

The effect of ventilation strategies of child care centers on indoor air quality and respiratory health of children in Singapore

Abstract This paper reports the effects of ventilation strategies on indoor air quality (IAQ) and respiratory health of children within 104 child care centers (CCCs) in a hot and humid climate. The CCCs were categorized by ventilation strategies: natural (NV), air-conditioned and mechanically ventilated (ACMV), air-conditioned using split units (AC), and hybrid (NV and AC operated intermittently). The concentration levels of IAQ parameters in NV CCCs are characterized by the influence of the outdoors and good dilution of indoor pollutants. The lower ventilation rates in air-conditioned CCCs result in higher concentrations of occupant-related pollutants but lower outdoor pollutant ingress. This study also revealed lower prevalence for most asthma and allergy, and respiratory symptoms in children attending NV CCCs. In multivariate analyses controlled for the effects of confounders, the risk of current rhinitis among children is significantly higher if they attend mechanically ventilated CCCs compared to NV CCCs. Air-conditioned CCCs were also associated with higher adjusted prevalence ratio of severe phlegm and cough symptoms and lower respiratory illness. Finally, children attending CCCs with hybrid ventilation are at high risk for almost all the respiratory symptoms studied.

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Practical Implications

This large field study indicates that different ventilation strategies employed by child care centers can cause significant variations in the indoor air quality and prevalence of asthma, allergies and respiratory symptoms of attending children. The higher prevalence rates of allergic and respiratory symptoms among young children, whose immune system is still under-developed, in child care centers, whether fully or partially air-conditioned, suggest that ventilation and plausible growth and propagation mechanisms of allergens and infectious agents be further investigated.

Introduction

Pediatric asthma and associated respiratory allergy epidemiology have been published for school-age children such as the 6–7 year old and 13–14 year old age groups (Asher et al., 1995; Goh et al., 1996). However the preschool age appears to be a crucial time for the onset of asthma, and less is known or published on the association of asthma and allergic symptoms in preschool children with the indoor environment. Although the home environment is where the children spend most of their time, children of working parents can spend a considerable 45 h/week in child care centers (CCCs). In

Singapore, more than 90% of the children within this age group attend CCCs. Unfortunately, children attending CCCs have been reported to be more susceptible to infectious disease compared with those cared for at home (Hernandez et al., 1999; Jaakkola, 2000 and the references therein), and are exposed to conditions that may increase the risk of allergies and even asthma (Hagerhed-Engman et al., 2006; IOM, 2000).

There is evidence that the indoor environment within CCCs can influence the health of children. In Karlstad, Sweden, it was reported that differences in indoor environmental factors might have led to significant differences in the prevalence of allergic symptoms and

respiratory infections within 34 CCCs (Forsman, 2001). Koskinen et al. (1997) found significantly increased risk of sore throat, purulent and non-purulent nasal discharge, nasal congestion, hoarseness and cough in children (3–7 years old) attending two Finnish day care centers with visible mold growth on interior walls compared with those in two reference day care centers (without any mold growth). A key factor as to how the indoor environment varies depends on how it is ventilated. Supply of less outside air may elicit symptoms by causing higher concentrations of indoor-generated pollutants (Jaakkola, 2000).

In Singapore, the ventilation strategies adopted by the CCCs can be conventionally classified as (i) naturally ventilated (NV), (ii) air-conditioned and mechanically ventilated (ACMV) and (iii) hybrid (natural + air-conditioning) ventilated (HB) and (iv) air-conditioned (AC). For this study, ACMV CCCs are defined as those with a dedicated or shared air-handling unit, filtration and fresh air provision (typically about 10%), HB CCCs as those that incorporate air-conditioning for a portion of the day to provide thermal comfort and relying on natural ventilation at other times of the day, NV CCCs as those that rely on open windows only for ventilation and AC CCCs as those that incorporate split unit air conditioners for conditioning air without any provision of fresh air. Children within these CCCs are exposed to indoor contaminants and also outdoor pollution brought indoors. Pollutants emanating from indoor sources may be elevated in poorly ventilated CCCs as documented in a Nordic study (Lundqvist et al., 1982). Locations of the centers (critical considering the restricted land space use in highly urbanized surroundings), the permeabilities of building envelope, and performance of the ventilation and air filtration systems, all of which can influence the outdoor–indoor pollutant penetration. The hot and humid conditions which favor the proliferation of fungi on indoor surfaces (Lim et al., 1989) and conflagration of airborne fungal spores in ambient air (Lim et al., 1998) further emphasize the importance and consequential effects of ventilation strategies on indoor exposures. Indeed, there is a need to understand how pollutants of indoor and outdoor sources are affected by the different ventilation strategies adopted by the CCCs.

Studies documenting ventilation effects on health in CCC within Singapore or elsewhere is rare in the literature. Despite the numerous epidemiologic studies on office worker symptoms within multiple office buildings of different ventilation types (Mendell et al., 1996, 2003), there has been no similar study on respiratory health symptoms of children in CCCs. Due to the large number of children attending CCCs, small excess risks associated with the ventilation strategies could have significant public health consequences. This research investigates the impact of CCCs with different ventilation systems on the indoor air quality (IAQ) characteristics (environmental and rep-

resentative pollutants of indoor and outdoor sources) and health symptoms of attending children.

Research methods

Child care center selection

From the Ministry of Community Development, Youth and Sports' database of 687 CCCs in Singapore, 120 CCCs (18%) were randomly selected and identified under each of the four categories. All the CCC buildings were inspected and details of their characteristics noted, such as type of ventilation system, year and type of construction, building materials, presence of open shelves, pets, smells, fabrics and potted plants, duration of daily ventilation, use of air-cleaner, proximity to traffic pollution and/or parks, and visible signs of dampness and mold in the construction. Furthermore, the maintenance staffs were asked about the cleaning frequencies in the CCCs. The CCC characteristic information was determined using a standardized evaluation form (available on request).

Objective measurements

For each CCC, two indoor classrooms and an outdoor sampling point (not exceeding 5 m away from the building) were randomly selected for air sampling. At each of these three locations, temperature, relative humidity (RH), air velocity, ventilation, carbon monoxide, carbon dioxide, bacteria, and fungi were sampled simultaneously. For measurements of ozone and fine particle mass concentration ($PM_{2.5}$), a central indoor location within the CCCs and an outdoor location were simultaneously monitored. The pollutants selected for this study are those whose sources originate from the indoors, outdoors or both.

Indoor air temperature and RH data were collected continuously by battery-operated HOBO H8 Family data loggers with internal sensors (Onset Corporation, Bourne, MA, USA). The HOBO loggers were interfaced with carbon dioxide monitors, which utilized non-dispersive infrared principle (Telaire, Santa Barbara, CA, USA) for tracking CO_2 levels. Data were downloaded onto the BoxCar Pro software (Onset Corporation, Bourne, MA, USA) and then exported for data management. Carbon monoxide measurement was made using three T15v Langan CO Measurers (Langan Products, Inc., San Francisco, CA, USA). Fine particle mass concentration ($PM_{2.5}$) was measured using two TSI Model 8520 DustTrak aerosol monitors (TSI Incorporated, St Paul, MN, USA) utilizing light scattering technique. Ozone was analyzed using a pair of UV-absorbance ozone analyzers (2B Technologies Inc., Golden, CO, USA). All the measurements were conducted from 8 AM to 5 PM at 1-min intervals.

