

2018 ROOMVENT VENTILATION



FINNISH SOCIETY OF
INDOOR AIR QUALITY
AND CLIMATE

A!

Aalto-yliopisto



PROCEEDINGS

Roomvent&Ventilation 2018:
Excellent Indoor Climate and
High Performing Ventilation

Proceedings

Risto Kosonen
Mervi Ahola
Jarkko Narvanne
(Editors)

Table of Contents

Organisers and supporters	2
Foreword	5
Scientific Committee	6

PROCEEDINGS

TRACK 1 – PERSONAL CONDITIONS: THERMAL COMFORT (TC1)

Required Temperature Distribution Based on a Clothing Insulation and Metabolic Rate Survey, <i>Masanori Ukai</i>	13
Effects of Air Temperature Steps on Older People's Thermal Comfort and Skin Temperature, <i>Zi Wang</i>	19
A Study on the Influence of Environmental Adjustment Behaviour of Residents on the Thermal Environment Performance of Passive Town, <i>Sinwon Jeong</i>	25
An Experimental Study on Airflow Control to Improve Intellectual Concentration, <i>Soma Kawamoto</i>	31

TRACK 1 – PERSONAL CONDITIONS: THERMAL COMFORT (TC2)

Gender Difference in Diurnal Change in Psychological and Physiological Responses to Consistent Relative Humidity, <i>Naoshi Kakitsuba</i>	37
An Experimental Study on Integrated Thermal Control of Office Room and Break Room to Improve Intellectual Concentration, <i>Kimi Ueda</i>	43
A Preliminary Study of Optimal Thermal Comfort Criteria in a New Nv Office Building in Norway, <i>Niels Lassen</i>	49
Influence of Gender on Thermal Sensation and Comfort in Indoor Enironments with Displacement Ventilation, <i>Kai Rewitz</i>	55
Factors Influencing the Evaluation of Bed Thermal Environment, <i>Arsen Melikov</i>	61
Behavioural Adaptation Characteristics of Occupants in Urban and Suburban Parks, <i>Junta Nakano</i>	67

TRACK 1 – PERSONAL CONDITIONS: AIR QUALITY (AQ)

Evaluation of Residential Ventilation Accompanied with Indoor Particle Filtration, <i>Tengfei Zhang</i>	73
Emission of Chemicals After Experiencing Negative Pressure in Newly Built Detached Houses, <i>Hoon Kim</i>	79
Particle Transfer Through a Heat Wheel in a Highly Insulated Building, <i>Hans Martin Mathisen</i>	85
Water Vapour Mobilises Building Related Non-Volatile Chemicals and Mycotoxins and May Be Used to Remove Substances of Potential Health Hazard from Indoor Surfaces, <i>Panu Harma</i>	91
Study on IAQ of Residential Buildings Based on Site Investigation and Online Monitoring, <i>Yu Zhao</i>	97

TRACK 1 – PERSONAL CONDITIONS: DEMAND CONTROLLED VENTILATION (DCV)

Improvement of Supply Air Temperature Reset Control by Targeting ATF for VAV Systems, <i>Eikichi Ono</i>	103
Validation and Optimization of Air Quality Sensor Based Occupancy Detection Algorithms, <i>Felix Nienaber</i>	109
Control Procedure for Demand Controlled Ventilation Performance, <i>Mads Mysen</i>	115
The Influence of Indoor Air Flow on the Optimum Sensor Position, <i>Ralf Gritzki</i>	121
A Parametric Study of Adaptive Ventilation Strategy in Workspaces with Ductless Split Air-Conditioners, <i>S Shriram</i>	127
Demand Response of Space Heating and Ventilation - Impact on Indoor Environmental Quality, <i>Kristian Martin</i>	133

TRACK 1 – PERSONAL CONDITIONS: PERSONALIZED VENTILATION (PV)

