visual comfort	"Lighting"	"Lighting provision"	"Lighting design"	"Lighting"	N/A
7. Acoustic comfort	"Sound-proofing"	"Sound-proofing system"	"Sound insulation"	"Sound-proofing"	"Sound-proofing"
8. Indoor air quality	"Indoor air"	"Indoor air quality"	"Indoor air"	"Indoor environment"	"Quality of indoor environment"
9. Hygiene	"Clean environment"	"Cleaning"	N/A	"Hygiene condition"	"Cleaning condition"
10. Security	N/A	N/A	"Personal safety"	"Security"	"Personal safety"

Note: "N/A" means that the participant neither provided any response nor agreed on the proposed performance factors.

Three groups of information are summarised in Table 2: i) answers from the FGD participants, ii) agreed performance factors, and iii) voting results. The answers from the participants are the contents in the double quotes. After recording their answers, the researcher proposed a performance factor term to summarise their answers and asked the participants to vote their agreement on the proposed performance factor. For example, after the second question was asked, one of the participants brought up "room configuration". The rest of the participants mentioned "shape of the room, floor plan, space", "room and floor configuration", "room configuration" and "shape of the floor area, not just the room, but also the whole floor area". The researcher examined the answers and proposed to use building layout to represent all the answers from the five participants and each participant was asked whether they agree on the proposed factor to summarise his/her answer. "N/A" means that the participant neither provided any response nor agreed on the proposed performance factors.

The 10 factors were grouped into three categories: design aspects, IEQ, and management services. As shown in the affinity diagram (Figure 5), each category umbrellas around two to four building performance factors. According to the student residents' sharing, four types of attitudes/tones towards the building performance factors were identified based on the notes: positive, negative, inconsistent, and neutral (marked as '+', '-', '±', and '/', respectively, in Figure 5). For "access to facilities on campus", "public facilities and equipment", and all the IEQ related factors, students' attitudes are consistent. For "building layout" and "interior design", some FGD participants were positive while some others were negative, (marked as '±' in Figure 5). For "hygiene" and "security", the FGD participants were neither positive nor negative towards the factors (marked as '/' in Figure 5).

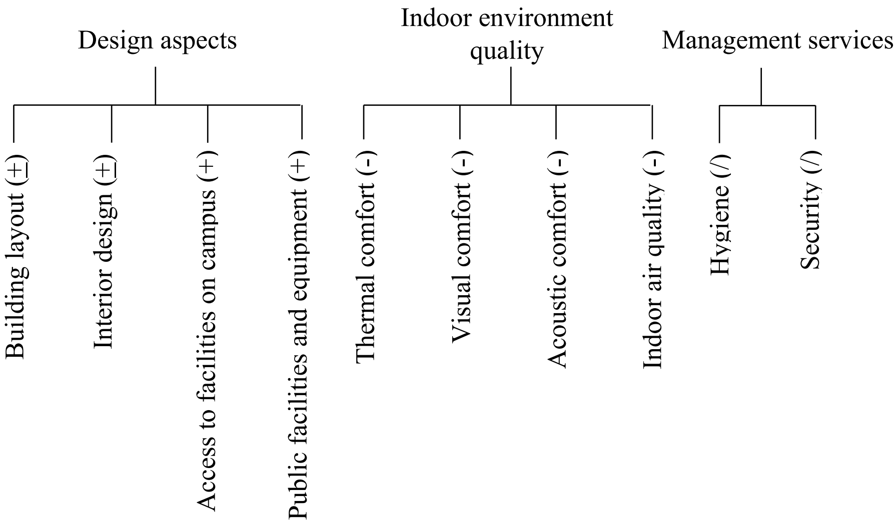


Figure 5. Themes and factors identified from the focus group discussion

Based on the discussion time recorded during the FGD, concern indexes (namely the number of students who spent more than 10 minutes talking about their concerns on the same factor) were calculated. As shown in Figure 6, the concern indexes of the IBE factors range from 1 to 5; none of the factors recorded a zero index value, indicating that the students were concerned about all the factors. Among them, IEQ-related factors arouse broader discussions, almost all the students spent more than 10 minutes to talk about them, especially on thermal quality and IAQ.