For biological air sampling, airborne viable bacteria and fungi were sampled in the indoor and outdoor locations using a single stage Andersen impactor (Graseby-Andersen, Atlantis, GA, USA). All the biological measurements were conducted in the morning between 8 and 11 AM. The protocol involves the collection of duplicate samples for each location and employing a field and a laboratory blank for each CCC. Tryptone soy agar was used as culture media for human- and environment-related bacteria (NIOSH, 1998). Malt extract agar and dichloran glycerol 18 agar were used as culture media for mesophilic and xerophilic fungi respectively (NIOSH, 1998). Due to the high loading, sampling durations were 1 and 2 min for bacteria and fungi respectively. Incubation conditions for human- and environment-related bacteria were 37°C for 2 days and 25°C for 5–7 days respectively (NIOSH, 1998). For fungi samples, the incubation period was 25°C for 5–7 days. The bacterial and fungal colonies were then enumerated and concentrations evaluated in CFU/m³ after making adjustment for positive hole correction (Macher, 1989).

The equipments were placed at the breathing zone of children (approximately 0.5–0.7 m). All the analyzers were calibrated as per recommendation of the manufacturers. Zero checks were conducted on the ozone analyzer (copper oxide cartridge), DustTrak (HEPA filters) and Telaire monitors (99.9% nitrogen gas) in the laboratory prior to use. Periodic zero checks were also conducted throughout the course of sampling in the field.

Using the measured carbon dioxide as a tracer gas, ventilation rates of the CCCs were analyzed using the TGD software (LESO-PB, EPFL, Lausanne, Switzerland) validated by Roulet and Foradini (2002). The fresh air amounts per occupant in the CCC were calculated using the classroom volume. Air velocity was measured using a hot wire anemometer (Kanomax Climomaster, Osaka, Japan) in the morning.

Questionnaire survey

The parents of the children attending these CCCs were the respondents for the questionnaire survey. All the children who were on full-time enrollment (45 h/week) were included in this study. The questionnaires were distributed to the children based on the CCC's registers and collected by the respective class teachers after up to three reminders. For asthma and allergic symptoms, the International Study of Asthma and Allergies in Childhood (ISAAC) written questionnaire (Asher et al., 1995) was used. We concentrate on current wheezing episodes, exercise-induced wheezing, nocturnal cough unrelated to respiratory infection, doctor's diagnosis of asthma, current allergic rhinitis and rhinoconjunctivitis, current eczema and flexural rash symptoms. For respiratory symptoms, the American

Thoracic Society and the Division of Lung Diseases (ATS-DLD) of the National Heart, Lung, and Blood Institute, USA respiratory symptom questionnaire was used (Ferris, 1978). The questionnaire also included questions on potential confounders which include the child's age, gender, ethnicity, housing characteristics (dampness, floor and wall types, air-conditioning, outdoor pollution), food allergy, maternal and paternal smoking [current environmental tobacco smoke (ETS) exposure], maternal and paternal atopy, preterm births, breastfeeding, number of siblings, current pet exposure and current symptoms of respiratory infections. Socio-economic status (SES) of the children was assessed by including questions on household income (Goh et al., 1996). The parents were asked to state whether they had chosen to avoid air-conditioned CCCs because of allergic diseases in the family ('an avoidance behavior'), that is, whether they had avoided air-conditioned CCCs because of allergy in the family (yes/no), or had changed CCC for the same reason (yes/no).

Statistical analysis

The measured IAQ parameters among the four categories of CCCs were compared. The normality for the distribution of concentration levels was first determined using the Kolmogorov–Smirnov test. The distributions of air velocity, air change rates, fresh air amounts, bacteria and fungi were not normal and were converted to log-normal distributions. The statistical significance of the differences was tested using one-way analysis of variance (ANOVA) with subsequent Bonferroni test as a post-hoc analysis. The Kruskal–Wallis one-way ANOVA by ranks was used for ordinal data. Analysis of covariance (ANCOVA) was used to evaluate the effects of ventilation strategies and covariate factors (e.g traffic density, mold problems). The correlation between the indoor air factors was determined using either Pearson or Spearman analysis depending on the distribution.

We studied the relationship of ventilation strategies of CCC and prevalence rates of above questionnaire-based morbidity endpoints. The questionnaire data were initially analyzed by cross-tabulation and evaluated where appropriate, using the χ^2 test. Further statistical analysis were performed by computation of the prevalence ratios (PRs) and 95% confidence intervals (95% CI) using the modified Cox proportional hazard regression model, with assumption of a constant risk period as recommended for cross-sectional studies (Lee, 1994; Zocchetti et al., 1997). Stepwise multiple regression analysis was used to determine which personal, home and CCC confounders were associated with each symptom. The variables included as potential confounders were age, gender, race, SES, type of housing, food allergy, ETS exposure, maternal and paternal atopy, preterm birth,

breastfeeding, avoidance behavior, respiratory infections (for asthma and allergies), asthma (for respiratory symptoms), pet exposure, number of siblings, home dampness, air conditioner in the child's bedroom, home traffic, wallpaper in the child's bedroom, PVC floor in the child's bedroom, CCC floor area, CCC dampness, CCC traffic densities, CCC occupant densities and CCC PVC floor. Any confounder that was significant at $P < 0.15$ level for a given symptom was included in the final multivariate model of CCC ventilation strategies effects for that symptom. All tests were considered to be statistically significant at $P < 0.05$. Procedures from the SPSS software package version 13.0 were used (SPSS Inc., Chicago, IL, USA).

Results

Among the 120 randomly selected CCCs, 104 (86.7%) agreed to participate in the IAQ measurements while 97 (80.8%) agreed to participate in the questionnaire survey. Eleven CCCs declined to participate in any form of measurements, five had closed down or in the middle of relocation, and seven declined participation in the questionnaire survey only. For the objective measurements, the characteristics of the 104 CCCs are summarized in Table 1. Within the 104 CCCs studied, there were in total 346 classrooms where 208 (60.1%) were monitored for temperature, RH, air velocity, ventilation, carbon monoxide, carbon dioxide, bacterial and fungal levels while 104 classrooms (30.1%) were monitored for ozone and fine particle mass concentrations. Table 2 summarizes the mean and standard deviations of the indoor environmental and IAQ parameters.

Environmental parameters

ANOVA showed statistical differences for indoor RH, temperature and air velocity but not their outdoor levels. Indoor temperatures were statistically similar for NV and HB CCCs, both being higher than ACMV and AC CCCs. Indoor RH was the highest in NV CCCs and lowest for ACMV CCCs. The indoor

temperature and RH were significantly correlated with the corresponding outdoor levels ($P < 0.001$). Air velocities were significantly higher in NV CCCs. Significant differences in all the ventilation parameters were found. Air change rates were lowest for ACMV and AC CCCs at 0.6 and 0.7/h respectively, indicating inadequate ventilation associated with these strategies. These levels correspond to actual fresh air amounts of 1.0 and 1.6 l/s/person which were lower than the guideline values of 3.6 l/s/person recommended by the local building authority (BCD, 1983). In contrast, the air change rates and fresh air amounts were adequate and high for HB and NV CCCs.

IAQ parameters

The mean concentration of CO₂ was highest for AC CCCs which exceeded local guideline of 1000 ppm (ENV, 1998). ANOVA revealed that the differences between groups of CCCs were significant. For CO and PM_{2.5}, there was no difference in concentrations among the groups. The difference was statistically significant for ozone where concentrations were low in ACMV and AC CCCs but elevated in NV and HB CCCs. The indoor PM_{2.5} and ozone were significantly correlated with the outdoor levels ($P < 0.001$).

