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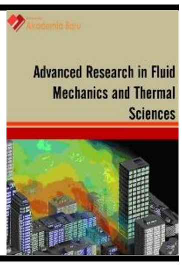

Assessments on the Effect of Ventilation System Associated with Children Respiratory Symptoms in Child Care Centers

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ABSTRACT

The aim of this paper is to report the findings of indoor air quality study at childcare centers in Malaysia. Modified American Thoracic Society and the Division of Lung Diseases (ATS-DLD-78) questionnaire was used to gather information from parents regarding their children's respiratory symptoms. IAQ parameters were measured for air temperature, humidity, carbon dioxide, carbon monoxide, respirable particles (PM2.5), bacteria, fungi and air change rate. CCC characteristics were collected via inspection and interviews. Multivariable analysis on respiratory symptoms showed significantly high risk among those attending ACMV CCCs. Significant symptom was persistent cough AOR: 3.20 (CI: 1.03; 9.96)] and productive cough with phlegm) AOR: 5.56 (2.21; 14.20). The amount of ventilation rates determine in this study was 2.3±1.6L/s/person and the air exchange rate for ACMV CCCs at children breathing zone was 5.1 ACH.

1. Introduction

The quality of indoor air is a major public health concern because most of us spend more than 90% of time in buildings. Preschool children (age three months to four years) with working parents spend a considerable amount of 40 to 50 hours a week in childcare center [1-2]. In comparison to adults, children breathe twice the amount of air per kilogram of body weight as they have a larger lung surface area to the body weight ratio [3]. There is increasing evidence demonstrating the role of indoor air pollutants and respiratory diseases in children in developed countries [4].

Research on IAQ involve a multidisciplinary group of scientists with various study methods consisting of cross-sectional, case-control, experimental and numerical simulations. Intervention and experimental studies basically focus on manipulating the ventilation rates [5-8] and impacts of indoor air pollutants, health, performance and economic benefits. The simulation study conducted in office building [9], test chamber [10] and childcare center (CCC) [11] was mainly to validate the experimental data. In addition, simulation studies were conducted in various conditions such as office

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building [12], home [13], hospital [14], food plant [15], CCC [11], aircraft cabin [16] and Museum and church [17]. Effective scientific approach for ventilation studies is still a combination of experiment, theory and simulation. This research investigates indoor air quality (IAQ), children respiratory symptoms, ventilation rate and air change rate focus on CCC.

In Malaysia, childcare centers operate in various type of building and ventilation system. In modern buildings the building zone has changed dramatically from natural ventilation building in the past to mechanical ventilation. Despite numerous studies that has associated indoor air quality and children's health, there are still limited number of investigations on the ventilation effect on children breathing zone at CCC served by centralized air conditioning and mechanical ventilation. Due to the increasing number of children attending CCC, with an estimate of 300% by 2020, the effect of centralized ACMV on IAQ and children's health could have a significant impact on public health, productivity and economy.

2. Methodology

From the Social Welfare Department (SWD) database of 103 registered CCCs in Putrajaya, 30 CCCs (30%) were randomly selected with the assumption that CCCs at the workplace would be using ACMV. The modified questionnaire from the American Thoracic Society and the Division of Lung Diseases (ATS-DLD) of the National Heart, Lung, and Blood Institute, [18] was used to gather information on respiratory symptom of children attending CCCs and building characteristic. Children's parents or guardian were requested to answer the questionnaire.