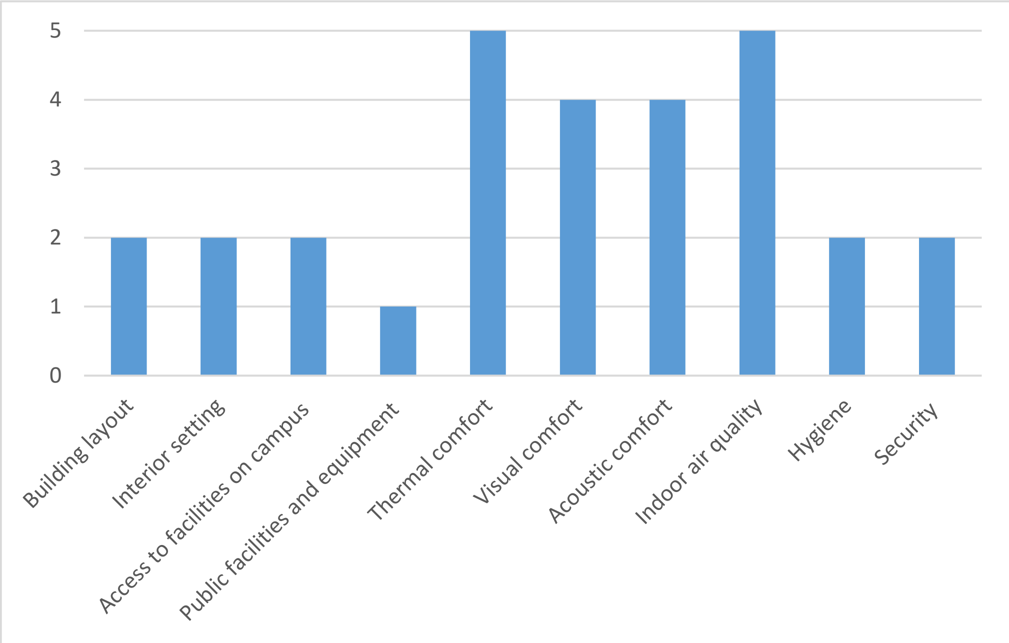


Figure 6. Concern indexes of the indoor built environment factors

Based on the results shown in Figures 5 and 6, the student residents were most satisfied with "access to facilities on campus" and "public facilities and equipment", since they all showed positive attitude towards these factors and there was not too much to be discussed about them. The student housing is located in the center of the campus and thus, it is easy to access various facilities on the campus such as the teaching buildings, university gyms, and the other student housing blocks. The student housing was built in 2017 and developed in the form of joint-development between a private developer and one of the largest student housing associations in the Netherlands. It was well planned and therefore, public facilities and equipment such as a supermarket, a café, a restaurant, bicycle parking spots and laundry rooms were integrated as a whole in the student housing.

For "building layout", "interior design", "hygiene" and "security", the comments were manifested in two ways: 1) some FGD participants raised negative points while some others held an opposite attitude (marked as '±' in Figure 4); and 2) the FGD participants were neither positive nor negative towards the factors (marked as '/' in Figure 4). Some highlights of the comments are as follows:

- ***Building layout and interior design*** **(±)**

  A - "I think the building layout is adequately designed. Since it is a modular building, the layouts of every floor are the same and most of the apartments are the same too. Also, even though the interior design is not outstanding, it is good enough."

  C - "…The apartment is a bit too 'long' in terms of its length, but the windows are big enough for introducing natural lighting. I am fine with the layout and the interior design…"

- ***Hygiene*** **(/)**

  B – "The building is very clean. But there is one hygiene issue, which is related to the design of the building. I personally find that it is difficult to clean the taints on the floor of the bathroom (the bathroom is a prefabricated module built in each apartment). Probably it is also a design issue."

E – "The management office sends cleaning staff to clean the public common area regularly and the hygiene level of this building is satisfactory."

- ***Security*** **(/)**

A – "Security is the most important factor to me and it is on the top of the list when I choose student housing. No watchman is assigned and students access using the magnetic key. So far, no significant security issues happened."

D – "The campus is a safe community. I feel safe to live in a student housing within the campus area."

For the IEQ aspects - "thermal comfort", "visual comfort", "acoustic comfort" and "indoor air quality", they were the FGD participants' biggest concerns since they provoked the most negative and most extensive discussion. The participants were not satisfied with all the factors related to environmental quality. Some highlights of the comments are as follows:

- ***Thermal comfort*** **(-)**

C – "It could be that the apartment is a bit too long and the radiator is located at one side of the apartment, so people feel cold when they stay near the other side of the room (image c in Figure 4)."

E – "I feel quite hot when I turn on the radiator and it is difficult to adjust it. I need to adjust it from time to time to ensure my comfort in my apartment.

- ***Visual comfort*** **(-)**

A – "Two sets of ceiling lamp holders are provided in each room, which is rectangular in shape with a high aspect ratio （image d in Figure 4）. The residents are required to install their own lamps. The distance between the two lamp holders is far away from each other, which leads to an inadequate lighting provision in some parts of the room."

B – "The lighting in the corridor is too bright, which may lead to a higher consumption of energy."

- ***Acoustic comfort*** **(-)**

B – "I can hear noise coming from the construction site outside."

D – "Each module comprises two units of room with a partition wall in between. I assume that the partition wall in each module is not soundproof because I can hear my neighbor on one side, but can barely hear the one on the other side."

- ***Indoor air quality*** **(-)**

A – "I think in general the air quality in the apartment is good. The apartment is equipped with a ventilation grille (image e in Figure 4) and we can open the window for natural ventilation."

E – "I am not aware of the ventilation grille. I normally don't turn it on and only rely on the windows for natural ventilation. But I think the air quality is not that bad; there is no strange smell."

In addition, the discourses among the student residents varied significantly. For example, some of the students felt too hot in their apartments, while some of them considered it too cold; some of them were bothered by the noise generated by their neighbours, while some of them suffered from the outside construction noise; some of them thought that the passive ventilation grille per room is not enough to guarantee good indoor air quality during the COVID-19 pandemic, and some of them even did not notice the ventilation grille and never used it. In order to delve into any reasons behind their varied responses, the researcher intervened in the discussion using probing techniques by asking questions such as "can you explain a bit more in detail?" The participants then elaborated their behavioural preferences (e.g. opening or closing the window) against their experiences of satisfaction or dissatisfaction (e.g. feeling too hot or too cold). In light of this, a field study was conducted to follow up with the FGD to collect data for evaluating the IEQ and investigating its relationships with different occupant behaviours. The results of this field study are presented in the following section.