Human-related bacterial concentrations were elevated for all CCCs but were exceedingly high for those in ACMV and AC CCCs. These levels were very much higher than those sampled outdoors ($P < 0.001$). For environmental bacteria, the difference approached significance for the concentrations between ventilation groups ($P = 0.096$). The indoor concentrations were lower than those sampled outdoors for ACMV and AC CCCs. Concentrations of mesophilic fungi were highest in NV CCCs, followed by AC, HB and ACMV CCCs. For xerophilic fungi, it was found that there was no difference in the concentrations between ventilation groups. But the indoor levels could be influenced by the outdoor levels. The indoor environmental bacteria, mesophilic and xerophilic fungi were significantly correlated with the outdoor levels ($P < 0.001$).

Table 1 Description of the 104 child care centers categorized by their ventilation strategies

CCC characteristics	NV ($n = 59$)	HB ($n = 21$)	ACMV ($n = 5$)	AC ($n = 19$)
Mean floor area (m ²)	267 ± 77	241 ± 113	248 ± 100	280 ± 152
Mean age of CCC*	9.4 ± 5.9	8.3 ± 5.2	3.7 ± 2.5	6.1 ± 4.2
Mean no. of children*	78 ± 26	59 ± 21	74 ± 36	93 ± 61
Type of building*	Ground floor of high rise residential apartments	Landed property single houses/churches	Office buildings	Ground floor of high rise residential apartments
Traffic density (%) ^a	53	48	100	63
Dampness/mold (%)	24	19	40	37
PVC flooring (%)	20	24	60	47
Mechanical fans (%)*	100	100	20	74

NV, naturally ventilated; ACMV, air-conditioned and mechanically ventilated; HB, hybrid (natural + air-conditioning) ventilated; AC, air-conditioned.

^aMedium or heavy.

* $P < 0.05$ by ANOVA or Kruskal–Wallis tests.

Table 2 Mean environmental and indoor air quality parameters measured for the child care centers (CCCs) grouped

CCC	Indoor				Outdoor			
	NV (<i>n</i> = 59)	HB (<i>n</i> = 21)	ACMV (<i>n</i> = 5)	AC (<i>n</i> = 19)	NV (<i>n</i> = 59)	HB (<i>n</i> = 21)	ACMV (<i>n</i> = 5)	AC (<i>n</i> = 19)
Environmental								
Temperature [†] (°C)	29.3 ± 2.1 ^a	29.5 ± 1.0 ^a	23.7 ± 1.4 ^b	26.5 ± 1.9 ^b	30.2 ± 2.4	30.8 ± 1.9	30.6 ± 3.1	30.0 ± 2.7
Relative humidity [†] (%RH)	75.2 ± 7.7 [*]	67.7 ± 9.8 [*]	51.2 ± 14.8 ^a	60.6 ± 9.9 ^a	71.6 ± 11.6	65.8 ± 10.8	69.0 ± 14.4	72.3 ± 12.4
Air velocity [†] (m/s)	0.5 ± 0.9 ^a	0.5 ± 0.8 ^{a, b}	0.3 ± 0.5 ^{b, c}	0.4 ± 0.7 ^{b, c}	0.5 ± 0.9	0.5 ± 0.8	0.4 ± 0.6	0.5 ± 0.8
Air change rates [‡] (h ⁻¹)	4.8 ± 7.7 ^a	3.9 ± 6.6 ^a	0.6 ± 1.6 ^b	0.7 ± 1.2 ^b	—	—	—	—
Fresh air amounts [‡] (l/s/person)	16.4 ± 29.5 [*]	8.6 ± 18.9 [*]	1.0 ± 1.6 ^a	1.6 ± 2.0 ^a	—	—	—	—
Indoor air quality								
Carbon dioxide [†] (ppm)	466 ± 72 ^a	538 ± 147 ^{a, b}	930 ± 175 ^{b, c}	1163 ± 575 ^c	380 ± 50	358 ± 41	377 ± 53	372 ± 51
Carbon monoxide [†] (ppm)	1.0 ± 0.8	1.3 ± 0.7	0.7 ± 0.4	1.2 ± 1.0	0.8 ± 0.6 ^a	1.2 ± 0.8 ^b	1.5 ± 1.7 ^{a, b}	0.9 ± 0.7 ^{a, b}
PM _{2.5} [†] (μg/m ³)	71.0 ± 32.5	66.8 ± 28.3	48.1 ± 18.1	71.5 ± 38.6	70.9 ± 33.6	67.8 ± 29.2	91.2 ± 44.6	80.5 ± 45.9
Ozone [†] (ppb)	36.8 ± 16.4 ^a	32.3 ± 14.8 ^a	12.1 ± 9.5 ^b	18.0 ± 12.4 ^b	45.9 ± 19.0	49.1 ± 22.3	40.3 ± 16.9	56.3 ± 30.0
Viable bacteria [†] (CFU/m ³)								
Human related	1172 ± 2269 ^a	1295 ± 2461 ^{a, b}	4112 ± 6990 ^{b, c}	4208 ± 8416 ^c	311 ± 684	354 ± 602	599 ± 1318	297 ± 624
Environmental	736 ± 1325	759 ± 1139	341 ± 642	593 ± 1067	663 ± 1260	743 ± 1189	705 ± 1340	769 ± 1384
Viable fungi [†] (CFU/m ³)								
Mesophilic	820 ± 1312 ^a	489 ± 929 ^b	470 ± 987 ^{a, b, c}	677 ± 1151 ^{a, b, c}	828 ± 1325 ^a	493 ± 986 ^b	608 ± 1309 ^{a, b, c}	590 ± 1062 ^{a, b, c}
Xerophilic	678 ± 1220	628 ± 1068	480 ± 816	501 ± 952	597 ± 1194	562 ± 1124	660 ± 1188	507 ± 811

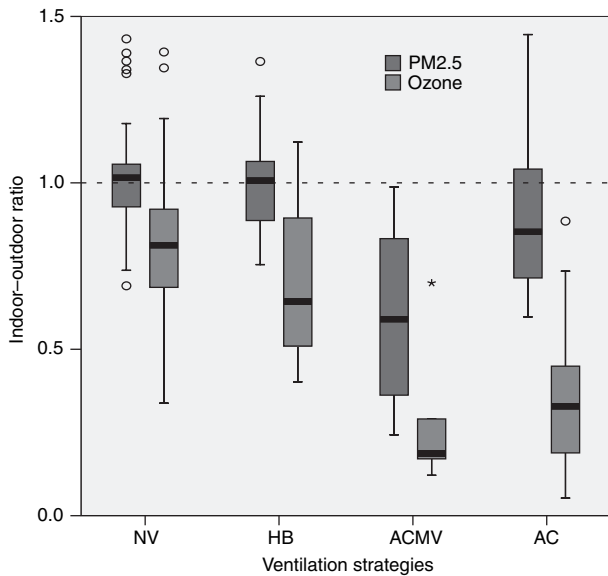
NV, naturally ventilated; ACMV, air-conditioned and mechanically ventilated; HB, hybrid (natural + air-conditioning) ventilated; AC, air-conditioned.

[†]Arithmetic mean and standard deviation.

