REVAMPING FOR BETTER INDOOR AIR QUALITY IN HOUSING: A RENTAL HOUSE RENOVATION IN HO CHI MINH CITY, VIETNAM

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Abstract. Over the past decade, the population of Ho Chi Minh City (HCMC) has doubled, resulting in a rise in low-income hostels. Rental homes for low-income families are usually small, ranging from 12 to 15 square meters, serving as a multi-purpose space. This type of accommodation is the most suitable option for those who cannot afford larger housing. This article aims to assess the effect of ventilation-related renovations on indoor air quality through a case study of a rental house in HCMC. Fieldwork was conducted to collect information on the house's original state, followed by renovations. Air pollutants, such as CO_2, CO, $PM_{2.5}$, and TVOC, were measured before and after renovation. Further analysis was conducted to identify factors that could enhance ventilation conditions in the house. The findings indicated that using exhaust fans with louvers and frequently opening doors and windows significantly improved indoor air quality. Therefore, mechanical ventilation is a simple and effective intervention to improve indoor air quality in tiny homes, especially near areas where residents sleep and have at least one motorbike.

Keywords. renovation, rental house, mechanical ventilation, indoor air quality.

1. INTRODUCTION

Good indoor air quality is essential for the occupants' health and contributes to the home environment and a general sense of comfort, health, and well-being. However, indoor air pollutants deteriorate, and indoor air quality becomes a significant concern as indoor air concentrations of pollutants are greater than those found outdoors [1-3]. Previous studies have found that indoor air was a concern because most people spend about 90% of their lifetime indoors, with 50% paid for in their homes [4-6]. A study in China [7] found that house layout and ventilation-related characteristics play essential roles in the risk of lung cancer. Women who lived in larger and better-ventilated houses, such as multi-story houses with more windows, separated kitchens, installed ventilators, and frequently opened windows, experienced a lower risk than those who lived in tiny and poorly-ventilated houses. However, most data on pollutant concentrations were based on measurements conducted outdoors, in one or more central monitoring sites. These outdoor pollutant concentrations may not be reliable indicators of indoor and personal pollutant sources [8]. Therefore, more attention should be paid to indoor air quality, as it can significantly impact people's health and the environment we live in, making it worthy of research.

Vietnamese citizens may spend more time indoors due to high ambient temperatures and cultural family factors that may boost indoor activities. According to recent statistics from the Ministry of Health, respiratory diseases are the most common illnesses in the country. These diseases are often caused by air pollution that contains particulate matter, SO_2, NO_2, and other harmful substances, leading to respiratory inflammation, asthma, tuberculosis, allergy, chronic bronchitis, and cancer. Residents of urban areas are more likely to suffer from respiratory diseases than those in rural areas.

Ho Chi Minh City (HCMC), the largest city in Vietnam with a rapidly growing population and economy, has a high concentration of low-income residents who work in industrial zones or are students from other provinces. These individuals often struggle to find suitable housing, as the local government supplied only 5% of the total demand, with the rest being self-managed [9]. People who cannot afford to buy or rent a spacious house are more susceptible to developing chronic respiratory diseases.

Rental housing for low-income families is usually located in urban, semi-urban, or rural areas with limited living space. These houses are semi-permanent or temporary but have residential registration or land use rights certificates. Each house typically consists of one or two rooms and can be as small as 6 sqm, far below the national target of 15 sqm per person by 2016 [10]. These rental houses serve as a multifunctional space and are typically 3x4 square meters in size. They consist of a living area separated from a toilet and kitchen by a wall, with a sleeping area built as a mezzanine floor (Figure 1).

The rental houses in HCMC are not equipped with hoods, stoves, or exhaust fans and are constructed with a sheeting roof and brick masonry walls, lacking air supply from the ceiling or walls. The only air supply comes from windows and doors, making the houses more sealed or "tight," trapping combustion products inside and preventing outdoor air from entering for ventilation. As a result, these rental houses can contribute to the high rates of respiratory diseases in the city.

In Vietnam, there were several studies on air pollution in general, including [11-13], and [14]. Still, no quantitative information was available on the indoor air pollutant characteristics in dwellings, nor any previous studies that investigated the presence or concentration of pollutants in indoor air directly or indirectly. To our knowledge, no data was available that described how to improve the indoor air quality of homes occupied by families. This paper aimed to assess the effectiveness of applied renovation measures in improving indoor air and environmental quality by using a typical rental house for low-income people in HCMC as a case study. In various conditions, the pollutant concentrations in the house were measured before and after renovation to test the short-term and long-term effects a few weeks after the renovation. Unique aspects of our study included using participants rather than researchers to record real–time activity dairies, which avoided recall bias and encouraged consistency. For the first time, the study quantified the seriousness of air pollution in houses in Vietnam. It was also one of the first studies in Southeast Asia to collect accurate–time activity data and shed light on the impact of the renovation on pollutant concentrations. These results provided a starting point for further studies on reducing Chronic Respiratory Diseases by using markers of the indoor housing environment.

