Ventilation reliability: A pilot study on window opening behaviour in a primary school

Lara Tookey*[1], Mikael Boulic[1], Barry McDonald[2], Wyatt Page[3], Pawel Wargocki[4] and Hennie van Heerden[1]

[1]*Massey University*
School of Built Environment,
Auckland, New Zealand
**l.tookey@massey.ac.nz*

[2]*Massey University*
School of Mathematical and Computational Sciences,
Auckland, New Zealand

[3]*Massey University*
School of Health Sciences,
Wellington, New Zealand

[4]*Technical University of Denmark*
Department of Environmental and Resource Engineering Indoor Environment,
Denmark

ABSTRACT

Most New Zealand schools are designed to be naturally ventilated, using openable windows (Ministry of Education Design Quality Standard Guidelines). Furthermore, they must meet the New Zealand Building Code Clause G4 - Ventilation. Clause G4 requires the "net openable area of windows in a classroom to be no less than 5% of the combined habitable floor area to achieve sufficient ventilation". Although they are designed to code, there is no end-user operational or systems requirement for them to be opened. Assessing teacher behaviour in schools can improve indoor environmental quality in naturally ventilated classrooms where window operation behaviour directly impacts air exchange rates. This pilot study will use a multidisciplinary approach to monitor six naturally ventilated classrooms in one primary school in Auckland, New Zealand, during non-heating seasons. The state of the windows and external doors will be monitored using contact sensors and visual observations. Reflections on on-site management and difficulties will also be detailed. Data will be retrieved from the local meteorological station for ambient environmental data (temperature, humidity, solar radiation). The classroom environment will also be monitored (temperature, relative humidity, carbon dioxide). This data could inform on potential predictors to trigger open window/door openings. Correlational tests will be used to identify how opening of windows are affected by environmental predictors. This study will provide evidence of natural ventilation practices and their potential impact on classroom air quality.

KEYWORDS

natural ventilation; indoor air quality; indoor environmental quality; sensors; primary schools; windows; window operations

1 INTRODUCTION

Occupant behaviour plays a significant role in determining the Indoor Environmental Quality (IEQ) and energy consumption in buildings. The way, occupants interact with the building's systems, such as heating, ventilation, and air conditioning (HVAC), can affect the overall building performance (Asadi et al., 2017).

The perceived ability or inability to adopt adaptive behaviours in a building can physiologically affect occupants and impact their overall comfort (Sundstrom & Nilsson, 2022). The psychological effect of adaptive behaviour may differ for children in classrooms compared to adults in other types of buildings. Children have different physical and physiological needs, which can affect their perception of the indoor environment and their ability to adopt adaptive behaviours (Barrett et al., 2013). For example, children may need help understanding the control systems for heating and cooling in the classroom, which can limit their ability to adjust the indoor environment to their liking. They may also be more sensitive to noise and temperature changes than adults, impacting their comfort levels (Fanger, 1982).

Furthermore, research suggests that classroom environment factors like air quality and temperature can affect children's cognitive performance, health, and behaviour (Dadvand et al., 2015; Mendell et al., 2005; Shaughnessy et al., 2006). Therefore, it is essential to consider the psychological effects of adaptive behaviour when designing classrooms, especially for children.

To the authors' knowledge, at the time of writing this paper, there were no other studies in New Zealand (NZ) investigating the window-opening behaviours of teachers. This study aims to bridge the gap between the impact of window opening behaviour and IEQ.

This paper presents the outline of a pilot study being conducted at one Auckland primary school. By conducting this pilot study, the researcher can identify potential problems or challenges that may arise during the data collection process and make necessary adjustments before conducting the more extensive study. They can also assess the participants' acceptability of the data collection tools and test the analysis plan and determine whether modifications are necessary.

2 NEW ZEALAND CONTEXT

2.1 New Zealand climate

The New Zealand (NZ) Ministry of Education (MoE) owns more than 35,000 teaching spaces distributed over 2,100 schools (MoE, 2022). These schools are widely distributed around NZ, a long, narrow country extending 1,600 km along its north-north-east axis, with a maximum width of 400 km.

As such, there are six climatic regions, as identified in Figure 1, in which these schools operate. These climatic regions are mainly influenced by the temperate latitude, prevailing westerly winds, oceanic environment, and the Southern Alps mountains.

A series of mountain chains extending the length of NZ provides a barrier to prevailing westerly winds, dividing the country into climate regions. A summary of the mean annual values for rainfall, sunshine, temperature, frost, and wind is presented in Table 1 for consideration.

