Contribution ID: **68** Type: **Poster**

Determinants of indoor ventilation rates in South African clothing and textile factory work spaces using low-cost CO2 sensors

Objective: Higher ventilation rates of work spaces are generally associated with reduced presence of airborne pathogens and improved health outcomes. The spread of respiratory pathogens such as SARS-CoV-2 and tuberculosis, as well as building-related illness are associated with poor air quality in specific work spaces. The clothing and textile industry is a large employer and important contributor to the economy in South Africa. This study investigated the environmental and workplace factors associated with poor ventilation in work spaces in South African textile factories.

Methods: Workplace health risk inspections and assessment of indoor air quality were conducted in the production areas, canteens, offices and boardrooms of 20 clothing and textile factories from May to December 2024. All factories, employing an average of 136 workers per factory, were located in the Western Cape province. Parameters measured in all areas included room depth (m), width (m), ceiling height (m), area (m2), ceiling height/depth, occupation density (person/m2), and the number of windows and doors in each space. Low-cost cloud-connected Airwits CO2 plus sensors (Connected Inventions Oy) were placed for two continuous days in the four work spaces of each factory to measure carbon dioxide (ppm), temperature ($^{\circ}$C), and relative humidity (%). In total, 56 measurements were obtained from all work areas. The CO2 monitoring devices were allowed to calibrate for 15 minutes each morning (06h00) before continuous readings over the two days were recorded. Monitors were placed at 1.5 m above the floor level. Data obtained from the inspections and the CO2 recordings were used to calculate per-person ventilation rates (L/s per person), which were natural log-transformed prior to analysis since the data was not normally distributed. Data analysis, including simple and multiple linear regression modelling used STATA 17.0 statistical computer software (StataCorp, College Station, Texas, USA). The end of shift (16h00) CO2, temperature, and relative humidity data collected on day 1 of monitoring was included in the analysis.

Results: A total of 20 clothing and textile factories underwent inspections and CO2 monitoring. Almost all factories were naturally ventilated (n=19), while one had work areas with both natural and mechanical ventilation. While all factories had a common production area (n=20), fewer factories had a separate or demarcated canteen (n=17), office (n=14) or boardroom (n=5).

In general the lowest CO2 levels were measured in the canteen (median: 506ppm, IQR: 465 - 595) while the highest measured CO2 levels were in the boardroom (median: 1560 ppm, IQR: 648 - 1631). There were 2 (10%) production areas, 2 (11%) canteens, 4 (29%) offices, and 3 (60%) boardrooms that exceeded the recommended 700ppm CO2 concentration limit value. On the other hand, per person ventilation rates ranged between 0.234 L/s per person and 0.697 L/s/person and were classified as being very low (< 5 L/s/per person) in 95% of work areas evaluated (n=53). Overall, production areas had better ventilation (median: 0.697 L/s per person, IQR: 0.328 - 2.021) compared to canteens (median: 0.234 L/s per person, IQR: 0.133 - 0.413), despite the canteens having the lowest CO2 levels. The occupation density was also lowest in production areas (mean: 0.128, SD: 0.082 occupants/m^2) and highest in canteens (0.406, SD 0.207 occupants/m^2).

Simple linear regression analysis revealed that person ventilation rates were positively associated with number of windows and doors (β= 0.1323, p<0.001) and negatively associated with occupation density (β=-1.1507, p=0.045). Working in the canteen relative to the production area was also negatively associated with person ventilation rates. In the final multivariate model, which adjusted for outdoor CO2, temperature and humidity, the major determinants of per person ventilation rates were working in the canteen (β=-0.6301, p=0.002), and the number of windows and doors (β=0.12961, p<0.001). This model explained 73% of the variability in the per person ventilation rates (AdjR2=0.73, p<0.001), but the occupation density in the factory was not statistically significant and therefore did not appear to be a major determinant.

Conclusion: This study has demonstrated that the poor design of work spaces such as canteens can significantly impact on indoor air quality in clothing and textile factories. Simple administrative measures such as increasing the number of windows and doors have the potential to significantly improve ventilation rates in different areas of the factory. The use of low cost CO2 sensors provide an important adjunct tool for assessing the adequacy of ventilation in these work spaces. It is anticipated that the study findings will contribute to the promotion of indoor air quality in clothing and textile factories and mitigate the risk of inhaling airborne pathogens.

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