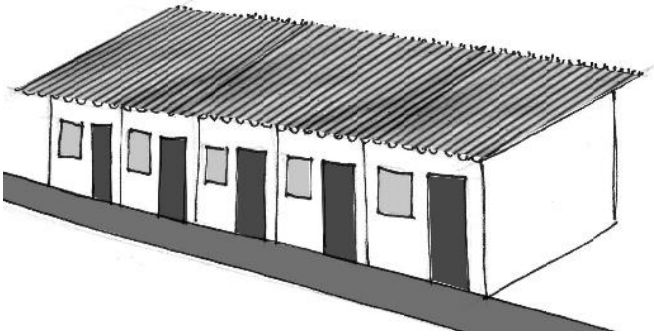


Figure 1. Typology of a rental house in HCMC

2. METHODS

2.1 Sample House Selection

Ho Chi Minh City gathers a large population in Vietnam. Therefore, the houses investigated in this survey represent typical Vietnamese urban residential houses. A large-scale field measurement survey to collect data on housing characteristics and IAQ was undertaken between October 2013 and May 2015 inside 100 residential dwellings in 24 central districts of HCMC. These districts were selected as part of a stratified random sample and provided a comprehensive representation of ethnic groups, a wide range of housing characteristics with accessibility and adequate staff resources (Districs 1 to 12; Binh Chanh, Binh Tan, Binh Thanh, Go Vap, Nha Be, Phu Nhuan, Tan Binh, Tan Phu, Thu Duc Districts; Hoc Mon, Cu Chi and Can Gio rural areas). Housings were divided into five categories: tube houses, apartments, rental houses, slum houses, and rural houses. Each housing type for 20% shares similar typology characteristics to ensure statistical robustness between each housing type cohort. Housings were selected using random cluster sampling, including 80 houses from urban and suburban areas and 20 in rural areas. In each district, except the rural area, three houses were finally selected, including one tube house, one rental house, and one apartment. Indoor air quality was improved mainly through ventilation. Twenty slum houses were near District 8, District 4, and Binh Thanh District drainage canals.

The first phase of the PIC project revealed that rental homes had a higher risk of poor air quality and needed ventilation improvement. Based on this finding, a rental home was selected as the pilot for remediation. The chosen house had specific characteristics: it was one of the 26 homes in the "high" RIAP group, airtight,

and had indoor pollutants that were difficult to exhaust. In addition, the occupants of the house needed to be cooperative and knowledgeable enough to address any feng shui issues and allow for remediation. Finally, the sample house designated as REN-05 in the previous study (Figure 2) met all these requirements. The sample house was a typical low-income rental property in a housing block with two rows of small units, expected in new urban areas in Ho Chi Minh City (Figure 2a). The people who lived here were sewing clothes all day, releasing a lot of dust. The owner of the rental house was a kind man who assisted in choosing a place with a couple as occupants. The husband worked while the wife was pregnant and stayed home all day. The owner helped monitor the equipment and allowed us to renovate the house later. Gas and electric stoves were commonly used in rental houses due to their compact size and convenient features. Some residents used gas for cooking in combination with other fuels such as oil, coal, electricity, or wood to boil water or prepare street food for sale. In this case, the occupants cooked using a gas stove for less than 1 hour daily (from 18:00 to 19:00) due to their simple cooking style (Figure 2c).
In Vietnam, it is common for families to park their vehicles inside their homes, as the size of scooters and motorbikes allows them to fit comfortably within living spaces. This sample rental house was no exception, as an old motorbike was stored inside, and the room took on the scent and felt of a garage during nighttime hours. The house's surroundings were composed of a large, unpaved soil area, which contributed to high levels of dust and dirt entering the home, particularly in areas without vegetation or trees to keep the soil in place (as seen in Figure 2f).

(a) A row of rental houses was where our sample house was located on the left side.

(b) The living area

(c) The cooking area, equipped with a gas stove

(d) The motorbike was stored inside the house

(e) Worship locations where incense was burned for religious purposes

(f) The soil surrounding the house was not paved with concrete.

