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Revealing the widespread existence and serious adverse health consequences of low-price rental housing in urban villages in Xiamen, China

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Xiamen, China, currently experiencing rapid development, needs to house large numbers of migrant workers who receive relatively low pay, prompting original residents in urban villages to repurpose and rebuild their original houses for low-price letting. In this conglomerate study, we firstly gauged the scale of existence of low-price rental housing (LPRH) in the city's rental housing market and the severity of their indoor environmental deficiencies. Questionnaires were then employed to reveal the actual living experience of their renters and the consequences on their health. Finally, statistical analyses were used to find the origin of any reported health problems. It was found that partitioned rural rental housings (PRRHs), the specific type of LPRH developed in Xiamen, represented the majority of rental housing supply in most areas of the city, and that the indoor environment parameters were mostly negative, both from the on-site measurements and from renters' experience. The sub-standard environmental parameters also showed correlational relationships to the renters' health. This research highlights the significant presence of PRRHs in Xiamen and their disservice for renters' health, calling governmental intervention throughout the lifetime of LPRHs in all cities including formulating adequate housing plans to house population explosions and renovating and replacing existing LPRHs.

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Introduction

In the process of urbanisation, influx of large numbers of migrant workers increases the demand for housing continuously (Kaufmann and Strebel 2021). The housing plans of the government usually cannot fully meet the growing demand for low-price rental housings (LPRHs) by these immigrants (Scheba and Turok 2020). Hence, a variety of special housing models with fast construction timeframes and low costs were developed spontaneously by the market (Mwangi 1997; Gilbert 2016). The usually accompanying low construction quality has been a common problem around the world as seen in the rapid-growth stages of major cities (Li et al. 2019; Durst 2019; Wachsmuth et al. 2016; Ghasemi et al. 2018). Examples include the back-to-back houses in Birmingham, Liverpool and Manchester in the UK during the industrial revolution in the 1760s (Timmins 2013), the backyard accommodation shelters in Cape Town and Johannesburg in South Africa in the 1920s (Gilbert et al. 1997), the informal housing built by residents in poverty-stricken areas in Brazil or rented out by merchants in the 1950s (Koster 2012), the squatter settlements in city centres in Pakistan due to the migration of rural population into cities from the 1950s to the 2010s (Malik et al. 2020), and similar squatters for the overly concentrated urban population in Singapore in the 1960s (Ooi and Phua 2007).

Accompanying their low cost and poor construction quality, LPRHs usually suffer from substandard indoor environmental quality, which could potentially bring serious health consequences. People spend more than 90% of their time indoors (Dovjak and Kukec 2019), and the quality of people's housing heavily affects their health (Helldén et al. 2021; Krieger and Higgins 2002; Stolwijk 1991). As early as the 1970s, people complained about specific indoor spaces like bedrooms and reported uncomfortable symptoms, which triggered widespread attention (Repace 1982). Consequently, the World Health Organization (WHO) put forward the concept of "Sick Building Syndrome" (SBS) based on the study of the complaint cases, describing a series of non-specific symptoms (headache, irritation of the eyes, nose, and throat, lethargy, inability to concentrate, objectionable odours, nausea, dizziness, chest tightness, etc.) related to the use of certain indoor environments (World Health Organization 1997; Environmental Protection Agency 1991). Although these symptoms are not life-threatening, long-term living in an unhealthy indoor environment do impact people's comfort of living, physical and mental health, work performance, and general quality of life (Dhungana and Chalise 2020).

Studies have shown that SBS was affected by both environmental factors (such as physical environment (Belachew et al. 2018) and air quality (Takigawa et al. 2009)) and individual social factors (such as gender (Li et al. 2015), education level (Sahlberg et al. 2009), social status (Barmark 2015), etc.). Between the two, environmental factors have a more direct impact (Mentese and Tasdibi 2016; Lu et al. 2016). Specifically, the prevalence of SBS is very high in low-quality houses. For example, in a study of the residents of the small and old apartments in Japan (Saijo et al. 2009), it was found that the improper temperature and humidity there led to a variety of SBS symptoms, mainly mucosal symptoms. In another study of the residents of multiple types of apartments in South Korea (Lee and Sohn 2014), it was found that improper building ventilation design could increase the prevalence of SBS by 1.5 to 2 times.

Since Xiamen was designated as a special economic zone city in 1980, rapid economic development was seen, attracting large numbers of migrant workers to seek employment opportunities. According to the seventh national census, the inflow population of Xiamen in 2020 was 2.715 million, an increase of 47.13% compared to that in 2010. Affected by institutional barriers and their own capabilities, despite the high work intensity of the migrant workers, their income has been generally lower than that of the permanent population, resulting in a surge in demand for LPRHs (Wu 2004; Zhu 2007). In this context, the informal redevelopment of urban villages in Xiamen has become an effective tool to create large numbers of LPRHs to meet the demands. Xiamen is confronted with significant challenges in accommodating low-end migrant workers who move to the city. As a result, there has been a proliferation of LPRHs. Although both the country and the Xiamen government are taking active steps to address the housing challenges faced by immigrant groups, issues such as resettlement and ensuring adequate living conditions have not been fully resolved due to factors such as the size of the immigrant population, property rights of the housing, available land resources, and construction funds. Therefore, discussions on the situation of this type of housing and the associated problems have a valuable warning and reference function for cities encountering similar situations in China and worldwide.

Urban villages are rural villages situated in urban areas. As the city developed in Xiamen, much of the nearby farm and agriculture land has been taken over by urban developments, while leaving the rural villages unremoved and unrenovated limited by land property rights. This has created a situation of interwinding rural villages and urban developments in these previously suburban areas. Urban villages of Xiamen are economically prosperous, and thus some of the residents migrated to the urban area, making their rural homes surplus. As a result, they have renovated or expanded their homes and rented them out as small units. The prices of such lettings are generally much lower than nearby urban developments due to poorer conditions. With stable payback and ever increasing demand, the owners have since rebuilt their original rural houses with larger areas, more floors, and more rooms, thanks to the previous regulations allowing the construction of private residential buildings by residents on their own residential land without presenting corresponding construction guidelines or specifications. These houses were built to be partitioned into multiple studio-like rental units and the main design principle was to create as much space and as many rental units as possible. We call these houses partitioned rural rental houses (PRRHs).

Hence, with Xiamen's PRRHs as a sample system, we aim to answer the following research questions with a research framework outlined in Fig. 1: what is the stock status of the PRRHs in

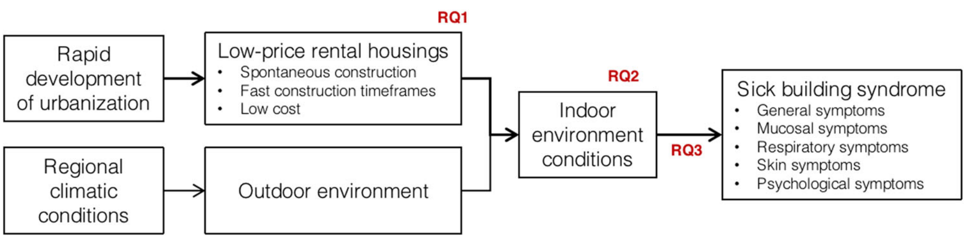

Fig. 1 Theoretical framework of this study.

urban villages in Xiamen? How is the indoor environmental quality of these rental houses? How are the environmental experience and residential health of the renters? Herein, we crawled a major renting website to obtain information on the rental housing market in Xiamen and analysed the stock status of PRRHs. Subsequently, we tested their indoor air quality and physical environment and compared the results to Chinese and international healthy building standards. Finally, referring to the SBS standard scale, a questionnaire survey was launched to investigate the living environment experience and residential health of the renters, and correlation analysis was performed between the residential health and the living environment experience to explore the indoor environment factors that affect the residential health of the renters. Using the epidemiological theory of sick building syndrome and its research methods, this study found that more than half of the occupants in the widespread LPRHs were affected by SBS. This reveals the social problem of disorderly house construction in the rapid urban development, and highlights the need for proper advance planning and supervision.

