



Original Article

INDOOR AIR QUALITY IN SRI LANKAN UNIVERSITY DORMITORIES: ON-SITE INSPECTION AND MEASUREMENT

Samali Ayoma Marasinghe^{1*}

Abstract

We spend about 90% of our time indoors, exposed to various indoor environmental pollutants. This study investigated Indoor Air Quality (IAQ) in student dormitories at the Rajarata University of Sri Lanka, comparing environmental parameters with national and international standards. The research was conducted in two phases: Phase I involved a cross-sectional questionnaire survey, using multi-stage sampling methods to select participants, while Phase II was a nested case-control study based on the Phase I data. This encompassed 388 students from 245 dormitory rooms in Sri Lanka. The findings revealed high CO₂ concentrations (1160 ppm), exceeding the limits of both local and international standards (Sri Lankan standard: 1000 ppm; WHO guideline: 1000 ppm), during nighttime in the dormitories, although other parameters, temperature (28.2 °C), relative humidity (81.3%), particulate matter PM_{2.5} (12 µg/m³) and PM₁₀ (17 µg/m³), and formaldehyde (0.03 mg/m³) remained within acceptable ranges according to both standards. These findings highlight the need for improved ventilation systems and reduced occupancy rates to lower CO₂ levels in the dormitories. The study's implications extend beyond immediate IAQ improvement, suggesting potential policy revisions for university housing regulations in Sri Lanka to promote better indoor environments. Continuous IAQ monitoring and corrective measures are essential for ensuring a healthier living space for students, aligning national standards more closely with international best practices.

Keywords: Indoor Air Quality, Temperature, CO₂, PM, Humidity, Dormitories

¹ Department of Environmental Management, Rajarata University of Sri Lanka, Mihinthale

***Corresponding Author:**
Samali Ayoma Marasinghe
marasinghe@ssh.rjt.ac.lk



This article is published under the Creative Commons **CC-BY-ND** License (<https://creativecommons.org/licenses/by-nd/4.0/>). This license permits use, distribution and reproduction, commercial and non-commercial, provided that the original work is properly cited and is not change anyway.



1. INTRODUCTION

Research has consistently demonstrated that Indoor Air Quality (IAQ) poses significant concerns for human health (Dales et al., 2008a), largely because people typically spend between 80% and 90% of their time indoors (Borràs-santos et al., 2013; Dales et al., 2008a). Prolonged exposure to indoor environments makes them vulnerable to various factors influencing IAQ, including physical, chemical, and biological elements (Dales et al., 2008b; Huang, 2016; Huang et al., 2020; Langer & Bekö, 2013; Zhao et al., 2004).

The literature consistently underscores the health risks associated with poor Indoor Air Quality (IAQ) (Cincinelli & Martellini, 2017; Singleton et al., 2017; World Health Organization, 2018; Zhang & Smith, 2003), highlighting issues such as particulate matter exposure (Huang et al., 2016; Phillips et al., 2016) and the impacts of environmental CO₂ levels, temperature, and humidity in residential settings (Hou et al., 2021; Cheng, et al., 2019). Formaldehyde exposure has also been linked to adverse health effects (Garrett et al., 1999; Rumchev et al., 2002), as have volatile organic compounds (VOCs) (Jaakkola et al., 2004). Despite extensive research on the harmful effects of indoor pollutants, significant gaps remain particularly within the context of Sri Lanka. While IAQ research in other countries has explored a wide range of indoor pollutants and their impacts, (Cincinelli & Martellini, 2017; Singleton et al., 2017; World Health Organization, 2018; Zhang & Smith, 2003), there is relatively limited research specifically focused on Sri Lankan residential settings, particularly dormitories. Previous studies on IAQ in Sri Lanka have primarily addressed residential homes and offices, often overlooking the unique environment of student housing, where overcrowding and limited ventilation may exacerbate IAQ issues. The use of new building

materials and chemicals in cleaning agents has contributed to increased indoor air pollution (Zhang et al., 2013; Zhang et al., 2020; Wang et al., 2010). Additionally, modern building designs often result in poor ventilation and the accumulation of indoor pollutants (Sun et al., 2019; Houg et al., 2018), highlighting the need for comprehensive IAQ assessment and management.

Although many studies have extensively examined IAQ (Bornehag, Sundell, & Sigsgaard, 2004; Wang et al., 2016; Wierzbicka et al., 2018) the research on IAQ in Sri Lankan dormitories is still in its beginning, with little to no in-depth analysis of key indoor air parameters in university housing. This study aims to address this gap by thoroughly assessing the IAQ in university dormitories in Sri Lanka through systematic on-site measurements and observations. Through this approach, the study produces essential empirical data that will enhance the existing body of IAQ literature specific to the Sri Lankan context, with potential implications for informing evidence-based policy development and practical interventions.

2. METHODS

2.1 Study Population

The Sri Lankan Student Health (SLSH) study includes two phases (Figure 1: Study Area). Phase I involved a cross-sectional questionnaire study, and Phase II was a nested case-control study.

Phase I: Cross-sectional Questionnaire Study

In Phase I of this study, a multi-stage cluster sampling technique was employed to gather self-reported information about the health and indoor environment of students residing in the hostel. Randomly selected seven buildings from a pool



of 14, and randomly selected 502 rooms ensured that the study captured diverse environmental conditions and living situations, thus enhancing the generalizability of the results. The study utilized a well-structured questionnaire, similar to those used in previous studies conducted in Sweden, Bulgaria, and China (Bornehag et al., 2005; Naydenov et al., 2008; Sun et al., 2018), which was modified for Sri Lankan climate, environment, building characteristics, socioeconomic status, food behavior, and student status (Bornehag, Sundell, Weschler, et al., 2004). The questionnaire consisted of four sections including, general student information, student health outcomes, dormitory environment, and food habits. Students were instructed to complete the questionnaire within two days and return it to the hostel officer with marked building and room numbers. All questionnaires were securely returned to the researcher by the dormitory offices. The survey was conducted in May 2020.

