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ABSTRACT

Carbon monoxide (CO) is harmful to human health, yet there is limited evidence concerning emissions associated with biomass fuel cooking in occupational settings. Real-time 48-hour monitoring of CO concentrations at breathing height, was undertaken in staff and student kitchen and serving areas of two commercial canteens. We characterized two diurnal CO peaks coinciding with cooking activities. Peak CO concentrations of 255.5 ppm and 1-hour average of 76.3 ppm (IQR: 57.8–109.0 ppm) were observed in the student kitchen; the staff kitchen levels were 208.5 ppm, and 76.3 ppm (IQR: 52.5–114.0 ppm), respectively. High magnitude CO concentrations (8-hour average: 40.7 ppm SD: 40.0 ppm) which exceed World Health Organisation (WHO) Indoor Air Quality standards were observed. Further investigation of personal exposure and health impacts among kitchen staff is required, to inform interventions in this setting.

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Biomass; carbon monoxide; charcoal; commercial canteens; indoor air pollution; occupational exposure

Introduction

Wood, dung, agricultural residues, charcoal and coal,[1,2] are used by 3 billion people worldwide[3–8] as a primary source of cooking fuel.[9,10] Typically, these biomass fuels are relatively inexpensive and readily available,[11–13] with the highest usage in Low and Middle Income Countries (LMICs).[14] Rwanda is a rapidly developing country with a Gross Domestic Product (GDP) per capita of $748.3 in 2017[15] and a high prevalence of biomass fuel usage, presenting long-term health, environmental and economic issues. Incomplete biomass combustion in poorly ventilated settings[2,16] produces carbon monoxide (CO), a colorless and odorless gas[17] which reduces blood oxygen-carrying capacity causing tissue hypoxia[18] and oxidative stress.[19] In addition, biomass fuel collection and production contributes to increased carbon emissions, deforestation and environmental degradation,[20] increasing, for example, the risk of land and mudslides hilly terrain around the capital Kigali.[21]

University canteen environments, as an exemplar of commercial kitchens in other settings, present potential prolonged Household Air Pollution (HAP) exposure risk to staff and students who use them on a daily basis. Multiple stove use increases both the intensity and magnitude of emissions. There remains a paucity of evidence of exposure assessment in LMIC occupational kitchen settings; with an existing research focus on domestic rather than industrial cooking emissions, even though restaurants, hotels and schools typically rely upon traditional large cooking stoves.[22]

In the UK, EU Indicative Occupational Exposure Limit Values (IOELVs) legislation defines CO Workplace Exposure Limits of 30 ppm (35 mg/m^3) as an 8-hour Time Weighted Average (TWA) and short-term exposure limit 200 ppm (232 mgm^3).[23] However, the World Health Organisation (WHO) Indoor Air quality (IAQ) guidelines for a domestic setting has a TWA limit value of 6.1 ppm (7 mg/m^3) for 24 hours, 8.7 ppm (10 mg/m^3) for 8 hours, 30.6 ppm (35 mg/m^3) for 1 hour and 87.3 ppm (100 mg/m^3) for 15 minutes of exposure.[24] These levels along with short-term exposures of a magnitude (>200 ppm) are recognized to be seriously hazardous to human health. Exposure-response studies have shown acute and chronic health events[18] as a result of oxidative stress from CO exposure above threshold values, which include

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Figure 1. Outside view of the staff and student canteen.

exacerbation of symptoms of myocardial ischemia,[18] increased blood pressure[25] and adverse pregnancy outcomes[26] including low birth weight,[26] as a result of chronic hypoxia of the placenta from biomass smoke exposure in pregnancy,[27] and can be fatal at extreme concentrations.[18]

This study aimed to characterize patterns of CO emissions associated with charcoal fuel cooking in; (i) the kitchen, and (ii) the serving area, of two commercial canteens (staff/student) in a tertiary educational setting in Kigali, Rwanda.

Materials and methods

Setting

This observational study was conducted in the solid brick buildings of the staff and student canteens at the Nyarugenge Campus, University of Rwanda College of Science and Technology (UR-CST) (Figure 1). Each kitchen provides morning tea, lunch and dinner, with stoves being lit at 05:30 and 07:00 in the student and staff kitchens, respectively and main cooking sessions between 8:30–11:30 and 16:00–19:00. Morning tea involves brewing tea with milk and sugar. Lunch, the main meal of the day, and dinner consists mainly of beans, plantain, isombe (spinach, aubergine and cassava), umutsima (corn) and vegetables. A total of 18 staff work in the student kitchens and 5 in the staff kitchen, on a rotating shift basis, with 11 hour average shift duration. A total of 550 staff and students are catered for by the two kitchens each day, with the majority consuming their meals in a covered serving area. All study fieldwork was conducted in January 2019, at the end of the wet season, with the occasional rain shower in the afternoon and ambient temperatures of 18–29 °C.

The student kitchen was set up for mass catering with six large fixed wood fuel stoves, each with a diameter of 1 meter. Above each stove, on the wall behind, is a small opening window (0.5 m × 0.5 m) and ventilation bricks at a height of 2 m (Figure 2), with no other structural or mechanical methods of ventilation. The kitchen is directly adjacent to the canteen serving area, situated in the corner of the hall. The seating area was situated in the opposite corner to the serving area, with open, vented windows situated along one side opposite the kitchen.