Figure 2. The appearance of the sample house

2.2 Study Design

The study was designed as a controlled house experiment to measure pollutant concentrations in various areas of the house before and after renovation. Data on the indoor environment and ventilation patterns were recorded during three monitoring periods. The first period involved taking baseline measurements of the existing conditions in the house to determine the levels and sources of chemical contaminants and gather evidence regarding the house's inadequate ventilation. This was done by visiting the house at least twice, each time for 1-2 weeks, before the renovation (BF measurement). Next, the house was renovated, and the effects were recorded in measurements taken after the renovation (AF measurement). During these monitoring periods, the concentrations of CO_2, CO, $PM_{2.5}$, and TVOCs were continuously monitored using a 3M™ EVM series environmental monitor (Table 1 and Figure 3). Measurements were taken at one-minute intervals in the kitchen, living room, and main bedroom for three days, covering the times of daily activities for the BF measurements and 24 hours for the AF measurements.

The occupants were asked to answer a range of questions about the features of their housing while also keeping a daily diary documenting their ventilation practices, including the opening and closing times of ventilation facilities. The occupants were given a questionnaire to complete to gather additional insights about the interventions. At the end of the experiment, their experiences were reviewed and discussed with them. This observational approach provided qualitative data for our study.

Table 1. Measurements in EVM-7 monitor

Parameters	Base Units	Display Range	Accuracy/Repeatability
$PM_{2.5}$ (Particulate Matter)	mg/m^3	0.000-199.9	± 15%
CO_2 (Carbon Dioxide)	ppm	0-20,000	± 2% of signal, ± 50 ppm between 0 and 2500
CO (Carbon Monoxide)	ppm	0-1000	± 5% / 2% of signal
TVOC (Total Volatile Organic Compounds)	ppb	0 – 50.000	± 5% / 2% (relative isobutyle) at cal value
Temperature	ºC	-10.0-60.0	± 1.1 ºC
Relative humidity	% humidity	0.0-100	± 5% RH of signal between 10 and 90%

The 3M™ EVM series environmental monitor - model EVM-7

The EVM-7 monitor in a sample house

Figure 3. The indoor air quality monitoring device - the 3M™ EVM series environmental monitor model EVM-7

A well-written questionnaire can provide important or potentially informative information to the investigator. Still, a walk-through and making interviews let the investigator clarify information and gain further details not written in the questionnaires. Listen to what they said without a preconceived notion, and follow up with questions to get a clear focus on that individual's concerns. Even if an unexplained sense of something wrong should occur, an attempt could identify the reason. We always knew an open mind is the investigator's most excellent tool.

An occupant diary was used to gain information on activities during the measurement period, which might have affected the results. It was recorded through a tick-box method. The diary was compressed to one A4 page for each measurement day to reduce the burden on the occupants (Figure 4). One adult per household (who was the housewife) was suggested to fill in the diary. Participating families were asked to continue their regular daily routines.

The article was a small part of my overall research. The study surveyed and measured indoor air quality in 20 rental houses, recording the living habits and measuring pollution levels over 21 days in each house. The rental house referenced in this article, REN-05TT, was selected from the 20 surveyed for renovation. In this article, the author aimed to provide practical information about indoor air quality in a typical rental house, which showed signs of indoor air pollution due to living habits and poor ventilation design. Although only measured in one sample house, multiple measurements were taken over 36 hours, with a measurement interval of 1 minute for each parameter, allowing for the establishment of panel data.