The Phase II of this study was a nested case-control study involving students from the cross-sectional study. The selection criteria for Phase II cases were those with at least two of the following symptoms: doctor-diagnosed asthma, current wheeze, and current rhinitis, as identified in the screening questionnaire completed in Phase I. Out of 2234 participants in the cross-sectional study, 190 were selected for the case-control study after meeting inclusion criteria, which required them to have reported at least two of the three listed symptoms and not any renovation work since the survey. Healthy controls were selected from participants who reported no asthma or allergy symptoms in the baseline questionnaire. Among them, 198 students were selected for the survey, after meeting inclusion criteria, which required them to have reported no symptoms in the baseline questionnaire and not to have reported any renovation work since the survey. In total, 190 students with allergy symptoms and 198 healthy students (non-cases) were included in the case-control study, all living in 245 rooms.

Phase II: Case-Control Study with Dormitory Room Inspection

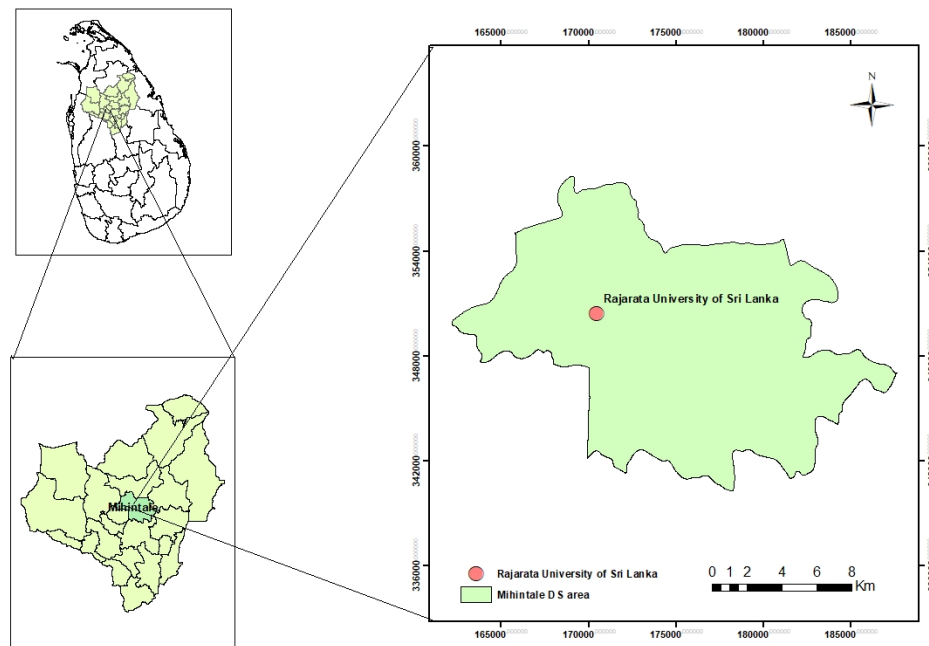


Figure 1: Study Area (Rajarata University of Sri Lanka)



Inspectors visited the rooms of these students and measured indoor environmental parameters Temperature, CO₂, Humidity, formaldehyde, PM_{2.5}, and PM₁₀. Ten inspectors, who were blinded to the students' health information from Phase I, were assigned to inspect and measure the dorm room. Each room was visited by two inspectors who completed the relevant checklists.

The study's dormitory buildings, varying from one to four stories, have diverse architectural designs. Located in rural areas, these dormitories in Sri Lanka are designed for natural ventilation. Air enters through windows with louvers, which can be fully opened on one or both sides. Students sometimes close these louvers for privacy or noise control. While specific data on air change rates in these dormitories is not available, they comply with local regulations requiring window areas to be at least 1/7th of the room's floor area. In student dormitories, cooking facilities are usually located in common kitchen areas. Some students tend to use kerosene and electricity for cooking.

2.2 Measured Environmental Parameters in the University Dormitories

(1) CO₂, RH, and Temperature Measurement

The technical inspection and measurements in the dormitory room started in August 2020. Indoor environment and physical parameters, such as temperature, relative humidity, and carbon dioxide, were measured in the dormitory rooms. Indoor environmental pollutants like PM_{2.5}, PM₁₀, and formaldehyde were also measured. While Sri Lanka experiences a relatively stable annual temperature due to its tropical climate, precipitation can vary significantly between seasons, potentially influencing indoor humidity levels and ventilation patterns. To account for seasonal variations, measurements were taken during two

different periods, reflecting both dry and wet seasons. Physical environmental parameters (temperature, relative humidity, and CO₂ concentration) were measured 24 hours a day using the monitor AZ 7798 Taiwan. CO₂ measurement accuracy was $50 \text{ ppm} \leq \pm 5\%$ of reading (measuring range: 0-9999 ppm), temperature accuracy was $\pm 0.6 \text{ }^\circ\text{C}$ (measuring range: -10 to +60 $^\circ\text{C}$), and relative humidity was $\leq \pm 3 \%$ (measuring range: 5.0%-95.0%). All instruments were calibrated prior to data collection, and CO₂ sensors underwent recalibration following the manufacturer's guidelines to ensure accurate readings during the study period. Potential sources of error included the influence of nearby doors, windows, and occupants, which could alter air circulation and skew readings. To minimize these influences, monitors were placed away from windows, doors, room corners, and occupants. The devices were positioned approximately 1.1 meters above floor level at the center of the room, as per standard protocols. We requested the room members to record the volume of the room, the weight, and height of students who slept in the room during the measurement, and the opening status of windows/doors (closed, slightly open, half-open, or fully open) during day and night.