The staff kitchen area comprises of large portable charcoal stoves for cooking, in one enclosed room, with an open door leading into an enclosed courtyard (Figure 3). The two ends of the charcoal kitchen are constructed of two-thirds wall, and one-third wire fencing. The staff kitchen, also contained three gas cooking rings, located in an adjacent room. The kitchen connects to the staff canteen via stairs, leading upwards to a well-ventilated serving area with adjacent open balcony. The canteen dining area is an open plan area, along with a covered balcony.

Data collection

Carbon monoxide

Real-time CO concentration measurements were taken at 1-minute intervals for a 48-hour duration using electrochemical EasyLog EL-USB-CO Carbon Monoxide Data loggers (Lascar Electronics Ltd, Erie, PA), with an accuracy of ±7ppm and lower Limit of Detection (LOD) of 3 ppm; and a temperature range of −10 to +40 °C. Monitoring was performed at a fixed location in each setting. In the student and staff kitchens, monitors were located at a respirable height of 150 cm and distance of 100–150 cm from the main cooking stove. The monitors in the canteen were positioned at the serving desk, as this being a common area is visited by staff and students, positioned at a vertical height of 100–150 cm (respirable height). All monitoring commenced at 18:00 on a weekday and was performed at 1-minute intervals for a continuous period of 48 hours (Wednesday to Friday evening), therefore capturing two full days of cooking activities. CO levels below the lower LOD were assigned a value of 1.5 ppm (one half the lower LOD). Data were downloaded using EasyLog USB software (Lascar Electronics Ltd) to a text file for data cleaning prior to statistical analyses. Instrument calibration was undertaken by the manufacturer with accompanying laboratory calibration certificate.

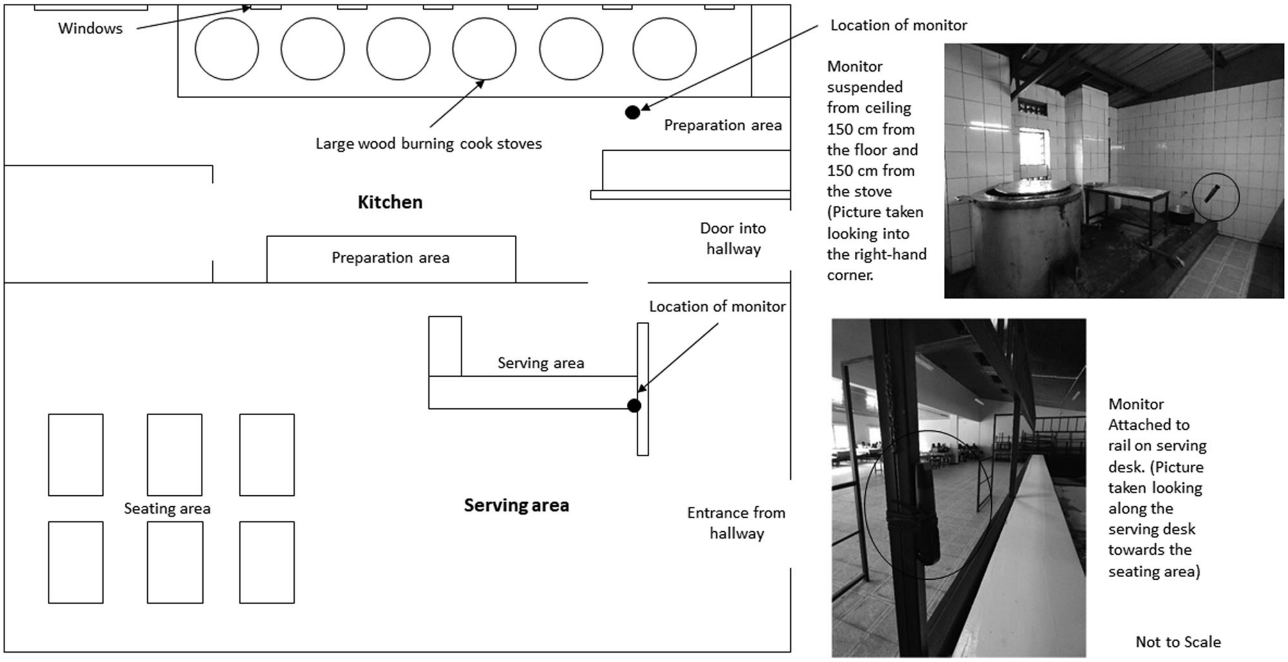

Figure 2. Layout of student kitchen and serving area, with position of monitors.