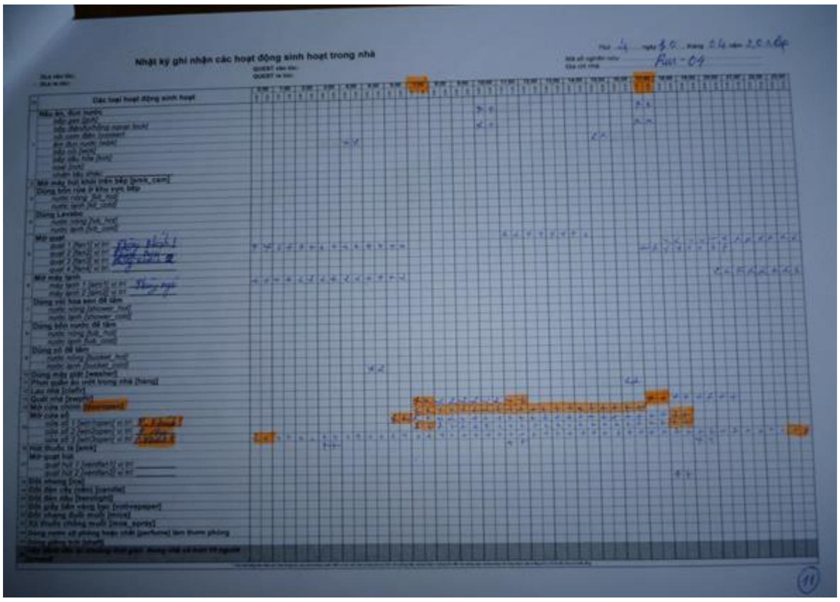

Nhật ký ghi nhận các hoạt động sinh hoạt trong nhà

Figure 4. A daily diary in fact

2.3 Solutions for Improving Ventilation in Renovation

Indoor air quality can be affected by a variety of factors, including emissions from motor vehicles kept inside an airtight space and the breath of occupants. In such cases, where the control of indoor sources was not feasible, the solution lies in improving ventilation. Additionally, the indoor temperatures were often perceived as being too high, causing the occupants to prefer to open windows even at the risk of security and loss of privacy at night.

To address these issues, the following steps were taken:

1) Increasing Fresh Air Supply: To reduce indoor air pollutants, it was proposed to install louvre/jalousie windows. These types of windows were believed to have a greater ability to pass air, deposit particles, reflect noise, and reflect direct sunlight. The old metal windows were replaced with a new window design that was larger in size and had a jalousie configuration (as shown in Figure 5b). The new design was expected to provide greater reduction in TVOC levels, due to the angled surfaces that could cause wind to pass through even when the window was kept closed for security. Experiments were conducted to evaluate the proposed window design's ability to reduce TVOC levels in real-life conditions.
2) Exhausting Indoor Air Pollutants: To quickly exhaust high levels of indoor air pollutants when all entrances, doors, and windows were closed, an exhaust fan was installed on the wall above the small opening spaces of the house. The fan was designed to operate smoothly and with acceptable noise levels (as shown in Figure 5c).

2.4 Data analysis

The data collected from the field, including the questionnaire responses and indoor monitoring data, was transcribed into Microsoft Excel using a double data entry method for accuracy. Descriptive statistics were generated using R for Windows to provide an overview of the data in the study. This included the calculation of the mean, standard deviation, minimum, maximum, percentiles over the standards, and the quantile of 10%, 25%, 50%, 75%, and 90% for all pollutants measured in the dataset, using 1-minute average measurements. The results were presented in table format and sometimes visually using plots or boxplots. In the boxplots, the bottom and top of the boxes represent the 25th and 75th percentiles, respectively, and the line at the middle of the box represents the median. The ends of the whiskers indicate the 10th and 90th percentiles.

(a) Installation of Exhaust Fan through Brick Wall

(b) Upgrade and Replace the Previous Window. The new window was a type of louvered window that has fixed horizontal slats to allow for air to flow through

(c) The sample house underwent renovation with the installation of a new window and an exhaust fan

Figure 5. Some photos taken during the renovation of the sample house

3. RESULTS AND DISCUSSION

The results presented in this paper represent a selected portion of the complete study and highlight the most noteworthy findings. A challenge with indoor air quality regulations and standards is the lack of a universal standard, with each country having its own unique regulations. In Vietnam, there are no health-based standards for most indoor air pollutants. The most relevant guidance available is provided by the QCVN 05:2013/BTNMT. To evaluate the indoor pollutant concentrations measured in this study, we used cut-off values based on guidelines proposed by various Asian countries, the World Health Organization, and the Vietnam Standards and Quality Institute. The results were analyzed in relation to housing characteristics and occupants' activities.

3.1 Air Pollutant Levels Before the Renovation

The measurement set taken before the renovation (BF) was conducted under the original conditions of the house, which included the following features:

- The house had old steel doors and windows that were only opened on one side, preventing cross-ventilation.
- The doors and windows were opened and closed at different times during the day, such as when the occupants left the house in the morning and when they took a nap at noon.
- The doors and windows were closed all night.
- An old motorbike was parked next to the house overnight.

The occupants stated that they opened the doors and windows regularly in the morning and during the day while they were at home. However, they closed the doors and windows for brief periods of rest or privacy during the evening and nighttime. This was concerning as the house lacked any windows that opened to the outside and had no exhaust fan, which could result in poor ventilation during the time when the doors and windows were closed.