(2) PM and Formaldehyde Concentration Measurement

Furthermore, two indoor environmental pollutants, namely formaldehyde and PM_{2.5} and PM₁₀, were measured in the dormitory rooms. Formaldehyde was measured using portable direct-reading instruments (model MEF 500), and the detection range was 12-800 $\mu\text{g}/\text{m}^3$ with an accuracy of $\pm 10\%$. A direct reading instrument measured PM_{2.5} and PM₁₀ in the dormitory room. The tool was Extech VPC300; the detection range and accuracy were 0-1000 $\mu\text{g}/\text{m}^3$, $\pm 0.1 \mu\text{g}/\text{m}^3$, respectively. It was placed in the middle of the room, approximately 1.5–1.8 m above ground level and 1/3 longitudinal depth



from the outer wall. PM_{2.5}, PM₁₀, and formaldehyde were measured for 5 minutes in our study. We placed the device away from vents, windows, and heat sources such as computers,

and sunlight. All descriptions of sampling devices used and measured parameters in the case-control study are detailed in Table 1.

Table 1: Description of Sampling Devices and Parameters Measured in the Case-Control Study

Parameters	Detection range and accuracy	Location	Instrument	Total duration
CO ₂	CO ₂ : 0-9999 ppm; 50 ppm ± 5% of reading %	Instruments were located 1.0-1.5 m above the floor: to avoid corners, walls, and occupants in the home.	Portable CO ₂ monitors (AZ® 7798, Taiwan)	Measured at least 24 hours of air temperature, RH, and CO ₂
Temperature	T: -10 to +60 °C; ± 0.6 °C			
RH	RH: 5% - 95%; ± 5%			
Formaldehyde	12-800 µg/m ³ ; ±10%	Center of the student’s room (1m above the floor)	Sensology MEF 500	5 minutes
PM _{2.5} PM ₁₀	± 0.1µg/m ³ ; 0-1000 µg/m ³	Center of the student’s room (1 m above the floor)	Extech VPC300	5 minutes

2.3 Air Sample Analysis

This study used the CO₂ tracer gas method to measure the air change rate (ACR) in a child’s bedroom. Specifically, the study recorded CO₂ concentrations at night when the CO₂ output from sleeping participants was relatively consistent. To illustrate, Fig 2. presents two rooms’ CO₂ concentrations measured for one day and one night. This technique, which was originally proposed by Stavova (Stavova, 2004), has been employed in previous studies to determine ACR (Bekö et al., 2010; Hou et al., 2018; Langer et al., 2016; Sun et al., 2011) ACR was calculated based on the changes in CO₂ concentration over time intervals, as described in Equation (1):

$$\Delta C = (\Delta\tau / V) \cdot [F \cdot 10^6 - ACR \cdot V \cdot (C_1 - C_0)] \quad (1)$$

Where ΔC is the unit concentration change (ppm), $\Delta\tau$ is the unit time interval (h), V is the volume of the zone (m³), F is the emission rate of

CO₂ (m³/h), ACR is the air change rate (h⁻¹), C_1 is the initial CO₂ concentration of time interval $\Delta\tau$ (ppm), and C_0 is the outdoor CO₂ concentration (ppm). The CO₂ emission rate, F , can be calculated as in Equation (2) (Persily, 1997)

$$F = RQ \cdot 0.00201 \cdot H^{0.725} \cdot W^{0.425} \cdot M / (0.23 \cdot RQ + 0.77) \quad (2)$$

Where F is the CO₂ (m³/h) emission rate, RQ is a respiratory quotient (usually 0.83), H is the occupant's height (m), W is their weight (kg), and M is their metabolic level (met).

The CO₂ at the end of the time interval (C_2) can be used as the initial concentration (C_1) and the unit increase of concentration (ΔC). A theoretical exponential curve was generated by performing the analysis and repeating it for each new time interval. A least squares analysis was used to fit this theoretical curve to the measured data. This iterative procedure produced the best-fitting air flow and CO₂ emission rates.

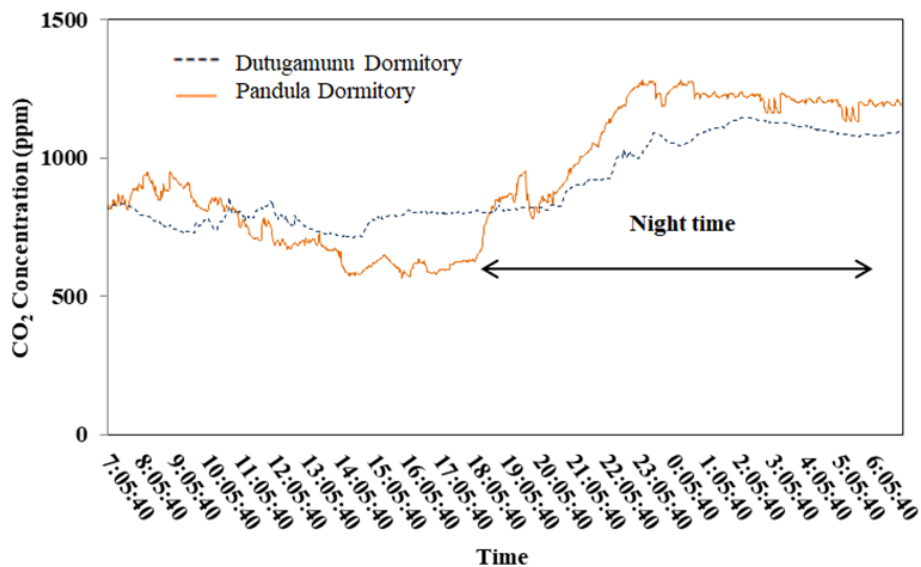


Figure 2: Example of the CO₂ Concentration Measured in Rooms in the Two Hostels
(The night periods were used to calculate the air change rate.)