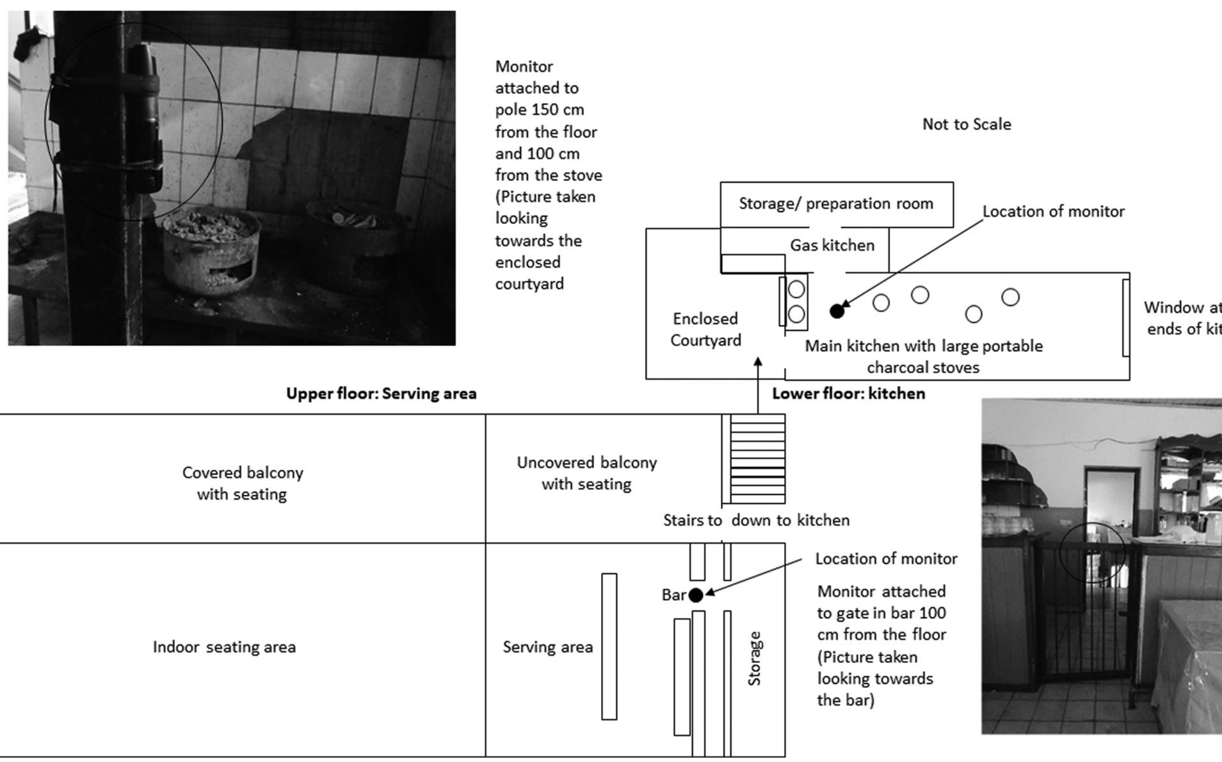

Figure 3. Layout of staff kitchen and Serving area, with position of monitors.

Kitchen characteristics

Kitchen characteristics were observed and recorded by local trained fieldworkers (final year undergraduate students at the University of Rwanda), including location of windows, doors and vents and number of stoves. Information on cooking characteristics, including timing of stove lighting and details of meal preparation was collected verbally from catering staff and by observation during daily fieldwork visits.

Statistical analysis

We calculated descriptive statistics for average (arithmetic mean, geometric mean, median) and peak CO concentrations in each monitoring location, with real-