Investigation of the Reliability of an Efficient Supply Air Control Method in Air-Cooled Data Centers with Aisle Containment, <i>Ken Jesse Lindenberg</i>	139
Computational Fluid Dynamics Simulations of Personalised Ventilation: The Effect of Distance and Temperature on Thermal Comfort and Air Quality, <i>Natalie Gilkeson</i>	145
Perception of Constant and Adjustable Cooling Jets in Warm Office Environment, <i>Henna Maula</i>	151
Characterization of Personal Comfort Systems by Means of Subjective Comfort Investigation, <i>Marco Perino</i>	157
Development and Evaluation of the Cool Chair 2016 Model, <i>Yusuke Dai</i>	163
Effect of Airflow Interaction on Temperature and Velocity at the Breathing Zone of Seated Person, <i>Eva Zavri</i>	169

Heat Transfer Enhancement of Free Convection Flows with Kármán Vortex Streets in Vertical 3d-Channels Heated from Two Sides, <i>Paul Mathis</i>	541
Warm and Cold Air Temperature Setpoints in Dual-Duct Ventilation Systems with Extract Air Recirculation, <i>Aleksandra Przydrozna</i>	547
Numerical Study on Energy Loss Through Door Open While Air Conditioner Running, <i>Sihwan Lee</i>	553

TRACK 3 – ENERGY AND VENTILATION: MODELS FOR VENTILATION AND ENERGY PERFORMANCE (VEP3)

Early Design Tool for Earth Tubes in Canada, <i>Sébastien Brideau</i>	559
Numerical Study of Thermal Performances of a House Equipped with Airflow Windows - Comparison to Conventional Double-Glazed Windows, <i>Ghislain Michaux</i>	565
Assessment of Modelling Techniques for Interzonal Air Exchange in the Context of Residential Dwellings., <i>Matthias Lux</i>	571
Preservation Risk Reduction by Adaptive Ventilation: The Case Study of Historical Fresco, <i>Michala Lysczas</i>	577
The Challenges of Ventilation in Buildings with Tight Envelope in Cold Climate, <i>Lari Eskola</i>	583

TRACK 4 – APPLICATIONS: NATURAL VENTILATION (NV1)

Tracer Gas Measurement of Natural Ventilation Systems: Impact of Unsteady Airflows, <i>Gabriel Remion</i>	589
General Wind Pressure Coefficient Database and Its Application for Estimation of Natural Ventilation Rate of Mid- to High-Rise Office Building, <i>Yoshiko Kawawake</i>	595
Methodology Approach for Natural Ventilation Potential Assessment at District Level in Tropical Climates, <i>Valentin Delplanque</i>	601
Validation of Steady Rans for Natural Ventilation Flow Through Louvered Window Openings, <i>Twan Van Hooff</i>	607
Simplified Estimation of Wind-Induced Natural Ventilation Rate Caused by Turbulence for a Room with Minute Wind Pressure Difference, <i>Tomohiro Kobayashi</i>	613
Evaluation of the Thermal Environment and Effect of the Natural Ventilation in the Green Building with Large Thermal Capacity, <i>Hiroshi Muramatsu</i>	619

TRACK 4 – APPLICATIONS: NATURAL VENTILATION (NV2)

Nydalen Vy: A Nearly Zero Energy Building in Norwegian Climate with Natural Ventilation, <i>Maria Myrup</i>	625
Indoor Air Quality and Health in Naturally Ventilated Residential Buildings in Nigeria, <i>Catherine J Noakes</i>	631
Simulation Study on Optimizing the Hygrothermal Condition of an Underfloor Ventilation Chamber, <i>Yoshinori Honma</i>	637
Condensation Prevention Algorithm Experiment by Controlled and Occupancy Situation, <i>June Hae Lee</i>	643
Experimental Evidence of Effective Single Sided Natural Ventilation Beyond 20ft or 2.5 Floor to Ceiling Heights in Open Plan Office Spaces, <i>Guilherme Carrilho Da Graça</i>	649
A Systematic Approach for Improving the Accuracy of Cross-Ventilation Airflow Calculation Using Adaptive Discharge Coefficient for Unsheltered and Sheltered Building Conditions, <i>Parham Mirzaei Ahranjani</i>	655