2.4 Statistical Analysis

The data on environmental parameters was analyzed using various descriptive analytical techniques. These included filtering to refine the data, calculating summary statistics to provide an overview, determining the median values for central tendencies, and computing percentages to understand the distribution and proportion of different variables. Since the data were not normally distributed, non-parametric tests, such as the Mann-Whitney U test, were used to compare the measured parameters with national standards. All data analyses were performed using SPSS 21 software package. The Faculty of Medical and Allied Science at the Rajarata University of Sri Lanka, granted ethical approval to the Sri Lankan Student Health (SLSH) study.

3. RESULTS

3.1 Demographic Information

In Phase I, 2,234 students responded to the study,

yielding a response rate of 76%. The survey was conducted in May 2020. The majority of the student population comprised females, representing 71.4%. A significant proportion of students, approximately 46.2%, were born between 1994 and 1996. About 11% of students reported a family history of allergies. Regarding socio-economic status, a substantial majority, 60.1%, come from families with a monthly income of more than 14,000 SLR.

3.2 Background Information of the Measured Rooms in University Dormitories (Phase II)

Background information on the student's dormitories is presented in Fig. 3. As per the findings, most dormitory buildings (91.5%) were less than 10 years old, while single dormitory buildings accounted for 10.0%. Nearly 33.0% of rooms were on the second floor. More than half (56.0%) of Windows were framed with aluminum. Nearly 61% of students relied on natural ventilation by opening windows.

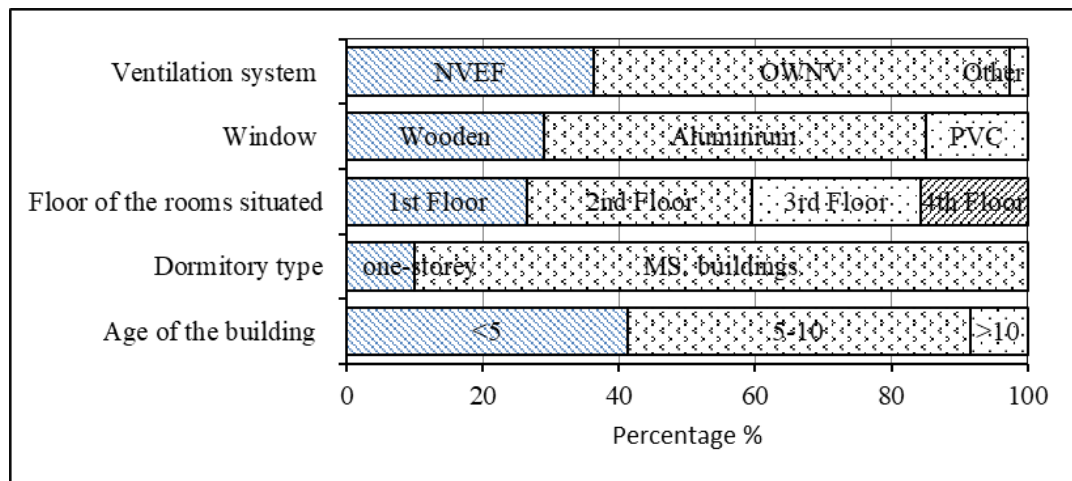


Figure 3: Background Information of the Measured Dormitory Rooms in Sri Lanka (NVEF: Natural ventilation with electric fans, OWNV: open window for natural ventilation, MS.: Multi-storey buildings)

3.3 Measured Indoor Environmental Parameters in Dormitories in Sri Lanka

Sri Lanka is a tropical region characterized by abundant warmth and sunshine throughout the year. The most significant climatic variation in Sri Lanka is rainfall. Table 2 presents the distribution of measured indoor environmental parameters in the dormitories of Rajarata University of Sri Lanka. The parameters measured included temperature, relative

humidity, CO₂ concentration, air change rate, PM_{2.5}, PM₁₀, and formaldehyde. The median indoor environmental temperature for 24 hours was 28.3°C, with a relative humidity of 81.2%. The median CO₂ concentration at night was 1160 ppm, which exceeds the national limit of 1000 ppm, showing a statistically significant difference ($p < 0.05$). The ACR during the night was 0.86 h⁻¹, indicating suboptimal ventilation. Indoor environmental chemical parameters such as PM_{2.5}, PM₁₀, and formaldehyde did not exceed the national limits ($p > 0.05$) (NEA 2008).

Table 2: Median Distribution of the Measured Indoor Environmental Parameters in the Dormitory of the Rajarata University of Sri Lanka

Parameters	N	Min.	25th percentile	50th percentile	75th percentile	Max.
Physical environmental parameters						
Temperature for 24 h ^a (°C)	245	25.2	27.6	28.3	28.8	30.7
RH for 24 h ^a (%)	245	68.6	77.7	81.2	85.9	97.2
CO ₂ at night time ^b (ppm)	245	521	1047	1160	1360	2283
ACR at night time ^b (h ⁻¹)	245	0.43	0.70	0.86	1.08	3.20
Chemical, environmental parameter ^c						
PM _{2.5} (µg/m ³)	245	10	13	15	16	35
PM ₁₀ (µg/m ³)	245	13	16	17	20	48
Formaldehyde (mg/m ³)	245	0.01	0.02	0.03	0.06	0.59