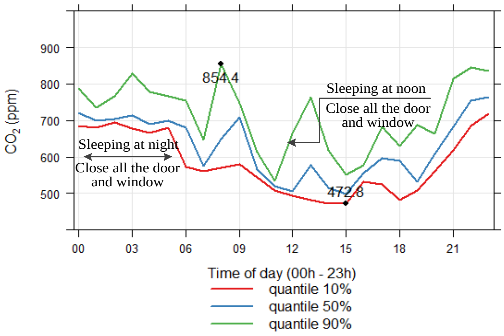
The data in Table 2 reveals that the indoor CO_2 levels ranged from 456 ppm to 1,015 ppm, with an average of 595.8 ± 92.5 ppm during the day-time and 732.2 ± 52.2 ppm at night-time. Figure 6a shows that indoor CO_2 levels had sharp peaks in the 90% quantile during the day-time, which were due to the occupants carrying out private activities such as bathing, cooking or taking a nap. The CO_2 levels started to increase from 19:00 as the occupant attached his motorbike to the room and closed all doors and windows for security and privacy. The CO_2 levels stabilized at a saturation level of around 700 ppm at night, indicating a lack of night ventilation and an accumulation of pollutants in the room.

Table 2. Descriptive Statistics of Indoor Air Quality Parameters for Measurement Setting BF

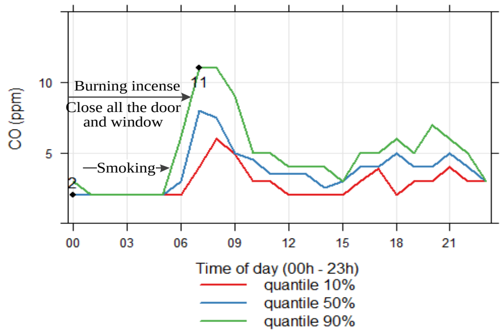
Pollutants	Mean	SD	Range (min-max)	Quantile 10%; 50%; 90%	Cut-off*
CO_2 (ppm)					
day-time	595.8	92.5	456.0 – 1,015.0	491.0; 577.0; 739.0	0.05%
night-time	732.2	52.2	625.0 – 937.0	680.0; 716.0; 813.1.0	0.0%
CO (ppm)					
day-time	4.5	2.1	2.0 – 19.0	2.0; 4.0; 7.0	2.6%
night-time	2.4	0.7	2.0 – 5.0	2.0; 2.0; 3.0	0.0%
$PM_{2.5}$ (µg/m^3)					
day-time	139.5	237.8	20.0 – 5,275.0	49.0; 68.0; 284.0	99.6%; 85.5%
night-time	83.3	55.6	35.0 – 496.0	48.0; 67.5; 133.2	100%; 88.4%
TVOC (ppb)					
day-time	537.9	361.4	0.0 – 2,582.0	306.0; 402.0; 1,005.2	29.1%
night-time	1,159.1	222.1	459.0 – 1,824.0	942.9; 1,141.5; 1,447.0	99.5%

The levels of indoor CO were found to be between 2 to 19 ppm, with the average concentrations during the day and night being 4.5 ± 2.1 ppm and 2.4 ± 0.7 ppm, respectively. The results indicate that the CO level in this house was relatively low due to the fact that the majority of occupants were single and spent minimal time at home. However, significant spikes were observed during times of peak combustion activities such as burning incense, cooking, and smoking, and also during times of ventilation. When no activities were taking place, the indoor CO values dropped to a minimum with concentrations in all quantiles below 2 ppm, indicating a lack of proper ventilation in the room.

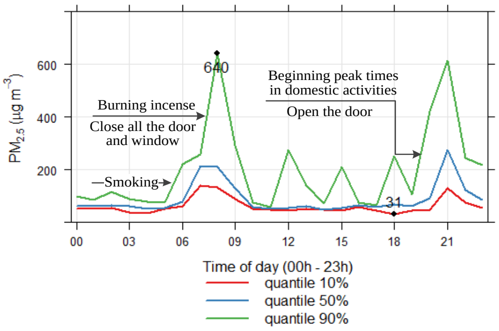
The concentrations of indoor $PM_{2.5}$ varied greatly, ranging from 20 µg/m^3 to 5,275 µg/m^3, with the average levels recorded during the day-time and night-time being 139.5 ± 237.8 µg/m^3 and 83.3 ± 55.6 µg/m^3, respectively. The $PM_{2.5}$ levels in the BF setting were high, with 90% of values higher than 121 µg/m^3, 50% higher than 200 µg/m^3, and 10% over 640 µg/m^3 (Figure 6c). Indoor $PM_{2.5}$ concentrations displayed peaks during the day-time across all quantiles. The daily maximum was observed during the morning period of 07:30-09:00, with 90% of the concentrations reaching around 640 µg/m^3. This peak was likely due to emissions from burning incense in the enclosed space when the occupants went out for breakfast. The evening peak between 18:00 and 21:00 (with 90% of the concentrations reaching 640 µg/m^3) was likely associated with activities such as cooking the main meal, smoking, or sweeping. In addition, there was a problem with the soil surrounding the house not being paved with concrete, which led to a high loading of particulates that could be carried into the house, resulting in a minimum background value of 35 μg/m^3 at night, which was higher than the WHO standard.