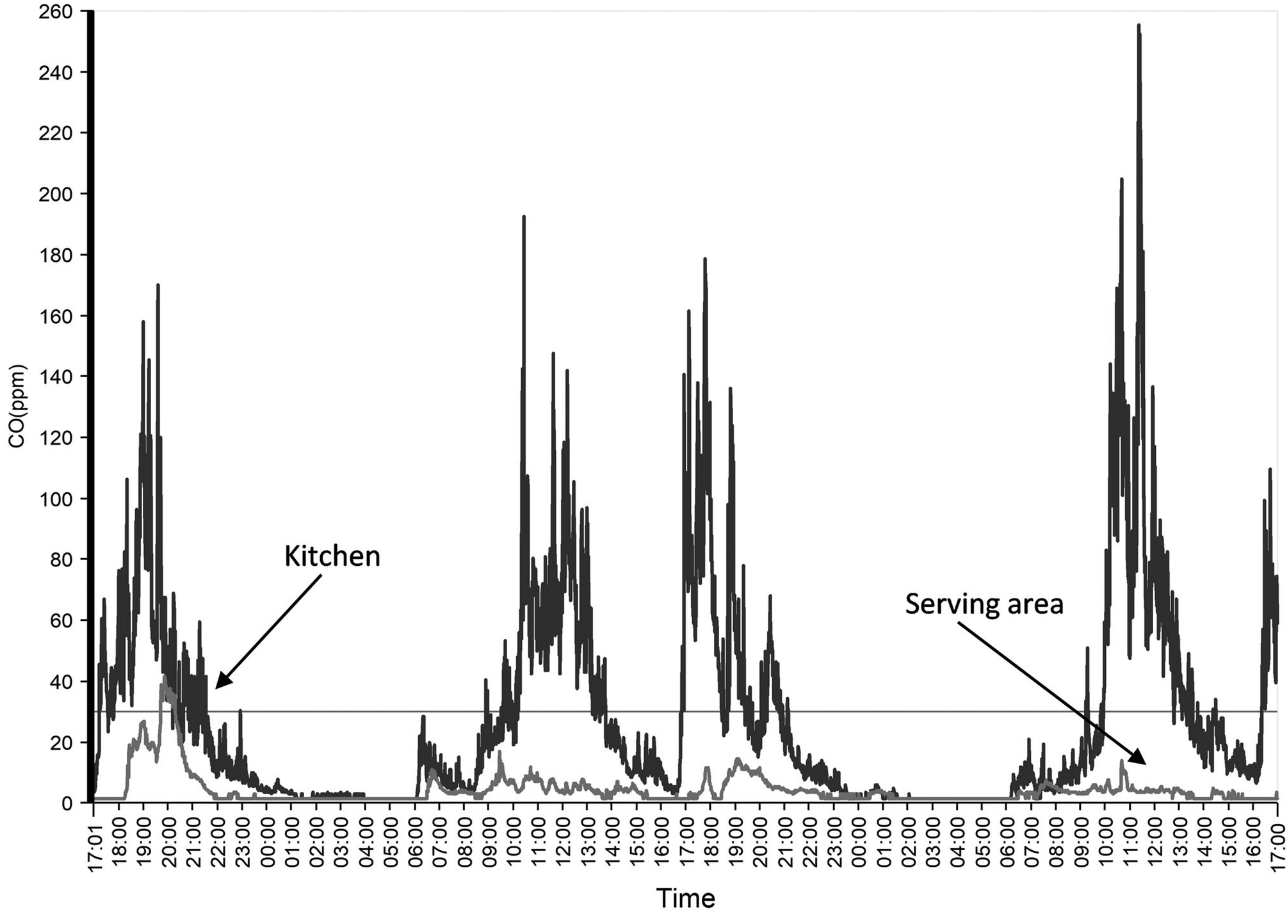

Figure 4. Variation in 1-minute CO concentrations (ppm) levels across 48 hours (Wednesday–Friday) within the student kitchen (Black line) and student serving area (Grey line) showing two diurnal cooking peaks in 12 hours. Reference denotes the UK occupational standard of 30 ppm.

time concentrations averaged over the total sampling and 8-hour and 11-hour shift durations respectively. With two 11-hour periods being assigned to cover the main working hours (06:00–17:00 and 09:00–22:00). All statistical analyses were performed in Stata v15,[28] including descriptive statistics and time-series analyses to identify peak and average (mean and median) CO concentrations. 8-hour time weighted averages (TWA) were calculated as the average of all data points (1-minute intervals) for the specified 8-hour time frame. Pearson's correlation was used to measure the association between CO concentrations in the kitchen and serving area. A Man-Whitney U test was used to compare CO concentration between hourly average and shifts averages within each sampling area.

Ethical approval

Ethical approval for this study was gained through the University of Rwanda, approval number: No 317/CMHS IRB/2017.

Results

Variation in CO across 48 hours

Student kitchen and canteen

CO levels in the student kitchen were observed to increase rapidly at 06:00 (Figure 4), coinciding with initial morning stove lighting. Figure 4 shows two distinct daily periods of high CO levels between 08:00–16:00 and 16:00–23:00 respectively, depicting the two main cooking periods. Each peak is characterized by a rapid increase in CO concentration, followed by a gradual decline, with levels remaining elevated above precooking levels between cooking events. The highest CO value was recorded on Friday at 11:00 with a 1-minute value concentration of 255.5 ppm, with the lowest background concentration of 1.5 ppm during nocturnal hours. We observed a large variation in CO levels across 48-hours, with a median value of 13 ppm (IQR: 3.5–40.0 ppm) (Table 1). CO concentrations at the student canteen serving area, were moderately associated with concentrations in the kitchen area ($r = 0.38$, $p < 0.001$), but at lower average levels,

Table 1. 48-hour average CO concentration in the Staff and Student kitchen and serving areas.

	Number of observations	Arithmetic Mean (SD)		Geometric mean (SD)		Median (IQR)		Minimum	Maximum
Student Kitchen	2880	27.4	(34.0)	11.8	(1.4)	13.0	(3.5, 40.0)	1.5	255.5
Student Serving area	2880	4.4	(5.4)	3.0	(0.8)	3.0	(1.5, 4.5)	1.5	41.5
Staff Serving area	2880	1.6	(0.7)	1.5	(0.2)	1.5	(1.5, 1.5)	1.5	15.0
Staff Kitchen	2880	15.1	(25.9)	4.8	(1.5)	1.5	(1.5, 18.0)	1.5	208.5

Number of observation recorded by one monitor.
Arithmetic Mean = Arithmetic Mean CO (ppm) concentration across 48 hours.
Geometric Mean = Geometric Mean CO (ppm) concentration across 48 hours.
SD = standard deviation of the mean.
Median = Median CO (ppm) concentration across 48 hours.
IQR = Interquartile range of concentrations across 48 hours.
(Min, Max) = the minimum and Maximum CO (ppm) concentration across 48 hours.

with peak 1-minute concentration of 41.5 ppm observed at 19:53.

Staff kitchen and canteen

Figure 5 shows CO concentrations increasing from 08:00 with highest recorded concentration 208.5 ppm between 09:00–10:00. CO levels decreased from late morning, with a second smaller evening peak occurring at around 19:00. The average (median) 48-hour staff kitchen was 1.5 ppm (IQR: 1.5–18 ppm) (Table 1), which is below the lower LOD. Peak staff canteen serving area magnitude was 15 ppm, with levels increasing during cooking periods (09:00–13:00).