^a 24 hour

^b Night time 0.00- 07.00

^c For 5 minutes



4. DISCUSSION

The evaluation of Indoor Air Quality (IAQ) in the student dormitory at Rajarata University of Sri Lanka reveals critical insights when compared to national and international standards (Table 3). Notably, the average CO₂ concentration of 1160 ppm exceeds all referenced standards, which typically suggest levels below 1000 ppm. This indicates inadequate ventilation and potential overcrowding, necessitating urgent attention to improve air exchange rates and reduce CO₂ accumulation. Several factors likely contribute to the elevated CO₂ levels observed, with room occupancy being a major one. In many university dormitories, including those in Sri Lanka, rooms

are often overcrowded, with up to ten students in a 30 m² room or four in an 18 m² room. This high occupancy leads to increased CO₂ production from respiration, especially during nighttime when windows are typically closed for security and comfort, allowing CO₂ to accumulate more rapidly. This is compounded by the reliance on natural ventilation, where most dormitories in this study depended on natural ventilation (opening windows) rather than mechanical ventilation systems. The use of natural ventilation alone, especially in poorly ventilated buildings or multi-story dormitories, limits the ability to effectively exchange indoor air with fresh outdoor air, particularly at night.

Table 3: The Comparison of Measured Parameters with National and Chinese Nation's Standards

Measured environmental parameters	SLSH study IAQ ^a	IAQ national standards in Sri Lanka (NEA, 2008)	IAQ national standards in China (Bai et al., 2003)	IAQ national standards by the WHO (WHO, 2010)	US EAP (USEPA, 2012)	Note
Relative humidity (%)	81.3	- ^b	40-80	-	-	Summer
Temperature (°C)	28.2	-	23-28	-	-	Summer
CO ₂ (at night 0.00-0.07)	1160	-	<1000	1000	800	
ACR (h ⁻¹) (at night 0.00-0.07)	0.86	-	0.5	-	-	
PM _{2.5} (µg/m ³) (for 5 minutes)	12	50	≤75	25/15	65	24h
PM ₁₀ (µg/m ³) (for 5 minutes)	17	100	≤150	50/45	150	24h
Formaldehyde (mg/m ³)	0.03	-	≤0.08	0.1	0.92 (8 h)	1 hourly average

^a Median values

^b Not available

There have been no previous studies in Sri Lanka examining indoor air quality in university dormitories by measuring indoor environmental parameters across different locations (Table 4). However, these findings are consistent with similar studies conducted in university dormitories in other countries. For instance, a

study in Tianjin, China, reported similar concerns regarding CO₂ levels, particularly during the heating season when doors and windows were kept closed. In rooms with 3 to 6 occupants, CO₂ concentrations ranged from 1011 ppm to 1483 ppm (Sun et al., 2011). The higher CO₂ concentration in our study may be attributed to the larger number of students per room, which emphasizes the importance of proper room



occupancy allocation to prevent overcrowding and maintain adequate air quality (Marasinghe & Sun, 2021). As students in Sri Lankan dormitories often stay for longer periods (3 to 4

years), exposure to low indoor environmental quality over such extended periods could have adverse health impacts (Jayasooriya et al., 2020).

Table 4: Monitored Indoor Air Temperature, CO₂, RH, PM_{2.5} and Formaldehyde Concentration in Sri Lanka

References	Different Places in Sri Lanka	Year	Number of Households and Place of Measurements	Pollutant	Results
(Halwatura & Rawshan, 2012)	Kandy	2020	Indoor and outdoor different 7 places in Kandy	CO ₂	City center CO ₂ concentration 900-1100 ppm
(Jayasooriya et al., 2020)	Sri Jayewardenepura University	2020	5 classrooms	CO ₂ RH T	CO ₂ concentrations were 6223 ppm and 7645 ppm in two classrooms. RH 45-75% Temperature 26.0-31.5°C
(Michael et al., 2016)	Kopiwatta, near Kandy, in central	2016	53 homes	PM _{2.5}	Indoor PM _{2.5} in the cooking area 200 µg/m ³ .
(Nandasena et al., 2012)	Colombo	2012	20 public places (restaurants, bars, cafes, and entertainment venues)	PM _{2.5}	Average indoor PM _{2.5} ranged from 33 to 299 µg/m ³
(Nandasena, Wickremasinghe, 2011)	Colombo and Panadura	2011	65 urban permanent 67 urban semi-permanent 66 semi-urban Main living room	PM _{2.5}	Clean fuels in the urban setting PM _{2.5} = 47.3 µg/m ³ clean fuels in a semi-urban setting PM _{2.5} = 47.3 µg/m ³ median PM _{2.5} levels in biomass using: urban = 122.3 µg/m ³ ; semi-urban = 39.1 µg/m ³
(Ranasinghe et al., 2015)	Colombo	2010	6 households Main living room	PM _{2.5}	Average 143.7 µg/m ³ (range 122.8- 190.6 µg/m ³)
(Amarasekara, 2008)	Kandy	2008	20 households Measurements were done in 4 kitchen types (5 in each type) Improved stove with chimney (K1) Improved stove without chimney (K2) Un-improved stove with chimney (K3) Un-improved stove without chimney (K4)	PM _{2.5}	K1: PM _{2.5} = 0.077 mg/m ³ K2: PM _{2.5} = 1.874 mg/m ³ K3: PM _{2.5} = 1.838 mg/m ³ K4: PM _{2.5} = 5.406 mg/m ³



The relative humidity measured at 81.3% surpasses the upper limit of the Chinese national standard, which could foster mold growth and other humidity-related issues. Although the temperature falls within acceptable ranges, and formaldehyde levels are comfortably below permissible limits, this suggests that the air is relatively free from common pollutants typically associated with respiratory issues.

