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Research article

Acoustic characteristics of bedrooms in two types of long-term care facilities in China

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A R T I C L E I N F O

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A B S T R A C T

The aim of this study was to quantitatively determine the acoustic characteristics of bedrooms in two types of long-term care facilities in China. Objective acoustic conditions, including noise levels and reverberation times, were measured through a series of acoustic measurements in twelve bedrooms in two nursing homes and three adult care homes in Kunming city, China. The impacts of noise and sound preferences were evaluated through a questionnaire survey administered to residents and nursing staff. In terms of the sound field, the background noise levels in most measured bedrooms exceeded the WHO's recommended value (30 dBA) by approximately 10–15 dBA. Compared to those in adult care homes, the noise levels in nursing homes were approximately 5–7 dBA higher during the daytime and 2–3 dBA higher during the nighttime due to frequent nursing activities. Moreover, noise levels were 5–15 dBA higher in roadside bedrooms. The reverberation time of five bedrooms reached 0.8 s at low frequency (125 Hz) due to their large space and absence of sound-absorbing materials. The questionnaire showed that noise sources were mainly perceived as coming from corridors and out-of-windows by residents and nursing staff. Traffic noise, residents' yelling in pain (just in nursing homes) and footsteps were considered the most noticeable noises, which may have had negative effects on participants' sleep quality, health, and emotional state. Moreover, the residents in roadside bedrooms reported that noise had a greater impact on their sleep ($p < 0.01$). Compared to artificial and mechanical sounds, participants preferred nature sounds, such as streams and birds, which were significantly ($p < 0.01$) positively correlated with age.

1. Introduction

It is commonly acknowledged that everyday exposure to excessive noise can negatively affect both physical and mental health [1–7]. Elderly people are more sensitive to their surroundings than are healthy adults; thus, noise can profoundly impact their sleep, emotional state, and physiological indicators [8–13]. Therefore, the WHO and several countries have strict acoustic regulations or guidelines that limit the noise levels in bedrooms in healthcare buildings for older adults to 30–35 dBA [14–16]. However, numerous studies have shown that the noise levels in long-term care facilities (LTCs) exceed these limitations [17–20]. Moreover, the acoustic environment for LTC facilities has become more challenging during the COVID-19 lockdown since residents spent more time in their bedrooms [21,22]. A previous study indicated that after the implementation of the necessary restrictions associated with COVID-19, the noise levels of nursing units increased by 4–6 dBA during nighttime hours [23].

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As one of the countries with the fastest aging populations in the world, China's elderly population (those older than 60 years) reached 264 million in 2020, accounting for 18.70% of the total population, and is expected to exceed 300 million by 2025 [24]. By the end of 2020, China had constructed 38,000 LTC facilities, with more than 8.2 million beds [25]. The LTC facilities that serve the elderly population include two main types of housing: nursing homes (NHs) and adult care homes (ACHs). NHs are facilities that provide 24-h long-term specialist care for residents with illnesses or serious injuries, while ACHs are temporary or permanent accommodations for older adults who can care for themselves; these facilities provide food, hygiene and personal care depending on individuals' needs. To make more rational use of medical resources, most of the currently built LTCs in China are ACHs [26].

Compared with ACHs, NHs can provide medical care, including daily nursing activities and medical device monitoring, for residents, which might lead to a high noise level in their bedroom and result in negative impacts on both residents and nursing staff regarding comfort and health. The noise levels in the bedrooms of NHs in China have been found to be 15–25 dBA higher than the Chinese national standard, with the main noises coming from indoor human activity [27,28]. Bharathan T et al. [18] compared two types of urban teaching hospitals and NHs and found that human activities are the main causes of noise pollution, which can result in psychological stress for frail residents. Laura L et al. [29] indicated that noise in NHs can cause stress and agitation in elderly individuals with dementia, depending on noise levels, space, and agitation levels. Siegmann S et al. [30] reported that noise in NHs can also be stressful for nursing staff and result in a greater error rate. Astrakianakis G et al. [31] measured acoustic indices and assessed stress indicators in LTC facilities and found that noise can cause greater stress for employees and lead to burnout.

The acoustic environment of LTC facilities for older adults has received an increasing amount of attention in recent years. However, research on the detailed information of the acoustic features of bedrooms in ACHs, including the types of sound sources, noise levels, and noise impacts on residents and nursing staff, is still limited. Therefore, the aims of this study were to reveal the acoustic characteristics of bedrooms in typical LTC facilities and the differences between NHs and ACHs in China. The acoustic characteristics, including noise level, noise variation, frequency over a 24-h period and reverberation times, were revealed through objective acoustic measurements. Moreover, a subjective questionnaire survey was administered to residents and nursing staff to explore the impacts of noise and their sound preference.