4.2 Results of the field study

4.2.1 CO_2 concentration, temperature and relative humidity

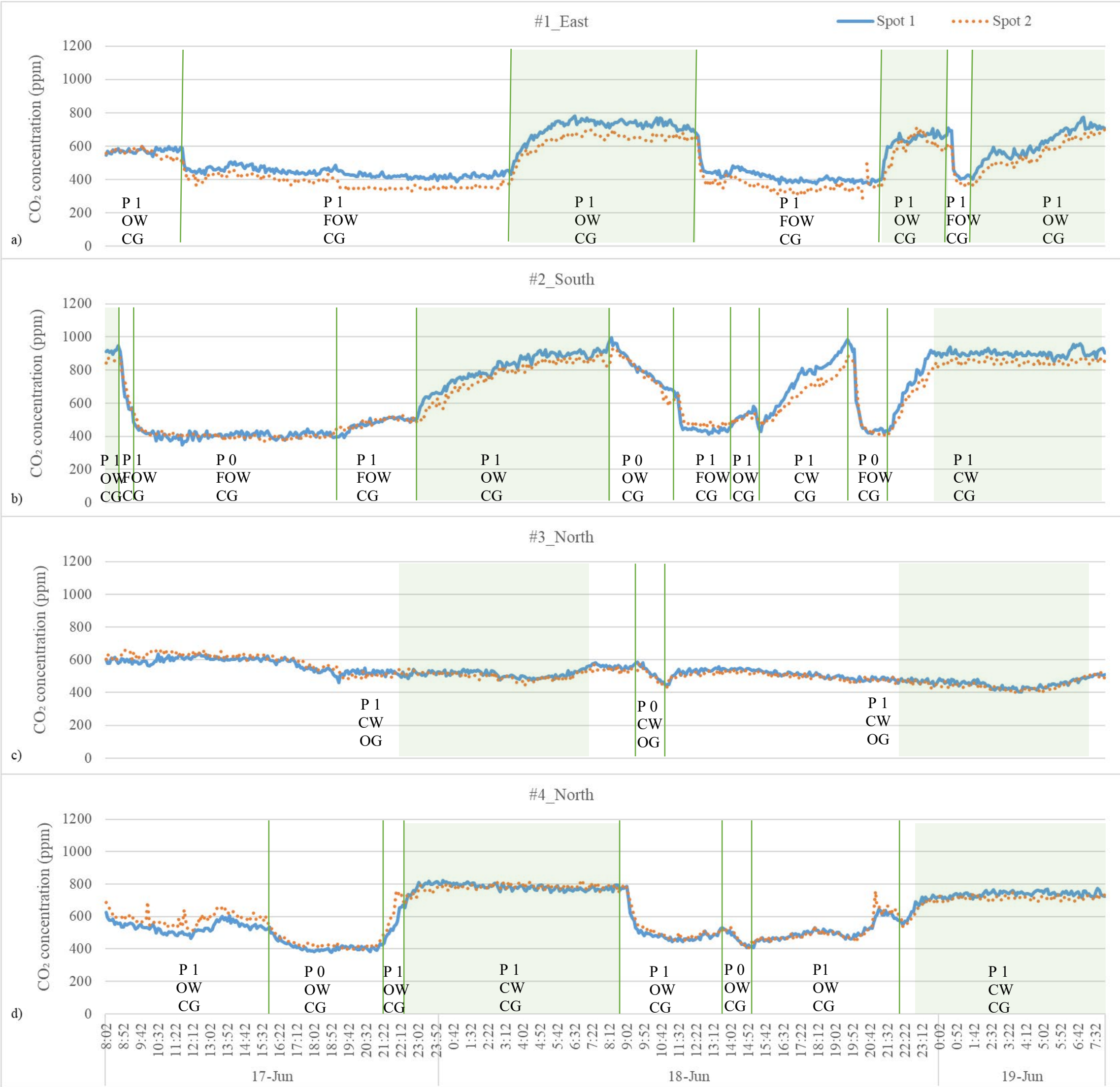
The variations of CO_2 concentration, T, and RH at the eight measurement locations (in four apartments) during the monitoring period are shown in Figures 7 and 8. All the investigated apartments share the same window design and each window can be fully opened from the side (recorded as 'fully open') or tilted from the top (recorded as 'open'). In addition, a passive ventilation grille, located above the window, can be opened or closed manually. These ventilation devices (window and ventilation grille) can lead to six possible ventilation conditions in the apartments, as shown in Table 3.

Table 3. Six possible ventilation conditions and their abbreviations

Device	**Status**					
Window	Close	Close	Open	Open	Fully open	Fully open
Grille	Close	Open	Close	Open	Close	Open
	(CW&CG)	**(CW&OG)**	**(OW&CG)**	(OW&OG)	**(FOW&CG)**	(FOW&OG)

Note: Status abbreviations are shown in parentheses

During the measurement period, only four of the six possible ventilation conditions were identified in the investigated apartments, viz. CW&CG, CW&OG, OW&CG, and FOW&CG, as boldfaced in Table 3. Figure 7 shows the monitored CO_2 concentrations in the apartments. All the results were lower than 1000 ppm. However, there were remarkable differences in CO_2 concentrations between the apartments. The highest CO_2 concentration appeared in apartment 2, while the lowest concentration appeared in apartment 1.