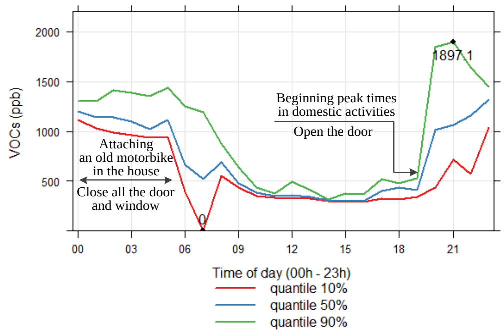
(a) CO_2



(b) CO



(c) $PM_{2.5}$



(d) TVOC

Figure 6. Analysis of Indoor Pollutant Concentration as Quantiles in the BF Measurement Setting

The indoor total volatile organic compound (TVOC) concentrations varied from 0 ppb to 2,582 ppb, with average levels recorded during the day-time and night-time of 537.9 ± 361.4 ppb and 1,159.1 ± 222.1 ppb, respectively. Results showed that 29.1% of the TVOC concentrations were higher than the threshold of 500 ppb during the day-time, and 99.5% during the night-time. As seen in Figure 6d, the indoor TVOC concentrations remained at moderate levels (around 500 ppb) during the day-time, from 9:00 to 19:00. The concentration increased at around 19:00, peaking at 21:00 with concentrations at the 90% quantile of around 1,897 ppb. From 12:00 to 1:00, the TVOC concentrations stabilized and then remained steady or decreased very slowly until 6:00 when the doors and windows were opened. This overnight behavior of TVOC concentrations was due to a constant source such as gasoline vapor escaping from the motorbike fuel tank, rather than from common daily activities since the occupants were still sleeping at that time. The TVOC remained approximately 1,000 ppb higher at night-time than day-time from midnight to 6:00. Like CO_2, the TVOC was an indicator of insufficient or poorly designed ventilation, and both CO_2 and TVOC concentrations were always much higher at night-time than day-time, indicating poor night ventilation. Because of the ineffective designs of the house, it was often easy for smoke to flow back into the room. Additionally, occupants attached the motorbike in the house. They often smoked cigarettes indoors when they closed all the doors and windows for the night-time, which added to the deterioration of the indoor air quality. One time, we found that the air in the house was so poor that we could hardly breathe in the early morning.

3.2 Air Pollutant Levels After the Renovation

After the renovation was completed, the measurement was tested under the following conditions:

- A new larger louvered window replaced the old steel window.

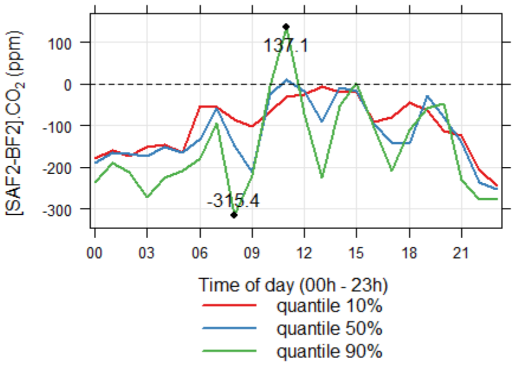
- The house was equipped with a mechanical extract ventilation system, which was installed and operated during activities such as cooking, smoking, burning incense, and sleeping.
- The doors and windows were temporarily closed in the morning when the occupants went out and opened again, then closed for a short nap at noon and opened again.
- The doors and windows were kept closed all night.
- A motorbike was parked inside the house during the night.

Table 3. Descriptive Statistics of Indoor Air Quality Parameters by Measurement Setting AF