TRACK 4 – APPLICATIONS: HOSPITAL VENTILATION AND INFECTION CONTROL (HV1)

Operating Room Ventilation: CFU Concentration Measurements, <i>Aleksanteri Setälä</i>	661
Indoor Environment and Influenza Air-Borne Infection Risks in Facilities for the Elderly in Japan and Finland, <i>Motoya Hayashi</i>	667
The Influence of Indoor Air Distribution on Airborne Spread of Expiratory Droplet Nuclei Between Occupants: A Review and Some New Findings, <i>Zhengtao Ai</i>	673
A Numerical Study of an Operating Room Ventilation with Unidirectional Flow Ceiling, <i>Two Surgeons and a Patient</i> , <i>Laurentiu Tacutu</i>	679
Experimental Measurements of the Exposition to Exhaled Contaminants from Different Breathing Modes, <i>Félix Antonio Berlanga Cañete</i>	685
Influence of the Shape of Surgical Lamps on the Airflow and Particle Distribution in Operating Rooms, <i>Cong Wang</i>	691

TRACK 4 – APPLICATIONS: HOSPITAL VENTILATION AND INFECTION CONTROL (HV2)

Healthcare Worker Exposure to Patient Exhaled Airborne Contaminants in Hospital Isolation Rooms, <i>Petri Kalliomäki</i>	697
Use of a Live Vaccine Virus as a Tracer for Infection Control-Related Air-Sampling and Ventilation Studies, <i>Julian Tang</i>	703
CFD Simulation of Health Care Workers' Direct Exposure to Patient's Exhaled Air in Hospital Isolation Rooms, <i>Hannu Koskela</i>	709
Patients' Perception of the Thermal Environment in Selected Hospital Wards, <i>Anna Bogdan</i>	715
Door and Passage Induced Air Exchange Across Hinged Door, <i>Trond Thorgeir Harsem</i>	719
Influence of Air Distribution and Room Pressurisation on Air Velocity and Air-Change Effectiveness in a Bay-Designed Ward with Dedicated Outdoor Air System, <i>Majeed Oladokun</i>	725

INDOOR AIR QUALITY AND HEALTH IN NATURALLY VENTILATED RESIDENTIAL BUILDINGS IN NIGERIA

Oluwafemi K. Akande^{1, 2}, Marco-F King^{1*}, Catherine J. Noakes¹

¹School of Civil Engineering, University of Leeds, Leeds LS2 9JT, UK

²Department of Architecture, Federal University of Technology, Minna, Nigeria

*Corresponding email: M.F.King@leeds.ac.uk

SUMMARY

Bacterial Meningitis is a large-scale health problem in Sub-Saharan Africa, with up to 200,000 cases every year across 14 countries including Northern Nigeria (Basse et al 2009). There are suggestions that poor air quality, including in houses where numerous family members both congregate and sleep contribute negatively to infection transmission. According to the World Health Organisation, cities in Nigeria are considered the most polluted in the world with PM10 values regularly over thirty times recommended levels (WHO, 2016). The objective of this study is to investigate relationship between indoor air quality parameters, housing design and reported health of local residents.

Health questionnaires and overnight monitoring of CO₂, temperature, PM2.5 and PM10 were conducted in 115 houses separated into eight districts in Bauchi, central north-eastern Nigeria. Air quality parameters were measured using Airnode sensors (Airvisual, USA) whose CO₂ values were calibrated against a Rotronic CL11 (Rotronic, BSRIA, Bracknell, UK). Questionnaires included demographics, reported health issues and symptoms and operation of the building. A building audit recorded room and window sizes, location and orientation and aspects such as cooking fuel sources.