Materials and methods

Rental information crawling. To gauge the condition of the rental market and the basic characteristics of the PRRHs, we crawled the data of rental housings in Xiamen. Due to the problem of duplicate data, we chose to only crawl data from one source. For that, 58.com was selected as the house renting, as opposed to other major renting websites Anjuke and KE, as it contained the highest number of units for rent and had the widest coverage, giving significantly more output data than the other two websites combined. The conditions for the crawling included: 1) The rental unit needed to be situated in Jimei district, Haicang district, Tongan district, and Xiangan district. 2) The rental unit needed to be managed by the owner directly to avoid duplicate information put up by the owner and their agency. From the six districts of Xiamen, the said four were selected as they contained the said situation of interwinding urban developments and villages, creating opportunities for the PRRHs to be developed, while the other two districts were small central districts with only newly built urban areas (Xiamen Municipal Bureau of Statistics 2021). Information was obtained with Octopus collector v8.2.2 2014SR149170 from 58.com on 09/09/2021.

Air quality and physical environment measurement. To test the conditions of the indoor environment of PRRHs, measurement of the indoor air quality and the physical environment parameters was conducted in recruited one-bedroom PRRH units. Climate in Xiamen is humid and hot. Therefore, thermal insulation and conditioning in summer is much more important than in winter. Hence, to ensure typicality, the experiments were conducted on typical summer days. In the meantime, the selection of one-bedroom units were because it was the most common kind as found in the investigation in the preceding section.

For the air quality measurements, 20 one-bedroom units located in Jimei and Tongan districts were recruited. CO_2, TVOC, $PM_{2.5}$ and PM_{10} were used as the parameters to characterise the indoor air quality of PRRHs. Among them, CO_2 was mostly produced by human breathing and thus reflected the impact of human activities on the indoor air. TVOC reflected the total concentration of volatile organic compounds, which were mostly considered pollutants. Similarly, the amount of particulate pollutant was characterised by $PM_{2.5}$ and PM_{10}. Air quality monitoring of 20 PRRH units were carried out using the methods specified in the Chinese "Indoor Air Quality Standards". As per the specification, as the area of the monitored rooms were all less than 50 m^2, one measuring point was arranged at the diagonal intersection of each room, and the instrument was placed at a height of 1.1 m from the ground for testing. TSI7575 air testing system equipped with No. 982 probe was used to measure the CO and CO_2 concentrations. TSI7575 air testing system equipped with No. 986 probe was used to measure the TVOC concentration. DUSTTRAK DRX8533 inhalable particulate matter detector was used to measure the $PM_{2.5}$ and PM_{10} concentrations. Appropriate calibration was conducted prior to the measurements.

The experiment was conducted from 15/09/2020 to 18/09/2020. During the period, the outdoor sunshine was strong and the temperature profiles were in line with local typical summer days. The air quality of the 20 rooms were tested in the morning (7:00–9:00), midday (12:00–14:00) and evening (16:00–18:00) respectively, and the total time of each test was 45 min. Each room was monitored for two days. Affected by the high temperature and hot climate in Xiamen in summer, most renters chose to close their doors and windows and to adjust the indoor environment through active temperature adjustment devices such as air conditioners and fans. To understand the characteristics of indoor air pollutant concentration when doors and windows are closed for a long time, the renters were asked to close the doors and windows of the tested room for at least 12 h before testing, and to keep the doors and windows closed during the monitoring period.

48-hour continuous physical environment measurement was conducted in six of the units to reveal the pattern of their indoor physical conditions. We selected air temperature, relative humidity, wind speed, and indoor illuminance as parameters. More specifically, air temperature, relative humidity and wind speed characterised the indoor thermal environment, while illuminance characterised the indoor light environment. The monitoring was carried out using the methods specified in the Chinese "Standard of Testing Methods of Building Thermal Environment". Similar to that in the standard for air quality, the selection of measuring points is determined according to room area. Here, one measuring point was arranged at the intersection of the diagonals of each room as the central measuring point of the room. Except for the wind speed measurement, where the equipment was positioned 1.6 m above the ground, the other instruments were fixed at a height of 1.1 m above the ground by using tripods, stools and other tools during the test, as required by the specification. Hengxin AZ8829 temperature and humidity metre was used to measure the temperature and relative humidity. TESTO425 Hotline Anemometer was used to measure the wind speed. Konica Minolta CL-200 illuminance metre was used to measure the indoor illuminance. Appropriate calibration was conducted prior to the measurements.

The experiment was conducted from 14/09/2020 to 16/09/2020, which are had typical summer weather conditions of Xiamen. Summer is also the season of year where SBS-related symptoms are likely to be the most severe and easiest to probe. During the test, the dry bulb temperature, relative humidity, were automatically recorded every 30 min. Indoor illuminance was manually recorded by the experimenter and recorded every one hour. Indoor wind speed was recorded as the three minutes average wind speed manually every one hour. The automatic tests were conducted continuous for 48 h and the manually recorded tests were conducted for 12 h every day for two days. Because this physical environment test was aimed at understanding the characteristics of the climate adaptability of the rooms and the real-time conditions of the indoor physical environment, the doors of the tested rooms were kept closed and the windows open during the test period, and this remained unchanged during the test period. There were no active temperature conditioning equipment running and the doors were only opened when the experimenter entered and exited, but the frequency of opening the door was small and the opening time was very short each time, so the influence on the indoor air condition is very small and can be ignored.

Questionnaire survey. To understand the subjective living condition, living experience, and health of the renters in PRRHs, a cross-sectional questionnaire survey was launched from 20/08/2020 to 31/08/2020. There are a total of 147 villages within the four administrative districts of Xiamen City (Xiamen Municipal Bureau of Statistics 2021), where the PRRHs share considerable similarities in terms of spatial form, layout, and construction and decoration material selection. We selected two urban villages from each of these four districts, amounting to eight villages in total to distribute the questionnaires. Specifically, these include Suncuo and Fenglin Villages in Jimei District, Jinli and Jianmei Villages in Haicang District, Wulv and Sikouzhen Villages in Tong'an District, and Anbian and Nei'an Villages in Xiang'an District. The study referred to the standard questionnaire MM040EA for the study of the SBS (Andersson 1998).

The questionnaire was divided into four parts: basic information of the renters, basic characteristics of the PRRH units, subjective evaluation of the indoor environment, and self-evaluated SBS symptom. The questionnaire is given in Supplementary Table S1. The first part on the basic information of the renters asked about their gender, age, occupation, education level, smoking status, health history, and the time they spent at home on weekdays. The second part was on the basic characteristics of PRRH units and asked about the number of rooms in their rental unit, height and architectural form of their rental house, duration of renting, refurbishment situation after move-in, and number of people living together. The third part was on the subjective evaluation of the indoor environment and 11 statement phrases related to indoor environmental conditions were used with a five-level Likert-like scale. Responses with "Somewhat agree" and above were considered to indicate a problematic environment (Dhungana and Chalise (2020). The final part of self-evaluated SBS symptoms included five types of a total of 13 symptoms. Four-level phrases of "Always", "Often", " "Sometimes" and "Never" were used and responses of "Sometimes" and above were considered to indicate presence of the symptom, and the participants who had reported at least one symptom was considered to have SBS. The recall period of the questions was three months, meaning this would capture an average experience of renters in the summer season, which is normally the harshest season year round. This duration was long enough to avoid the memory effect, and short enough for effective follow-up research if remedial measures were taken (Andersson 1998).