Average hourly concentration

Student kitchen and canteen

Due to observed daily variations in CO levels, hourly average (median) values provide a more accurate indication of continuous personal concentration levels. Nocturnal levels are lower than daytime average concentrations ($p < 0.001$), below the lower LOD at 1.5 ppm for four hours overnight (Appendix 1, Supplementary material). The peak hourly average concentration 76.3 ppm (IQR: 57.8–109 ppm), occurs at 10:00–11:00, with a large increase from 09:00 (22.8 ppm, IQR: 18–29 ppm) and remaining elevated until midday (67.5 ppm, IQR: 53.3–83.3 ppm) (Figure 6). The evening peak occurs at 18:00–19:00 (61.3 ppm, IQR: 42–77.8 ppm). Corresponding peak 1-hour averages occur in the student canteen at 10:00–11:00 (CO: 6.3 ppm IQR: 4–8 ppm) and 17:00–18:00 (CO: 1.8 ppm IQR: 0–3 ppm), correlating with temporal changes in kitchen concentrations. However, these peak 1-hour average concentrations are not significantly different to the hour before or after, apart from the student canteen 10:00–11:00 ($U = 5.3$, $p < 0.001$) and 17:00–18:00 ($U = -7.4$ $p < 0.001$).

Staff kitchen and canteen

The staff kitchen has the highest 1-hour average at 09:00–10:00 (76.3 ppm, IQR: 52.5–114 ppm – Figure 7) ($U = 3.7$, $p < 0.001$), with a second non-significant peak of lower magnitude at 18:00–19:00 (15.3 ppm IQR: 1.5–30 ppm, $U = -1.0$, $p = 0.32$) and nocturnal concentration 1.5 ppm (Appendix 2, Supplementary material). Average hourly concentrations in the staff canteen were 1.5 ppm.

Average 8-hour and 11-hour concentrations

The greatest 8-hour average concentrations occurred during the first cooking periods (06:00–14:00) in both student (mean 40.7 ppm, SD: 40.0 ppm) and staff (mean 34.7 ppm, SD: 35.8 ppm) kitchens respectively (Table 2). However, the first shift in the student kitchen was not significantly different from the afternoon shift ($U = -1.7$, $p = 0.08$). The highest mean 8-hour concentration for the serving area was recorded in the student serving area during the afternoon shift at a concentration of 7 ppm (SD: 8.2 ppm), but was not significantly different from the morning shift ($U = 1.5$ $p = 0.14$). In comparison, the greatest 11-hour average (Table 2) concentration occur in between 09:00–22:00 in the student kitchen (mean 43.5 ppm, SD: 35.4 ppm) and 06:00–17:00 in the staff kitchen (mean 25.0 ppm, SD: 29.9 ppm). The student serving area held the greatest 11-hour average concentration between 09:00–22:00 (mean 5.9 ppm, SD: 6.6 ppm). An 11-hour limit level was calculated from the WHO IAQ limit levels, at 8.2 ppm (9.4 mg/m^3).

Discussion

To the best of our knowledge, this is the first study to obtain primary pollutant measurements in a commercial catering setting in Rwanda, where biomass fuel combustion represents over 85% of overall energy consumption.[29] Although high CO levels (TWA range of 4.9–50 ppm) have previously been reported within domestic settings in sub-Saharan Africa,[30–33] our findings suggest workplace CO concentrations are of a greater peak intensity and longer duration. Peak