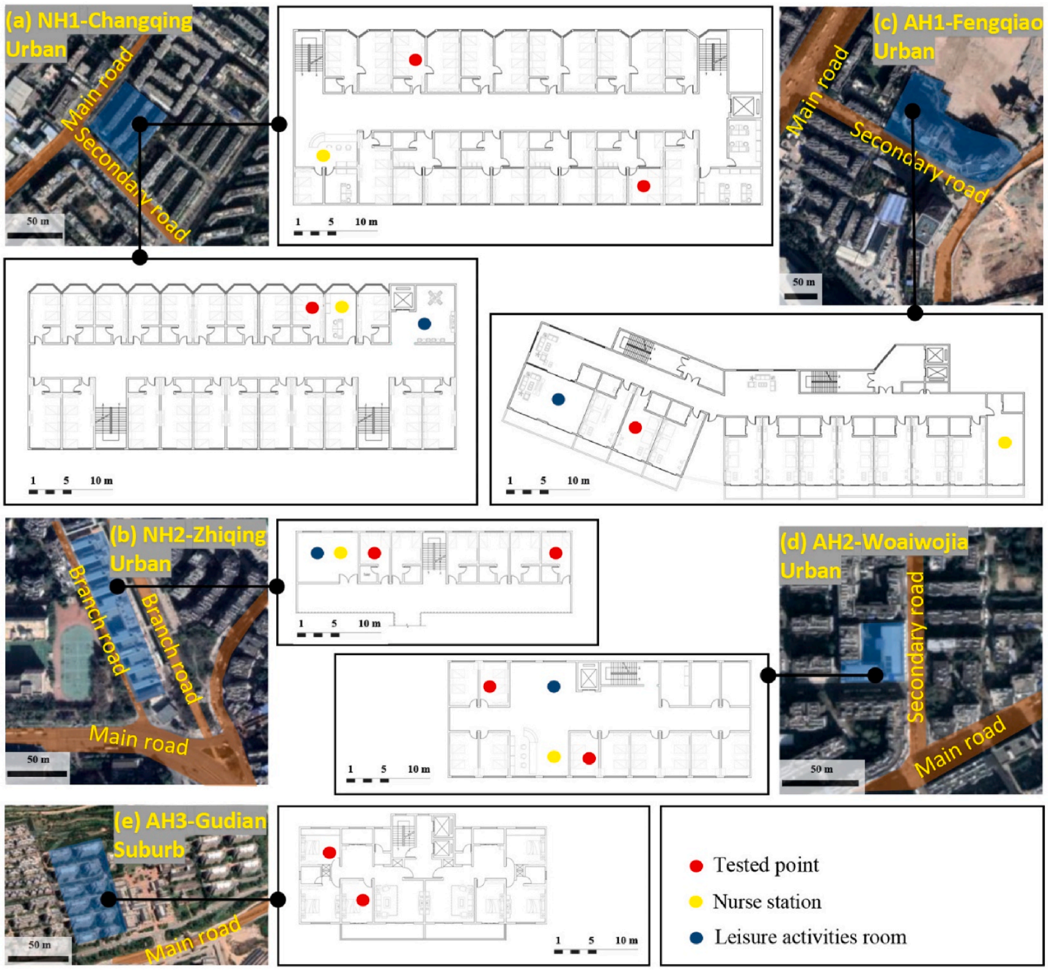


Fig. 1. Site locations, corresponding floor plans and acoustic test points used in the study.

2. Methods

2.1. Case study sites

Due to its comfortable natural environment and advanced healthcare industry, Kunming city, located in southwestern China, was ranked as one of the most livable cities in 2021 according to the China Livable Cities research [32]. As shown in Fig. 1, twelve typical bedrooms in five LTCs in Kunming city were chosen as the study sites. Two NHs (Fig. 1a-b) and two ACHs (Fig. 1c-d) were located in urban areas, and one ACH (Fig. 1e) was located in a suburban area. None of the tested rooms had HVAC systems. Fig. 1 displays the site locations and corresponding layout plans of the measured bedrooms in the LTC facilities. The study was carried out from August 2021 to June 2022.

2.2. Measurement procedures

Objective acoustic indices are an important basis for studying whether the sound environment of bedrooms in LTC facilities meets relative standards.

The background noise levels of unoccupied bedrooms with doors and windows closed and the continuous sound level while the rooms were fully occupied by residents were recorded on weekdays using three Aihua AWA6228+ sound level meters (compliant with IEC61672–1:2013 Class 1, measurement range 20–142 dBA, frequency range 10 Hz–20 kHz ±1 dB, real-time 1/3 OCT). The meters were suspended on the ceiling of the bedrooms at a minimum distance of 0.5 m away from any reflected surfaces to reduce disruption to everyday routines. The 24-h equivalent noise level, noise level variation, impulsive peak noise level (L_{10}), background noise level (L_{90}), and noise frequency of the twelve bedrooms were analyzed in Microsoft Office Excel 2016.

On the other hand, a long reverberation time (RT) can be detrimental to speech intelligibility, which can impact indoor communication quality. The impulse response method recommended by ISO 18233:2006 [33] was chosen to measure the reverberation time of the twelve bedrooms in unoccupied conditions with doors and windows closed. Balloon pops were recorded, and the T_{30} was determined using a Norsonic Nor-121 acoustic analyzer (compliant with IEC 61260 Class 0, measurement range of -10–140 dB, frequency range of 1–20 kHz ±0.5 dB, real-time 1/3 OCT, and reverberation time measurements).

2.3. Questionnaire survey

The questionnaire survey was administered to the residents and nursing staff and consisted of two sections. The first section was designed to collect basic information about the participants, including gender, age, education, health status and information about their bedrooms, such as roadside and nonroadside status and the number of beds. The second section mainly included questions on the following topics: (1) satisfaction rating of the acoustic conditions between LTC facilities and their own homes, (2) participants' perceptions of various sound sources in LTC facilities, (3) the impact value rating of noises on participants' communication, mental states, sleep, and health, and (4) preferences for various sound sources, including sounds from people, sounds from outdoors, entertainment sounds, and natural sounds.

The elderly individuals who participated in the questionnaire survey had all been residents for more than 4 weeks, and the nursing staff had all been working longer than 6 months. A total of 140 questionnaires were distributed within the five LTC facilities through the researchers' one-on-one questionnaire administration method, resulting in the collection of 131 valid questionnaires (response rate 93.6%), including 88 questionnaires from residents and 43 questionnaires from nursing staff. The basic information is shown in Table 1. The residents who came from NHs were elderly; those with device-helping status accounted for 72.9% of the sample. In addition, only 29.2% and 20.0% of the NHs and ACHs, respectively, had single rooms, and more than half of the bedrooms in LTC facilities were located on roads.

Table 1
Characteristics of the study participants (n = 131).