Note: P denotes number of occupants inside the apartment; verticals the changes of denote ventilation-related behaviours; shadows denote sleeping periods

Figure 7. CO_2 concentrations in the apartments: a) apartment #1: east-oriented; b) apartment #2: south-oriented; c) apartment #3 north-oriented; d) apartment #4: north-oriented)

Figure 7 also demonstrates the influence of the residents' behaviour on the CO_2 concentration. In general, when there was no occupant inside the apartment, the CO_2 concentration was the lowest, no matter under which ventilation condition; when there was an occupant and when both the window and grille were closed, the CO_2 concentration was the highest. Among the four apartments, apartment 2 recorded rather wide fluctuations in CO_2 concentration (350 -998 ppm) and was found with higher frequencies of changes in the occupant behaviour. In apartment 3, the fluctuations in CO_2 concentration were comparatively less (383-680 ppm) and the occupant behaviour seldom changed.

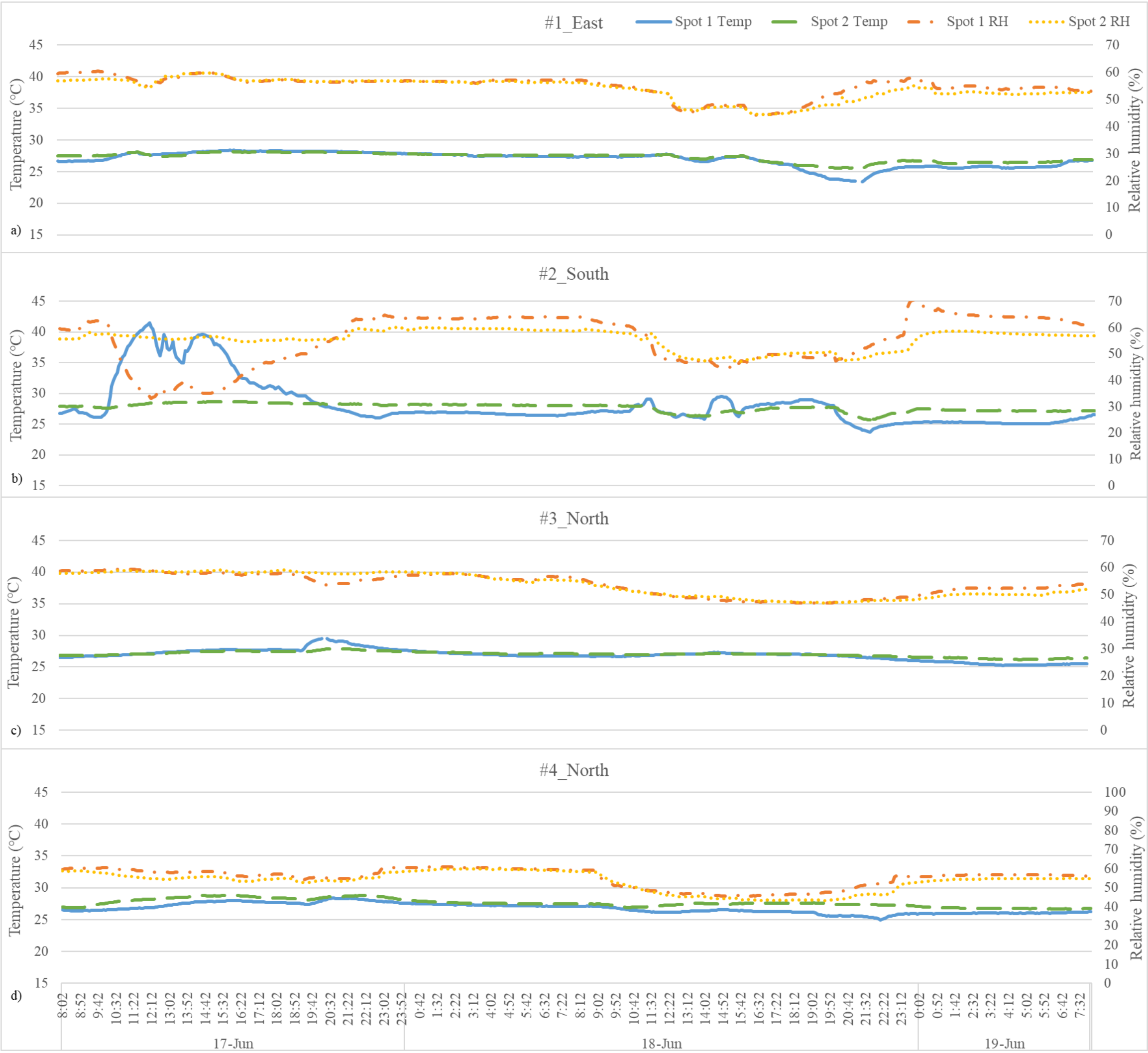


Figure 8. Temperature and relative humidity in the apartments: a) apartment #1: east-oriented; b) apartment #2: south-oriented; c) apartment #3 north-oriented; d) apartment #4: north-oriented)

For T and RH, as shown in Figure 8, they also varied between the apartments, although the absolute differences were small. The highest T and RH were in apartment 2 (south-facing), while the lowest T and RH were in apartment 3 (north-facing). The average outside T and RH were 22℃ (range: 16-29℃) and 76% (range: 51-94 %) during the monitoring period. The widest fluctuations of T (24-41℃) and RH (33-71%) were also found in apartment 2, while in the other apartments, the T and RH were relatively stable. This difference might be due to the apartment orientation. According to ASHRAE standard 55 (ASHRAE, 2020), the T range of the thermal comfort zone is from 19.4 ℃ (minimum) to 27.7 ℃ (maximum). For the four apartments, the total hours when the monitored T exceeded the maximum level were 14.6, 22.3, 4.3, and 11.7 respectively.