Preliminary results suggest that buildings tend to be well ventilated, with average CO₂ levels in bedrooms rarely surpassing 1000ppm over an eight-hour period. Houses were often in fenced compounds or a courtyard design so inhabitants could safely leave their windows open. On the other hand, PM10 values often surpassed 1000µm/m³ and PM2.5 ranged from 10 to 1800µm/m³. Analysis will be reported to correlate the indoor air measurements to the occupant survey. Pending health survey analysis, a simplified tick-box style questionnaire framework could, in future, provide a meningitis risk analysis tool for local healthcare workers based on building type and window size assessment. This could potentially dispense with lengthy health questionnaires or environmental monitoring.

Keywords: indoor air quality, health, natural ventilation, residential buildings, meningitis

1 INTRODUCTION

Urbanization is a global phenomenon rapidly occurring in developing countries such as Nigeria; a lower-middle-income and Africa's most populous country (approximately 193 million). Within these populations, the poorest socioeconomic groups of about 50.2 per cent of its urban populace disproportionately suffer from inadequate supply of urban housing thereby living in slums (UN-Habitat, 2016). Consequently, this has led to growing millions of sub-standard/poorly design houses resulting in ill-health of most occupants. Natural ventilation and indoor air quality in millions of the houses are often poor, resulting in the prevalence of airborne disease transmission. Among the health related problems is the prevalence and incidence of increasing meningitis outbreaks. The World Health Organisation (WHO) estimates that at least 1.2 million cases of bacterial meningitis occur each year out of which 135,000 are fatal (Rouphael *et al.*, 2012; Jafri *et al.*, 2013). In 2017, a total of 14,513 cases with 1,166 deaths were reported particularly in Northern Nigeria. Although part of the efforts to prevent meningitis outbreak was reactive vaccination however, the immunization strategy for meningitis control is insufficient to reduce the burden of the disease. Further, the prevention of the disease is also faced

with challenges of insufficient funding for vaccine supply and unaffordability of multivalent conjugate vaccines making them not routinely available (McVernon *et al.*, 2004a, b; Segal and Pollard 2004). Despite significant advances in vaccine administration and the gains achieved from meningitis control through immunization strategy interventions, little still is known about the dynamics of the indoor environment and building characteristics influencing the transmission of meningitis leaving an enormous unmet public health's need.

According to Kembel *et al.*, (2012) buildings are complex ecosystems that house trillions of microorganisms interacting with each other, with humans and with their environment. Previous work on indoor air in buildings shows that poor indoor air quality contain various bacteria, viruses, and fungi leading to increase the risk of infections (Emmenlin, 2007; Kovesi, *et al.* 2007; Ishihama *et al.*, 2009). WHO (2005) identified indoor air quality as the eight most important risk factor and responsible for 2.7% of the global burden of disease. Similarly, poor ventilation, accumulation of biological pollutants, and infection potential have been reported to seriously deteriorate indoor environments (Graudenz *et al.*, 2005). The indoor air quality causes more concern as places are crowded with people are at risk of spreading diseases caused by airborne bacteria. Although several studies demonstrates the significant health impact of housing and socioeconomic characteristics on the burden of meningitis and other diseases in developing countries; most studies failed to investigate association between indoor air pollutants and building characteristics and infectious diseases risks such as meningitis outbreak. This paper seeks to address this knowledge gap; it aims to investigate relationship between indoor air quality parameters, housing design and reported health of local residents living in naturally ventilated residential buildings (NVRBs) in Nigeria.

2 METHODS

2.1 Study design and population

This study employed a cross-sectional study design that reflected in the data collection methods. It involves a household survey, building audit, PM and CO₂ monitoring. The study took place in a low income urban setting of area of Bauchi metropolis, Northern Nigeria (Figure 1). One hundred and fifty (150) households were invited to participate and 115 agreed to take part in the study. All the 115 consented for indoor air quality monitoring. Approval for the study was granted by the University of Leeds Research Ethics Committee, United Kingdom and a signed informed consent was obtained from each participating household. The cross-sectional survey was conducted between 13th and 31st October 2017.