Variables		Residents from NHs	Residents from ACHs	Nursing staff from NHs	Nursing staff from ACHs
Numbers		48	40	31	12
Gender	Female	31 (64.6%)	24 (60.0%)	27 (87.1%)	9 (75.0%)
	Male	17 (35.4%)	16 (40.0%)	4 (12.9%)	3 (25.0%)
Age (years)	Max.	93	92	65	51
	Min.	56	52	22	26
	Avg.	79 ± 7	68 ± 10	41 ± 11	40 ± 9
Education	Middle school or less	21 (43.7%)	11 (27.5%)	12 (38.7%)	7 (58.3%)
	High school	13 (27.1%)	3 (7.5%)	7 (22.6%)	0 (0.0%)
	College/university/graduate	14 (29.2%)	26 (65.0%)	12 (38.7%)	5 (41.7%)
Health status	Self-helping	13 (27.1%)	23 (57.5%)	N/A	
	Device-helping	35 (72.9%)	17 (42.5%)		
Roadside	Yes	21 (43.7%)	22 (55.0%)	18 (58.1%)	8 (66.7%)
	No	27 (56.3%)	18 (45.0%)	13 (41.9%)	4 (33.3%)
Number of beds	<2	14 (29.2%)	8 (20.0%)	N/A	
	≥2	34 (70.8%)	32 (80.0%)		

2.4. Statistical analysis

Microsoft Office Excel 2016 and Origin 9.0 were used for statistical analysis of the significance of noise levels and residents' and nursing staff' subjective evaluations. A *t*-test was used to analyze differences in noise levels between the bedrooms of NHs and ACHs at the five LTC facilities. In addition, because the results of the questionnaire were not normally distributed, a nonparametric test was used to test the correlation between sound preferences and sociodemographic indices among the participants. A correlation test was subsequently used to analyze the influence of the sound environment of the bedrooms on the psychological state of the residents and nursing staff. For all tests, the significance level was set at 5% ($p = 0.05$), with * indicating $p < 0.05$ and ** indicating $p < 0.01$.

3. Results

3.1. Noise levels

As shown in Table 2, the background noise levels of all twelve unoccupied bedrooms were higher than the Chinese national standard during both day (40 dBA from 06:00–22:00) and night (30 dBA from 22:00–06:00) [34] when the doors and windows were closed. Notably, the noise levels in the roadside bedrooms were 4–8 dBA greater at urban sites and 15–20 dBA greater at suburban sites than those in the nonroadside bedrooms. The installation of sliding windows led to the poor sound insulation of the outside environment.

In the fully occupied condition with indoor activities, the daytime noise levels (L_{eq_1hr} from 06:00–22:00) of the NH bedrooms were 5–7 dBA higher ($t = 3.843$, $p = 0.000$) than those of the ACH bedrooms, with L_{eq_day} values ranging from 53.6 to 59.3 dBA, and the nighttime noise levels (L_{eq_1hr} from 22:00–06:00) were 2–3 dBA higher ($t = -2.519$, $p = 0.014$), with L_{eq_night} values ranging from 41.3 to 49.3 dBA. in L_{max} (5–15 dBA) between the two types of LTC facilities. However, the average peak SPL (L_{10}) and background noise level (L_{90}) were not significantly different.

In addition, traffic noise may significantly contribute to the noise levels in the roadside bedrooms of ACHs; values 5–15 dBA higher for L_{eq_day} and 10–20 dBA higher for L_{eq_night} were measured in the roadside bedrooms than in the nonroadside bedrooms. However, relatively small difference in the L_{eq} values between the roadside and nonroadside bedrooms in NH bedrooms during the daytime or nighttime. Additionally, in some cases, the L_{eq} value was found to be greater in nonroadside bedrooms, indicating that indoor noise sources in the NH had a more significant effect on noise levels than did traffic noise interference.

The variance in noise levels in the five NH bedrooms (see Fig. 2a) was strongly correlated with their routine nursing activities. The noise levels increased sharply to approximately 60 dBA at the beginning of the day at approximately 6:00 when the resident got up and the nursing staff started their activities. Afterward, the trends were relatively flat until the lunch break between 12:00 and 14:00 and dropped to approximately 30–40 dBA after 22:00, when most residents went to sleep. However, numerous sudden changes in noise level were found at night between 22:00 and 6:00; these changes were caused by some residents feeling pain and related nursing activities.

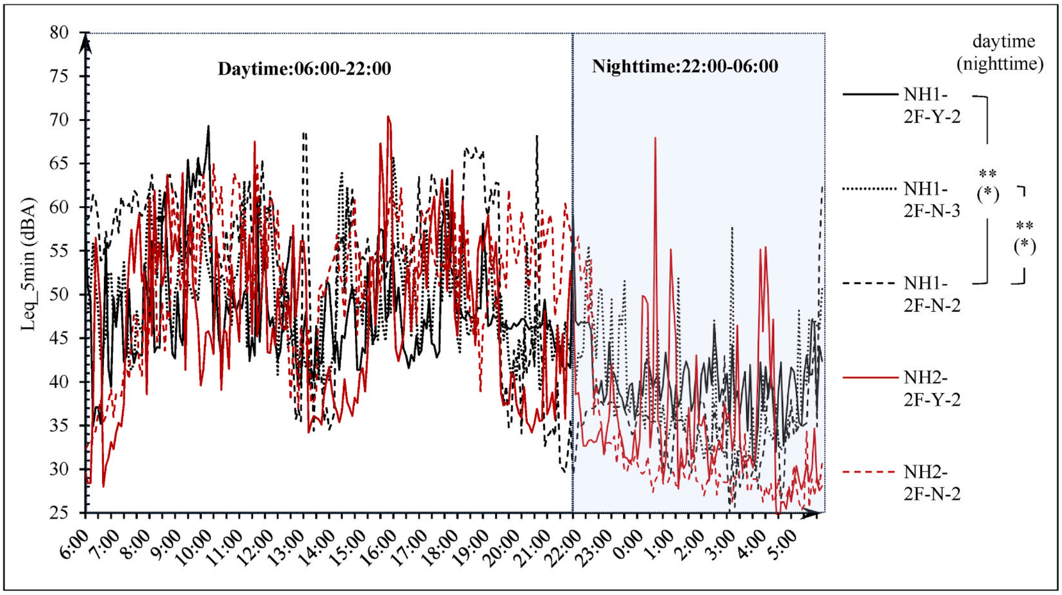
The ACH bedrooms had lower noise levels with few fluctuations (see Fig. 2b) due to the absence of nursing activity. However, a significant difference in L_{eq_5min} was found between roadside and nonroadside bedrooms in ACH3 during both daytime and nighttime (see Fig. 2b). The noise level measured in the roadside bedroom (ACH3-4F–Y-1) ranged from 50 dBA to 60 dBA, mainly due to the contribution of constant traffic on the main road adjacent to the building (see Fig. 1e). In contrast, the nonroadside bedroom (ACH3-4F–N-1) was significantly quieter than the other bedrooms, and the variation in noise level was attributed to the residents' own daily activities, such as communicating with visitors, radio sounds, and cooking (see Fig. 2b).