In total, 270 questionnaires were given out and 248 valid ones were recovered. Six trained investigators were grouped into three pairs and gave out questionnaires at the main entrances, exits, squares, shops and other public spaces of the selected urban villages with relatively dense people instead of distributing questionnaires by house visits to avoid the subjective bias when selecting houses to enter. A participant was considered qualified if they had lived in a PRRH unit for at least three months before filling out the questionnaire. Data entry, screening, processing and figures output were conducted with Microsoft Excel 2016 and SPSS 19.0. All variables involved in the questionnaire were tested for normality, and it was found that some variables did not obey the normal distribution. Therefore, they could not be analysed by parametric statistical test method. Hence, all variables were analysed by non-parametric statistical test in the correlation analysis and the logistic regression. The statistical analyses were standard functions of the said software and were used as provided.

Results

The stock situation of PRRHs in Xiamen. From the crawling, a total of 1097 pieces of rental information were obtained. Each data was manually checked to remove duplicates and housings for non-residential purposes. 40 were identified and removed. Then, the remaining data were divided into urban rental units and units in PRRHs according to their land types. In total, 590 units in PRRHs and 467 urban rental units were summarised.

Inspecting the 590 PRRH units, it was found that they were generally of substantial height. Among them, 18.6% were of one to three stories, most (62.5%) were of four to six stories, with ones reaching seven to nine stories (16.8%) or even more than ten stories (2.1%). Indicating no appropriate limits for the height or capacity ratio were properly enforced when they were built. 64.7% of the units had one bedroom, followed by two-bedroom (21.5%) and three-bedroom or more (13.8%). This was a significantly higher proportion of one-bedroom units compared to their urban counterparts (26.6%). The owners tended to divide their buildings into more smaller units to pursue higher profit. It can be seen from Fig. 2 that units of PRRHs had a universal distribution in the four districts other than Siming and Huli districts where no land was classified as rural land and hence it was impossible to build the PRRHs. The average rent per bedroom (*RPB*) was an indicator for the overall renting cost and was calculated by dividing the rent of a unit by the number of bedrooms it contained. It can be seen that the *RPB* of PRRH units were slightly higher the nearer to the city centre. Urban rental units followed the same trend, but significantly higher *RPB* was seen than PRRH units (65.3% higher, $p < 0.01$). Apart from the *RPB*, the number of available PRRH or urban rental units also reduced further away from the central locations. Overall, partly thanks to the interwinding localities of urban and rural areas, PRRHs were generally built-in accessible locations and rented for low prices. Their low prices were not due to weaker locations, but rather due to their smaller areas and lower quality. These conveniences of low price and prime location matched migrant workers' demand for low-cost renting very well and have thus made PRRHs become more and more common.

Indoor environment of PRRHs. As can be seen in Table 1, every investigated air quality and physical environment parameter except for relative humidity displayed significant degree of excess over the health specifications of the indoor environment (T/ASC 02-2016: Assessment standard for healthy building, WHO global air quality guidelines, WELL v2TM, etc.). Two subsequent parameters were used to describe the degree of excess, the proportion of excess (*PoE*) and the proportional excess (*PE*). The *PoE* referred to the proportion of measurement data that did not meet the standard, and the *PE* was the average percentage over the maximum or below the minimum.

In terms of the air quality, the measured values of all indicators have exceeded the standard to varying degrees. Among them, TVOC ($PE = 64.1\%$; 82.0%) (*PE* over national; international standards, same below) and CO_2 ($PE = 38.7\%$; 50.4%) had a relatively high degree of excess. The former could be due to the low-quality decoration materials used or the inferior furniture that releases excessive volatile aromatic hydrocarbons and alkanes. The latter could be due to the relatively small per capita air space due to limited area. In addition, the recorded $PM_{2.5}$ values significantly exceeded the standard ($PE = 36.3\%$; 186.3%). Due to the mixed functions of the PRRH unit, the living space and the kitchen space were intertwined, and cooking could lead to

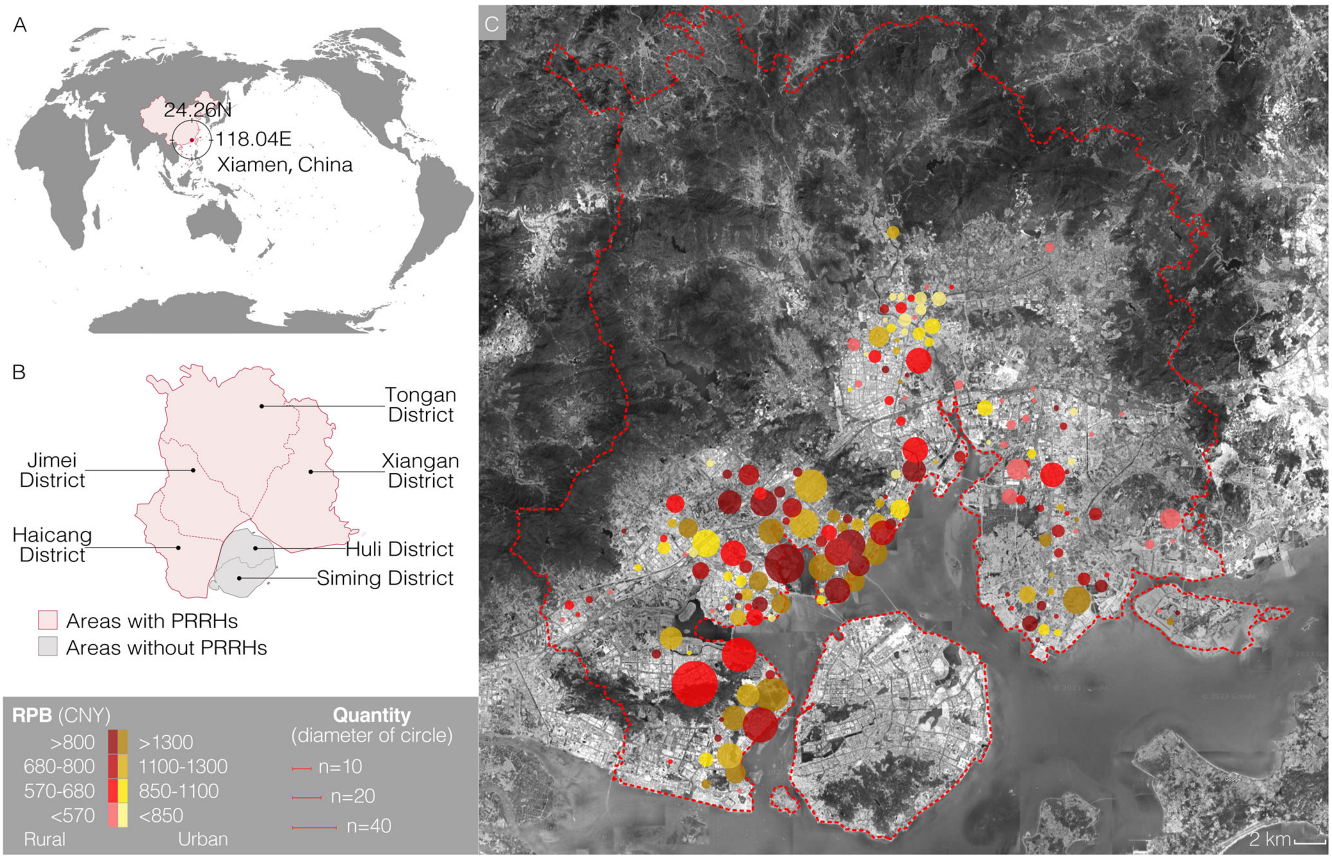

Fig. 2 Overview of the study setting. A The location of Xiamen in the world; **B** The administrative division of Xiamen into districts; **C** The spatial distribution of PRRHs and urban rental houses in Xiamen (Note: The red dashed line represents the boundary of the Xiamen city. As shown in the legend, the colour of the circles represent the rent per bedroom of the rental units and the diameter of the circles were proportional to *quantity* $^{0.7}$).