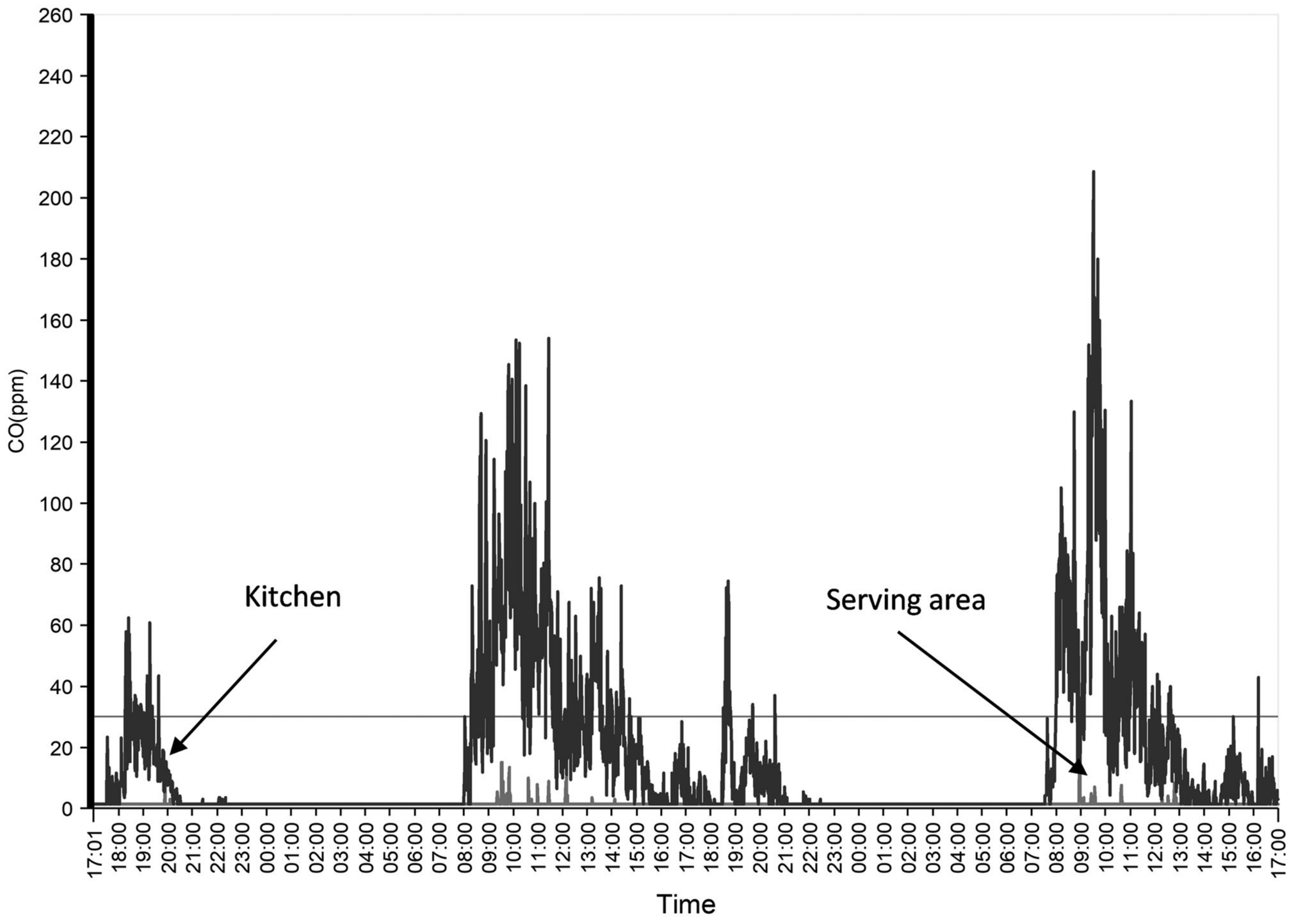

Figure 5. Variation in 1-minute CO concentrations (ppm) across 48 hours in the staff kitchen (Black line) and staff serving area (Grey line) showing two cooking phases in 12 hours. Reference line denotes the UK occupational standard of 30 ppm.

kitchen concentrations during lunch (Student = 255.5 ppm and Staff = 208.5 ppm) and dinner (Student = 170.0 ppm and Staff = 74.5 ppm) cooking sessions, with the calculated 8-hour average exceeding the WHO domestic IAQ 8-hour time-weighted average (TWA) limit values which emphasizes the concentrations are hazardous for human health.

Through use of real-time monitoring we identified two characteristic diurnal CO peaks coinciding with cooking activities, consistent with temporal patterns reported in domestic biomass fuel settings.[34–37] Peaks are characterized by a rapid increase in CO emissions coinciding with stove lighting and cooking onset,[38] followed by gradual decline and plateau above background values for several hours after the main cooking periods (Figures 4 and 5). In the student kitchen nocturnal CO levels remained elevated above background values, at a range of 1.5–30.5 ppm. These high-intensity, prolonged duration pollutant episodes differ from temporal patterns reported previously in domestic settings which are typically characterized by short intensity peaks.[3,39,40] However, to the best of our knowledge, there are no previous time-series investigations of CO levels associated with wood and charcoal stoves in occupational environments, therefore limiting detailed comparisons. Indicative differences may reflect cooking period and quantity and number of stoves deployed in a commercial canteen environment in comparison to single meal preparation in a domestic kitchen. The observed increase in CO levels at the end of cooking sessions in our study may reflect extinguishing the stoves[3,39,41]. Temporal and spatial differences may be attributable to fuel moisture content, fuel density or ventilation[34,38,42,43], therefore further detailed investigation of the relative contribution of these factors is merited in this setting.

8-hour average CO levels observed in canteen serving areas used by both university staff (1.6 ppm SD: 0.7 ppm) and students (4.4 ppm SD: 5.4 ppm), were lower than respective kitchen concentrations and did not exceed WHO 8-hour IAQ limit values, reflecting increased distance from the pollutant source, creating greater dispersion.[44] The main difference in the level of ventilation between the two areas was the opportunity for circulating airflow through the entrance and balcony doors in the staff

