INDICATORS OF NATURAL VENTILATION EFFECTIVENESS IN TWELVE NEW ZEALAND SCHOOLS

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ABSTRACT

Classrooms in New Zealand schools are mostly low rise buildings with natural ventilation designs, sized for summer cooling. This study has investigated winter ventilation performance in twenty-four classrooms in twelve primary schools in the Wellington region. Its purpose has been to provide baseline data on the effectiveness of existing natural ventilation, along with approximate pollutant profiles on which to base new mixed mode ventilation designs. Detailed measurements of indicator airborne micro-organisms, total volatile organic compounds, respirable particulates, and formaldehyde were completed in twelve classrooms, along with longer term logging of carbon dioxide concentrations and physical conditions. Records of metabolic carbon dioxide were used to estimate ventilation rates, which were later compared with mean infiltration rates determined from airtightness measurements. Airtightness data for the twenty-four classrooms followed the same trend seen in residential buildings, which is for modern construction to be much more airtight than older buildings. In contrast to residential buildings the indicated ventilation rates were much higher than background infiltration rates.

INTRODUCTION

New Zealand building code requirements [1] for naturally ventilating school buildings can be satisfied when openable window area exceeds 5% of the floor area. While this option has remained constant over many years, the airtightness of buildings has increased, occupant management of windows is likely to have changed and design fresh air delivery rates for mechanical ventilated buildings have changed. NZS 4303 "Ventilation for acceptable indoor air quality" [2] currently calls for 8 l/s per person for classrooms with an assumed maximum occupancy of 50 people per 100 m^2 of floor area. This standard, along with various guidelines for contaminant concentrations in indoor air are used in this study as benchmarks for the natural ventilation performance of classrooms.

SCHOOL DESCRIPTIONS

Twelve primary schools were selected for this study (labelled A to L) in the Wellington area. Two classrooms (labelled 1 and 2) were chosen in each school, to sample a wide range of building ages and types of construction. Some rooms were relocatable stand-alone buildings and others formed part of larger blocks connected with internal corridors. All were open plan spaces ventilated with openable windows on at least two faces, and in some cases high level windows opening into corridor space. Only one classroom (I2) contained purpose built wall ventilators. These were closed during the winter time measurements described here.

CONTAMINANT PROFILES

Concentrations of indicator airborne micro-organisms, volatile organic compounds, respirable particulates, and formaldehyde were measured in 12 classrooms and the results summarised in Table 1. While this is too small a sample of buildings to comment on the general standard of air quality in classrooms in New Zealand, the data does provide base level information on the effectiveness of natural ventilation in densely populated spaces. New Zealand guidelines for acceptable concentrations of many air-borne contaminants have not been established for non-workplace environments, so alternative standards for healthy indoor environments have been referenced. Even these guidelines, however, may not account for the epidemiology of classroom populations.

All contaminants measured were sampled over most of a school day and expressed as six-hour average concentrations. Formaldehyde levels were within US and Canadian guidelines for residential buildings given in Table C-1 of NZS 4303 [2] in all classrooms. Volatile organic compounds (VOC's) were trapped in charcoal filters and later desorbed into a gas chromatograph linked to a mass spectrometer to identify individual compounds. The concentration of Total Volatile Organic Compounds (TVOC) is reported in Table 1 for each classroom and referenced to the < 0.5 mg/m^3 guideline [3] for mechanically ventilated buildings. One limitation of the TVOC measurement is that it can exclude compounds of very low concentration, or very low or very high volatility, which escape detection. For individual VOC's for which no standard or guideline exists, NZS 4303 [2] recommends that $1/10^{th}$ of the Threshold Limit Value (TLV) be adopted. All VOC's separately identified were below this level.

Table 1: Six-hour average contaminant concentrations in 12 primary school classrooms during winter (<dl = below detectable limit).