Table 1 Measurement data for the parameters for the indoor air quality and physical environment and comparison with relevant standards.

	Parameter	*n*	Average	Max	Min	T/ASC 02-2016	PoE (%)	PE (%)	WELL v2TM	PoE (%)	PE (%)
Air quality ($n = 20$)	TVOC (ug/m^3)	120	800	1600	500	600[a]	65.8	64.1	500	81.7	82.0
	CO_2 (ppm)	120	1213	1958	646	1000	68.3	38.7	900	74.2	50.4
	$PM_{2.5}$ (ug/m^3)	120	70	216	10	75	37.5	36.3	25/75[b]	95.0	186.3
	PM_{10} (ug/m^3)	120	91	230	22	150	7.5	12.7	50/150[b]	85.8	99.1
Physical environment ($n = 6$)	Temperature (°C)	288	28.9	32.6	27.6	18–30	13.9	4.1	18–27[c]	100.0	7.1
	Humidity (%)	288	71.3	78.5	61.6	40–80	0	0	30–60	100.0	18.9
	Wind (m/s)	144	0.05	0.09	0.02	0.30[a]	100.0	−82.3	0.35l/s, m^2[c]	-	-
	Illumination (lx)	144	37.7	267	0.02	50.0	68.8	−86.5	204.4	98.6	−83.1

n sample number, *TVOC* Total Volatile Organic Compounds, *CO_2* Carbon Dioxide, *$PM_{2.5}$* Fine Particulate Matter, *PM_{10}* Inhalable Particles.
[a]From GB/T18883-2002: Indoor air quality standard.
[b]Equivalent WHO global air quality guidelines.
[c]From ISO 17772-1: Energy performance of buildings – Indoor environmental quality.

a sudden increase in $PM_{2.5}$ concentration, similar to what was concluded from another publication on open-plan cooking spaces in tiny Hong Kong homes (Cheung et al. 2019). In addition, the excess of all indicators could have been exacerbated by the poor ventilation of the units.

For the physical environment parameters, the recorded values of temperature ($PoE = 13.9\%$; 100.0%) and humidity ($PoE = 0\%$; 100.0%) were generally higher than their corresponding standards, and illuminance ($PoE = 68.8$ %; 98.6%) and wind speed ($PoE = 100.0\%$; –) were below the limits. The former was likely caused by the poor climate-adaptive design of PRRHs given the hot and humid climate of Xiamen, while the latter was likely caused by the dense construction, crowded space, insufficient lighting and ventilation. Similar findings have been reported in previous studies. Majdan (Majdan et al. 2012) observed higher levels of indoor CO and CO_2 during winter, potentially due to inadequate indoor ventilation. Kim et al. (Kim et al. 2022) also found that residential air quality significantly varies between homeowners and renters, with rental properties having significantly poorer air quality.

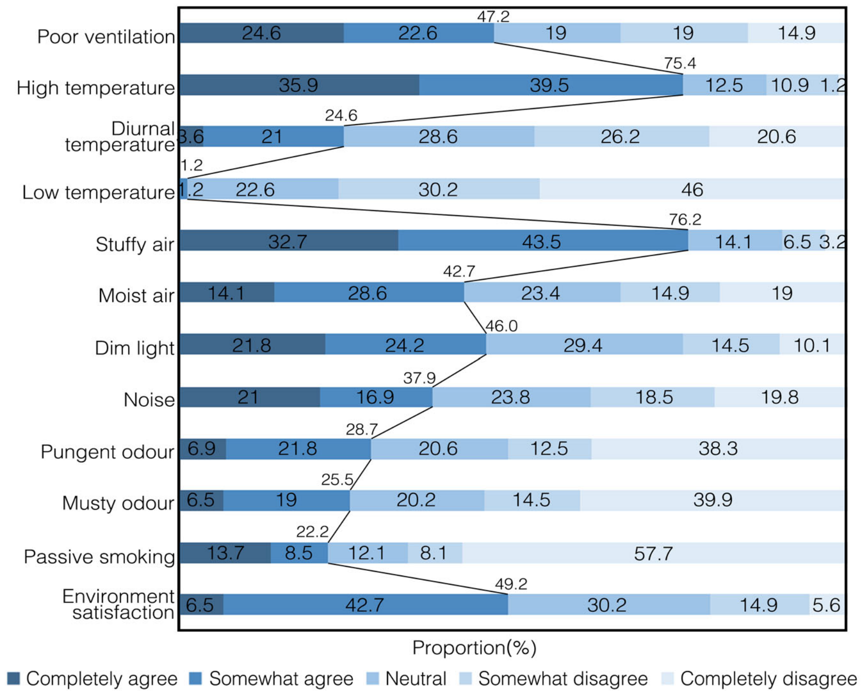

Fig. 3 Summary of the results of the participants' responses to the questions about their indoor environmental satisfaction.

Overall, the environmental situation in PRRHs was not positive. As reflected by the *PE* and *PoE* values. These highly excessive air contaminants and adverse physical environmental conditions had the potential to cause serious health implications. It is therefore accurate to assert that the PRRH units are not fit for living at their present state.

Residential health of PRRH renters. The questionnaire data passed the reliability test (Cronbach's Alpha = 0.769, >0.7) and validity test (Kaiser–Meyer–Olkin = 0.776, >0.6). The basic information of the participants was summarised in Supplementary Table S2. As the survey was a random interview questionnaire, the composition of respondents had a certain sampling value. They were mainly migrant workers (70.2%) and people who were engaged in housework or unemployed (12.9%), with a small number of students (16.9%). They were mainly 20–40 years old (71.8%) and education level of high school and below account for 50.4%. It is worth noting that 46.4% of the respondents had been renting in their PRRH unit for more than two years, which shows that it was not a short-term transitional option.

As shown in Fig. 3, nearly half of the participants were satisfied with their living environment, and only 20.5% were unsatisfied. Despite this overall positive rating, when the question was decomposed into statements on specific environmental problems, the participants still signalled problems of varying degrees. Among them, more than 70% of the participants reported problems of excessively high temperature and stuffy air, while only 1.2% believed that the indoor temperature was low. More than 40% of the participants reported poor ventilation and excessively humid air. The self-evaluated SBS symptoms data were summarised in Fig. 4. The most common occurrence were the psychological symptoms, accounting for 66.5% of the participants. 55.2% of the participants reported mucosal symptoms, 42.7% reported respiratory symptoms, 40.3% reported skin symptoms, and 37.5% reported general symptoms. Only 17.7% of the participants did not report any related symptoms. Overall, the indoor environment of PRRHs were evaluated as problematic and significant proportion of the participants experienced various SBS-related symptoms, between which we envisaged strong relations existed.