As shown in Fig. 3, the difference between roadside and nonroadside bedrooms can also be clearly identified by the noise spectra. For the roadside bedrooms, the dominant frequencies were mainly approximately 125 Hz and 1 kHz, which were mainly caused by

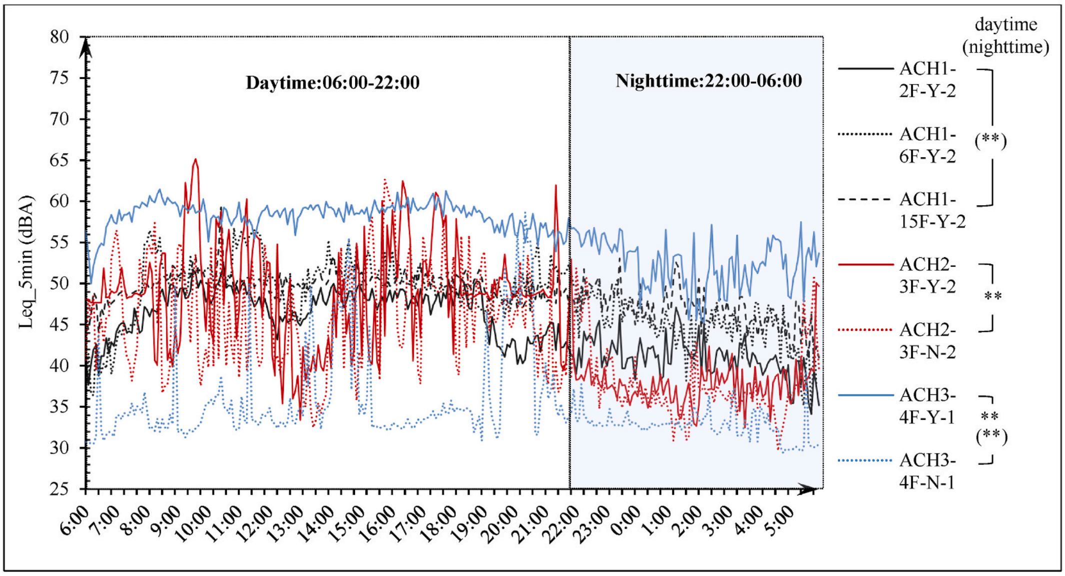
Table 2
L_{eq}, L_{10}, L_{90} and L_{max} values of the twelve tested bedrooms (dBA).

Building #	Bedroom #	L_{eq} (unoccupied)		L_{eq} (full-occupied)			L_{max}		L_{10}		L_{90}	
		day	night	day	night	24 h	day	night	day	night	Day	night
NH1	2F–Y-2	52.1	37.7	54.3 ± 6.2	41.3 ± 3.5	52.6 ± 6.7	69.3	47.1	58.1	44.6	42.1	35.6
	2F–N-3	42.3	42.0	53.6 ± 5.7	44.8 ± 6.6	52.1 ± 7.9	65.7	57.8	57.4	48.2	42.2	31.7
	2F–N-2	45.9	43.3	59.3 ± 9.6	44.0 ± 5.0	57.6 ± 12.1	68.7	62.3	63.4	38.0	35.5	29.6
NH2	2F–Y-2	49.3	42.4	55.8 ± 9.2	49.3 ± 7.7	54.5 ± 10.5	70.4	68.0	59.1	47.2	35.5	28.1
	2F–N-2	45.6	40.2	56.0 ± 7.5	41.7 ± 6.2	54.4 ± 12.0	65.0	56.7	60.1	35.1	38.9	26.8
ACH1	2F–Y-2	46.5	39.8	47.4 ± 2.9	41.6 ± 2.4	46.2 ± 3.8	52.2	47.1	49.8	44.4	42.2	38.7
	6F–Y-2	48.3	42.1	51.2 ± 3.9	45.7 ± 3.2	50.0 ± 4.3	56.8	50.4	54.7	48.3	45.1	40.9
	15F–Y-2	48.2	46.8	50.3 ± 1.6	47.5 ± 2.6	49.5 ± 2.5	59.3	53.1	51.4	50.0	47.9	43.6
ACH2	3F–Y-2	47.5	36.5	53.7 ± 6.4	39.4 ± 2.8	52.0 ± 7.6	65.2	50.1	57.9	39.9	40.2	35.4
	3F–N-2	42.2	39.3	50.8 ± 6.4	40.5 ± 4.2	49.2 ± 7.1	62.7	51.0	54.7	44.4	38.2	34.2
ACH3	4F–Y-1	54.8	50.7	58.5 ± 1.9	53.3 ± 3.0	57.4 ± 3.5	61.5	57.5	59.9	56.2	56.0	48.1
	4F–N-1	40.6	32.8	43.7 ± 2.6	33.1 ± 0.5	42.1 ± 2.2	58.7	39.4	47.7	34.6	32.0	30.1

Notes for Bedroom # column: F represents floor number, Y/N represents roadside/nonroadside, and 1/2/3 represents the number of beds in the bedroom. Notes of the hour range: day: 06:00–22:00, night: 22:00–06:00 [35].



(a)



(b)

Fig. 2. The noise variation over 24 h in the twelve tested bedrooms **(a)** NH bedrooms; **(b)** ACH bedrooms.

traffic (125 Hz) and car horns (1 kHz). In contrast, the 500 Hz frequency was dominant during the daytime in nonroadside bedrooms because residents and their relatives frequently talked in their bedrooms (see Fig. 3a). Notably, traffic noise became more noticeable in roadside bedrooms at night as a result of the cessation of indoor activities (see Fig. 3b).