Room ID	TVOC (mg/m^3)	Formaldehyde (ppm)	Total Fungi (cfu/m^3)	Total Bacteria (cfu/m^3)	Particulates TSP ($\mu g/m^3$)
B1	0.11	0.029	146	168	42
E1	0.08	0.035	174	171	69
E2	0.9	0.005	184	592	14
F1	<dl	0.016	220	111	172
G1	<dl	<dl	152	57	44
H1	0.09	0.028	244	851	265
H2	<dl	0.025	546	188	156
I1	0.16	0.024	215	1596	353
J1	3.04	0.013	394	311	169
J2	0.38	0.008	280	380	425
L1	<dl	0.010	160	451	137
L2	0.15	0.037	155	217	168
Guidance level	<0.5 (mg/m^3) [3]	<0.1 ppm [2]	<400 cfu/m^3 [4]	<100 cfu/m^3 [4]	<260 $\mu g/m^3$ [2]

Airborne fungi and bacteria were cultured to identify species from samples collected by drawing a known volume of air through a gelatin filter. Concentrations are expressed in Table 1 as culture forming units per cubic meter of air (cfu/m^3). Penicillium was the most common species followed by Cladosporium/Alternaria. In all but one case, concentrations were below the Biodet guideline [4] for non air-conditioned buildings. Less common pathogenic species (Cryptococcus) were found in five classrooms at low levels but the more concerning Aspergillus species, Stachybotrys and Histoplasma were not identified in any classrooms. The most common fungi identified are associated with damp conditions and this indicates that, in common with residential buildings in New Zealand, indoor moisture can initiate significant air-borne contamination. Bacterial counts measured in all but one classroom exceeded the Biodet guideline (100 cfu/m^3) [4] for non-mechanically ventilated buildings. This is considered to reflect the level of hygiene (with regard to sneezing and coughing) which may be lower for children than adults, as well as the occupant density, which is higher than for office spaces. Once again, the presence of indoor moisture was indicated by air-borne concentrations of Gram Negative bacteria (Pseudomonas and Flavobacterium).

Particulate concentrations are known to vary greatly in indoor spaces and to cause nuisance throat and skin irritations. Total Suspended Particulates (TSP) were captured with glass fibre filters in modified personal sampling heads and measured gravimetrically. Guidelines for suspended particles in indoor air expressed as TSP are not well defined in New Zealand so the national outdoor air guideline of the United States (Table C-1 in [2]) of < 120 μg/m^3 has been adopted as a reference. Eight of the twelve classrooms exceeded this level, indicating that further work is needed to understand the sources and health implications of particulates in classroom environments.

Carbon dioxide concentrations were measured at five minute intervals over a full week in 18 classrooms using a TSI non-dispersive infrared detector and logger. The averaged CO_2 concentration in 18 classrooms is given in Figure 1 plotted against time of day.