To find out the relationship between the participants' subjective evaluation of the indoor environment and self-evaluated SBS symptoms, we employed Spearman's correlation coefficient analysis as the data were not normally distributed. As shown in Table 2, except for skin symptoms, significant correlations were observed between the reporting of each of the symptoms and many of the indoor environment problems. Notably, general symptoms were most strongly affected by poor ventilation ($r = 0.329^{**}$) and pungent odours ($r = 0.329^{*}$), and the total number of reported symptoms was strongly affected by poor ventilation ($r = 0.319^{**}$). Besides, while 38.3% of the participants reported noise interference to varying degrees, no significant correlation was observed between this and any of the reported SBS symptom. It was speculated that although they experienced some noise interference, it was generally only discretely observed. This non-continuous situation was not sufficient to trigger long-term consequences in the form of SBS-related symptoms.

To further interrogate the simultaneous effect of the participants' subjective evaluation of the indoor environment on their self-evaluated SBS symptoms, binary logistic regression analysis was applied after transforming the original five-level and four-level data into binary (present or not) data. The subjective evaluation of indoor environment involved 11 problems in six types of environments including wind environment, thermal environment, humid environment, light environment, auditory environment and air quality. The above 11 environmental problems were screened and the most frequently reported items of various environmental issues were selected as the main criteria for judging such environmental issues. This is because the items with lower frequency of reports can usually be covered by higher items for the same environment. The final six problems represented the six environmental problems involved in PRRHs, answering "somewhat agree" and "completely agree" to the above question was regarded as determining that the environment in the room where they are rented was poor. The final

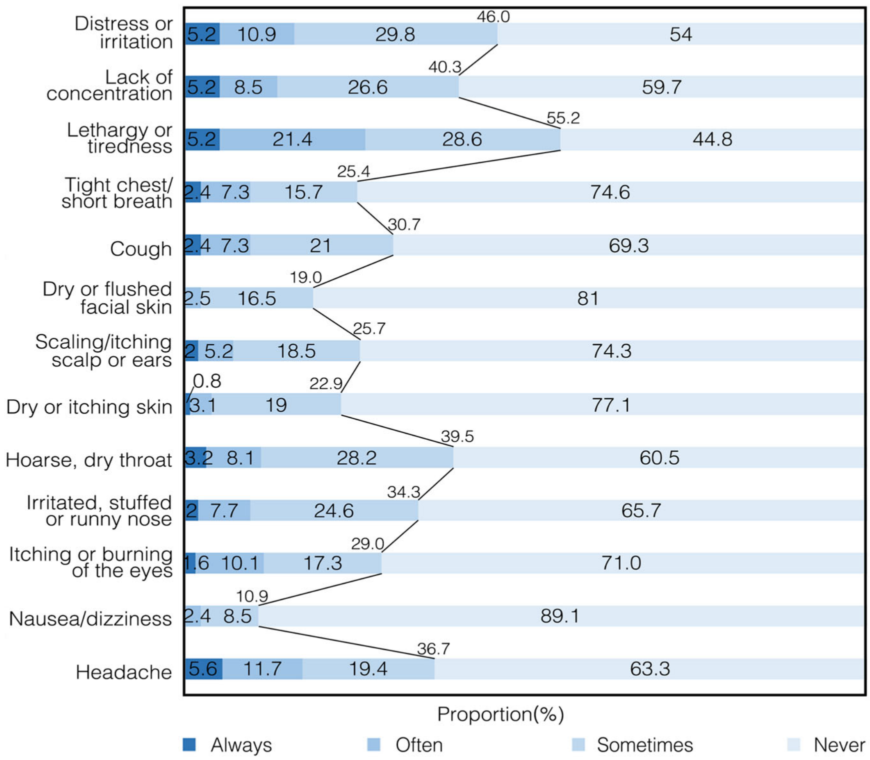

Fig. 4 Summary of the results of the participants' responses to the questions about the occurrence of their SBS-related symptoms.

environmental subjective evaluation data processing results are shown in Table 3. The independent variable and the dependent variable need to be assigned values before the binary logistic analysis. The value assignments are shown in Table 4. These data were put into SPSS 19.0 for binary logistic regression. Co-linearity checks conformed that for all variables the VIF values were close to one, confirming that there were no co-linearity and hence the data were suitable for binary logistics regression. As prior research has found that the prevalence of SBS in renters was also significantly related to their gender, age, education level, smoking status, history of skin diseases, architectural form and height of the rental house, and the number of rooms in the rental unit, these factors were added as adjustment variables to the binary logistic regression model.

To prove the robustness of the binary logistic regression, we employed the events per variable (EPV) method (See Supplementary Table S3) (van Smeden et al. 2019). It was shown that the EPV value of general symptoms, mucosal symptoms, respiratory symptoms, skin symptoms, and psychological symptoms were 15.5, 18.5, 17.7, 16.7, and 13.8, respectively. All EPV values were greater than 10, suggesting sufficient confidence on the regression result (Peduzzi et al. 1996). As can be seen in Table 5, mucosal symptoms were significantly correlated with high room temperature (AOR = 2.631, 95% CI = 1.316–5.26) and poor air quality (AOR = 2.931, 95% CI = 1.442–5.959), which is consistent with previous publication (Reinikainen and Jaakkola 2001). General symptoms and poor air quality were significantly correlated (AOR = 3.341, 95% CI = 1.683–6.634). Similarly, Francisco et al. have suggested that improving indoor ventilation can enhance indoor air quality and promote the health of occupants, which in turn significantly reduces headaches in children and contributes to stress relief in adults (Francisco et al. 2017). Psychological symptoms were significantly correlated with high room temperature (AOR = 2.666, 95% CI = 1.354–5.248), and skin symptoms were significantly correlated with poor air quality (AOR = 2.13, 95% CI = 1.099–4.129).

In general, high occurrence of SBS was observed among the renters of the PRRH units and their residential health was closely related to the thermal environment and air quality of the PRRHs. These problems were common in PRRHs and were potentially caused by poor house insulation, insufficient indoor ventilation and substandard air quality, which were the consequences of their low construction costs and qualities.

Discussion

Overall, the research presented here investigated the LPRHs constructed during the rapid development of Xiamen, the PRRHs. They represented a significant proportion of all available lettings in Xiamen thanks to their low prices and convenient locations. Meanwhile, their indoor environment indicators severely exceeded Chinese and international healthy building standards, which was subsequently found to be significantly related to the health problems of their residents, as characterised by the Sick Building Syndrome.

Xiamen is not alone in experiencing this problem. For countries and cities that had experienced the rapid development and urbanisation stage, painful prices had been paid for the disorderly construction of LPRHs to accommodate low-income groups (Ghasemi et al. 2019; Sarvari et al. 2021). For example, back-to-back housing in the UK, which have gradually turned to slums, bringing about long-term social security problems (Timmins 2013). Those housing types all showed features like non-expert design, dense construction and interwinding with other buildings due to the rapid demand, free construction and limited land. Even with the local government having built large numbers of social housing to curb the growth of such disorderly and spontaneously constructed houses, success was limited due to the local land property rights avoiding the forced demolition of such houses (Hopkins 1986). In South Africa, the need for low-cost renting led to the development of backyard accommodation shelter, which was gradually scaled up (Koster 2012). However, the rental model

Table 2 Results of the correlation analysis between the participants' self-reported SBS-related symptoms and their subjective evaluation of the PRRH environmental problems.