2.1 Monitoring and Biological Sampling

Monitoring surveys were carried out during routine school activities (from 8.00am to 5.00pm). The parameters in this study included air temperature, relative humidity, carbon dioxide (CO_2), carbon monoxide (CO), total volatile organic compound (TVOC), formaldehyde, particulate matter ($PM_{2.5}$), bacteria and fungi count. Indoor air temperature and relative humidity data were measured continuously using battery-operated HOBO U12-02 data loggers with internal sensors. The HOBO loggers were interfaced with CO_2 monitor, which utilized non-dispersive infrared principle for tracking CO_2 level and ventilation indicator purposes. Fine particle mass concentration ($PM_{2.5}$) was measured using TSI Model 8534 DusTrak RX aerosol monitors. TVOC was measured with TSI velocicalc multi-function ventilation meter 9565 with pre-calibrated 985 probe and carbon monoxide (CO) measurement was made using EVM7 environmental monitor. Formaldehyde (HCHO) was measured using formal Demeter htV-m.

Modified NIOSH Manual and Analytical Method (NMAM 0800) [19] was used as the sampling method for total bacteria and total fungi. Anderson single stage sampler was used as the equipment to measure microbiological samples.

2.2 Ventilation Measurement

Ventilation rates were determined using duct traverse by the log-Tchebycheff (log-T) rule with a minimum of 25 measurement points inside the outdoor air intake duct [20]. Multi-function ventilation meter VelociCalc®, 9565 with thermoanamometer probe, 964 were used for duct traverse measurement. For naturally ventilated buildings, measurement of CO_2 was conducted at children breathing zone throughout the day using EVM7 environmental monitor. CO_2 was used in this experiment as the tracer gas. The air exchange rate measurements with decay method [21] conducted in an infant room with volume of 40.5m^3 in accordance with modified standard method ASTM E741 [22]. The room is mechanically ventilated using a fan coil unit with provision of fresh air and located at the last diffuser of the system.

The measurement of CO_2 concentration was carried out at two different heights (adults and child's average height). This method is based on the continuity equation as seen in Eq. 1.

$$V\frac{dC}{dt} = F(t) + N(t)\cdot C_{oa} - N(t)\cdot C(t) \quad (1)$$

where, V = the volume of the air in the room (m^3), C = the tracer gas concentration in the room air (m^3/m^3),
$F(t)$ = the rate of introduction of tracer gas in the room (m^3/h), C_{oa} = the concentration of tracer gas in outdoor air (m^3/m^3) and $N(t)$ = the air flow through the room (m^3/h).

The air change rate, N, was estimated by dividing the flow rate through the compound by its volume, with the assumption that C_{oa} = 0. Three sampling location were used in this experiment: two inside the room and one sampling located outside for the ambient CO_2 concentration. Concentration of CO_2 have been recorded by using Telaire 7001 attached with HOBO data logger.

2.3 Statistical Analysis

The collected data on building survey, measured IAQ parameters and children respiratory symptoms were analyzed using statistical package SPSS version 20. The questionnaire data were initially analyzed by cross-tabulation and evaluated where appropriate; Odds ratio and multiple regression analysis were used to calculate crude and adjusted risk. All tests were statistically significant at $p \leq 0.05$.

3. Results and Discussion

Among the 103 registered CCCs at Social Welfare Department, 31(30.0%) CCCs were randomly selected with all CCCs agreed to participate in questionnaire survey. Respondents consisted of 338 (54.5%) male and 282 (45.5%) female. Table 1 shows the current prevalence of respiratory symptoms of children attending CCCs. The highest percent of children's experience were cough and/or cold (53.9%), followed by wheezing (38.2%) and cough with phlegm (28.7%). Persistent cough and/or cold (≥4 days per week within 12 months), persistent cough with bring up phlegm and persistent wheezing (more than 3 months) were 31.1%, 28.7% and 11.2% respectively. We employ the multiple logistic regression for each symptom to determine the significant covariates. Table 2 present risk of respiratory symptoms among children attending CCC with different ventilation system. Multivariable analysis on respiratory symptoms showed significantly high risk among those attending ACMV CCCs. Significant symptom was persistent cough AOR: 3.20 (CI: 1.03; 9.96)] and productive cough with phlegm) AOR: 5.56 (2.21; 14.20). Results are consistent with previous studies by [2, 23] that a high prevalence productive cough experience child attending ACMV CCCs.