To ensure higher speech intelligibility in older adults with some degree of hearing loss, the reverberation time (T_{30}) in bedrooms should not exceed 0.6 s in the frequency range of 125 Hz–4 kHz, as recommended by the WHO [14]. As shown in Fig. 4, the reverberation time in the range of 500 Hz–4 kHz in bedrooms without any acoustic treatment was tested from 0.3 to 0.6 s, except for NH1–2F–N-2, which had the largest room size. However, nearly 75% of the tested rooms exceeded the recommended value at a low frequency of 125 Hz. According to Sabine's formula, $T_{60} = 0.16V/A$ (where V represents volume and A represents sound absorption), without sound-absorbing materials such as an acoustical ceiling, a space with a larger volume and large windows can lead to excessive

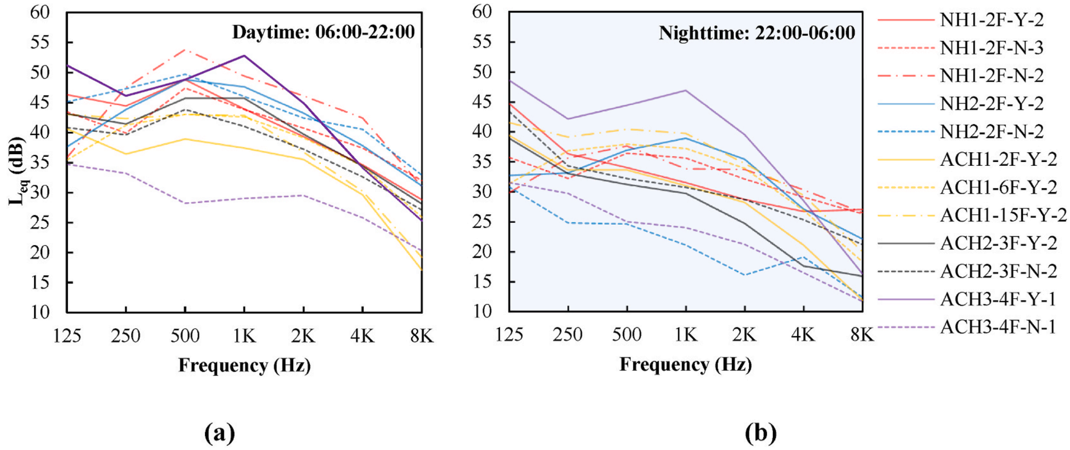


Fig. 3. The noise spectra of the twelve tested bedrooms during the **(a)** daytime and **(b)** nighttime.

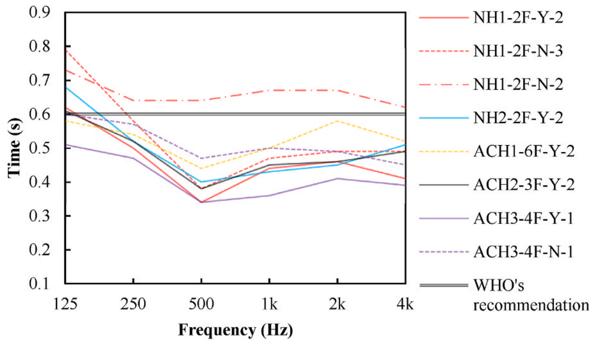


Fig. 4. Reverberation time (T_{30}) of the eight tested bedrooms.

reverberation time.

3.2. Satisfaction with the sound environment

As shown in Fig. 5a, both residents and nursing staff from the ACHs and NHs were less satisfied ($p < 0.01$) with the sound environment in the bedrooms than in their own homes, mainly because there were more complicated sound sources in the LTC facilities. Compared with ACHs, there were more nursing activities and high noise events in NHs, which resulted in lower levels of satisfaction ($p < 0.05$) with the sound environment of NHs being reported by both residents and nursing staff.

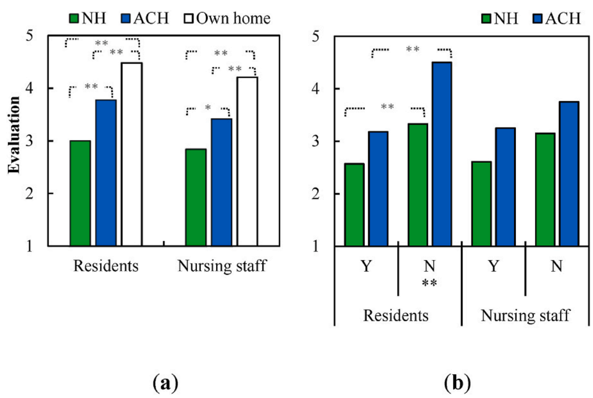


Fig. 5. Satisfaction ratings (1 = not satisfied, 3 = neutral, 5 = extremely satisfied) of the sound environment of bedrooms between (**a**) LTC facilities and their own homes and (**b**) roadside bedrooms and nonroadside bedrooms. Notes: Y = roadside, N = nonroadside.

On the other hand, the residents from roadside bedrooms were significantly less satisfied ($p < 0.01$) with the sound environment than were those from nonroadside bedrooms in both NHs and ACHs (see Fig. 5b). However, no marked difference was found among staff members. A possible reason was that residents spend more than 12 h per day in their bedrooms compared with the nursing staff, which makes residents more sensitive to traffic noise, especially at night. In addition, regardless of whether the ward was facing the street, residents of NHs reported significantly lower satisfaction levels ($p < 0.01$) with the sound environment than did residents of ACHs.

3.3. Sound sources

As expected, traffic noise was considered a more significant sound source in both NHs and ACHs, as shown in Fig. 6. However, the perception of each sound source was more pronounced among participants in the NHs than among those in the ACHs. In the NHs, yelling was the most obvious sound source perceived by the participants, with more than 70% of the nursing staff noticing it. The perception of yelling was much more sensitive among nursing staff, mainly due to their need to be alert to residents' physiological responses. In addition, residents perceived the sound of nursing activities and footsteps more than the nursing staff. With the need for medical care, sounds from medical devices such as ventilators and ECG machines were only present in NHs. In contrast, most of the sound sources in ACHs came from residents' own daily activities, and they were less influenced by others.