In contrast, the levels of particulate matter (PM_{2.5} and PM₁₀) in this study were found to be well below the recommended national and international standards, which differs from previous studies conducted in Sri Lanka (Nandasena and Wickremasinghe, 2011; Ranasinghe et al., 2015). For instance, a study conducted in the Colombo metropolitan and Panadura area monitored indoor PM_{2.5} in 198 homes and found higher PM_{2.5} levels in households that used biomass for cooking (Nandasena and Wickremasinghe, 2011). The study reported that PM_{2.5} levels in all households in the Colombo urban area and 70% of households that used biomass in Panadura exceeded the WHO-approved standards (50µg/m³) (Nandasena and Wickremasinghe 2011). Another study in the same area found that the average PM_{2.5} concentration was 143.7µg/m³. Similarly, a previous study conducted in Kandy, a hill area, reported that PM_{2.5} concentration was higher compared to other studies conducted in Sri Lanka (Amarasekara, 2008). The major source of indoor PM_{2.5} in Sri Lanka is biomass for cooking (Elledge et al., 2010). However, our study found PM_{2.5} levels below the recommended national and international standards because our research area is the rural setting of the university with fewer industries, low urbanization, and a university that does not allow cooking inside the dormitory. Additionally, the low smoking prevalence among students and Sri Lankan women, who are predominantly non-smokers due to cultural norms, likely contributed to lower indoor PM_{2.5} concentrations.

Studies conducted in other countries also report higher indoor PM_{2.5} concentrations, particularly in residential settings. For instance, a multi-country study across seven Asian countries found that average indoor PM_{2.5} concentrations were 137µg/m³, while a study in Shanghai, China, reported levels of 61µg/m³ (Lee et al., 2010).

5. CONCLUSION AND RECOMMENDATIONS

These results indicated that indoor air quality in the student dormitories at Rajarata University of Sri Lanka requires improvement. The study found that while most IAQ parameters such as particulate matter (PM_{2.5} and PM₁₀) and formaldehyde were within acceptable limits, the average CO₂ concentration significantly exceeded national and international standards. These findings suggest an urgent need for targeted interventions to improve ventilation and air exchange rates in the dormitories to reduce CO₂ levels and enhance overall IAQ. To address these issues, it is recommended that policymakers mandate the installation of mechanical ventilation systems, set maximum occupancy limits for dormitory rooms, and require regular IAQ monitoring and compliance checks. Additionally, promoting the use of energy-efficient ventilation technologies and establishing clear guidelines for IAQ, in alignment with WHO standards, will ensure a healthier indoor environment for students. Implementing these measures will help align dormitory conditions with global health and safety standards, benefiting student well-being.

REFERENCES

- Amarasekara, R. M. and D. D. (2008). Report on the Measuring of Emissions in Kitchens Prior to Improvement and After Improvement. Integrated Development Association (IDEA), Kandy., August 2008.
- Andrew K. Persily. (1997). Evaluating Building IAQ and Ventilation with Indoor Carbon Dioxide. ASHRAE Transactions, 103(2), 1–12.



- Bai, Z., Wang, Z., Zhu, T., & Zhang, J. (2003). Developing Indoor Air Quality Related Standards in China. *Journal of Asian Architecture and Building Engineering*, 2, 55–60. <https://doi.org/10.3130/jaabe.2.55>
- Bekö, G., Lund, T., Nors, F., Toftum, J., & Clausen, G. (2010). Ventilation rates in the bedrooms of 500 Danish children. *Building and Environment*, 45(10), 2289–2295. <https://doi.org/10.1016/j.buildenv.2010.04.014>
- Bornehag, C. G., Sundell, J., Hagerhed-Engman, L., Sigsggard, T., Janson, S., & Aberg, N. (2005). “Dampness” at home and its association with airway, nose, and skin symptoms among 10,851 preschool children in Sweden: A cross-sectional study. *Indoor Air*, 15(10), 48–55. <https://doi.org/10.1111/j.1600-0668.2005.00306.x>
- Bornehag, C. G., Sundell, J., & Sigsgaard, T. (2004). Dampness in buildings and health (DBH): Report from an ongoing epidemiological investigation on the association between indoor environmental factors and health effects among children in Sweden. *Indoor Air*, 14(7), 59–66. <https://doi.org/10.1111/j.1600-0668.2004.00274.x>
- Bornehag, C. G., Sundell, J., Weschler, C. J., Sigsgaard, T., Lundgren, B., Hasselgren, M., & Hägerhed-Engman, L. (2004). The association between asthma and allergic symptoms in children and phthalates in house dust: A nested case-control study. *Environmental Health Perspectives*, 112(14), 1393–1397. <https://doi.org/10.1289/ehp.7187>
- Borràs-santos, A., Jacobs, J. H., Täubel, M., Haverinen-shaughnessy, U., Krop, E. J. M., Huttunen, K., Hirvonen, M., Pekkanen, J., Heederik, D. J. J., Zock, J., & Hyvärinen, A. (2013). Dampness and mould in schools and respiratory symptoms in children: the HITEA study. 681–687. <https://doi.org/10.1136/oemed-2012-101286>
- Cincinelli, A., & Martellini, T. (2017). Indoor air quality and health. *International Journal of Environmental Research and Public Health*, 14(11). <https://doi.org/10.3390/ijerph14111286>
- Dales, R., Liu, L., Wheeler, A. J., & Gilbert, N. L. (2008a). Public health: Quality of indoor residential air and health. *CMAJ. Canadian Medical Association Journal*, 179(2), 147–152. <https://doi.org/10.1503/cmaj.070359>
- Dales, R., Liu, L., Wheeler, A. J., & Gilbert, N. L. (2008b). Quality of indoor residential air and health. *CMAJ. Canadian Medical Association Journal*, 179(2), 147–152. <https://doi.org/10.1503/cmaj.070359>
- Elledge, M. F., Nandasena, S., Phillips, M. J., & Thornburg, V. E. (2010). Environmental Health Risk and the Use of Biomass Stoves in Sri Lanka. *Research Brief Environmental*, 5(October), 1–8.
- Garrett, M. H., Hooper, M. A., Hooper, B. M., Rayment, P. R., & Abramson, M. J. (1999). Increased risk of allergy in children due to formaldehyde exposure in homes. *Allergy*, 54, 330–337. <https://doi.org/10.1034/j.1398-9995.1999.00763.x>
- Halwatura, R. U., & R Mohammed Rawshan. (2012). Effect of Greenery on Co 2 Concentration Inside Dwellings. University of Moratuwa.
- Hou, Jing Zhang, Yufeng Sun, Y., & Wang, Pan Zhang, Qingnan Kong, Xiangrui Sundell, J. (2018). Air change rates at night in northeast Chinese homes. *Building and Environment*, 132(March), 273–281. <https://doi.org/10.1016/j.buildenv.2018.01.030>
- Hou, J., Zhang, Y., Sun, Y., Wang, P., Zhang, Q., Kong, X., & Sundell, J. (2018). Air change rates at night in northeast Chinese homes. *Building and Environment*, 132(November 2017), 273–281. <https://doi.org/10.1016/j.buildenv.2018.01.030>
- Huang, Chen Wang, Xueying Liu, Wei Cai, Jiao Shen, Li Zou, Zhijun Lu, Rongchun Chang, Jing Wei, Xiaoyang Sun, Chanjuan Zhao, Zhuohui Sun, Yuexia Sundell, J. (2016). Household indoor air quality and its associations with childhood asthma in Shanghai, China: On-site inspected methods and preliminary results. *Environmental Research*, 151, 154–167. <https://doi.org/10.1016/j.envres.2016.07.036>
- Huang, L., Qiao, Y., Deng, S., Zhou, M., Zhao, W., & Yue, Y. (2020). Airborne phthalates in indoor environment: Partition state and influential built environmental conditions. *Chemosphere*, 254, 126782. <https://doi.org/10.1016/j.chemosphere.2020.126782>
- Jaakkola, J. J. K., Parise, H., Kislitsin, V., Lebedeva, N. I., & Spengler, J. D. (2004). Asthma,