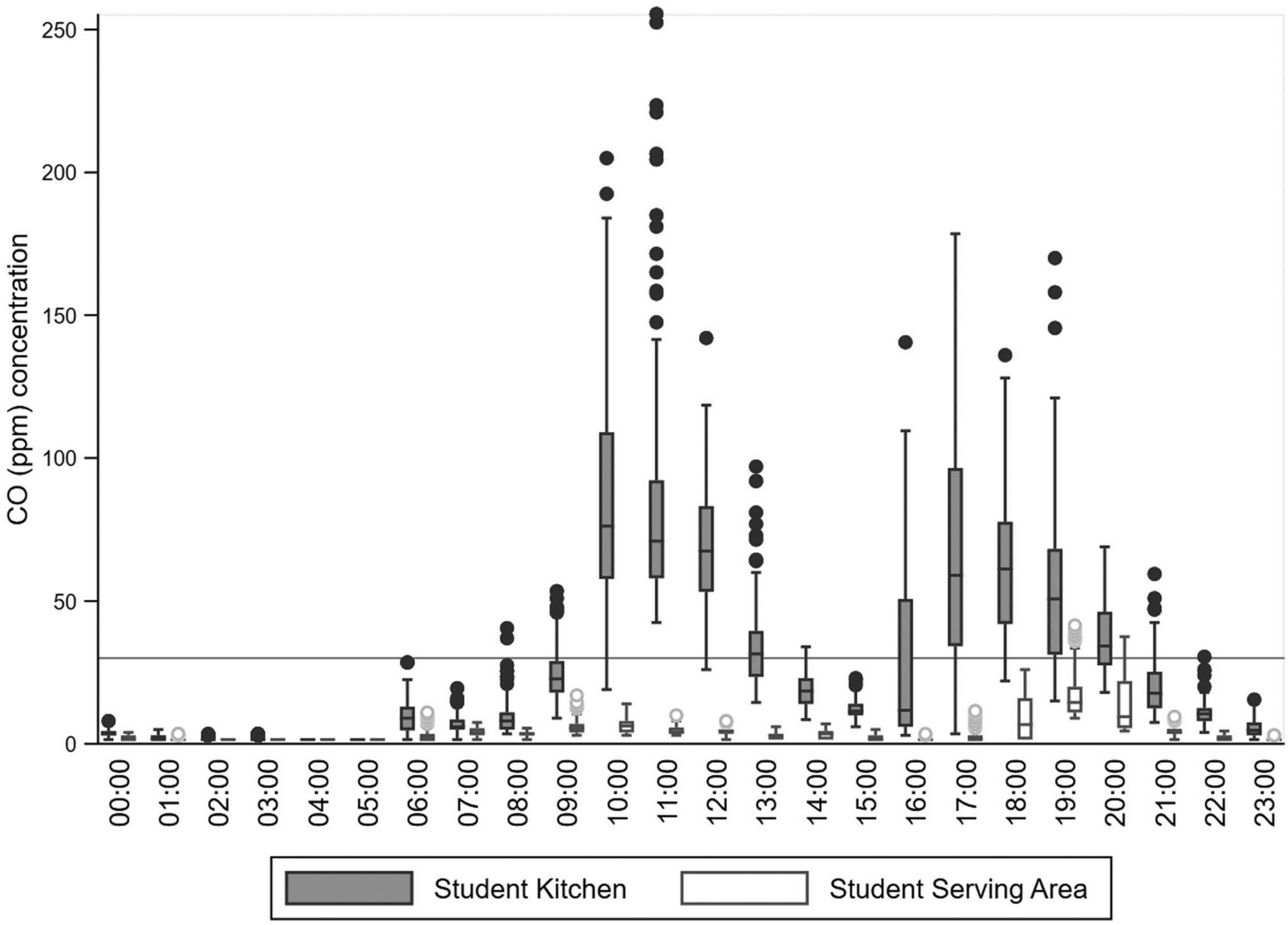

Figure 6. A box plot illustrating the average (median) hourly concentration of CO concentrations (ppm) in the student serving area by daytime working hour (06:00–22:00). Boxes represent the interquartile range, with the middle line indicating the median. Outliers are illustrated with points. 30 ppm reference line denotes UK occupational standard. (Numerical tables in Appendix 1, Supplementary material).

serving area and that the staff serving area was not directly connected to the kitchen, being separated by a stairway. However, concentrations in the student serving area were elevated above background levels and the high number of students attending for meals suggests a potentially greater population exposure level among this group compared to university staff; although the health effects, if any, at this level of exposure are unclear.

Exposure comparisons between studies are difficult due to varying micro environments, differing sampling strategies, including position, duration and calibration of monitoring devices.[45] There are some limitations to our work. Our observations were obtained by monitoring sessions of 48-hour duration in each study location but we did not attempt to account for variability in weather conditions or ventilation; therefore no dispersion modelling[46] could be undertaken. Although a 48 hour assessment of diurnal variation is relatively short in duration, it highlights regular periods in exceedance of the WHO guideline values, within a commercial biomass burning canteen setting. However, alternative sources of CO emissions were not investigated, but the kitchen and canteen settings were away from major roads and there were no electricity generators in close proximity to the study location suggesting these potential influences were of minimal relevance in this setting. Smoking prevalence is low in Rwanda, with a 4.7% smoking prevalence in 15–49 year olds;[47] and therefore was not considered as a major source in this context.

Absolute individual exposure cannot be inferred from this study, which is required to estimate the potential health harms, as we did not perform personal monitoring of staff which may yield different results to fixed site measurements.[48] However the monitoring location (1 m height, 1.5 m distance from the stove) was selected to represent typical breathing height during cooking and serving tasks. Further investigation of personal exposure assessment among catering staff, including investigation of health and