Additionally, as illustrated in Figure 8 b), a significant difference in T between the two spots was observed in apartment 2 during the daytime (9:00-18:00) on the first day. This was caused by the direct sunlight (the first day was sunny). Apartment 2 was facing south, thus the temperature near the window was much higher than that near the door.

4.2.2 Ventilation rates in the student housing

According to the different conditions in the apartments, the ventilation rates were calculated using different methods (see section 2.4.2) during different periods. Since the ventilation conditions (i.e., open/close window/grille) were repeated several times during the measurement period, the final ventilation rates in the apartments under these conditions were taken as the average values of the results calculated for each subdivided period corresponding to each ventilation condition (see Table 4).

Table 4. Ventilation rates under different ventilation conditions in the apartments

Apartment	CW & CG		CW & OG		FOW & CG		OW & CG	
	(l/s/p)	(l/s/m^2)	(l/s/p)	(l/s/m^2)	(l/s/p)	(l/s/m^2)	(l/s/p)	(l/s/m^2)
#1	/	/	/	/	117.8	4.9	14.5	0.6
#2	7.7	0.3	/	/	56.2	1.9	16.2	0.6
#3	/	/	20.0	0.7	/	/	/	/
#4	9.5	0.3	/	/	/	/	28.7	1.0

Note: '/' denotes the corresponding ventilation condition did not exist in the apartment. 'l/s/p' denotes 'litres per second per person' while 'l/s/m^2' denotes 'litres per second per square meter', both of them being units of ventilation rate.

As shown in Table 4, the ventilation performance in the investigated apartments was generally good. Under most conditions, the ventilation rates in the apartments were higher than 14 l/s, which is the minimum ventilation rate recommended for a dwelling with a floor area less than 47 m^2 (ASHRAE, 2019). When the window was fully open (which is not common since it often rains and the outdoor T is usually lower than 20 °C), the ventilation rate could reach 100 l/s. While when the window and the ventilation grille were closed, the ventilation rate in these apartments was lower than 10 l/s.

4.3 Comparison of measurement data by location and by apartment

According to the results of the paired samples t-tests (see Table 5), there were statistically significant differences in the CO_2 concentrations between the two measurement locations in the same apartment. However, the absolute differences between the two locations were less than the acceptable error range of the devices (±50 ppm) and the trends of variations at these locations were the same (see Figure 7). This suggests that such differences, which could be due to instrumental errors, are negligible. Therefore, the CO_2 concentration could be regarded as one obtained from a well-mixed condition in the small student apartments and one measurement location per apartment should be enough. The same explanation applies to the differences in RH between the two locations in the same apartment. However, regarding T, the significant differences between the locations found in apartments 1, 2, and 4 cannot be explained by the instrumental error since they are larger than the acceptable error range (±0.2 °C). As shown in Table 5, in the south-facing apartment 2, the T was significantly higher at 'Spot 1' (near window) than at 'Spot 2' (near door). While in the other apartments, the results were just the opposite.

Table 5. Comparison of the measurement results in the apartments

Position	#1	#2	#3	#4	F (p-value)[3]
CO_2					
Window[1]	534 (126)	667 (209)	522 (52)	604 (139)	**642.2 (<0.001)**
Door[1]	478 (125)	637 (185)	518 (64)	614 (130)	**950.5 (<0.001)**
Average[1]	506 (129)	652 (198)	520 (58)	609 (135)	**1485.7 (<0.001)**
t (p-value)[2]	**98.5(<0.001)**	**36.9 (<0.001)**	**8.6 (<0.001)**	**-15.6 (<0.001)**	
T					
Window[1]	26.9 (1.2)	28.0 (3.6)	26.9 (0.9)	26.8 (0.8)	**237.4 (<0.001)**
Door[1]	27.2 (0.7)	27.6 (0.7)	27.0 (0.4)	27.6 (0.6)	**675.0 (<0.001)**
Average[1]	27.1 (1.0)	27.9 (2.6)	27.0 (0.7)	27.2 (0.8)	**429.1 (<0.001)**
t (p-value)[2]	**-32.7 (<0.001)**	**5.7 (<0.001)**	-0.3 (0.754)	**-86.0 (<0.001)**	
RH					

Window[1]	54.8 (3.9)	55.3 (9.5)	53.7 (4.0)	55.2 (4.8)	**47.4 (<0.001)**
Door[1]	53.8 (4.0)	55.5 (3.8)	53.6 (4.4)	53.2 (5.2)	**150.3 (<0.001)**
Average[1]	54.3 (4.0)	55.4 (7.3)	53.7 (4.2)	54.2 (5.2)	**112.0 (<0.001)**
t (p-value)[2]	**35.1 (<0.001)**	-1.4 (0.169)	1.6 (0.116)	**72.9 (<0.001)**	