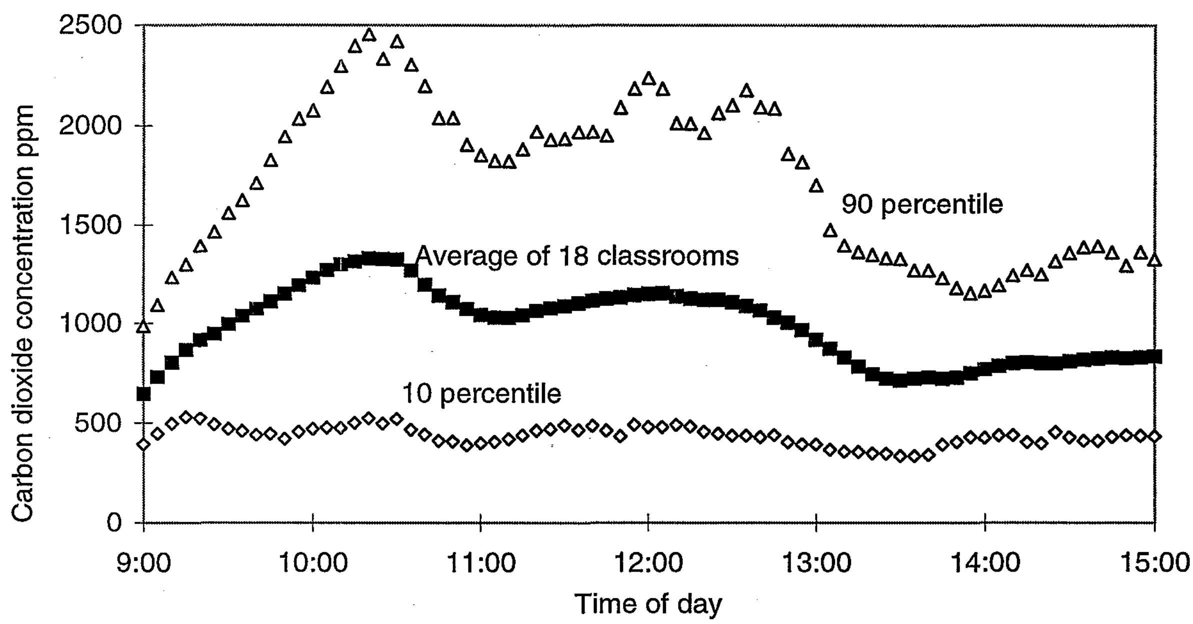

Figure 1: Average, 10 and 90 percentile of CO_2 concentrations in 18 classrooms.

As is common in naturally ventilated buildings, the concentration of CO_2 often exceeded recommendations [2] of 1000 ppm for mechanically ventilated buildings. While there are unlikely to be health effects specific to CO_2, the high concentrations are an early indicator of natural ventilation rates falling below current design standards for mechanical ventilation [2], and of possible bio-effluent problems. In most classrooms CO_2 climbed steadily in the early morning until temperatures reached about 20 °C, at which point windows were opened and the CO_2 level moderated. Beyond this, much of the additional structure in Figure 1 is due to class movements at morning and lunch break times.

VENTILATION CHARACTERISTICS

The airtightness of all classrooms in the survey was measured with a blower door and compared with trends in the airtightness of residential buildings. There is a well established trend in New Zealand for modern houses to be more airtight than older existing buildings [5]. This has been attributed to the increasing use of sheet lining materials, and more accurately fitting window and door joinery. Figure 2 illustrates this trend, and shows that the airtightness of classrooms falls within a similar range to that of houses. This is not unexpected since similar trade practices and materials have traditionally been used in both types of building. While there is insufficient data to desegregate the classroom data by age, it is worth noting that the three most airtight classrooms (A2, I1 and K1) were all built since 1990, as were all of the houses with measured airtightness levels below 4 ac/h at 50 Pa.

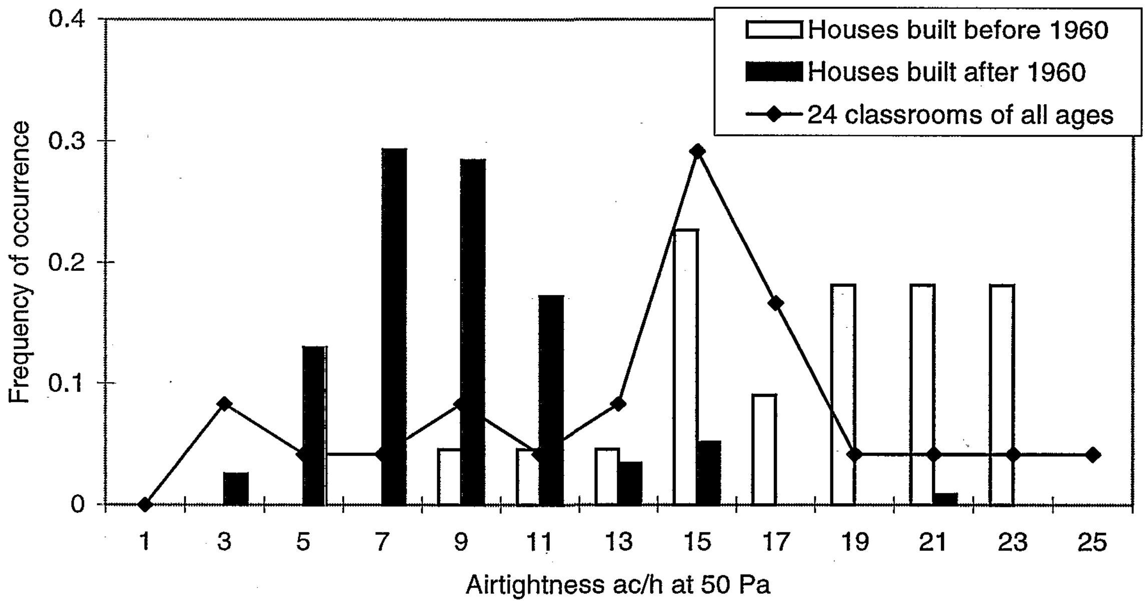

Figure 2: Comparison of classroom airtightness with houses built before and after 1960.