- Wheezing, and Allergies in Russian Schoolchildren in Relation to New Surface Materials in the Home. *American Journal of Public Health*, 94(4), 560–562. <https://doi.org/10.2105/AJPH.94.4.560>
- Jing Hou, Yuexia Sun, Xilei Dai, Junjie, Xiong Shen, H. T., Huang, Haiguo Yin, K., Yao Gao, Dayi Lai, W. H., Norbäck, X. Z. | D., & Chen, Q. (2021). Associations of indoor carbon dioxide concentrations, air temperature, and humidity with perceived air quality and sick building syndrome symptoms in Chinese homes. *Indoor Air*, 31(4), 1018–1028. <https://doi.org/10.1111/ina.12810>
- Langer, S., & Bekö, G. (2013). Indoor air quality in the Swedish housing stock and its dependence on building characteristics. *Building and Environment*, 69(2), 44–54. <https://doi.org/10.1016/j.buildenv.2013.07.013>
- Langer, S., Ramalho, O., Derbez, M., Ribéron, J., Kirchner, S., & Mandin, C. (2016). Indoor environmental quality in French dwellings and building characteristics. *Atmospheric Environment*, 128, 82–91. <https://doi.org/10.1016/j.atmosenv.2015.12.060>
- Lee, J., Lim, S., Lee, K., Guo, X., Kamath, R., Yamato, H., Abas, A. L., Nandasena, S., Nafees, A. A., & Sathiakumar, N. (2010). Secondhand smoke exposures in indoor public places in seven Asian countries. *International Journal of Hygiene and Environmental Health*, 213(5), 348–351.
- Jayasooriya V. M, Rajapaksha R.M.D.H, Ng A.W.M and Muthukumaran S. Associations of Indoor Carbon Dioxide Concentration and Symptoms of Sick Building Syndrome in Air-Conditioned Lecture Halls.
- Marasinghe, M. M. S. A., & Sun, Y. (2021). Indoor environmental quality and its impact on the health: a cross-sectional study. Conference Proceedings Vavuniya University International Research Conference (VUIRC) 2021 "Human Empowerment through Research Excellence," 1–5.
- Nandasena S, Wickremasingha A R, Sathiakumar N. Levels and determinants of indoor air quality in Sri Lankan households[C]. Proceedings of the ISES: Advancing Exposure Science for Environmental Health: International Society of Exposure Science, Balitmore: International Society of Exposure Science (ISES), 2011: 12-16
- Nandasena S, Wickremasinghe A R, Lee K, et al. Indoor fine particle (PM_{2.5}) pollution exposure due to secondhand smoke in selected public places of Sri Lanka[J]. *American Journal of Industrial Medicine*, 2012, 55(12): 1129-1136.
- Naydenov, K., Melikov, A., Markov, D., Stankov, P., Bornehag, C. G., & Sundell, J. (2008). A comparison between occupants' and inspectors' reports on home dampness and their association with the health of children: The ALLHOME study. *Building and Environment*, 43(11), 1840–1849. <https://doi.org/10.1016/j.buildenv.2007.10.020>
- Phillips, Michael J. Smith, E. A., & Mosquin, Paul L. Chartier, Ryan Nandasena, Sumal Bronstein, Katherine Elledge, Myles F. Thornburg, Vanessa Thornburg, Jonathan Brown, L. M. (2016). Sri Lanka pilot study to examine respiratory health effects and personal PM_{2.5} exposures from cooking indoors. *International Journal of Environmental Research and Public Health*, 13, 1–11. <https://doi.org/10.3390/ijerph13080791>
- Ranasinghe, R. S. A., Sugathapala, A. G. T., Lee, S. C., Hung, W. T., Ho, K. F., Chan, C. S., Huang, Y., & Cheng, Y. (2015). Exploratory study of the indoor and outdoor relationships and chemical compositions of particulate matter in urban households in Colombo. *Indoor and Built Environment*, 24(5), 597–606. <https://doi.org/10.1177/1420326X13517252>
- Rumchev, K. B., Spickett, J. T., Bulsara, M. K., Phillips, M. R., & Stick, S. M. (2002). Domestic exposure to formaldehyde significantly increases the risk of asthma in young children. *European Respiratory Journal*, 20, 403–408. <https://doi.org/10.1183/09031936.02.00245002>
- Singleton, R., Salkoski, A. J., Bulkow, L., Fish, C., Dobson, J., Albertson, L., Skarada, J., Kovesi, T., McDonald, C., Hennessy, T. W., & Ritter, T. (2017). Housing characteristics and indoor air quality in households of Alaska Native children with chronic lung conditions. *Indoor Air*, 27(2), 478–486. <https://doi.org/10.1111/ina.12315>
- Stavova, P. (2004). A method for air change rate measurements in dwellings based on carbon dioxide produced by people. Master Thesis Technical University of Denmark, Denmark, 15–20. Master Thesis Technical University of