Symptom type	Poor ventilation	High temperature	Diurnal temperature	Low temperature	Stuffy air	Moist air	Dim light	Noise	Pungent odour	Musty air	Passive smoking
General	0.329**	0.106	−0.059	−0.037	0.132*	0.228**	0.249**	0.094	0.329**	0.267**	0.010
Mucosal	0.210**	0.090	−0.032	−0.102	0.115	0.169**	0.170**	0.088	0.178**	0.159*	−0.007
Skin	0.061	0.038	0.045	−0.115	0.075	0.072	0.056	0.076	0.050	0.120	−0.038
Respiratory	0.187**	0.186**	−0.101	−0.077	0.172**	0.191**	0.162*	0.039	0.097	0.133*	0.041
Psychological	0.149*	0.209**	−0.079	−0.136*	0.216**	0.151*	0.122	−0.028	0.055	0.108	−0.019
Total types of symptoms	0.271**	0.182**	−0.066	−0.133*	0.207**	0.235**	0.218**	0.081	0.207**	0.230**	0.000
Total number of symptoms	0.319**	0.208**	−0.060	−0.125*	0.226**	0.263**	0.233**	0.098	0.248**	0.268**	−0.008

* indicates a significant correlation at the 0.05 level (two-sided); ** indicates a significant correlation at the 0.01 level (two-sided).

was accompanied by risks such as low building quality and fire safety, which continued to exist ever since (Magalhães et al. 2016).

Therefore, for cities yet to enter their fast-growth stage (Scheba and Turok 2020); Mwangi 1997), governments there need to be able to foresee the need for low-price renting and recognise the heavy costs of disorderly and lack-of-guidance construction of low-quality housing. With that advance recognition, settlements for migrant workers could be planned before the demand explodes. For example, despite the current ugly situation, Xiamen did make a lot of efforts to solve the housing problem of low-income families. Since 2000, the city government has built or renovated large numbers of buildings to create social housings, which were rented out to those in need cheaply. According to government statistics, at the end of 2021, a total of 22278 low-income families were housed in social housings. However, compared to the massive 2.715 million inflow population to the city, this is just a drop in the ocean. The vast majority of migrants still could only choose to live in the low-quality PRRHs. Limited by the available funds and land, in this situation, it is very hard for the government to greatly enlarge the scale of social housing to meet the demand. Some regions have tried to solve this problem with a more market-like approach (Buckley and Kalarickal 2005). For example, Nigeria government set up so called public-private partnerships in the rental housing market, taking private funds while building rental housings of sufficiently good quality, and sharing revenue from the rent afterwards (Ibem 2010). This is obviously a potentially viable option in releasing the strain in the rental market by combining governmental and private forces and offering reasonable profit sharing. Moreover, the government can establish supportive policies for enterprises to encourage them to relocate their labour demand to the suburbs. As a result, the subsequent rental demand will also shift accordingly, easing the housing pressure in urban centres and curbing the continued growth of the non-ideal private rental market there.

While the large-scale construction of PRRHs by the repurposing of urban villages and the rebuilding of rural houses is a brave attempt that has successfully accommodated the large immigrant population for Xiamen during its rapid expansion, the local government has recognised the large damage these PRRHs has brought to the sustainable development of the city. In this regard, they have started to formulate remedial policies. A recent opinion issued by the Xiamen municipal government in September 2021 emphasized that future construction of buildings in such areas shall be limited to three floors, and the construction area shall also be limited. However, although such policies would have certain positive influence on the future development of PRRHs, they have little effect on the existing ones. For those already built, appropriate assessment of the current condition and subsidies for renovation and replacement need to be offered. For example, Mozambique approved a bill for land use and corresponding grants aimed at improving the environment in local informal settlements (Mottelson 2019). Example can also be found in Kenya, where the government has set up a special fund for the construction of formal housing for migrant workers (Mwangi 1997; Gulyani et al. 2018). A more determined approach was seen in Guangzhou, China, where replacement accommodation or market-level compensation were offered to the owners of the LPRHs for their demolition, which was followed by the in situ redevelopment of large-scale housing complexes that adhered to the building specifications (Wu et al. 2013).

In addition, as is the case elsewhere (Timmins 2013; Malik and Wahid 2014), most of the users of this type of rental housing in Xiamen were migrate workers. They were at low socio-economic status and were restricted by their economic condition. Therefore, they tended to rent these low-cost and low-quality houses, which could cause serious adverse health consequences. Therefore,

Table 3 Summary of the data for the environmental satisfaction after the two-class processing.

	Disagree	Proportion (%)	Agree	Proportion (%)
Poor wind environment	131	52.8	117	47.2
Poor thermal environment	59	23.8	189	76.2
Poor humid environment	142	57.3	106	42.7
Poor light environment	134	54.0	114	46.0
Poor auditory environment	153	61.7	95	38.3
Poor air quality	177	71.4	71	28.7

Table 4 Assignment of values for the variables involved in the binary logistic regression.

Independent variable	Assignment	Dependent variable	Assignment
Wind environment	Problem not present = 0	General symptoms	Symptom not present = 0
Thermal environment	Problem present = 1	Mucosal symptoms	Symptom present = 1
Humid environment		Skin symptoms	
Light environment		Respiratory symptoms	
Auditory environment		Psychological symptoms	
Air quality		–	–

Table 5 Results of the binary logistic regression analysis between the participants' self-reported SBS-related symptoms and their subjective evaluation of the PRRH environmental problems.

	General symptoms AOR (95% CI)[a]	Mucosal symptoms AOR (95% CI)[a]	Respiratory symptoms AOR (95% CI)[a]	Skin symptoms AOR (95% CI)[a]	Psychological symptoms AOR (95% CI)[a]
Ventilation	1.446 (0.738, 2.835) ($p = 0.283$)	1.352 (0.706, 2.588) ($p = 0.363$)	1.514 (0.791, 2.898) ($p = 0.211$)	0.926 (0.480, 1.788) ($p = 0.819$)	1.162 (0.585, 2.306) ($p = 0.668$)
Thermal	1.201 (0.572, 2.524) ($p = 0.628$)	2.631** (1.316, 5.260) ($p = 0.006$)	1.729 (0.851, 3.513) ($p = 0.130$)	1.298 (0.650, 2.592) ($p = 0.460$)	2.666** (1.354, 5.248) ($p = 0.005$)
Humidity	1.455 (0.758, 2.794) ($p = 0.259$)	1.159 (0.615, 2.184) ($p = 0.649$)	1.700 (0.907, 3.185) ($p = 0.098$)	1.300 (0.696, 2.429) ($p = 0.411$)	1.716 (0.882, 3.339) ($p = 0.112$)
Lighting	1.521 (0.796, 2.906) ($p = 0.204$)	1.224 (0.653, 2.293) ($p = 0.528$)	1.410 (0.759, 2.619) ($p = 0.277$)	0.983 (0.527, 1.834) ($p = 0.957$)	0.707 (0.365, 1.367) ($p = 0.302$)
Noise	1.748 (0.957, 3.192) ($p = 0.069$)	1.112 (0.619, 1.995) ($p = 0.723$)	0.871 (0.492, 1.542) ($p = 0.636$)	0.933 (0.528, 1.648) ($p = 0.811$)	1.599 (0.874, 2.924) ($p = 0.128$)
Air quality	3.341** (1.683, 6.634) ($p = 0.001$)	2.931** (1.442, 5.959) ($p = 0.003$)	1.449 (0.748, 2.808) ($p = 0.272$)	2.130* (1.099, 4.129) ($p = 0.025$)	1.067 (0.524, 2.170) ($p = 0.858$)

*Statistically significant at $p < 0.05$; **Statistically significant at $p < 0.01$.
[a]Adjusted for gender, age, education level, smoking status, history of skin diseases, architectural form and height of the rental house, and the number of rooms in the rental unit.

attention to the residential health of urban migrant workers needs to be sufficient and sustained. For example, the government could give out targeted renting subsidies to low-income groups. An alternative possibility is to provide enterprises with dedicated resettlement funds, incentivizing them to offer housing subsidies or increase salaries for immigrant workers. While offering them more choices with renting, handing out these subsidies could also stimulate the rental market to construct LRPHs with slightly higher rent and higher standards (Zhang et al. 2021).