3.4. Noise impacts

As shown in Fig. 7a, both residents and staff members reported that noise had a greater negative impact on their health and sleep, while it had only a relatively minor impact on their communication and work. Because there are more noise sources available indoors in NHs, such as nursing activities and medical devices, the impact of noise on residents from NHs was considerably worse than that on residents from ACHs in terms of communication ($p < 0.01$), relaxation ($p < 0.01$), anger ($p < 0.01$), anxiety ($p < 0.01$), health ($p < 0.01$), and sleeping ($p < 0.01$). In addition, compared with residents, nursing staff from ACHs reported that noise had a greater impact on their mental states of relaxation ($p < 0.01$), anger ($p < 0.01$) and anxiety ($p < 0.05$). According to the results of a comparable study, noise at work may increase one's stress-related tension and increase sensitivity to noise [36].

Moreover, traffic noise may result in greater impacts on the daily life of residents living in roadside bedrooms, as shown in Fig. 7b. For the ACHs, the residents in roadside bedrooms reported a greater impact of noise on their reading ($p < 0.01$), relaxation ($p < 0.05$), anxiety ($p < 0.05$), health ($p < 0.01$), and sleeping ($p < 0.01$). For the NHs, noise from only exterior windows had the most significant effect on interrupting residents' sleep ($p < 0.01$) in roadside bedrooms (extremely 4.5 ± 0.5). In addition, compared with ACHs, noise had a greater impact on the communication ($p < 0.05$), relaxation ($p < 0.01$), health ($p < 0.05$), and sleeping ($p < 0.01$) of the residents in the roadside bedrooms of NHs and a greater impact on the communication ($p < 0.05$), reading ($p < 0.01$), relaxation ($p < 0.01$), anger ($p < 0.05$) and anxiety ($p < 0.01$), health ($p < 0.01$), and sleeping ($p < 0.01$) of residents in the nonroadside bedrooms. Traffic

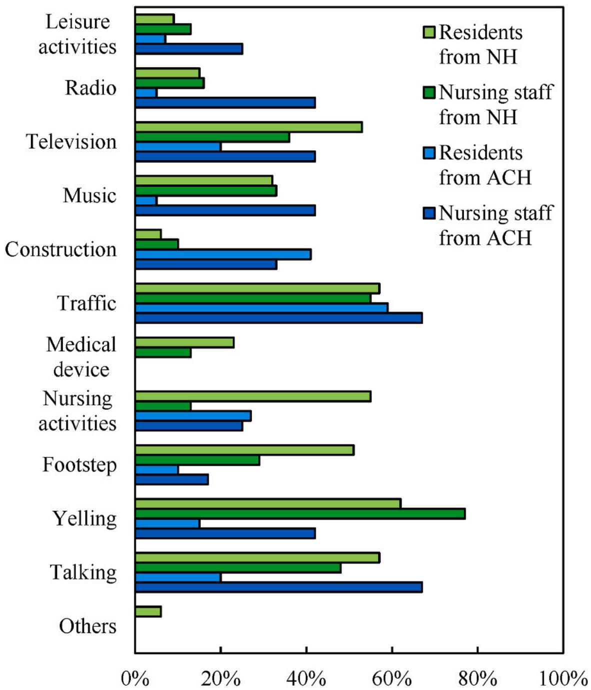


Fig. 6. Perception of sound sources.

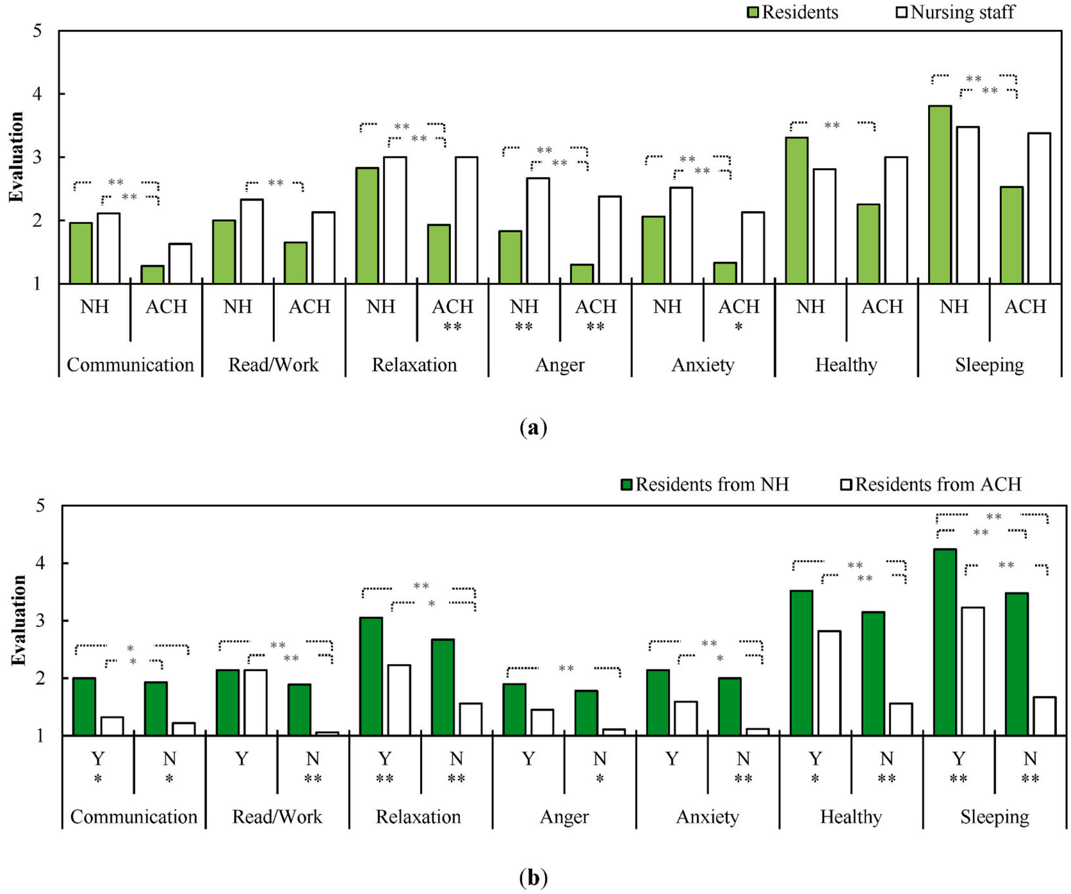


Fig. 7. Noise impact rating (1 = not at all, 5 = extremely) for various aspects of different groups: (**a**) residents and staff members; (**b**) residents of roadside bedrooms and nonroadside bedrooms. Notes: Y = roadside, N = nonroadside.

noise was not the main factor affecting the sound environment of NHs.