Table 1
Frequency of respiratory symptoms

Variable		*n*	%
Cough and/or cold	Yes	334	53.9
	No	286	46.1
Prevalence cough and/or cold	Yes	193	31.1
(≥4 days per week in 3 months)	No	427	68.9
Productive cough	Yes	178	28.7
	No	422	71.3
Prevalence cough with phlegm	Yes	126	20.3
(≥4 days per week in 3 months)	No	494	79.7
Wheezing or whistling	Yes	237	38.2
	No	383	61.8
≥3 month (wheezing)	Yes	68	11.2
Day/night(wheezing)	Yes	199	32.1
	Nocturnal	44	7.1
Wheezing until short of breath	Yes	73	11.8
	No	547	88.2
Wheezing attack during play	Yes	16	2.6
	No	604	97.4
Ear infection (external)	Yes	54	8.7
	No	566	91.3
Frequency (Ear infection)	1-2 times	41	6.6
	2-5 times	10	1.6
	≥5 times	3	0.5
Positive asthma	Yes	25	4.0
	No	595	96.0
Current asthma	Yes	14	2.3
	No	606	97.7
On medication(asthma)	Yes	11	1.8
	No	609	91.2
Pneumonia(hospitalized)	Once	48	7.7
	Twice	8	1.3
	3 times	3	0.5
Been kept in hospital after born	Yes	73	11.8

N=620

Table 2
Risk of respiratory symptoms among children according to childcare center (CCC) ventilation system

	Adjusted odd ratio and 95% confident interval		
	NV	ACMV	AC
Frequent cough and/or cold	1.00	0.73(0.09; 6.00)	1.48(0.89; 2.48)
Persistent cough	1.00	3.20(1.03;9.96)*	2.33(0.91;5.97)
Productive cough (cough that bring up phlegm)	1.00	5.56(2.21;14.20)*	2.29(0.90;5.85)
Persistent productive cough	1.00	0.78(0.06;10.42)	1.37(0.53;3.54)
Wheezing or whistling	1.00	1.06(0.34;3.27)	0.82(0.63;0.71)

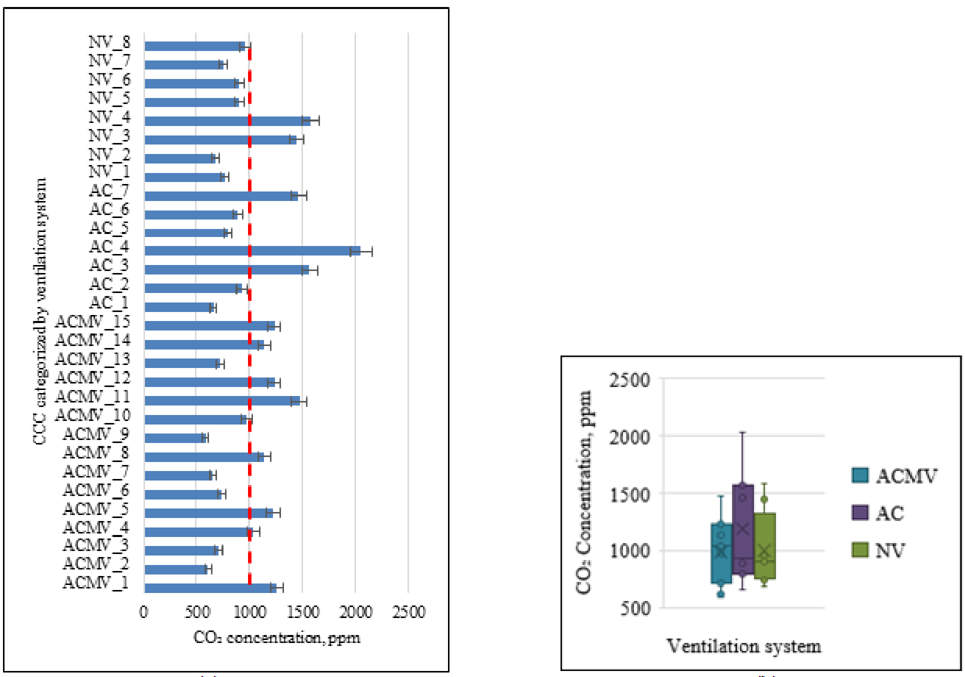
NV, natural ventilation; ACMV, air conditioning and mechanical ventilation; AC, air-conditioning