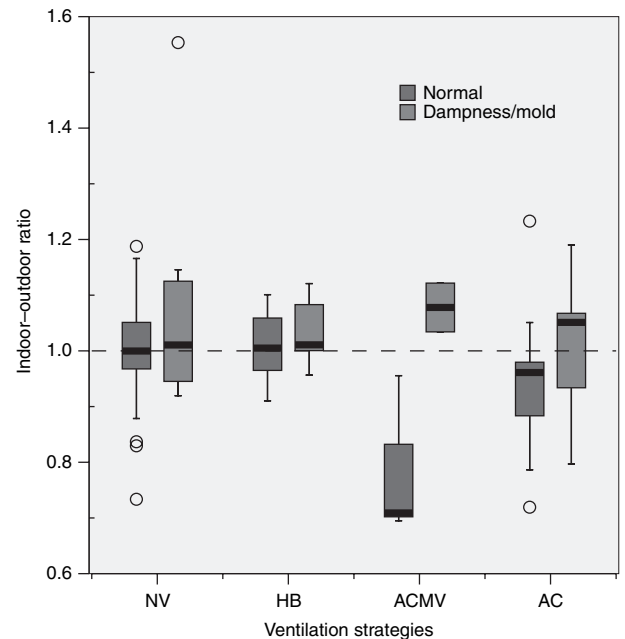
[‡]Geometric mean and standard deviation.

Mean values sharing the same letter are not significantly different ($P > 0.05$).

* $P < 0.05$ by ANOVA test.


Fig. 1 Indoor–outdoor ratios of PM_{2.5} and ozone

The box-plots of indoor–outdoor concentration ratio for PM_{2.5} and ozone are illustrated in Figure 1 while fungi are shown in Figures 2 and 3. For PM_{2.5}, CCCs with natural ventilation were close to unity while those with air-conditioning were lesser (ACMV CCC has the lowest ratio). This trend across the ventilation strategies was similar for ozone and the two types of fungi where the CCCs have no dampness/mold. For CCCs with dampness/mold, the ratios were consistently higher than normal CCCs regardless of ventilation strategies. ANCOVA revealed significant differences between


Fig. 2 Indoor–outdoor ratios of mesophilic fungi

ratios of PM_{2.5} with ventilation strategies ($P = 0.005$) and its interaction with traffic densities ($P = 0.033$). For xerophilic fungi, there was significant differences between indoor–outdoor ratios with dampness/mold ($P = 0.05$), ventilation strategies ($P = 0.014$) and their interaction ($P = 0.006$). This is similar for mesophilic fungi where significant differences were observed for dampness/mold ($P = 0.001$), ventilation strategies ($P = 0.003$) and their interaction ($P = 0.001$).

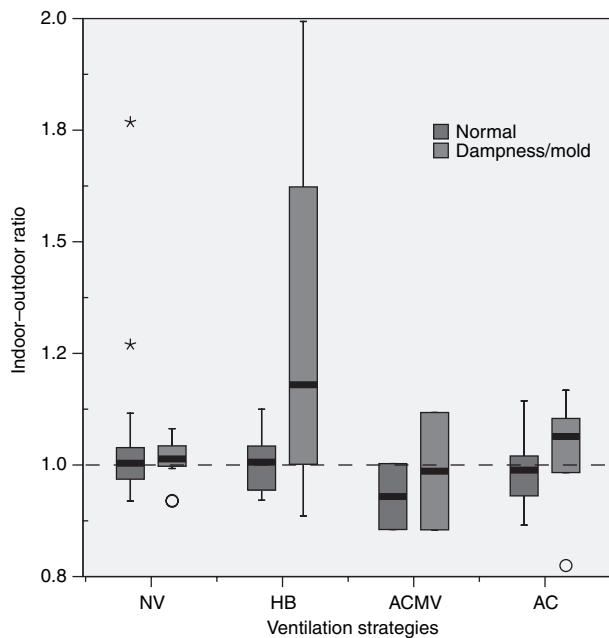


Fig. 3 Indoor-outdoor ratios of xerophilic fungi

Table 3 Demographic, socio-economic (personal) and home characteristics of the children

Characteristics	N	% ^a
Mean age	4.09 ± 1.24	
Gender		
Female	2083	46.2
Race		
Chinese	3701	82.1
Malay	393	8.7
Indian	227	5.0
Others	189	4.2
Type of housing		
Public residential apartments	3803	84.0
Private residential apartments	532	11.7
Single houses	194	4.3
Socio-economic status (total monthly income) ^b		
<\$2000	804	18.4
\$2000–4000	1457	33.3
\$4000–6000	960	22.0
>\$6000	1148	26.3
Food allergy	252	5.6
Maternal atopy	603	13.8
Paternal atopy	534	12.3
Avoidance behavior	1286	28.2
Preterm birth	409	9.0
Breastfeeding	1007	31.7
Sibling number	165	3.6
Home dampness	268	6.3
Home air-conditioning	2110	47.0
Home wallpaper use	61	1.4
Home PVC flooring	256	6.3
Home traffic density (heavy)	288	10.6
Pet exposure	262	5.7
ETS exposure	625	13.8

^aDenominator for each variable may vary because of non-response.

^b1US\$ = 1.52 Singapore Dollar.

Health data parameters

There were 4759 responses from the 97 CCCs, a response rate of approximately 70%. Of these, 4629 children attend full day program and were included in the analysis. Responses were checked for inconsistent answers to stem questions on asthma, rhinitis and eczema symptoms. The personal characteristics of the respondents are shown in Table 3, while Table 4 shows the current prevalence of asthma and allergies and respiratory symptoms in the different ventilation groups. Significant differences in prevalence were observed in most of the asthma and allergy, and respiratory symptom parameters analyzed. It can be observed that the lowest prevalence for most symptoms were from children attending NV CCCs. We employ multiple regression models to determine the significant covariates. Table 5 presents the multivariate relationships between risk of different symptoms and potentially relevant personal, home and CCC characteristics. Details of this finding will be presented elsewhere. To evaluate the relationship between ventilation strategies and respiratory health, multiple regression analyses were performed controlling for the covariates that were significant at $P < 0.15$ derived from the individual models presented in Table 5.

Table 6 shows the adjusted PRs of asthma, allergies and respiratory symptoms for children attending CCCs under different ventilation strategies (NV reference). Among the asthma and allergic symptoms, only children attending CCC with ACMV system had significantly higher adjusted PR of current rhinitis when compared with those attending NV CCCs (PR 1.42, 95% CI: 1.03–1.94). Reporting of cough with colds/flu at most days was significantly higher among children attending HB CCCs (PR 1.31, 95% CI: 1.05–1.64). Significant higher prevalence relating to symptoms of full of phlegm with colds/flu at most days were observed for children attending HB (PR 1.64, 95% CI: 1.27–2.12) and ACMV CCCs (PR 1.85, 95% CI: 1.07–3.19) were observed. Children attending HB CCCs had higher PR of attack of cough lasting more than 1 week (PR 1.26, 95% CI: 1.05–1.51) while the risk for children attending AC CCCs was also significant (PR 1.25, 95% CI: 1.00–1.56). For current lower respiratory illness, children are at higher risk if they attend HB CCCs (PR 1.26, 95% CI: 1.01–1.56) and AC CCCs (PR 1.44, 95% CI: 1.12–1.86). The PRs for the remaining respiratory symptom among children attending HB CCCs appear to be nearly statistically significant.