Furthermore, it was found that even as they lived in such low-quality houses, nearly half of the participants were still satisfied with their living environment. This was likely due to these residents having low awareness and expectations of the quality of their living environmental, leading to higher evaluations. When we decomposed the overall environmental satisfaction into statements about specific environmental problems that may occur, the participants discovered that they were still facing many unsatisfactory factors. As it has been shown that these environmental factors can have adverse health effects, in the process of letting or selling houses, renters should have a greater right to know the quality of the house itself and any health problems it could potentially bring by having reports of the indoor environmental quality of the house. Notably, around three quarters of the respondents finished high school, and even around half of them were university graduates, suggesting general education was not sufficient for people to fully appreciate the associated risks for such housing. Therefore, relevant professional background knowledge should also be properly popularised.

Conclusions

There has been unregulated large-scale spontaneous construction of LPRHs (the PRRHs) by local residents in Xiamen, China, a city undergoing rapid development, which was driven by the dual interests of the economic benefits for the owners and the low-cost renting needs of the migrant workers. This type of LPRH represented most of the available lettings in most areas of Xiamen. However, it was revealed that the PRRHs were severely substandard in their indoor environmental parameters, which was also confirmed by subjective reports from their occupants. Strong correlation was discovered between the adverse environmental factors and the occupants' SBS-related symptoms. The findings prove the direct public health harms caused by such disorderly construction behaviour. They also highlight the importance of governmental foresight and intervention during urban development as hidden dangers for future sustainable development were seen in cities that have experienced similar history around the world. Additionally, despite such adverse health implications, most of the occupants, many of whom received higher education, did not report overall dissatisfaction for the environment they lived in, emphasising the need for targeted education about healthy living environments to the general public.

The research was conducted during the summer season and did not cover all three typical seasons (summer, transition season, and winter) in Xiamen due to limitations in the research cycle and detection difficulty. However, Xiamen is characterised by a typical hot-summer and warm-winter climate, where the summer season has high temperatures, humidity, and low air velocity, representing the most severe local climate conditions. Accordingly, the indoor environment of PRRHs is particularly pronounced during this season, and thus the choice of summer is sufficient to demonstrate the hidden hazards of low-quality housing.

Future research will focus on the indoor environment and health issues of Public Rental Housing (PRH), which is also characterised by fast construction speed, low construction standards, and cost control, and is either funded or supervised by the Xiamen government or enterprises. By comparing the similarities and differences in living experience and health status between the two types of housing, we can better understand the reality of low-standard housing. The research findings may provide insights on how to better plan and construct low-standard housing.

Data availability

All data generated or analysed during this study are included in this published article and its supplementary files.

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References

Andersson K (1998) Epidemiological approach to indoor air problems. Indoor Air 8(S4):32–39. https://doi.org/10.1111/j.1600-0668.1998.tb00005.x

Barmark M (2015) Social determinants of the sick building syndrome: exploring the interrelated effects of social position and psychosocial situation. Int J Environ Heal R 25(5):490–507. https://doi.org/10.1080/09603123.2014.979776

Belachew H, Assefa Y, Guyasa G et al. (2018) Sick building syndrome and associated risk factors among the population of Gondar town, northwest Ethiopia. Environ Heahth Prev 23(1):1–9. https://doi.org/10.1186/s12199-018-0745-9

Buckley RM, Kalarickal J (2005) Housing policy in developing countries: conjectures and refutations. World Bank Res Obser 20:233–257. https://doi.org/10.1093/wbro/lki007

Cheung PK, Jim CY, Siu CT (2019) Air quality impacts of open-plan cooking in tiny substandard homes in Hong Kong. Air Qual Atmos Hlth 12(7):865–878. https://doi.org/10.1007/s11869-019-00705-9

Dhungana P, Chalise M (2020) Prevalence of sick building syndrome symptoms and its associated factors among bank employees in Pokhara Metropolitan, Nepal. Indoor Air 30(2):244–250. https://doi.org/10.1111/ina.12635

Dovjak M, Kukec A (2019) Creating healthy and sustainable buildings: an assessment of health risk factors. Springer Nature, Cham, Switzerland

Durst NJ (2019) Informal and ubiquitous: Colonias, premature subdivisions and other unplanned suburbs on America's urban fringe. Urban Stud 56(4):722–740. https://doi.org/10.1177/0042098018767092

Environmental Protection Agency. (1991) Indoor air facts no.4 (revised) sick building syndrome. https://nepis.epa.gov/Exe/ZyNET.exe/94007SSB.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1991+Thru+1994&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C91thru94%5CTxt%5C00000036%5C94007SSB.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL. Accessed 17 Nov 2021

Francisco PW, Jacobs DE, Targos L et al. (2017) Ventilation, indoor air quality, and health in homes undergoing weatherization. Indoor Air 27(2):463–477. https://doi.org/10.1111/ina.12325

Ghasemi K, Hamzenejad M, Meshkini A (2018) The spatial analysis of the livability of 22 districts of Tehran Metropolis using multi-criteria decision making approaches. Sustain Cities Soc 38:382–404. https://doi.org/10.1016/j.scs.2018.01.018

Ghasemi K, Hamzenejad M, Meshkini A (2019) An analysis of the spatial distribution pattern of social-cultural services and their equitable physical organization using the TOPSIS technique: the case-study of Tehran, Iran. Sustain Cities Soc 51:101708. https://doi.org/10.1016/j.scs.2019.101708

Gilbert A (2016) Rental housing: the international experience. Habitat Int 54:173–181. https://doi.org/10.1016/j.habitatint.2015.11.025

Gilbert A, Mabin A, Mc Carthy M et al. (1997) Low-income rental housing: are South African cities different. Environ Urban 9(1):133–148. https://doi.org/10.1177/095624789700900111

Gulyani S, Talukdar D, Bassett EM (2018) A sharing economy? Unpacking demand and living conditions in the urban housing market in Kenya. World Dev 109:57–72. https://doi.org/10.1016/j.worlddev.2018.04.007

Helldén D, Andersson C, Nilsson M et al. (2021) Climate change and child health: a scoping review and an expanded conceptual framework. Lancet Planet Health 5(3):e164–e175. https://doi.org/10.1016/S2542-5196(20)30274-6

Hopkins E (1986) Working-class housing in Birmingham during the Industrial Revolution. Int Rev Soc Hist 31(1):80–94. https://doi.org/10.1017/S0020859000008075

Ibem EO (2010) An assessment of the role of government agencies in public-private partnerships in housing delivery in Nigeria. J Constr Dev Ctries 15(2):23–48

Kaufmann D, Strebel D (2021) Urbanising migration policy–making: urban policies in support of irregular migrants in Geneva and Zürich. Urban Stud 58(14):2991–3008. https://doi.org/10.1177/0042098020969342