3.5. Sound preferences

The results shown in Fig. 8 indicate that nursing staff and residents had similar sound preferences. Entertainment sounds, including music and radio, and natural sounds, including streams and birds, received a high preference rating from both staff and residents. In contrast, some indoor sounds made by people, including yelling and footsteps, and some sounds from outdoors, including traffic and construction, were the noise sources that were disliked.

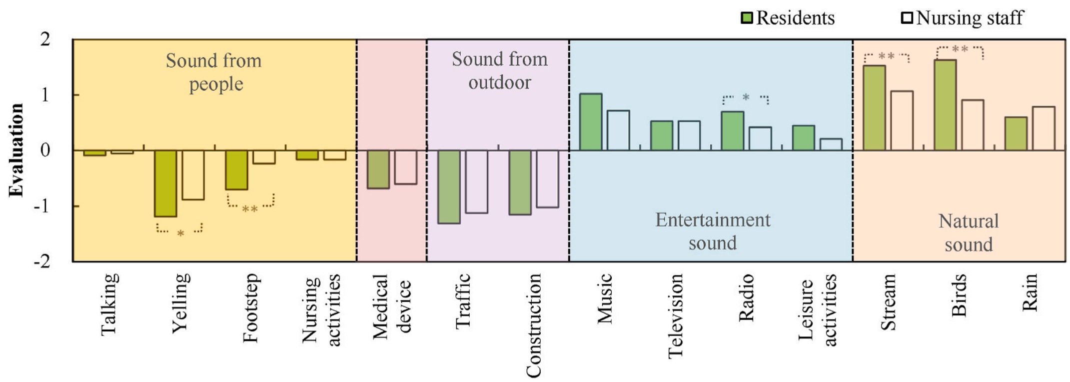


Fig. 8. Evaluation of preferences for various sound sources (−2 = very annoying, 0 = neither annoying nor pleasant, 2 = very pleasant).

Moreover, some marked differences in sound preference were found between the residents and nursing staff. Compared with those from nursing staff, yelling ($p < 0.05$) and footstep ($p < 0.01$) sounds received significantly lower ratings from residents. According to interviews with the participants, yelling and footsteps can seriously affect their rest and sleep quality, especially at night. In addition, residents reported greater preferences for entertainment sounds coming from a radio ($p < 0.05$) and the natural sounds coming from streams ($p < 0.01$) and birds ($p < 0.01$) than did the nursing staff.

As shown in Fig. 9, according to Spearman's correlation analysis, the preferences for television ($p < 0.01$), radio ($p < 0.01$), streams ($p < 0.01$) and birds ($p < 0.01$) were positively correlated with age in both the resident and staff groups; these results were comparable with those of another study [21,37]. Notably, preferences for footsteps ($p < 0.05$), traffic ($p < 0.01$), construction ($p < 0.01$), music ($p < 0.01$) and radio ($p < 0.01$) were negatively correlated with education. As the level of education increases, a relatively quieter space is preferred. Similar studies have also indicated that with increasing age and higher education levels, residents prefer natural sounds and are more annoyed by artificial noises [38–40]. Compared with the female group, the male group significantly preferred the sound from "television" ($p < 0.05$) and "leisure activities" ($p < 0.01$).

4. Discussion

Since the COVID-19 lockdown, the bedrooms of LTC facilities have become the main spaces in which residents conduct their daily lives; thus, the quality of the sound environment has become particularly important. While the previous studies have provided detailed information on the acoustic characteristics of bedrooms in nursing homes, the acoustic environment of ACHs and its differences from NHs is still limited. The current study attempted to reveal the differences in acoustic features between NHs and ACHs in terms of reverberation times, noise levels, types of sound sources, and their impact on the residents. In addition, statistical methods were utilized to demonstrate the associations between sound preferences and sociodemographic factors among the subjects. The findings of this study have the potential to inform the design of typical LTCs, with a focus on creating a comfortable acoustic environment for the residents.

For the NHs in this study, the sound environment of the bedrooms was similar to that found in European countries and the United States. The main noise sources were talking and nursing activities, with $L_{eq\text{-}24}$ at approximately 50 dBA [19,20,41]. For the ACHs, which have received less attention in previous studies, the noise levels were significantly lower than those of the NHs ($p < 0.01$), especially at night. However, the noise levels of all the tested ACH bedrooms still exceeded the WHO's recommendation (30 dBA), with a large deviation. Because most of the participant residents from ACHs were in healthy physical condition, no heavy load medical devices or less regular care activities were found in relation to their room. Thus, sounds from talking, communication and entertainment activities such as TV, music and radio were more noticeable. According to Fig. 3, talking might be the primary sound source in the bedrooms of ACHs. However, in terms of subjective evaluations, residents were not sensitive to the sounds either they or their relatives made because they wanted to receive information by talking with others.

The impact of traffic noise on bedrooms should not be ignored. There is no denying that traffic noise can have an impact on roadside bedrooms in urban areas due to the high density of road networks and buildings. Unexpectedly, traffic noise had a greater impact on roadside bedrooms in suburban areas, where noise levels were 5–10 dBA greater than those in urban areas (see Fig. 2). On the one hand, this may be because the epidemic suppressed people's travel demand, causing a decrease in urban traffic volume. On the other hand, the presence of many transport vehicles traveling at fast speeds and a lack of sound barriers at the suburban site could have contributed to these findings. During the COVID-19 pandemic, the WHO and the National Health Commission of China suggested that good ventilation could help reduce the concentration of indoor air pollutants [42,43]. Due to the lack of HVAC systems in bedrooms, residents had to open windows for ventilation even when doing so mean that they were disturbed by traffic noise. However, the results of the subjective evaluation indicate that traffic noise has a significant impact on people's sleep and health.