Discussion

In hot tropical Singapore, a significant number of CCCs are naturally ventilated despite the high outdoor temperatures (Tables 1 and 2). The high indoor temperature and RH levels in NV and HB CCCs are consequences of

Table 4 Number and prevalence of asthma and allergies and respiratory symptoms among children according to child care center (CCC) ventilation strategies

	NV <i>n</i> = 3121		HB <i>n</i> = 725		ACMV <i>n</i> = 152		AC <i>n</i> = 631		
	<i>n</i>	% ^b	<i>n</i>	% ^b	<i>n</i>	% ^b	<i>n</i>	% ^b	<i>P</i> -value ^c
Asthma and allergies ^d									
Wheezed in the past 12 months	450	14	129	18	26	17	111	18	<0.05
Doctor-diagnosed asthma	227	8	53	8	11	8	41	7	NS ^c
Wheezed after exercise in the past 12 months	101	3	26	4	4	3	23	4	NS ^c
Nocturnal cough in the past 12 months	838	28	190	27	48	33	177	29	NS ^c
Rhinitis in the past 12 months	742	24	210	29	50	33	178	28	<0.001
Rhinoconjunctivitis in the past 12 months	217	7	76	10	15	10	49	8	<0.05
Eczema in the past 12 months	363	12	112	15	24	16	84	13	<0.05
Flexural rash in the past 12 months	305	10	103	14	22	15	72	11	NS ^c
Respiratory symptoms ^e									
Cough with cold/flu in the past 12 months	2072	68	526	74	104	71	422	68	<0.05
Cough with cold/flu at most days in the past 12 months	578	25	148	28	29	29	114	24	NS ^c
Full of phlegm with cold/flu in the past 12 months ^a	1175	39	338	47	64	44	232	38	<0.001
Full of phlegm with cold/flu at most days in the past 12 months	375	20	122	29	23	37	68	20	<0.001
Gets attack of cough lasting more than 1 week in the past 12 months	714	24	229	33	39	27	166	28	<0.001
Lower respiratory illness in the past 12 months ^f	457	18	167	27	38	28	140	26	<0.001

NV, naturally ventilated; ACMV, air-conditioned and mechanically ventilated; HB, hybrid (natural + air-conditioning) ventilated; AC, air-conditioned.

^a χ^2 test, comparing prevalence of symptoms and disease by exposure to CCC ventilation strategies.

^bDenominator for each variable may vary because of non-response.

^cNS, not significant.

^dISAAC questionnaire.

^eATS-DLD questionnaire.

^fPositive answers to bronchiolitis, bronchitis, pneumonia and croup questions in the past 12 months.

the outdoor conditions. Additionally, the levels were consistently higher than in ACMV and AC CCCs where the lower temperature and RH in these centers were due to the cooling and dehumidifying effects of the air-conditioning. Indeed, the facilitation of outdoor air ingress through open windows, the air movement caused by the indoor mechanical fans and ventilation extracts to remove the heat from the space in NV CCCs are designed for the thermal comfort of the occupants. The thermal conditions within these non-airconditioned environments are satisfactory for tropically acclimatized occupants as shown by a previous study on thermal sensation and acceptance experienced by tropically acclimatized subjects in naturally ventilated premises (Wong et al., 2002). The high RH levels indicate that the high ACH has not been effective in removing the indoor-generated moisture mainly attributable to the occupants.

Air-conditioned centers have significantly lower air change rates when compared with naturally ventilated centers. The high ventilation rates in NV CCCs lowered the concentrations of IAQ parameters of indoor origin such as CO₂ and human-related bacterial concentrations. The fresh air amount for NV CCCs determined in this study was 16.4 L/s/person while for AC and ACMV CCCs the ventilation rates were 1.0 and 1.6 L/s/person respectively. For NV CCCs, this is considerably high compared with those (3.8 L/s/person) reported for cold Nordic countries (Ruotsalainen et al., 1993) where the ventilation rates were reduced to prevent the cold outdoor air from coming in. Consequently, the indoor-generated pol-

lutants have been documented to be high in these countries (Lundqvist et al., 1982; Ruotsalainen et al., 1993). In this study, the fresh air amounts were lower in AC and ACMV CCCs resulting in high CO₂ and human-related bacterial levels. This highlights the ventilation inadequacies in diluting the pollutant generated by the children

In NV and HB CCCs, the high air change rates attributable to the untreated outdoor air have facilitated the penetration of outdoor pollution. Ozone is a common photochemical product outdoors (Weschler, 2000) and its indoor sources were absent in the CCCs studied. For PM_{2.5}, ANCOVA showed that traffic densities play a significant role in the indoor PM_{2.5} I/O levels. These pollutants are of particular concern because of their association with asthma exacerbations in Singaporean children (Chew et al., 1998a, 1999). Our study shows that indoor PM_{2.5} and ozone concentrations in centers with NV and HB strategies were significantly higher than those in ACMV and AC CCCs. In ACMV and AC CCCs, the lower PM_{2.5} concentrations may be attributable to the filters installed in the ventilation system and air-conditioning units and the lower ventilation. For ozone, its indoor-outdoor ratio was significantly lower than PM_{2.5} (0.30 vs. 0.52; *t*-test, *P* < 0.001) in ACMV CCCs. As ozone is highly reactive (Cano-Ruiz et al., 1993; Weschler, 2000), there is evidence to suggest that lower I/O ratios result from a larger surface deposition and indoor reactions via heterogenous and homogeneous pathways. Furthermore, the high recirculation scenario (typically 90–100%) under the ACMV CCCs

Table 5 Prevalence ratios for personal, home and child care center (CCC) characteristics associated with asthma and allergies and respiratory symptoms