Model were adjusted for sociodemographic characteristic (gander; female, age; ≥ 4 years, parent income, ETS exposure), building characteristic (CCC location; house, provision of fresh air, type of building; low-rise, floor area per child; ≥ 3.5m^2, operable window and exhaust fan) and selected indoor air quality parameter (Temperature; ≥24°C, RH; 35-65%, CO_2; <1000 ppm, CO < 1 ppm, TVOC ≤ 3 ppm, Total bacteria; ≤ 500 CFU/m^3, Total fungi; ≤ 100 CFU/m^3 and $PM_{2.5}$≤25 µg/m^3).

3.2 Ventilation Rate and Air Exchange Rate

Figure 1(a) shows the indoor CO_2 concentration in 30 CCCs categorized by ventilation system while boxplot illustrated in Figure 1 (b) showed there was no statistical significance in the level of CO_2 concentration between CCCs with different ventilation system. Mean CO_2 concentrations were 981, 1190 and 996 ppm for ACMV, AC and NV CCCs respectively. The mean concentration of CO_2 in AC CCCs exceeds local guideline of 1000 ppm [24]. Among the 30 CCCs surveyed, about 43% CO_2 exceeded this threshold limit for the 8 hours mean values. The differences in indoor concentrations between groups of CCCs were not significant. The mean ventilation rate in ACMV CCCs is 2.3±1.6L/s/person. Result of environment and indoor air quality parameters measured for the childcare centers served by ACMV are as shown in Table 3. Figure 2 (a) shows ventilation rates in 30 CCCs with only 1 NV CCC which recorded a reading of 7.0 L/s/person closed to recommended ventilation rate in *The* ASHRAE Standard 62.1 2010 while the boxplots illustrated in Figure 2 (b) shows ventilation rates in three ventilation groups. To our knowledge, there was no standard ventilation available for childcare center in Malaysia. As compared to ASHRAE standard 62.1, ventilation rates in CCCs in this study were unacceptable.

Air exchange rate was determined using tracer decay method with carbon dioxide (CO_2) as a tracer gas in. In this CCC, the initial indoor CO_2 concentration was 523 ppm and outdoor CO_2 was 347 ppm. Figure 3 (a) shown the CO_2 concentration against time for CCC with centralized air-conditioning ventilation. It was found that CO_2 concentration at children breathing zone was higher compared to adult breathing zone. From the graph, air change at adult's breathing zone was about 5.1 ACH which is slightly lower than the ACH at children's breathing zone as shown in Figure 3 (b). Since the gap between measured (2.3±1.6L/s/person) and calculated (7.5±2.0L/s/person) ventilation rates was quite significant, increasing intake of outdoor air might be the most reasonable suggestion. Result of environment and indoor air quality parameters measured for the childcare centers served by ACMV can be referred to Table 3.