Note: [1] these numbers are mean (standard deviation) values; [2] Paired samples t-test results; p-values less than 0.05 are boldfaced; numbers in the parentheses are either; [3] One-way ANOVA test results; p-values less than 0.05 are boldfaced. [2]

Regarding the comparison of CO_2, T, and RH between different apartments, the differences were significant and cannot be ignored since the absolute differences between the averaged values measured in different apartments were larger than the accuracy of the measurement devices. For CO_2 concentration, the highest average value was in apartment 2 (652 ppm), while the lowest was in apartment 1 (506 ppm), where the window was often fully open. The difference between them was significant (146 ppm). For T and RH, the highest results were also found in apartment 2 (27.9 ℃ and 55.4%), and the lowest results were found in apartment 3 (27.0 ℃ and 53.7%).

5. Discussion

5.1 A new methodology for IBE performance evaluation

This study proposed a methodology, including both qualitative and quantitative methods, to assess IBE performance in modular student housing. For the qualitative research, it adopted a user perspective to evaluate the IBE performance of the student housing and the results reveal: 1) the student residents' perceptions of the IBE performance and; 2) the relationships between the IBE in their apartments and their behaviour patterns. In this study, the co-relations between IBE and student residents' behaviour were mainly reflected on the IAQ aspect. Student residents' perceptions were obtained through the FGD and qualitative data was collected and analysed to understand whether the student housing IBE suits the residents' needs and preferences. The FGD was designed and implemented based on grounded theory with the aim to develop understanding of student housing residents' discourses. It allowed the student residents to actively share their perceived IBE performance factors, of which their personal needs and behavioural habits were revealed during the interactive discussion. The dynamic, qualitative findings help to confirm the satisfactory performance factors and unveil the less satisfactory ones of the IBE. More importantly, the interactive effects between the residents' behaviours and their perceived IBE performance were also elucidated from the FGD. The qualitative data, which was channeled by way of human discourses, embraces two types of important information: first, the objective IBE performance that building designers or facilities managers can hardly examine regularly due to privacy issues even though automatic and remote sensing devices are available nowadays; second, the human intervention to the facilities and the IBE of the student housing – the IBE performance is subject to the intervention of occupant behaviour. The qualitative findings contribute to the understanding of the human-building relationship: human behaviour and cognitive perception influence each other in making building performance judgement. This proves the effectiveness of grounded theory application in built environment research.

In further investigating the real IBE condition in the student housing and the impact of the student residents' behavior on the IBE, quantitative data on two most important aspects, i.e., thermal quality and IAQ (according to students' concerns and in view of the COVID-19 pandemic), were collected. Such quantitative data were analysed in two steps: first, compare the data with relevant recommendations of the ASHRAE standards; second, compare the data based on time, measurement location and orientation of the apartment windows. The analysis results provide clear indications of the IEQ performance that is related to the comfort and health of the residents. In addition to the revelation that occupant behaviour (or user habit) leads to the different perceptions of the IEQ, the results obtained from the quantitative data analysis complement the counterpart drawn from analyzing the qualitative FGD findings.

The combination of qualitative and quantitative research methods could provide a comprehensive and in-depth understand of the IBE in student housing. The quantitative method, namely on-site measurement, relies on subjective data and could provide accurate results, but it might ignore occupants' personal difference and psychological effects. The qualitative method, namely FGD, focuses on occupants' perception and could explore their attitudes and behaviour in-depth, but its results might be influenced by the moderator. The integration of these two methods could complement each other and produce more thorough understanding of IBE in student housing and propose targeted solutions to improve it.

5.2 IBE in the investigated student housing

By applying the above-mentioned framework, this study investigated the IBE in a Dutch modular student housing. According to the FGD results, the student residents were not concerned much about the building design factors and management service factors. The relatively young age of the student housing may be the reason, as the newly built apartments were still in good condition in many aspects. Only the IEQ factors caused most of the concerns from the student residents.

Regarding the IEQ, students' perceptions in the investigated student housing were not positive. Almost all the students were not satisfied with at least one IEQ aspect of their apartment. For the acoustic quality, a consensus was reached: all the FGD participants were annoyed by the noise (either from outside or from neighbours). Noise, as a very common problem that exists in student housing, has been reported by many researchers over the world (Lai and Yik, 2009; Pride, 2012; Revington et al., 2020; Sanni-Anibire and Hassanain, 2016). However, no simple solution has yet been found for solving this problem. For the thermal quality and visual quality, although all the students were not satisfied, the complaints were not the same, which might be related to the orientation of the apartments and the users' personal preferences (Lai, 2014; Lai and Yik, 2007). As shown in Table 5, the average T in south-facing apartment could be 1 ℃ higher than it in the apartments with other orientations, and the difference was more significant during the noon period. Besides, according to the FGD results, even in the apartments with the same orientation, occupants' thermal sensations also could be different, which might be caused by their different personal characteristics. Similar results were found in a previous field study conducted in 21 Dutch schools where different IEQ perceptions, preferences, and/or needs were identified even in the same indoor environment (Zhang et al., 2018). For the air quality, students' complaints were more about the impact of COVID-19; besides this virus, they did not mention any other air pollutants. Since most indoor air pollutants, such as carbon monoxide (CO), nitrogen dioxide (NO_2), volatile organic compounds (VOCs) and particulate matter (PM), are odourless and colourless (Höfner and Schütze, 2021; US EPA, 2008), the IAQ issues are easily overlooked, especially during the non-pandemic period. Additionally, Langer et al. (2017) found that normal occupants are not sensitive to air pollutants as professional staff, therefore they usually perceive the air quality in their homes better than the real condition.