	Prevalence ratios												
	Wheeze	Doctor-diagnosed asthma	Wheezed after exercise	Nocturnal cough	Rhinitis	Rhinoconjunctivitis	Eczema	Flexural rash	Cough with cold/flu at most days	Full of phlegm with cold/flu	Full of phlegm with cold/flu at most days	Attack of cough lasting more than 1 week	Lower respiratory illness
Female	1.05	<i>0.70</i>	0.59	0.98	0.89	0.92	1.11	1.14	1.02	1.12	0.91	0.99	0.88
Age	0.53	2.56	0.44	0.80	1.72	2.26	1.06	1.28	<i>0.68</i>	<i>0.75</i>	0.82	<i>0.78</i>	1.29
Malay	1.81	1.74	0.98	0.65	0.77	0.92	1.08	1.10	0.94	0.97	1.04	0.81	0.40
Indian	<i>1.56</i>	<i>1.98</i>	1.99	0.93	1.01	1.41	0.72	1.28	0.90	0.90	1.18	0.73	1.30
SES	1.72	<i>1.03</i>	1.86	0.95	1.19	<i>1.55</i>	<i>1.37</i>	<i>1.68</i>	0.77	1.17	0.87	2.03	1.84
Landed property	0.84	1.18	1.09	1.01	0.73	1.20	1.31	1.41	0.76	0.81	0.56	0.79	<i>0.57</i>
Food allergy	1.49	1.97	3.86	1.07	1.49	1.88	2.40	2.96	<i>1.44</i>	1.16	<i>1.49</i>	1.28	<i>1.37</i>
Maternal atopy	1.57	1.65	0.80	1.57	1.36	1.70	1.75	1.52	<i>1.27</i>	<i>1.21</i>	1.00	1.17	1.19
Paternal atopy	<i>1.32</i>	2.22	1.76	1.24	1.67	1.83	1.05	1.22	1.45	1.12	1.42	<i>1.26</i>	1.80
Preterm birth	1.29	0.89	1.61	1.25	0.89	<i>0.60</i>	1.23	1.25	1.59	<i>1.20</i>	<i>1.47</i>	1.36	1.56
Breastfed	<i>1.34</i>	0.91	1.59	0.98	1.32	<i>1.41</i>	1.72	1.97	1.04	1.02	0.94	1.01	1.44
Avoidance behavior	1.48	1.30	1.14	1.25	<i>1.17</i>	1.10	0.81	<i>0.73</i>	0.97	<i>1.17</i>	1.05	1.07	1.42
Respiratory infections/asthma	3.07	1.38	4.32	2.02	1.43	2.34	1.47	1.50	<i>1.27</i>	1.52	1.50	1.65	2.31
ETS exposure	1.66	1.68	0.91	1.62	1.25	2.02	1.15	1.15	1.21	1.08	1.16	2.70	<i>1.36</i>
Pet exposure	1.16	0.57	1.52	0.96	0.91	<i>0.54</i>	0.71	0.71	0.75	1.23	1.25	1.05	1.06
No. of siblings	1.13	1.15	<i>1.21</i>	1.14	0.76	0.41	<i>0.60</i>	1.03	<i>0.93</i>	<i>0.67</i>	1.89	1.06	0.97
Home dampness	1.26	1.21	<i>1.87</i>	1.05	1.53	1.91	<i>1.42</i>	1.31	1.16	<i>1.25</i>	1.14	1.41	1.48
Home air-conditioning	1.15	1.27	0.93	1.09	<i>1.16</i>	1.24	1.07	1.03	0.95	1.04	0.93	0.99	1.05
Home traffic density	1.02	<i>1.61</i>	<i>1.89</i>	1.17	1.06	1.33	0.82	0.96	1.29	<i>1.22</i>	1.05	1.15	1.17
Home wallpaper	<i>2.58</i>	3.28	1.55	1.83	0.98	1.35	2.90	<i>2.60</i>	1.54	0.81	0.55	1.40	1.59
Home PVC floor	0.68	0.90	0.84	0.97	1.12	0.75	0.89	1.03	1.29	1.00	0.78	0.76	<i>0.44</i>
CCC floor area	0.96	1.47	2.18	1.01	0.95	0.94	1.19	1.07	0.89	0.99	<i>0.81</i>	0.90	0.97
CCC dampness	0.91	1.07	1.15	0.90	0.90	0.96	1.12	1.08	0.97	0.92	1.00	1.04	0.86
CCC traffic density	0.88	0.96	0.65	1.07	0.99	1.01	<i>0.78</i>	<i>0.67</i>	0.81	1.02	<i>0.65</i>	0.96	0.94
CCC PVC floor	1.01	1.19	2.02	1.03	0.92	1.01	1.03	1.08	0.74	1.03	0.72	0.98	1.24
CCC occupant density	1.03	0.97	1.17	1.07	1.07	1.19	<i>1.20</i>	1.00	<i>1.15</i>	1.16	1.26	1.29	<i>1.17</i>

Values in bold are $P < 0.05$, values in italics are $P < 0.15$. These variables are adjusted for each other. Variables that are statistically significant are included in the final adjustment model. Reference variables: gender, male; race, Chinese; age, 2 years; socio-economic status (SES), total monthly income <\$2000; type of housing, public residential apartments; no. of siblings, ≤ 2 ; home wall type, concrete; home and CCC traffic density, light; home and CCC floor type, ceramic tiles; CCC floor area, 1st quartile; CCC occupant density, 1st quartile.

Table 6 Risk of asthma and allergies and respiratory symptoms among children according to child care center (CCC) ventilation strategies

	Prevalence ratio and 95% confidence interval ^a			
	NV	HB	ACMV	AC
Asthma and allergies ^b				
Wheezed in the past 12 months	1.00	0.89 (0.69–1.13)	1.30 (0.85–2.00)	1.19 (0.92–1.54)
Doctor-diagnosed asthma	1.00	1.03 (0.71–1.52)	1.12 (0.54–2.32)	1.10 (0.72–1.67)
Wheezed after exercise in the past 12 months	1.00	1.01 (0.61–1.69)	0.73 (0.23–2.35)	1.16 (0.66–2.02)
Nocturnal cough in the past 12 months	1.00	0.82 (0.68–1.01)	1.19 (0.85–1.65)	1.05 (0.86–1.28)
Rhinitis in the past 12 months	1.00	1.07 (0.89–1.29)	1.42 (1.03–1.94)	1.18 (0.96–1.44)
Rhinoconjunctivitis in the past 12 months	1.00	1.08 (0.77–1.50)	1.07 (0.56–2.04)	1.08 (0.74–1.57)
Eczema in the past 12 months	1.00	1.10 (0.85–1.43)	1.22 (0.77–1.94)	0.98 (0.73–1.32)
Flexural rash in the past 12 months	1.00	1.04 (0.80–1.36)	1.01 (0.61–1.67)	0.92 (0.66–1.28)
Respiratory symptoms ^c				
Cough with cold/flu at most days in the past 12 months	1.00	1.31 (1.05–1.64)	1.31 (0.83–2.05)	1.11 (0.84–1.48)
Full of phlegm with cold/flu in the past 12 months	1.00	1.14 (0.98–1.32)	1.09 (0.80–1.47)	1.03 (0.85–1.24)
Full of phlegm with cold/flu at most days in the past 12 months	1.00	1.64 (1.27–2.12)	1.85 (1.07–3.19)	1.33 (0.95–1.87)
Gets attack of cough lasting more than 1 week in the past 12 months	1.00	1.26 (1.05–1.51)	1.06 (0.72–1.56)	1.25 (1.00–1.56)
Lower respiratory illness in the past 12 months ^d	1.00	1.26 (1.01–1.56)	1.37 (0.91–2.06)	1.44 (1.12–1.86)

NV, naturally ventilated; ACMV, air-conditioned and mechanically ventilated; HB, hybrid (natural + air-conditioning) ventilated; AC, air-conditioned.

^aModels were adjusted for personal, home and CCC characteristics variables that are in bold and italics in Table 5. Reference category is CCC with natural ventilation (NV).

^bInternational Study of Asthma and Allergies in Childhood (ISAAC) questionnaire.

^cAmerican Thoracic Society and the Division of Lung Diseases (ATS-DLD) questionnaire.

^dPositive answers to bronchiolitis, bronchitis, pneumonia and croup questions in the past 12 months.

would mean greater surface removal for ozone (Zuraimi et al., 2007).

The ratio between indoor and outdoor concentrations of pollutants offers an indication of the extent to which the pollutants found indoors are dominated by indoor generation. It is expected that in the absence of indoor sources, the ratios between I/O concentrations will be ≤ 1 (Jones et al., 2000) and the ratios should be greater than unity in the presence of strong indoor sources (Zuraimi et al., 2003). Fungi have both indoor and outdoor sources (Nevalainen and Seuri, 2005) and it is important to discriminate their origin. Figures 2 and 3 reveal that for centers without dampness/mold, the ratios followed similar trend for PM_{2.5} and ozone. Fungi I/O ratio was the lowest in ACMV CCCs and is attributed to the better filtration of the outdoor air by the ACMV system. In contrast, CCCs with dampness/mold for all types of ventilation systems have I/O ratios larger than unity indicating the strength of indoor sources.