- Denmark, Denmark,
- Sun, Y., Hou, J., Cheng, R., Sheng, Y., Zhang, X., & Sundell, J. (2019). Indoor air quality, ventilation and their associations with sick building syndrome in Chinese homes. *Energy and Buildings*, 197(May), 112–119. <https://doi.org/10.1016/j.enbuild.2019.05.046>
- Sun, Y., Hou, J., Kong, X., Zhang, Q., Wang, P., Weschler, L. B., & Sundell, J. (2018). “Dampness” and “Dryness”: What is important for children’s allergies? A cross-sectional study of 7366 children in northeast Chinese homes. *Building and Environment*, 139, 38–45. <https://doi.org/10.1016/j.buildenv.2018.05.013>
- Sun, Y., Hou, J., Sheng, Y., Kong, X., Weschler, L. B., & Sundell, J. (2019). Modern life makes children allergic. A cross-sectional study: associations of home environment and lifestyles with asthma and allergy among children in Tianjin region, China. *International Archives of Occupational and Environmental Health*, 92(4), 587–598. <https://doi.org/10.1007/s00420-018-1395-3>
- Sun, Y., Zhang, Y., Bao, L., Fan, Z., & Sundell, J. (2011). Ventilation and dampness in dorms and their associations with allergy among college students in China: A case-control study. *Indoor Air*, 21(4), 277–283. <https://doi.org/10.1111/j.1600-0668.2010.00699.x>
- THE NATIONAL ENVIRONMENTAL ACT, N. 47 O. 1980. (2008). *The Gazette of the Democratic Socialist Republic of Sri Lanka*. 26, 8–9.
- USEPA. (2012). Revised Air Quality Standards for Particle Pollution and Updates To the Air Quality Index (AQI). United States Environmental Protection Agency, Washington D.C, USA, 1–5. https://www.epa.gov/sites/default/files/2016-04/documents/2012_aqi_factsheet.pdf
- Wang, L. X., Zhao, B., Liu, C., Lin, H., Yang, X., & Zhang, Y. P. (2010). Indoor SVOC pollution in China: A review. *Chinese Science Bulletin*, 55(15), 1469–1478. <https://doi.org/10.1007/s11434-010-3094-7>
- Wang, X., Liu, W., Huang, C., Cai, J., Shen, L., Zou, Z., Lu, R., Chang, J., Wei, X., Sun, C., Zhao, Z., Sun, Y., & Sundell, J. (2016). Associations of dwelling characteristics, home dampness, and lifestyle behaviors with indoor airborne culturable fungi: On-site inspection in 454 Shanghai residences. *Building and Environment*, 102(March 2016), 159–166. <https://doi.org/10.1016/j.buildenv.2016.03.010>
- Wierzbicka, A., Pedersen, E., Persson, R., Nordquist, B., Stålné, K., Gao, C., Harderup, L. E., Borell, J., Caltenco, H., Ness, B., Stroh, E., Li, Y., Dahlblom, M., Lundgren-Kownacki, K., Isaxon, C., Gudmundsson, A., & Wargocki, P. (2018). Healthy indoor environments: The need for a holistic approach. *International Journal of Environmental Research and Public Health*. <https://doi.org/10.3390/ijerph15091874>
- World Health Organization. (2010). WHO guidelines for indoor air quality: selected pollutants (Vol. 35). https://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf
- World Health Organization. (2018). WHO Housing and health guidelines. <http://www.who.int/phe%0Ahttp://apps.who.int/bookorders>.
- Zhang, Qinghao Sun, Yuexia Zhang, Qingnan Hou, Jing Wang, Pan Kong, Xiangrui Sundell, J. (2020). Phthalate exposure in Chinese homes and its association with household consumer products. *Science of the Total Environment*, 719, 136965. <https://doi.org/10.1016/j.scitotenv.2020.136965>
- Zhang, J., & Smith, K. R. (2003). Indoor air pollution: A global health concern. *British Medical Bulletin*, 68, 209–225. <https://doi.org/10.1093/bmb/ldg029>
- Zhang, Y., Mo, J., & Weschler, C. J. (2013). Reducing health risks from indoor exposures in rapidly developing urban China. In *Environmental Health Perspectives* (Vol. 121, Issue 7, pp. 751–755). <https://doi.org/10.1289/ehp.1205983>
- Zhao, Y., Chen, B., Guo, Y., Peng, F., & Zhao, J. (2004). Indoor air environment of residential buildings in Dalian, China. *Energy and Buildings*, 36(12), 1235–1239. <https://doi.org/10.1016/j.enbuild.2003.09.011>