Regarding the measurement results, the average T and RH monitored in the four apartments were 27.0-28.0 ℃ and 53.7-55.4 % respectively. For most of the time, the T and RH in these apartments were within the comfort zone, according to ASHRAE Standard 55 (ASHRAE, 2020). However, overheating was observed in all the apartments, especially in the south-facing apartment 2. The T during 46% (22 out of 48 hours) of the monitoring period in apartment 2 exceeded the maximum level of the comfort zone and the T near the window could be as high as 41 ℃ (see Figure 8) during this period because there is no solar shading outside the window. As regards the measured CO_2 concentrations, they were all lower than 1000 ppm, which means that the ventilation in these apartments could meet the requirement of the relevant Dutch building regulations (Valk, 2013). However, remarkable variations of CO_2 concentration were observed during the monitoring period, which was closely related to the status (open/close) of the window/ventilation grille. Since the wind direction changes a lot during these two days (Time and date, 2021), its impact on ventilation in different apartments can be ignored in this study. When both of these devices were closed, the CO_2 concentration was the highest, and the ventilation rate could be lower than 10 l/s/p. Considering both the FGD and measurement results, the student residents' awareness of IAQ and ventilation should be improved.

5.3 Modular design element impact on the IBE performance

The modular design elements were frequently mentioned by the student residents during the FGD. It implies that the modular design elements, to a certain extent, lead to the negative comments. For example, the partition wall adjoining two apartments, which was built as a prefabricated component, presents a weak soundproof function. Also, the two lamp holders were installed too far (6.5 m) apart along the longitudinal direction of the apartment, which leads to insufficient illumination in the middle area of the apartment. The length of the apartment together with the location of the radiator was accused of causing the imbalance of heat flow. The built-in bathroom facilities also attracted complaints about hygiene problems.

Investigation on users' living experience in modular buildings has been rare. Past studies on modular buildings usually focus on: 1) how to enable the module design to meet the structural and functional requirements by local regulations and manufacturing feasibility (Blismas, 2007; Lawson et al., 2012); 2) barriers to and challenges of adopting modular construction (Choi et al., 2019; Ferdous et al., 2019); or 3) technologies innovation application in modular construction (Olawumi et al., 2021; Zhou et al., 2021). Academic attention is still placed on the construction period of modular buildings while the post-occupancy performance of modular buildings remains scant.

The findings from this study provide explicit evidence that the type of module design for the investigated student housing, in certain aspects, failed to meet the residents' needs. The module layout and the lean interior design of the housing manifest a key principle of modular construction, which is providing convenience and increasing construction efficiency. As a prime focus of modular building design is the integration of prefabricated builder's work (e.g., wall, floor, ceiling) modules with on-site building services installations, some of the design features may not be able to fully address occupants' comfort. This informs that there may be "design trade-off" in modular buildings and, therefore, occupants' perspective should be taken into the evaluation of IBE of modular buildings so that the "problematic modular design elements" can be reflected and avoided in future modular building development.

5.4 Occupant behaviour as an occupant-IEQ relationship mediator

The FGD findings showed that the student residents' behaviour played a role in affecting their perception of the IEQ in their apartments. The different students had different IEQ perceptions of their own apartments. They also behaved differently in terms of opening or closing the windows or ventilation grilles. These different behaviours caused the differences in CO_2 concentration, T, and RH in the apartments. The two ventilation-related behaviours, i.e., open/close window and open/close ventilation grille, were further investigated in the field study. The field study results showed that the ventilation rate varied significantly with the occupant's behaviour. This yields two crucial implications: 1) anticipated occupant behaviours should be considered when designing buildings; and 2) knowledge of both the hard side (physical performance of engineering facilities) and soft side (needs and behaviours of building occupants) is crucial to managing existing buildings or facilities.

The combined findings supported by the FGD and the field study indicate that occupant behaviour is a mediator affecting the occupant-IEQ relationship. The impact of occupant behaviour on IEQ has been investigated in many previous studies (Kim et al., 2017; Luo et al., 2019; Yang et al., 2020). The most commonly studied occupant behaviour includes thermal control, shade control, mechanical ventilation control, window opening/closing, and light control (Kim et al., 2017). The findings in the present study, which echo the conclusions of those previous studies, also imply that the IEQ can be adjusted by regulating the occupants' behaviour or adding active design elements. Arranging FGD can not only allow building stakeholders such as developers, designers, and facilities managers to understand occupant behaviour and its relationship with occupants' perceived IEQ performance, but also improve occupants' awareness of adapting their own behaviour to pursue their desired comfort level in the indoor environment. Thus, identifying the "mediators" is as important as identifying the building dysfunctional aspects in IBE studies.

5.5 Implication on regulating occupant behaviour to cope with COVID-19 and to improve IEQ

This study was conducted in 2021, when the COVID-19 pandemic prevailed. The study results raise attention to regulating occupant behaviour to change or adapt to IAQ. Occupants' ignorance of the impact of their behaviour on IAQ will probably lead to problematic outcomes, one of which could be the spread of the virus of COVID-19.