While ventilation strategies account for the differences in measured indoor environmental parameters in general, and may be effective in reducing their concentration levels, effort should be directed toward addressing the indoor sources within the CCCs. The high levels of human- and environment-related bacterial concentrations and fungi I/O ratios in mold-damaged centers, regardless of the type of ventilation, highlight the importance of source control and management.

This study showed that children attending ACMV CCCs have a higher risk of current rhinitis compared with those in NV CCCs, indicating a positive link between allergic rhinitis symptoms among children and type of ventilation systems employed in CCCs. In a cross-sectional study investigating 'building sickness' among office workers in two buildings, one fully air-conditioned with humidification and the other naturally ventilated (Robertson et al., 1985), rhinitis was found to be significantly more common in the air-conditioned building than the naturally ventilated building (28% vs 5%). While that finding may not be directly comparable with the current study in terms of the age of occupants and types of pollution sources, reviews have shown that components of ventilation systems can be emission sources of pollutants (Batterman and Burge, 1995), and indeed, the ACMV CCCs in this study are located in actual office buildings. Mendell et al. (2003) reported that poor maintenance can increase the risk of soiling and moisture in the ventilation system with consequent amplification of microbiological organisms. These amplifiers disseminate their products – allergens, irritants, or toxins – through the ventilation system. Many of these products have been associated with allergic rhinitis symptoms among children (Nevalainen and Seuri, 2005).

Likewise, moisture and debris in ventilation systems, possibly by supporting microbiologic growth, may

increase adverse respiratory effects. Mendell et al. (2003) had documented that workers in office buildings would have a higher risk in at least three of four work-related lower respiratory symptoms attributable to debris in ventilation air intake (OR 2.0, 95% CI: 1.0–3.9), and to poor drainage in air-conditioning drip pans (OR 2.6, 95% CI: 1.3–5.2). In an earlier study, Mendell et al. (1996) reported higher adjusted prevalence of lower respiratory symptoms associated with mechanical and air-conditioned ventilation relative to natural ventilation (mechanical: OR = 2.9, 95% CI = 0.7–11; air-conditioned: OR = 4.0, 95% CI = 1.1–15). In addition, the high levels of indoor-generated CO₂ and human-related bacteria in poorly ventilated air-conditioned CCCs suggest that viral agents causing respiratory infections among children might lead to their higher prevalence in these CCCs. A number of studies have indicated that buildings with inadequate ventilation can result in increased transmission of infectious respiratory diseases among occupants. Brundage et al. (1988) documented that low ventilation rate (0.85 L/s/person) increased the risk of acute respiratory disease. Drinka et al. (1996) documented that recirculation increased attack rates of influenza among elderly adults. Elsewhere, Myatt et al. (2004) have detected higher levels of airborne rhinovirus from occupants in buildings with elevated CO₂ concentrations. Our result showed that the relative risks were significantly higher for severe phlegm and cough symptoms, and lower respiratory illness in low ventilated and air-conditioned CCCs. In these aspects, the adverse effects of inadequate ventilation on children in CCC mirror those in working adults in offices. Because the immune system of young children attending CCCs are still underdeveloped, the results of this study indicate that adequate ventilation should be provided in CCCs.

Surprisingly, children attending HB CCCs appear to be at high risk for almost all the respiratory symptoms. Elsewhere, Chew et al. (1998b) reported that respiratory tract viral outbreaks of respiratory syncytial virus in the tropics were associated with higher environmental temperature, lower RH and higher maximal day-to-day temperature variations. Earlier, a similar association between incidence of flu and daily maximal fluctuations in temperature was observed (Doraisingham et al., 1988). Chew et al. (1998b) had hypothesized that the greater fluctuations in temperature may influence the respiratory epithelium which subsequently lead to changes in permeability and increase the susceptibility to infections (Deal et al., 1980). In our study, children in the HB CCCs are exposed to the cold and drier air via air-conditioning without ventilation for at least 2 h in the hot afternoon daily. It is plausible that the fluctuations in temperature as described by Chew et al. (1998b) above may play similar roles in increasing the prevalence of respiratory symptoms

among children attending HB CCCs. If this was true, the operation of CCCs in a hybrid mode with the intention of energy savings, should be discouraged.

Conclusion

This study provides information on the IAQ characteristics and the corresponding respiratory health symptoms of children attending CCCs under four different ventilation strategies operating in Singapore. Ventilation rates were significantly higher for NV CCCs than air-conditioned CCCs. IAQ parameters in NV CCCs are typified by the influence of the outdoors (ease of ingress of outdoor pollutants) and good dilution of indoor pollutants. The lower ventilation rates in air-conditioned CCCs result in higher occupant-related pollutant concentrations (CO₂ and human-related bacteria) but lower outdoor pollutant ingress. The filtration devices in the air-conditioning systems in AC and ACMV CCCs are effective in arresting outdoor viable and non-viable aerosols leading to a reduced exposure to these pollutants indoors. The low ventilation but high recirculation rates in AC and ACMV CCCs also result in lower ozone exposures when compared with NV CCCs. Indoor/outdoor ratios for concentrations of fungi were generally greater than

unity in mold-damaged CCCs demonstrating the influence of indoor sources.

This study showed lower prevalence for most asthma and allergy, and respiratory symptoms in children attending NV CCCs. Results are consistent with office studies that have demonstrated associations between air-conditioning with allergic rhinitis and respiratory symptoms among adult workers. After controlling for confounders, the risk of current rhinitis among children is significantly higher if they attend ACMV CCCs compared with NV CCCs. Air-conditioned CCCs were also associated with higher prevalence of severe phlegm and cough symptoms and lower respiratory illness. It is highly probable that the presence of biological agents in air-conditioning and ventilation systems is contributing to morbidity. Finally, children attending HB CCCs are at high risk for almost all the respiratory symptoms studied.