According to the sound source characteristics and development status of LTC facilities in China, the following three noise reduction interventions are proposed. For indoor anthropogenic noise, residents can be educated to be aware of the sound environment and reduce high noise levels by closing doors when they watch TV, for example. Restricting visits during typical rest and sleep times not only reduces the sound of talking and shouting [44] but also the accumulation of virus particles in the air. In particular, to address the noise of medical devices and nursing activities in NHs, managers should conduct noise-related training for nursing staff. A previous related study indicated that nursing staff are more careful in performing their tasks after implementing such measures; while the L_{eq} values remained the same, the peak noise levels were reduced by approximately 10 dBA [45]. For noise stemming from corridors, soundproof doors have a positive effect on improving the sound environment of bedrooms [46,47]. For traffic noise, auxiliary spaces such as activity rooms and rehabilitation rooms can be placed on the roadsides of buildings instead of bedrooms to avoid the impact of traffic noise on bedrooms and allow residents the freedom to open their windows without being exposed to traffic. In addition, for unavoidable roadside bedrooms, the sound insulation performance of the enclosure should be enhanced by using soundproof windows, for example. Moreover, HVAC systems should be installed to bring in fresh air from outdoors. However, replacing windows can be an inconvenience to daily operations. Thus, soundscape design can be considered a more efficient and feasible method for both new and existing LTC buildings. By installing an electroacoustic speaker that emits creative natural sounds such as streams that residents want to hear, this approach can help mask traffic noise [48–50]. Notably, the volume of such masking sounds should be controlled when applied to NHs to avoid affecting nursing staff's ability to hear call bells and medical alarms.

One of the limitations of this study was that the questionnaire was poorly understood by the residents. In the future, a questionnaire should be designed that is more suitable for residents. The second limitation was that the study explored only the impact of acoustic indicators on participants' psychology and ignored physiological indicators as an important basis for evaluating the physical status of the residents. The third limitation of the study pertains to the lack of information about drug use. Compared with noise, the subsequent

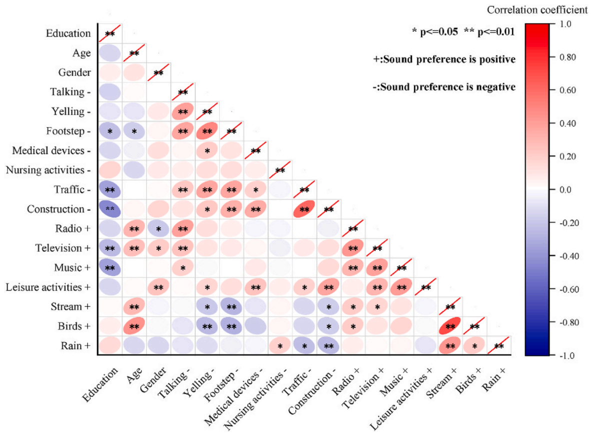


Fig. 9. Correlations between sound preferences and sociodemographic indices among the participants.

use of sedative drugs may have a greater impact on sleep quality, especially for elderly in NH. Such drug use will affect elderly people's judgment of the impact of noise on sleep quality. Furthermore, the participating NHs and ACHS were selected based on convenience; hence, not all LTCs in this region were included. This limitation might have affected the generalizability of the results to other regions but inside and outside of China. Therefore, supplementation with physiological and drug use indicators with the aim of increasing the quantity of samples used is necessary in our future work.

5. Conclusions

This study provides detailed information about the sound environment of bedrooms in two types of LTCs, namely, NHs and ACHs, in China through acoustic measurements and a questionnaire survey.

(1) In the unoccupied condition, the background noise levels in all twelve bedrooms exceeded the WHO's recommended value (30 dBA) by 15 dBA during both daytime and nighttime. The noise levels of two NHs and three ACHs did not show marked differences.
(2) In the fully occupied condition, due to frequent nursing activities, the NHs had L_{eq} values higher than those of the ACHs during the daytime and nighttime by 5–7 dBA and 2–3 dBA, respectively; furthermore, the L_{max} monitoring value of 15 dBA found for the NHs was greater than that of the ACHs. Both residents and nursing staff reported that the sound environment in NHs was worse than that in their homes, and noise had a more significant impact on NH residents' communication ($p < 0.01$), mental states ($p < 0.01$), health ($p < 0.01$), and sleep ($p < 0.01$).
(3) Due to the impact of traffic noise, higher noise levels of 5–15 dBA were found in roadside bedrooms. Notably, disturbances to sleeping ($p < 0.01$) and health ($p < 0.01$) were found to be a great issue for residents in roadside bedrooms. Traffic noise had a greater impact on the roadside bedrooms of ACHs compared to those of NHs, mainly due to the absence of indoor noise sources, such as medical devices and nursing activities.
(4) Residents and nursing staff had similar preferences for sound sources. Among them, yelling and footsteps were found to be the most unwanted sounds, while natural sound sources, namely, the sounds of streams and birds, were those that individuals most wanted to hear.
(5) To reduce the impact of noise, replacing windows and doors with soundproof windows and doors may reduce traffic noise and noise from corridors, such as yelling and footsteps. Furthermore, the introduction of some natural sounds may improve the acoustic comfort of the sound environment.

Data availability statement

The data associated with this study have not been deposited into any publicly available repositories. However, the data will be made available upon request.

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CRediT authorship contribution statement

Mingxuan Xie: Writing – original draft, Investigation, Formal analysis. **Zhixiao Deng:** Writing – review & editing, Writing –

original draft, Supervision, Methodology, Funding acquisition, Conceptualization. **Zhengnan Xiang:** Writing – original draft, Software.

Declaration of competing interest

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