Since the outbreak of COVID-19, many studies have been conducted. Among the multi-pronged control strategies for mitigation COVID-19, appropriate management control on engineering facilities is necessary (Law et al., 2021). Research has also revealed that opening windows, which enables air ventilation, would significantly reduce the spread of the virus (Dancer et al., 2021; Morawska et al., 2020). However, the student residents of the present study were not aware of the function of the ventilation grilles and some of them did not know how to operate the grilles. This was further confirmed by the field study, where most of the ventilation grilles were found to be kept-off in the investigated apartments. The significant impact of operations of ventilation devices (ventilation grille and window) on IAQ suggests that the awareness of using such devices can help to increase ventilation and this, to a certain extent, can help to prevent the spread of the virus.

Social distancing, which was among the first intervening measure to influence human behaviour upon the COVID-19 outbreak, facilitates two objectives: prevent inter-personal infection and control the number of occupants within indoor areas. The findings of this study reveal that even in the indoor spaces with a small occupant number, improper human behaviour would affect the indoor air quality. For example, lack of ventilation would lead to poor air circulation and thus increase the risk of COVID-19 virus spread. Also, even though the investigated student apartments were of single occupancy, shared student housing is very common in other countries/regions. Proper human behaviour, such as opening the window or turning on the ventilation system (e.g., grille or mechanical ventilation), would reduce the risk of COVID-19 transmission. Thus, all the student residents should be informed of the function and operation method of the ventilation systems and they should be encouraged to open windows to achieve a better IAQ, not only during the COVID-19 pandemic, but also after the pandemic especially when there are indoor air pollutants emitted from building materials, furniture, and carpets.

Besides, the findings provide implications for improving other IBE factors in the student housing in the Netherlands. To provide a more comfortable and healthy living (and studying) environment for students, the following suggestions are proposed. First, to improve the acoustic quality, students should be recommended to soundproof their apartment floor before they move in. As most long-stay Dutch student housing is roughhousing and students are required to refurbish the apartments by themselves, laying an extra sound absorbing mat under the floor to improve the acoustic quality is recommended. Second, to improve the visual quality, students could use ceiling lamps with higher lumen output (i.e., brighter) or add extra lighting (e.g., floor lamp).

5.6 Strengths, limitations, and future works

The methodological approach taken in this study is a mixed methodology based on two sets of data: subjective data obtained from a FGD and objective data collected via on-site measurements. This methodology is considered as novel as it, for the first time, integrates both types of data for synthetic analysis. Adopted in the investigation of a modular student housing, it has been proved to be feasible to identify the current IBE-related problems existed in modular student housing and to provide deeper insights into the reasons and possible solutions of these problems. This methodology is suitable to be adopted in buildings with occupants of various cultural backgrounds and residential habits. It helps to reveal the unique interactions between the occupants and the specific building, which thus provides implication on future design and management practice.

Furthermore, two limitations of this study are identified. Firstly, although the main aim of this study is to develop a new IBE performance evaluation methodology, the small sample size of the case study would to a certain extent reduce the explanation power of the methodology. However, these results are still relevant insights that could help researcher to understand the current IBE situation in the investigated student housing. Secondly, the measuring period was relatively short, therefore the results could only reflect the IBE conditions within one season and not be generalized. Nevertheless, the number of collected measurement data (2880 for each location) are large enough to get statistically meaningful results for the comparison between different measurement locations.

Considering these limitations, future studies on the current topic are therefore recommended. In future investigations, to get a more comprehensive understanding of IEQ in modular student housing, different weather conditions of modular student housing and more participants are suggested to be involved.

6. Conclusion

This study set out with the aim of developing a IBE performance evaluation methodology. As a demonstration of the suitability of the methodology, an investigation of the IBE in a Dutch high-rise modular student housing was conducted using both qualitative and quantitative methods. The results of this case study proved the feasibility of applying this mixed methods approach to post-occupancy evaluation and revealed the IBE problems that existed in the investigated apartments.

The two main stages of the study include a FGD to evaluate the IBE performance from the users' perspective and a field study to further investigate the IAQ and its relationship with occupant behaviour. The FGD enabled identification of the student residents' experience with and perception of the various IBE performance factors, with IAQ and thermal quality found to be the factors that the residents were most concerned about. Grounded upon the qualitative findings, the field study was carried out to further probe into the IBE of the apartments through logging the occupants' behaviour and measuring the IAQ and thermal parameters. The most significant findings were: first, the thermal condition (measured during summer time) in the apartments was sometimes uncomfortable, especially in the south-facing apartment where the T during 46% of the monitoring period exceeded the comfort level recommended by ASHRAE. Installations such as external sunshades are suggested for the apartments with south-facing windows. Moreover, occupant behaviour was found to have a significant influence on IAQ in the student housing. To improve ventilation performance and hence IAQ, all the students should be educated about the importance of ventilation and the operation of the ventilation device in their apartment, especially during the COVID-19 pandemic.

While this study has contributed useful evaluation results and implications to the future modular student housing development, it is limited by the lack of a large sample of apartments and occupants. The fact that the measurements were taken over a limited period during summer also constrains the generalisability of the measured findings. Future studies, therefore, should be endeavoured to follow the approach of this study to cover more samples of student housing and occupants, with the measurement period also extended to cover different weather conditions.

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