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References

- Asher, M.I., Keil, U., Anderson, H.R., Beasley, R., Crane, J., Martinez, F., Mitchell, E.A., Pearce, N., Sibbald, B., Stewart, A.W., Strachan, D., Weiland, S.K. and Williams, H.C. (1995) International Study of Asthma and Allergies in Childhood (ISAAC): rationale and methods, *Eur. Respir. J.*, **8**, 483–491.
- Batterman, S.A. and Burge, H.A. (1995) HVAC systems as emission sources affecting indoor air quality: a critical review, *Int. J. HVAC&R Res.*, **1**, 61–78.
- BCD (1983) *Handbook on Energy Conservation in Building and Building Services*, Singapore, Building Control Division, Public Works Department, Ministry of National Development.
- Brundage, J.F., Scott, R.M., Lednar, W.M., Smith, D.W. and Miller, R.N. (1988) Building-associated risk of febrile acute respiratory diseases in Army trainees, *JAMA*, **259**, 2108–2112.
- Cano-Ruiz, J.A., Kong, D., Balas, R.B. and Nazaroff, W.W. (1993) Removal of reactive gases at indoor surfaces: combining mass transport and surface kinetics, *Atmos. Environ.*, **27A**, 2039–2050.
- Chew, F.T., Goh, D.Y.T., Ooi, B.C. and Lee, B.W. (1998a) Time trends and seasonal variation in acute childhood asthma in tropical Singapore, *Respir. Med.*, **92**, 345–350.
- Chew, F.T., Doraisingham, S., Ling, A.E., Kumarasinghe, G. and Lee, B.W. (1998b) Seasonal trends of viral respiratory tract infections in the tropics, *Epidemiol. Infect.*, **121**, 121–128.
- Chew, F.T., Goh, D.Y., Ooi, B.C., Saharom, R., Hui, J.K. and Lee, B.W. (1999) Association of ambient air-pollution levels with acute asthma exacerbation among children in Singapore, *Allergy*, **54**, 320–329.
- Deal, E.C., Jr, McFadden, E.R., Jr, Ingram, R.H., Jr, Breslin, F.J. and Jaeger, J.J. (1980) Airway responsiveness to cold air and hyperpnea in normal subjects and in those with hay fever and asthma, *Am. Rev. Respir. Dis.*, **121**, 621–628.
- Doraisingham, S., Goh, K.T., Ling, A.E. and Yu, M. (1988) Influenza surveillance in Singapore: 1972–86, *Bull. World Health Organ.*, **66**, 57–63.
- Drinka, P.J., Krause, P., Schilling, M., Miller, B.A., Shult, P. and Gravenstein, S. (1996) Report of an outbreak: nursing home architecture and influenza-A attack rates, *J. Am. Ger. Soc.*, **44**, 910–913.
- ENV (1998) *Guidelines for the Prevention and Control of Infectious Diseases in Child Care Centres/Kindergartens/Pre-school Centres*, Singapore, Ministry of the Environment, Quarantine and Epidemiology Department (now under Ministry of Health, MOH).
- Ferris, B.G. (1978) Epidemiology standardization project, *Am. Rev. Respir. Dis.*, **118** (Pt 2), 1–53.
- Forsman, G. (2001) *Differences in Prevalence of Allergic Symptoms and Airway Infections between Different Day Care Centers in Karlstad, Sweden*, Report, Miljovetenskap C, Institutionen for Natur och miljo, Karlstads Universitet.
- Goh, D.Y., Chew, F.T., Quek, S.C. and Lee, B.W. (1996) Prevalence and severity of asthma, rhinitis, and eczema in Singapore schoolchildren, *Arch. Dis. Child.*, **74**, 131–135.
- Hagerhed-Engman, L., Bornehag, C.G., Sundell, J. and Aberg, N. (2006) Day-care attendance and increased risk for respiratory and allergic symptoms in preschool age, *Allergy*, **61**, 447–453.
- Hernandez, S.F., Morales, H.R., Cuevas, R.P. and Gallardo, H.G. (1999) The day care as a risk factor for acute respiratory infections, *Arch. Med. Res.*, **30**, 216–223.
- IOM (2000) *Clearing the Air. Asthma and Indoor Air Exposures*, Washington, DC, The Institute of Medicine, The National Academy Press.
- Jaakkola, J.J.K. (2000) Day-care centers and health. In: Spengler, J.D., Samet, J.M.

- and McCarthy, J.F. (eds) *Indoor Air Quality Handbook*, 69.1–69.20, New York, McGraw-Hill.
- Jones, N.C., Thornton, C.A., Mark, D. and Harrison, R.M. (2000) Indoor/outdoor relationships of particulate matter in domestic homes with roadside, urban and rural locations, *Atmos. Environ.*, **34**, 2603–2612.
- Koshinen, O., Husman, T., Hyvarinen, A., Reponen, T., Nevalainen, A. (1997) Two moldy day-care centers: a follow-up study of respiratory symptoms and infections, *Indoor Air*, **7**, 262–268.
- Lee, J. (1994) Odds ratio or relative risk for cross sectional data?, *Int. J. Epidemiol.*, **23**, 201–203.
- Lim, G., Tan, T.K. and Toh, A. (1989) The fungal problem in buildings in the humid tropics, *Int. Biodeterior.*, **25**, 27–37.
- Lim, S.H., Chew, F.T., Siti Dahlia, B.M.D., Tan, H.T.W., Lee, B.W. and Tan, T.K. (1998) Outdoor airborne fungal spores in Singapore, *Grana*, **37**, 246–252.
- Lundqvist, G.R., Iversen, M. and Korsgaard, J. (1982) Indoor climate in low ventilated day care institutions, *Environ. Int.*, **8**, 139–142.
- Macher, J.M. (1989) Positive-hole correction of multiple-jet impactors for collecting viable microorganisms, *Am. Ind. Hyg. Assoc. J.*, **50**, 561–568.
- Mendell, M.J., Fisk, W.J., Deddens, J.A., Seavey, W.G., Smith, A.H., Smith, D.F., Hodgson, A.T., Daisey, J.M. and Goldman, L.R. (1996) Elevated symptom prevalence associated with ventilation type in office buildings, *Epidemiology*, **7**, 583–589.
- Mendell, M.J., Naco, G.M., Wilcox, T.G. and Sieber, W.K. (2003) Environmental risk factors and work-related lower respiratory symptoms in 80 office buildings: an exploratory analysis of NIOSH data, *Am. J. Ind. Med.*, **43**, 630–641.
- Myatt, T.A., Johnston, S.L., Zuo, Z., Wand, M., Keadze, T., Rudnick, S. and Milton, D.K. (2004) Detection of airborne rhinovirus and its relation to outdoor air supply in office environments, *Am. J. Respir. Crit. Care Med.*, **1**, 1187–1190.
- Nevalainen, A. and Seuri, M. (2005) Of microbes and men, *Indoor Air*, **15**, 58–64.
- NIOSH (1998) *Sampling and Characterization of Bioaerosols*. NIOSH Manual Anal. Methods, **4**, 82–112.
- Robertson, A.S., Burge, P.S., Hedge, A., Sims, J., Gill, F.S., Finnegan, M., Pickering, C.A. and Dalton, G. (1985) Comparison of health problems related to work and environmental measurements in two office buildings with different ventilation systems, *Br Med J (Clin Res Ed)*, **10**, 373–376.
- Roulet, C.-A. and Foradini, F. (2002) Simple and cheap air change rate measurement using CO₂, *Int. J. Vent.*, **1**, 39–44.
- Ruotsalainen, R., Jaakkola, J.J.K. and Jaakkola, N. (1993) Ventilation and indoor air quality in Finnish daycare centers, *Environ. Int.*, **19**, 109–119.
- Weschler, C.J. (2000) Ozone in indoor environments: concentration and chemistry, *Indoor Air*, **10**, 269–288.
- Wong, N.H., Feriadi, H., Lim, P.Y., Tham, K.W., Sekhar, C. and Cheong, K.W. (2002) Thermal comfort evaluation of naturally ventilated public housing in Singapore, *Build. Environ.*, **37**, 1267–1277.
- Zocchetti, C., Consonni, D. and Bertazzi, P.A. (1997) Relationship between prevalence rate ratios and odds ratios in cross-sectional studies, *Int. J. Epidemiol.*, **26**, 220–223.
- Zuraimi, M.S., Tham, K.W. and Sekhar, S.C. (2003) The effects of ventilation operations in determining contributions of VOCs sources in air-conditioned tropical buildings, *Build. Environ.*, **38**, 23–32.
- Zuraimi, M.S., Weschler, C.J., Tham, K.W. and Fadeyi, M.O. (2007) The impact of building recirculation rates on secondary organic aerosols generated by indoor chemistry, *Atmos. Environ.*, in press.