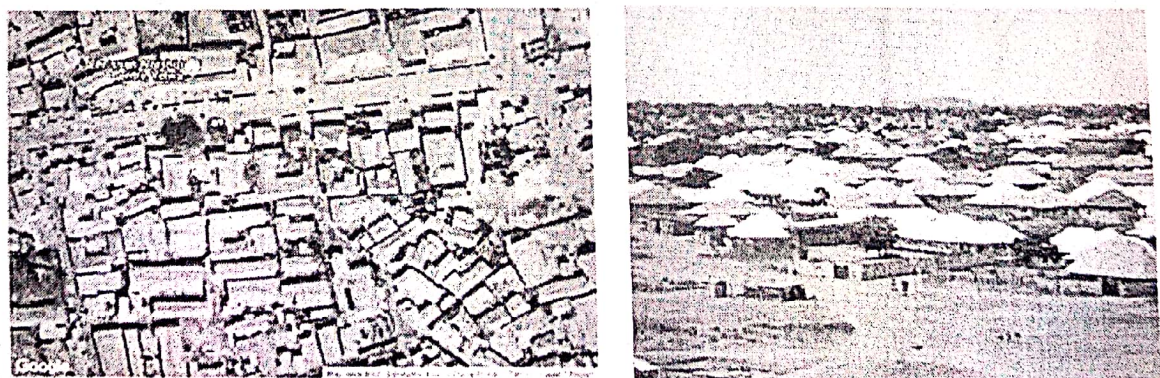


Figure 1. Area map and photographic view of the study area showing the residential layouts

2.2 Data collection

Households were randomly selected and a health questionnaire developed by the researchers was administered to the head of the household. The survey was carried out with the help of local community health workers and architectural technologists recruited and trained to administer the questionnaire in English and local language. The questionnaire consisted of two sections. Section one collected demographic data and information on household's health such as their experience of Tuberculosis (TB), Meningitis, Measles, and Chicken pox, Influenza, Asthma, Pneumonia and Malaria along with their symptoms in the last 5 years. Section two gathered information related to the building design characteristics (e.g. room and window sizes, window location and orientation etc.) and operation of the building by the occupants such as cooking fuel sources, indoor smoking and alternative source of lighting at night in the absence of electricity. Overnight monitoring of CO₂, temperature, PM_{2.5} and PM₁₀ were conducted in all the houses from eight neighborhoods. Air quality parameters were measured using Airmode sensors (Airvisual, USA) whose CO₂ values were calibrated against a Rotronic CL11 (Rotronic, BSRIA, Bracknell, UK). The environmental samplers were placed from a height of 1.3 m above the floor. Microsoft Excel 2010 was used to record, store, and organize all survey results and PM measurement data.

2.3 Statistical methods

In this study, incidence of occupant's health complaints were the main outcomes and were recoded as binary variables (1 = Yes for diseases/symptoms, 0 = No for disease/symptoms). Independent variables such as including housing design characteristics, building operation, PM and CO₂ variables were analysed using descriptive statistics generated for the outcome and independent variables. Bivariate analyses, including cross-tabulations and chi-squares tests, were performed for assessing unadjusted associations between the independent variables and the reported diseases/symptoms as outcome variables. As the current study is cross-sectional with common occurred health outcomes, a multivariable regression analysis to examine the adjusted association between diseases/symptoms and housing design characteristics and operation and PM and CO₂, were conducted. The multivariable modelling was carried out reporting in the paper variables found to be significantly associated with the health outcomes in the univariate analysis with $p < 0.05$. In each model, the goodness of fit (Nagelkerke R² value) and significance were evaluated. A Fisher exact or χ^2 test was used for categorical variables. Further analyses of significant results involved calculating raw odds ratios (ORs) and 95% CIs. Statistical analysis was performed using the IBM SPSS Version 23.0 for windows. The critical level of significance of 5% for all statistical tests (two-tailed) was used in this study.