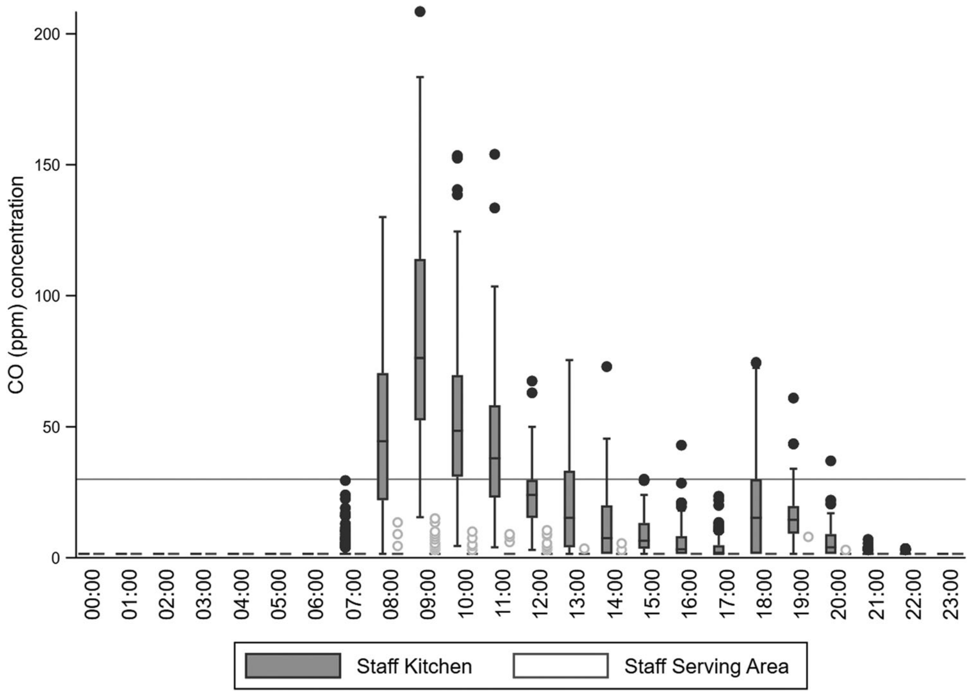

Figure 7. A box plot illustrating the average (meidan) hourly concentration of CO concentrations (ppm) in the staff serving area by working hour of the day (06:00–22:00). Boxes represent the interquartile range, with the middle line indicating the median. Outliers are illustrated with points. 30 ppm reference line denotes UK occupational standard. (Numerical tables in Appendix 2, Supplementary material).

Table 2. Descriptive Statistics by place of measurement per 8 and 11 hours.

8 hour average						
	Student kitchen			Student serving area		
	Mean	(SD)	(Min, Max)	Mean	(SD)	(Min, Max)
06:00–14:00	40.7	(40.0)	(1.5, 255.5)	4.5	(2.2)	(1.5, 17.0)
14:00–22:00	37.9	(31.5)	(3.0, 178.5)	7.0	(8.2)	(1.5, 41.5)
22:00–06:00	3.5	(3.6)	(1.5, 30.5)	1.7	(0.6)	(1.5, 4.5)
	Staff kitchen			Staff serving area		
	Mean	(SD)	(Min, Max)	Mean	(SD)	(Min, Max)
06:00–14:00	34.7	(35.8)	(1.5, 208.5)	1.7	(1.2)	(1.5, 15.0)
14:00–22:00	9.2	(11.2)	(1.5, 74.5)	1.5	(0.3)	(1.5, 8.0)
22:00–06:00	1.5	(0.1)	(1.5, 3.5)	1.5	(0.0)	(1.5, 1.5)
11 hour shift average						
	Student kitchen			Student serving area		
	Mean	(SD)	(Min, Max)	Mean	(SD)	(Min, Max)
06:00–17:00	38.0	(38.6)	(1.5, 205)	3.9	(2.4)	(1.5, 14.5)
09:00–22:00	43.5	(35.4)	(1.5, 223.5)	5.9	(6.6)	(1.5, 41.5)
	Staff kitchen			Staff serving area		
	Mean	(SD)	(Min, Max)	Mean	(SD)	(Min, Max)
06:00–17:00	25.0	(29.9)	(1.5, 128.5)	1.5	(0.4)	(1.5, 5.5)
09:00–22:00	20.3	(27.7)	(1.5, 180)	1.6	(0.8)	(1.5, 13.5)

Mean = Arithmetic Mean CO (ppm) concentration within the defined time period.
SD = standard deviation of the mean.
(Min, Max) = the minimum and Maximum CO (ppm) concentrations within the defined time period.

cognitive symptoms would provide more detailed understanding of the occupational risks of biomass fuel cooking in this setting.

Our findings indicate the need for effective and sustainable harm reduction strategies in catering environments using charcoal or wood fuel, such as through structural or behavioral modification or transition to a cleaner energy source (eg LPG). Transition would require financial investment and staff training and cultural acceptability, for instance, to address potential changes in food taste and logistical considerations for safe storage and usage.

Conclusion

Our findings indicate that charcoal and wood fuel combustion in this commercial catering setting in Rwanda was associated with 8-hour average kitchen CO concentrations which exceed WHO 8-hour IAQ guidelines and are of a hazardous level for human health. Further investigation of personal exposures and health impacts among catering staff would improve the evidence base concerning occupational exposure risks in this setting.

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Disclosure statement

The authors declare that they have no conflicts of interest

Author contributions

SEB and TK were responsible for developing the study design and provided oversight for data analyses and interpretation. Primary data collection was undertaken by KW, SEB and TK. KW undertook data analysis and production of draft manuscript. SEB, FDP, GNT and KB provided advice for data collection, statistical analyses and data interpretation, along with commenting on the draft manuscript. MP provided advice on statistical analyses. All authors have read and approved the manuscript for publication.

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