The ventilation rate in 18 classrooms has been estimated from metabolic carbon dioxide concentrations logged at five minute intervals over a full school week. The source strength of CO_2 was calculated from occupancy number, age and gender, using respiration rates from ASHRAE [6]. Initially the numbers present in the classroom were assumed from class size and the timing of break periods, but later on a more detailed log of attendance was used to show more clearly when classes were absent from the room. A dynamic (equation 1) form of the relationship between the indoor/outdoor CO_2 concentration difference (C_{in}-C_{out}) and the source strength S was necessary to estimate the ventilation rate Q because concentration equilibrium was rarely achieved between break periods. The volume of the classroom is V.

$$Q = \left[\frac{S}{V} - \frac{dC_{in}}{dt}\right] / (C_{in}-C_{out}) \qquad 1$$

The ventilation rates calculated from occupancy and metabolic CO_2 and illustrated in Figure 3 are more uncertain than measurements made with tracer sources of known and constant strength. In some instances occupancy levels will have been over estimated (leading to over estimated ventilation rates) and at other times, particularly at lunch time, under estimated (leading in some cases to indicated negative ventilation rates). The mean ventilation rates in Figure 3 for each school are considered to have a margin of uncertainty no better than 30%, and therefore must be regarded as indicative.

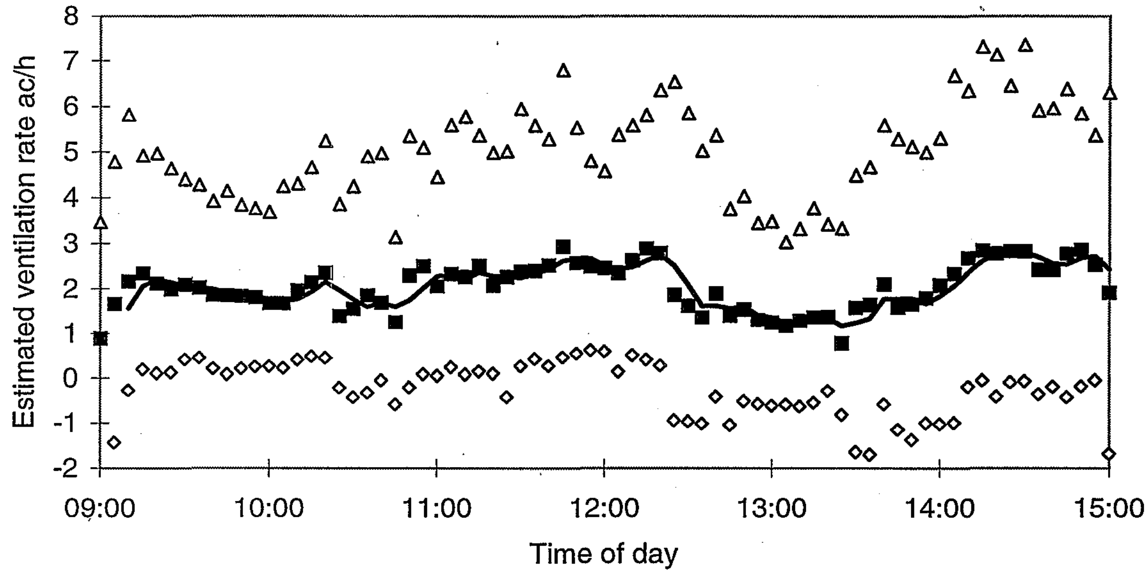

Figure 3: Average, 10 and 90 percentile of ventilation rates in 18 classroom estimated from respired carbon dioxide over one school week.