3 RESULTS

The majority (47.6%) of the respondents in this study had a monthly income less than N20,000 (\$50) (i.e. about \$ 1.25 per day) for a household with an average size of four family members in Nigeria. About 50% of the households use kerosene (0.7%), firewood (24.6%), charcoal (2.6%) and combination of the three (14%) for cooking purposes in the house. These produces more toxic fumes than other energy types (e.g. electricity and gas). Elevated concentrations of PM were observed in most (79.5%) of the houses. The mean concentrations of PM_{2.5} ($63 \mu\text{m}/\text{m}^3$) and PM₁₀ ($228 \mu\text{m}/\text{m}^3$) ranged from $10 \mu\text{m}/\text{m}^3$ - $231 \mu\text{m}/\text{m}^3$ (PM_{2.5}) and $20 \mu\text{m}/\text{m}^3$ - $1667 \mu\text{m}/\text{m}^3$ (PM₁₀). This result demonstrates that the majority of the households were exposed to higher than the WHO guideline value of $25 \mu\text{m}/\text{m}^3$ and $50 \mu\text{m}/\text{m}^3$. The mean concentrations of CO₂ (584 ppm) indicated that the ventilation was adequate having a range from 403ppm - 2201ppm. The mean temperature (28.9 °C) slightly exceeded the ASHRAE (2014) recommended guideline values (21°C - 26°C) and while the relative humidity (40.7%) is within recommended guideline values (30%-70%). Results from the analysis carried out found weak positive correlations between PM_{2.5} the main building orientation and orientation of window opening). Meanwhile, weak negative relationship was found between PM_{2.5} and the type of housing unit, type of window, window size and other variables such as type of cooking fuel, main source of lighting and size

of household. In the case of PM₁₀, weak positive relations were observed with only the main building orientation, orientation of window opening and other variables such as type of cooking fuel and main source of lighting. For CO₂, weak positive relationship were only noted for main building orientation and type of housing unit. PM_{2.5}, PM₁₀ and CO₂ were subjected to Point Biserial Correlation with the reported ailments (Table 1). Findings shows that PM_{2.5} was negatively correlated to the occurrence of most of the ailments but was positively correlated to TB, meningitis and chicken pox. However, none of the relationship has p-value less than 0.05; thus not significantly correlated to PM_{2.5}.

Table 1: Correlation between PM_{2.5}, PM₁₀, CO₂ and incidence of health complaints.

Variables	Participants' Responses	F	%	PM _{2.5}		PM ₁₀		CO ₂		Remarks	
				R _{pb}	Sig	R _{pb}	Sig	R _{pb}	Sig	No response	Total
Tuberculosis	No	63	45.3	0.093	0.452	0.097	0.431	-0.047	0.703	48	116
	Yes	5	4.3								
Pneumonia	No	52	44.8	-0.080	0.510	-0.044	0.714	0.136	0.257	45	116
	Yes	19	16.4								
Asthma	No	63	54.3	-0.074	0.541	-0.068	0.577	0.085	0.482	46	
	Yes	7	6.0								
Meningitis	No	52	44.8								116
	Yes	16	13.8	0.050	0.683	0.003	0.982	-0.008	0.948	48	116
Measles	No	48	41.4								116
	Yes	19	16.4	-0.35	0.777	-0.114	0.360	0.113	0.362	49	
Chickenpox	No	49	42.2								116
	Yes	24	20.7	0.177	0.133	0.285	0.014	0.081	0.494	43	
Influenza	No	28	24.1								116
	Yes	55	47.4	-0.115	0.299	0.055	0.622	-0.161	0.146	33	
Malaria	No	3	2.6								116
	Yes	100	86.2	-0.072	0.470	0.022	0.827	-0.008	0.939	12	