(a) (b)

Fig. 1. CO_2 concentration. (a) Concentration at 30 CCCs and (b) Categorized by ventilation system

Table 3
Environment and indoor air quality parameters measured for the childcare centers served by ACMV

Air Quality Parameter	ACMV N=15	Reference
Physical characteristic		
Temperature (°C)	23.8±1.2	[a]23-26
Relative humidity (%RH)	56.8±6.8	[a]35-65
Dew point (°C)	15.3±1.7	[b]≤12.8
Ventilation rate (L/s/person)	2.3±1.6	*7.5±2.0
Air exchange rate (ACH)	2.3±2.5	-
Chemical characteristic		
Carbon dioxide (ppm)	981±287	[a]1000
Carbon monoxide (ppm)	0.36±0.57	[a]10
Volatile Organic Compound (ppm)	0.156±0.147	[a]3
Formaldehyde (ppm)	0.018±0.015	[a]0.1
Airborne constituent		
Airborne bacteria (CFU/m³)	1097±737	[a]500
Airborne fungi (CFU/m³)	129±114	[c]500
Particulate matter, $PM_{2.5}$, (µg/m³)	18.8±15.3	[d]25

*Calculated based on ASHRAE STD 62.1.
[a]DOSH. (2010). Industry Code of Practice on Indoor Air Quality, Malaysia.
[b]Harriman, L. G., & Lstiburek, J. W. (2009). *The ASHRAE guide for buildings in hot and humid climates*: American Society of Heating, Refrigerating, and Air-Conditioning Engineers Atlanta.
[c]ASHRAE. (2013). ANSI-ASHRAE Standard 62.1-2013 Ventilation for Acceptable Indoor Air Quality.
[c]Heseltine, E., & Rosen, J. (2009).
[d]*WHO guidelines for indoor air quality: dampness and mould*: WHO Regional Office EuropeWHO. (2005). WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Geneva: WHO Press, World Health Organization.

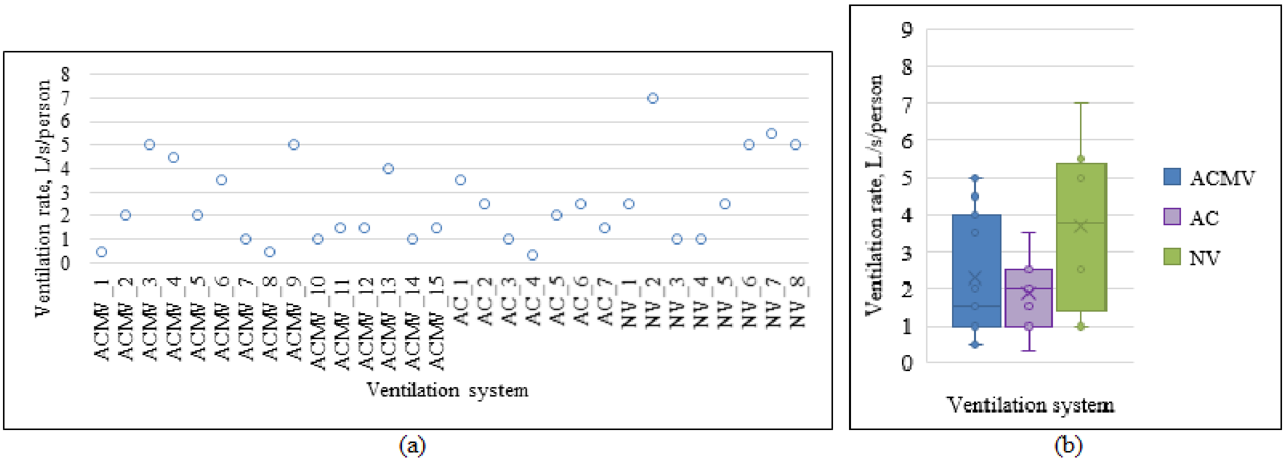


Fig. 2. Ventilation rate. (a) Ventilation rate at 30 CCCs and (b) Categorized by ventilation system