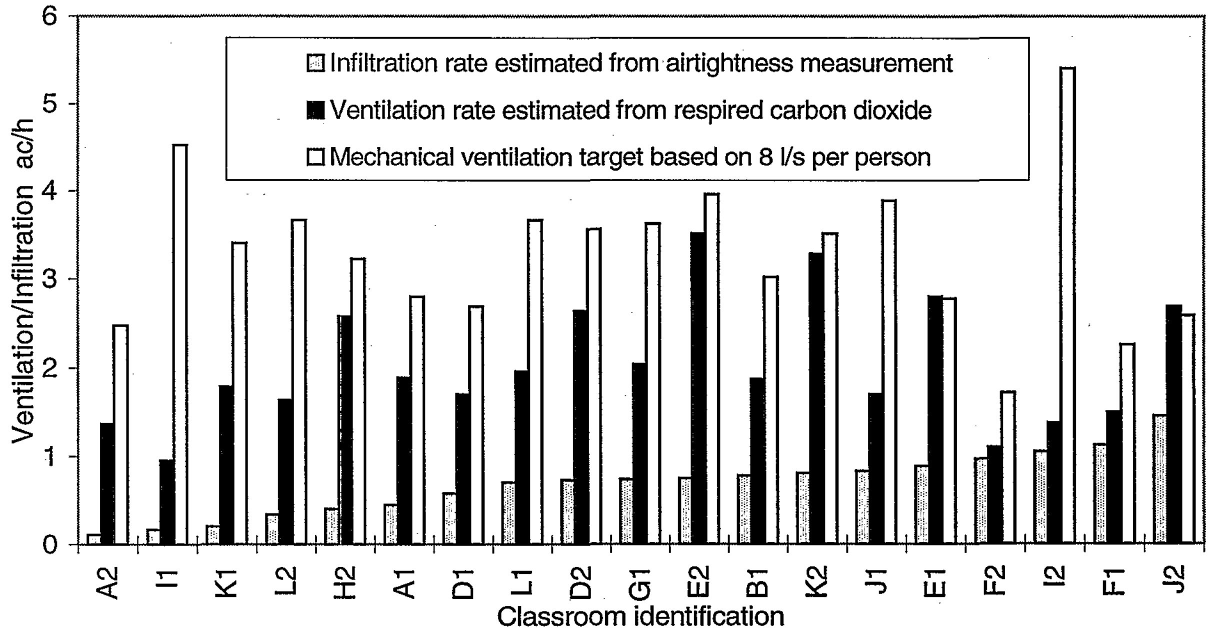

Figure 4: Estimated infiltration and ventilation rates in 18 classrooms.

Mean ventilation rates estimated for a full school week (9:00 to 15:00) are compared in Figure 4, with mean infiltration rates estimated from airtightness results and ventilation rates calculated on the basis of 8 l/s per person [2]. Estimated ventilation rates exceed average infiltration rates in all cases and there is no indication that ventilation rates are lower in the more airtight buildings. This contrasts with ventilation measurements in houses which tend to be closer to infiltration [5]. The reasons for this are thought to be attributed to the different occupancy patterns.

CONCLUSIONS

A preliminary study of the effectiveness of natural ventilation has been completed in twelve primary schools in the Wellington region with the following conclusions:

- Air contaminants measured in twelve classrooms have indicated concentrations of fungi and bacteria associated with damp conditions. This suggests that indoor moisture control may be as much an issue in classrooms as with other naturally ventilated buildings in New Zealand.
- Average carbon dioxide levels were higher than the design targets for mechanically ventilated buildings. Although not directly a health issue, the measured carbon dioxide levels indicate that ventilation rates may not deal effectively with bio-effluents.
- Modern stand-alone classrooms are more airtight than older examples, following a similar trend in New Zealand residential buildings, where improved airtightness is associated with sheet interior lining materials and tight-fitting window and door joinery.
- Ventilation rates estimated from metabolic carbon dioxide are appreciably higher than infiltration rates estimated from airtightness measurements, but are generally below the ventilation rate targets set for mechanically ventilated buildings.

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