Similarly, PM₁₀ was negatively correlated to the occurrence of Pneumonia, Asthma and Measles but positively correlated to the incidence of other reported ailments. In most of the cases none of the relationship has its p-value less than 0.05 except for chicken pox where $R_{pb} = 0.285$, $p < .05$. This implies that most of the disease occurrences are not significantly correlated to PM₁₀ except for Chicken pox. The result for CO₂ is also similar to PM_{2.5}. The occurrences of some of the ailments were negatively correlated with CO₂ while others were positively correlated with none of the correlation values possess values less than 0.05 and hence are not significant. The building characteristics were cross-tabulated with the incidence of the reported diseases to explore the association between them; Chi-square values and Fishers' exact test were computed at 0.05 level of significance. The results show that the main building orientation is significantly associated with the incidence of Measles ($p < 0.02$), Meningitis ($p < 0.03$) and TB ($p < 0.04$). Meanwhile the building floor materials are significantly associated with Meningitis ($p < 0.01$), Measles ($p < 0.02$) and influenza ($p < 0.002$) the materials used for floor covering. Their odds ratio are less than 1 implying that as the floor material improves from earth, wood, cement and to rug, the odds of incidence of the three ailments are reduced. Meanwhile, logistic regression analyses of the diseases along with indoor air quality shows no relationship with CO₂. However, PM₁₀ shows significant relationship with chicken pox (Wald = 4.029, $p = .045$) and Influenza (Wald = 4.002, $p = .045$); while PM_{2.5} (Wald = 6.263, $p = 0.012$) is significantly related to Influenza. Similar result was found with the number of bedrooms available in the building. PM₁₀ shows significant relationship with chicken pox (Wald = 3.890, $p = .049$) and Influenza (Wald = 3.987, $p = .046$); while PM_{2.5} (Wald = 5.726, $p = 0.017$) only show significantly relationship with Influenza.

4 DISCUSSION

This cross-sectional survey is a pilot study employed to uncover the prevalent factors in NVRBs design associated with PM, CO₂ and occupant's health with particular reference to meningitis and other diseases. In this study, elevated indoor concentration of PM was recorded and the possible explanation for this could be as a result of source of energy used by the households for cooking (i.e. firewood, charcoal and kerosene). Other major particle sources could also have been from the use of candles for lighting, unpaved roads and lack of green areas around the buildings. Although this study did not measure PM over a long-term period, however, the levels of PM within the buildings exceeded the WHO Guidelines (i.e. 24-h mean) for PM_{2.5} (25µg/m³) and PM₁₀ (50µg/m³) respectively. Surprisingly, this study did not find any significant association between the elevated PM in the indoor environment and several reported illness except for Chicken pox and influenza. This agrees with the findings of Bruce (2000) that most studies from developing countries failed to demonstrate a significant association between indoor air pollutants and certain illnesses. This is due to some reasons such as methodological limitations and small sample size to detect a strong association between the variables investigated; this the authors believe is the case in the current study. Other possible limitations that could have also affected the results is the fact that indoor air quality and CO₂ was monitored between 8-12hr in contrast to 24hr recommended by WHO. Further, findings in this study also suggests the buildings tend to be well ventilated, with average CO₂ levels in bedrooms rarely surpassing 1000ppm. This reason for this could be as a result of multiple interacting factors such as the way the occupants operated their buildings, many houses are within a secured fenced and around a courtyard. This allows households to leave their windows opened for long hours both night and day. This behaviour is common especially with occupants of NVRBs in Nigeria due to its tropical climate. Hence, PM from biomass and kerosene used in the buildings could become easily diluted by natural ventilation thereby reducing its effect on occupant's health. While at the same time the ambient air pollution from the surroundings could adversely impact indoor air quality.

5 CONCLUSIONS

This pilot study demonstrates association between certain building characteristics (i.e. the building orientation, wall and floor materials, housing type and number of rooms) as potential risk factors in NVRBs for certain diseases (i.e. Meningitis, Measles, Chicken pox and Influenza). Meanwhile, the PM were associated with Chicken pox and Influenza. Findings from this study can be used for future intervention studies. However, a large-scale with large sample size is recommended along with continuous measurements of indoor PM and CO₂. This is essential to capture the full range of air quality measurements and their association with occupant's health outcomes over time and space. Intervention studies have proved that poor indoor air quality can be improved significantly by using different intervention strategies such as improved ventilation through enlarged windows and introducing chimneys and smoke hoods into the kitchen design. Such intervention studies could improve scientific basis for developing a simplified tick-box style assessment framework, which in future could provide a meningitis risk analysis tool for local healthcare workers based on building type and window size assessment. This could potentially dispense with lengthy health questionnaires or environmental monitoring.