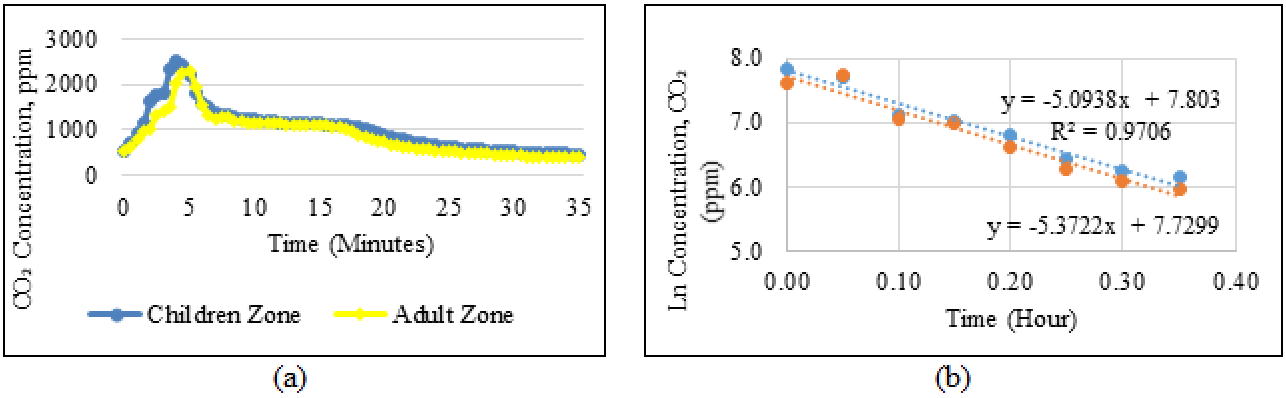


Fig. 3. 0 CO_2 concentration vs time. (a) Adult and Children breathing zone and (b) Logarithmically plot at 0.2m (children breathing zone) and at 1.5m (adult breathing zone)

A method of estimating ventilation rates also different, such as measuring exhaust air flows, decay method. The measurement of ventilation rates is important. Calculating outdoor air flow rates from measurement is tricky with regard to actual sources strength [25]. CO_2 measurement is not recommended because its production depends on the number of occupants as well as their activities [26]. However, many IAQ investigations estimate outdoor air ventilation using CO_2. This idea is that when a building is under ventilated, the CO_2 that people breathe out will build up from a background level. There some limitation to this approach. First, CO_2 should be measured when the space is fully occupied. Second, CO_2 should be measured when outdoor air is at minimum to establish the worst-case scenario. Third, CO_2 should be measured when space has reached equilibrium. Despite these problems, CO_2 concentrations are often reported as ventilation metrics without acknowledging the conditions required for them to be good indicators. In many cases when ventilation rates are presented, the measurement approaches are not described in sufficient detail to evaluate their quality or applicability to the study design [27]. About 25% used indoor CO_2 concentration as a ventilation metric, despite the well-known documented fact that it is generally not a good indicator of ventilation [28]. In this study, duct traverse was chosen as a main ventilation measurement method for ACMV CCCs due to the design and operation of ACMV in CCCs. Most of ACMV in those CCCs normally design for positive pressure. Ventilation system for CCC provide with only one AHU, a few FCUs of AHU with a few VAV box systems. The traverse method involves measuring measurement of air speed at multiple points across a duct cross section to determine the average air speed. The number of points depends on the size of the duct as found in engineering handbooks, standard and guidance documents [20,29-30]. Ventilation rates measured using traverse method gave quite similar results with the other method of measuring ventilation used in this study. Due to the design, operational and maintenan as well as occupancy and desrepency on CO_2 measurement, we recommend this method to be used together with the measurement of CO_2 levels in CCC to measure ventilation in ACMV CCCs.

4. Conclusions

Data obtained from this study provides information on IAQ, ventilation and corresponding respiratory symptoms of children attending childcare centers. After controlling for confounders, the risk of productive cough among children was significantly higher if they attended ACMV CCCs compared with NV CCCs. Based on the increasing number of CCCs operating in office buildings with centralized ACMV, further study should focus on the design and operation of ACMV in providing good indoor air quality for this susceptible population.

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