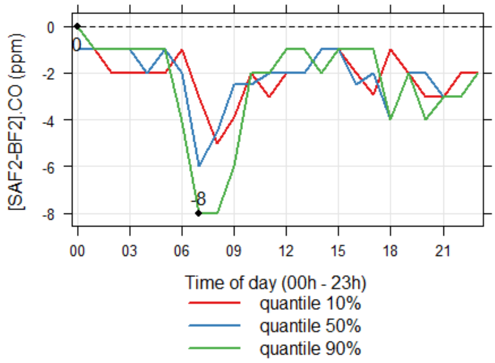
IAQ parameters	Mean		SD		Range	Quantile	Cut-off
	AF	AF/BF	AF	AF/BF	(min-max)	10%; 50%; 90%	
CO_2 (ppm)							
day-time	509.8	0.85	54.1	0.58	432.0 – 741.0	449.0; 498.0; 585.3	0%
night-time	531.5	0.72	22.8	0.45	464.0 – 694.0	508.0; 532.0; 555.0	0%
CO (ppm)							
day-time	1.8	0.40	1.0	0.45	0.0 – 8.0	1.0; 2.0; 3.0	0%
night-time	0.9	0.39	0.7	1.0	0.0 – 7.0	0.0; 1.0; 1.0	0%
$PM_{2.5}$ (µg/m^3)							
day-time	107.8	0.77	119.7	0.50	25.0 - 1,118.0	35.0; 69.0; 197.4	99.8%; 64%
night-time	70.4	0.84	100.2	1.80	32.0 - 1,547.0	40.0; 54.0; 90.0	100.0%; 63%
TVOC (ppb)							
day-time	324.3	0.62	204.8	0.56	141.0 – 1,930.0	196.0; 269.0; 532.0	11.4%
night-time	606.9	0.53	147.2	0.63	337.0 – 1,077.0	409.0; 606.0; 792.0	74.2%

As shown in Table 3, the mean values of CO_2 during the day and night were 509.8 ± 54.1 ppm and 531.5 ± 22.8 ppm respectively, with a maximum of 741 ppm. As illustrated in Figure 7a, all quantiles of CO_2 were lower during the day in the renovated condition (AF) compared to the before renovation condition (BF), with differences reaching up to 300 ppm. CO_2 concentrations remained low and stabilized at around 500 ppm throughout the day, which was lower than the measurements before renovation. The average CO concentration ranged from 0 ppm to 8 ppm and did not exceed the standard. These results were better than the measurements before renovation. The indoor $PM_{2.5}$ concentrations fluctuated from 25 µg/m³ to 1,547 µg/m³, with average concentrations recorded during the day and night being 107.8 ± 119.7 µg/m³ and 70.4 ± 100.2 µg/m³, respectively. $PM_{2.5}$ concentrations in the renovated condition (AF) were still high, with 64% of readings exceeding the Vietnamese standard during the day and 63% during the night.

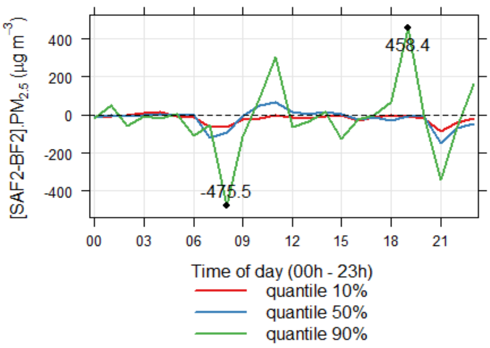
The differences in $PM_{2.5}$ concentration between AF and BF were shown to be similar in the plot of (AF-BF) $PM_{2.5}$ concentration (Figure 7c). The indoor TVOC concentrations fluctuated between 141 ppb and 1,930 ppb, with average values of 324.3 ± 204.8 ppb during the day and 606.9 ± 147.2 ppb during the night. As seen in Figure 7d, all quantiles of TVOC were lower in AF compared to BF during the day, with differences reaching up to 1,210 ppb, especially during the evening and sleeping time. The use of an exhaust fan along with the new large louvered window was found to allow for better ventilation, thus reducing the indoor TVOC concentrations from the old motorbike stored in the room. However, 11.4% of TVOC readings during the day and 74.2% of TVOC readings during the night were still above the recommended value of 500 ppb due to the occupants not regularly using the extractor fan.