ACKNOWLEDGEMENTS

The authors thank the Africa Research Excellent Fund (AREF) for providing a developmental fellowship to Dr Akande to carry out this study.

REFERENCES

- ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) (2014). Thermal Environmental Conditions for Human Occupancy. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 2014, Standard 55-2013. Available online: <https://www.ashrae.org/standards-research-technology/standards-guidelines>
- Bassey, E B, Vaz, R G et al (2009) Pattern of the meningococcal meningitis outbreak in Northern Nigeria, 2009. *International Journal of Infectious Diseases*, 43: 62-67
- Bruce, N, Perez-Padilla, R, Albalak, R. (2000). Indoor air pollution in developing countries: A major environmental and public health challenge. World Health Organization. *Bull World Health Organ*. 78, 1078–1092.
- Emmenlin, A, and Wall, S (2007). Indoor Air Pollution: a Poverty-Related Cause of Mortality among the Children of the World; *Chest*: 132. 1615-1623.
- Graudenz, G S, Oliveira, C H, Tribess, A, Mendes, C, Jr, Latorre, M R, Kalil, J. (2005) . Association of Air-Conditioning with Respiratory Symptoms in Office Workers in Tropical Climate; *Indoor Air*. 15, 62-66.
- Ishihama, K, Koizumi, H, Wada, T, Tanaka, I S, Yamanishi, T, Enomoto, A. (2009). Evidence of Aerosolized Floating Blood Mist during Oral Surgery; *J. Hosp. Infect.* 71, 359-364.
- Jafri, R Z., Asad, A, Nancy, E, Messonnier, C, Tevi-Benissan, D, Durrheim, J E, Florence, F, Keith, P K, Mary, R, Samba, S, Shao, Z, Zulfiqar, A B, Jon, A. (2013). Global epidemiology of invasive meningococcal disease. *Popul Health Metr.* : 11: 17.
- Kembel, SW, Jones, E, Kline, J, Northcutt, D, Stenson, J, Womack, A M, Bohannon, B, Brown, G Z, and Green, J L. (2012). Architectural design influences the diversity and structure of the built environment microbiome. *The International Society for Microbial Ecology (ISME) Journal* (2012) 6, 1469–1479
- Kovesi, T, Gibert, N L, Stocco, C, Fugler, D, Dales, R E, Guay, M, Miller, J D (2007). Indoor Air Quality and the Risk of Lower Respiratory Tract Infections in Young Canadian Inuit Children; *CMAJ*. 177, 155- 160.
- McVernon, J, Howard A J, Slack, M P, Ramsay, M E. (2004). Long-term impact of vaccination on Haemophilus influenzae type b (Hib) carriage in the United Kingdom. *Epidemiol Infect.* : 132:765–767.
- McVernon, J, Trotter C L, Slack, M P, Ramsay, M E. (2004). Trends in Haemophilus influenzae type b infections in adults in England and Wales: surveillance study. *BMJ.* : 329:655–658.
- Rouphael, N G and Stephens D S. (2012). Neisseria meningitidis: biology, microbiology, and epidemiology. *Methods Mol Biol.*; 799:1–20.
- Segal, S, and Pollard, A J (2004). Vaccines against bacterial meningitis. *Br Med Bull.*; 72:65–81. UN-Habitat The United Nations Human Settlements Programme (2016). Participatory Slum Upgrading Programme (PSUP – UN-Habitat): Available at: <http://unhabitat.org/initiatives-programmes/participatory-slum-upgrading/>
- WHO (2005) Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulphur Dioxide; World Health Organization: Geneva, Switzerland.
- WHO, (2016) Global Urban Ambient Air Pollution Database http://www.who.int/phe/health_topics/outdoorair/databases/cities/en/