Kim SD, Carswell AT (2022) The mediation effect of indoor air quality on health: a comparison of homeowners and renters. Indoor air 32(9):e13108. https://doi.org/10.1111/ina.13108

Koster M (2012) Mediating and getting 'burnt'in the gap: politics and brokerage in a Recife slum, Brazil. Crit Anthropol 32(4):479–497. https://doi.org/10.1177/0308275X12456643

Krieger J, Higgins DL (2002) Housing and health: time again for public health action. Am J Public Health 92(5):758–768. https://doi.org/10.2105/AJPH.92.5.758

Lee JH, Sohn YS (2014) A comparative study on sick building syndrome by apartment unit plan with and without cross ventilation. J Asian Archit Build 13(1):63–70. https://doi.org/10.3130/jaabe.13.63

Li J, Li D, Ning X et al. (2019) Residential satisfaction among resettled tenants in public rental housing in Wuhan, China. J Hous Built Environ 34(4):1125–1148. https://doi.org/10.1007/s10901-019-09667-x

Li L, Adamkiewicz G, Zhang Y et al. (2015) Effect of traffic exposure on sick building syndrome symptoms among parents/grandparents of preschool children in Beijing, China. PLoS One 10(6):e0128767. https://doi.org/10.1371/journal.pone.0128767

Lu C, Deng Q, Li Y et al. (2016) Outdoor air pollution, meteorological conditions and indoor factors in dwellings in relation to sick building syndrome (SBS) among adults in China. Sci Total Environ 560:186–196. https://doi.org/10.1016/j.scitotenv.2016.04.033

Magalhães F, Acosta Restrepo P, Lonardoni F et al. (2016) Slum upgrading and housing in Latin America. Inter-American Development Bank, Washington, American

Malik S, Roosli R, Tariq F (2020) Investigation of informal housing challenges and issues: experiences from slum and squatter of Lahore. J Hous Built Environ 35(1):143–170. https://doi.org/10.1007/s10901-019-09669-9

Malik S, Wahid J (2014) Rapid urbanization: Problems and challenges for adequate housing in Pakistan. J Sociology Social Work 2:87–110

Majdan M, Coman A, Gallová E et al. (2012) Assessment of the indoor environment and implications for health in Roma villages in Slovakia and Romania. Cent Eur J publ heal 20(3):199. https://doi.org/10.21101/cejph.a3719

Mentese S, Tasdibi D (2016) Airborne bacteria levels in indoor urban environments: the influence of season and prevalence of sick building syndrome (SBS). Indoor Built Environ 25(3):563–580. https://doi.org/10.1177/1420326X14562454

Mottelson J (2019) Interpositions: architectural interventions in Mafalala, Mozambique. Det Kongelige Danske Kunstakademis Skoler for Arkitektur, Design og Konservering

Mwangi IK (1997) The nature of rental housing in Kenya. Environ urban 9(2):141–160. https://doi.org/10.1177/095624789700900205

Ooi GL, Phua KH (2007) Urbanization and slum formation. J Urban Health 84(1):27–34. https://doi.org/10.1007/s11524-007-9167-5

Peduzzi P, Concato J, Kemper E et al. (1996) A simulation study of the number of events per variable in logistic regression analysis. J clinical epidemiology 49(12):1373–1379. https://doi.org/10.1016/S0895-4356(96)00236-3
Repace JL (1982) Indoor air pollution. Environ Int 8(1-6):21–36. https://doi.org/10.1016/0160-4120(82)90007-1
Reinikainen LM, Jaakkola JJ (2001) Effects of temperature and humidification in the office environment. Arch Env Heal Int J 56(4):365–368. https://doi.org/10.1080/00039890109604469
Sahlberg B, Mi YH, Norbäck D (2009) Indoor environment in dwellings, asthma, allergies, and sick building syndrome in the Swedish population: a longitudinal cohort study from 1989 to 1997. Int Arch Occ Env Hea 82(10):1211–1218. https://doi.org/10.1007/s00420-009-0444-3
Saijo Y, Nakagi Y, Ito T et al. (2009) Relation of dampness to sick building syndrome in Japanese public apartment houses. Environ Heahth Prev 14(1):26–35. https://doi.org/10.1007/s12199-008-0052-y
Sarvari H, Mehrabi A, Chan DW et al. (2021) Evaluating urban housing development patterns in developing countries: case study of Worn-out Urban Fabrics in Iran. Sustain Cities Soc 70:102941. https://doi.org/10.1016/j.scs.2021.102941
Scheba A, Turok I (2020) Informal rental housing in the South: dynamic but neglected. Environ urban 32(1):109–132. https://doi.org/10.1177/0956247819895958
Stolwijk JA (1991) Sick-building syndrome. Environ Health Persp 95:99–100. https://doi.org/10.1289/ehp.919599
Takigawa T, Wang BL, Sakano N et al. (2009) A longitudinal study of environmental risk factors for subjective symptoms associated with sick building syndrome in new dwellings. Sci Total Environ 407(19):5223–5228. https://doi.org/10.1016/j.scitotenv.2009.06.023
Timmins G (2013) Housing industrial workers during the 19th century: back-to-back housing in textile Lancashire. Ind Archaeol Rev 35(2):111–127. https://doi.org/10.1179/0309072813Z.00000000021
van Smeden M, Moons KG, de Groot JA et al. (2019) Sample size for binary logistic prediction models: beyond events per variable criteria. Statistical methods in medical research 28(8):2455–2474. https://doi.org/10.1177/0962280218784726
Wachsmuth D, Cohen DA, Angelo H (2016) Expand the frontiers of urban sustainability. Nature 536(7617):391–393. https://doi.org/10.1038/536391a
World Health Organization (1997) Report and presentations of a Joint Symposium on the Indoor Environment & Respiratory Illness, including Allergy. https://apps.who.int/iris/handle/10665/64243?search-result=true&query=sick+building+syndrome&scope=%2F&rpp=10&sort_by=score&order=desc Accessed 17 Nov 2021
Wu F, Zhang F, Webster C (2013) Informality and the development and demolition of urban villages in the Chinese peri-urban area. Urban Stud 50(10):1919–1934. https://doi.org/10.1177/0042098012466600
Wu W (2004) Sources of migrant housing disadvantage in urban China. Environ Plann A 36(7):1285–1304. https://doi.org/10.1068/a36193
Xiamen Municipal Bureau of Statistics (2021) Yearbook of Xiamen special economic zone. China Statistics Press, Beijing, China
Zhu Y (2007) China's floating population and their settlement intention in the cities: beyond the Hukou reform. Habitat Int 31(1):65–76. https://doi.org/10.1016/j.habitatint.2006.04.002
Zhang Y, Yang, B, Sui M et al. (2021) Evaluation and empirical research on the effect of the monetary subsidy policy for public rental housing. ICCREM, 730–739. https://doi.org/10.1061/9780784483848.084

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Author contributions

Conceptualisation: YZ; Methodology: JY, YH and YZ; Investigation: JL; Data curation: JL and JY; Formal analysis: JL; Writing - original draft: JL and JY; Writing—review and editing: YH and YZ; Supervision: YZ; Funding acquisition: YZ. All authors have read and agreed to the published version of the manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

The study was approved by the Ethics Committee of the School of Architecture and Urban Planning, Shenyang Jianzhu University. All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments.

Informed consent

All individuals invited to participate in the study were provided a statement of informed consent. The informed consent language clearly explained their rights as research subjects/participants. By entering the survey individuals affirmed their consent.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1057/s41599-023-01907-4.

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