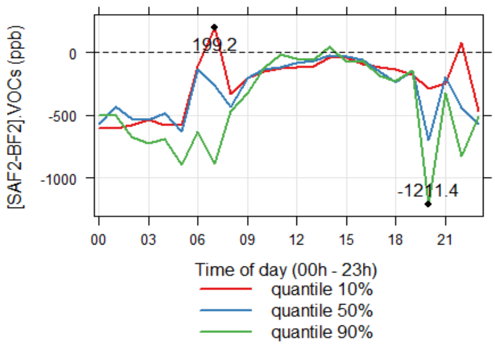
(a) CO_2



(b) CO



(c) $PM_{2.5}$



(d) TVOC

Figure 7. Quantile differences of pollutant concentrations between AF and BF

4. CONCLUSION

Although the exact proportion of rental housing types in Ho Chi Minh City remains unknown, it is evident that the prevalence of such housing will continue to rise due to the rapid pace of urbanization. Our research, conducted through the PIC and PCR projects, found that many low-cost rental houses were overcrowded. Tenants often prioritize affordability over indoor air quality due to a lack of awareness. Meanwhile, landlords frequently opt for cheaper materials and neglect ventilation systems to maximize profits, regardless of tenant requests. Consequently, the rental houses we studied lacked proper wall and ceiling ventilation, mechanical exhaust fans, and adequate air exchange in cooking and living spaces. The presence of motorbikes and furniture exacerbated the garage-like atmosphere in the living areas, particularly at night. The indoor CO_2 and total volatile organic compounds (TVOC) concentrations of the rental house were much higher than the guidelines during the night-time. Therefore, our renovation goal for this house was to reduce the concentration of these two gases at night. The results of our study indicated that making two key modifications to rental homes can greatly enhance ventilation and air quality. Replacing airtight metal doors and windows with louvered ones, and installing a well-functioning, quiet exhaust fan could allow for airflow. Our findings showed that following the renovations, the indoor air quality of the test house significantly improved. High levels of CO_2, CO, and $PM_{2.5}$ during cooking, smoking, or incense burning were eradicated. After the renovations, the occupants reported greater satisfaction with indoor air quality and thermal comfort, with notably lower CO_2 and TVOC levels at night. This also proved that the difference between the original and the renovated condition was significant in the house.

In conclusion, our initial data suggests that simple, low-cost ventilation renovations can bring benefits to landlords by enhancing indoor air quality and improving the health of those living in these rental homes in Ho Chi Minh City.

Limitation

The $PM_{2.5}$ concentrations were already at concerning levels of 25µg/m^3 in nearly 90% of readings prior to the renovation work. However, the average $PM_{2.5}$ levels sometimes even rose after the renovation was completed. The lack of concrete paving around the house resulted in a large influx of particulate matter each time the door was opened, contributing to the growing trend of $PM_{2.5}$ concentration in HCMC. This is believed to have been a factor in the elevated $PM_{2.5}$ levels observed during the renovation period. The PCR project will address this issue through further studies.

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CẢI TẠO ĐỂ CẢI THIỆN CHẤT LƯỢNG KHÔNG KHÍ TRONG NHÀ Ở: MỘT TRƯỜNG HỢP NGHIÊN CỨU VỚI KIỂU NHÀ TRỌ TẠI THÀNH PHỐ HỒ CHÍ MINH, VIỆT NAM

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Tóm tắt. Dân số của Thành phố Hồ Chí Minh (TP.HCM) đã tăng gấp đôi chỉ trong 10 năm qua, và điều này đã khiến cho các dãy nhà trọ dành cho người có thu nhập thấp mọc lên khắp nơi. Căn nhà cho thuê dành cho gia đình thu nhập thấp thường có diện tích ở từ 12 đến 15 mét vuông, nơi mọi sinh hoạt hàng ngày đều diễn ra trong không gian này. Đây là sự lựa chọn tốt nhất cho những người không có khả năng mua hoặc thuê một căn nhà rộng rãi hơn. Bài báo nhằm đánh giá hiệu quả của các biện pháp cải tạo liên quan đến hệ thống thông gió nhằm cải thiện chất lượng không khí trong nhà bằng cách sử dụng một căn nhà cho thuê tại TP.HCM như một trường hợp nghiên cứu điển hình. Nghiên cứu thực địa đã được thực hiện để điều tra tình trạng ban đầu của căn nhà mẫu trước; sau đó căn nhà được tiến hành can thiệp cải tạo lại. Nồng độ các chất ô nhiễm không khí như CO_2, CO, $PM_{2.5}$ và TVOC được đo đạc trước và sau khi cải tạo nhà. Sau đó, một số phân tích đã được thực hiện để tìm ra các yếu tố có thể cải thiện điều kiện thông gió trong nhà. Chúng tôi nhận thấy rằng việc vận hành quạt thông gió kết hợp cùng với dùng lam thông gió, thường xuyên mở cửa ra vào hoặc cửa sổ có thể cải thiện đáng kể chất lượng không khí bên trong căn nhà. Do đó, thông gió cơ học là một biện pháp can thiệp tương đối đơn giản và hiệu quả để cải thiện chất lượng không khí trong nhà ở những căn nhà nhỏ nơi lại luôn có ít nhất một chiếc xe máy để trong nhà, sát khu vực người cư trú ngủ nghỉ vào ban đêm.

Từ khóa. cải tạo nhà, nhà trọ, thông gió cơ học, chất lượng không khí trong nhà.

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