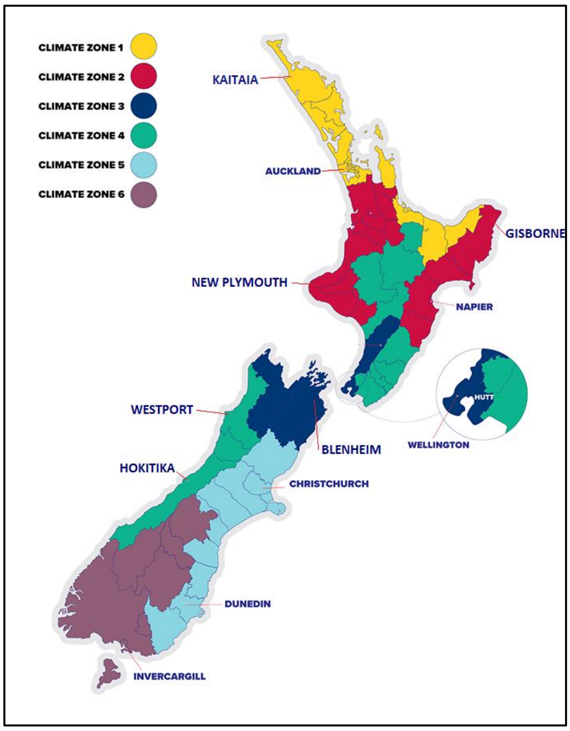

Figure 1: New Zealand climate zones (adapted from MBIE, 2023)

Table 1: Summary of Climate Information for Selected New Zealand Locations (NIWA, 2023)

	Rainfall	Wet-days	Sunshine	Temperature			Ground frost	Wind	Gale days
Location	mm	>= 1.0 mm	hours	Mean °C	Highest °C	Lowest °C	days	mean speed km/h	mean speed at least 63km/h
KAITAIA (zone 1)	1334	134	2070	15.7	30.2	0.9	1	15	2
AUCKLAND (zone 1)	1240	137	2060	15.1	30.5	-2.5	10	17	2
GISBORNE (zone 2)	1051	110	2180	14.3	38.1	-5.3	33	15	2
NEW PLYMOUTH (zone 2)	1432	138	2182	13.7	30.3	-2.4	15	20	5
NAPIER (zone 2)	803	91	2188	14.5	35.8	-3.9	29	14	3
WELLINGTON (zone 3)	1249	123	2065	12.8	31.1	-1.9	10	22	22
BLENHEIM (zone 3)	655	76	2409	12.9	36.0	-8.8	60	13	4
WESTPORT (zone 4)	2274	169	1838	12.6	28.6	-3.5	26	11	2
HOKITIKA (zone 4)	2875	171	1860	11.7	30.0	-3.4	54	11	2
CHRISTCHURCH (zone 5)	648	85	2100	12.1	41.6	-7.1	70	15	3
DUNEDIN (zone 5)	812	124	1585	11.0	35.7	-8.0	58	15	8
INVERCARGILL (zone 6)	1112	158	1614	9.9	32.2	-9.0	94	18	18

Table 1 shows mean annual temperatures range from 9.9 °C in the south (Invercargill) to 15.7 °C in the north (Kaitaia). Most areas experience between 648 (Christchurch) and 1249 mm (Wellington) of rainfall spread throughout the year. The wettest regions, Zone 4, received between 2274 and 2875 mm of rainfall throughout the year. The West coast of the South Island is the wettest region (Hokitika); however, just 100 km away to the east, over the mountains (Blenheim), is the driest. Wellington, and Invercargill are the windiest areas, with at least 18 days or more with a windspeed above 63 km/h.

One of the main challenges with providing 'fit-for-purpose' learning spaces in a geographically diverse country like New Zealand is the significant variation in climate regions. This diversity in climate can make it challenging to design and maintain learning spaces that are comfortable and conducive to learning for all students, particularly in regions that experience extreme temperatures or high humidity levels. For example, schools in warmer regions (zone 1-2) may require cooling systems or shading to prevent overheating classrooms. Schools in colder regions (zone 3-5) may require effective insulation and heating systems to ensure that classrooms remain warm and dry. This geographic distribution of schools can present some unique challenges for the NZMoE.

When designing learning spaces in NZ, the MoE has selected passive design strategies and natural ventilation systems to provide fresh air and maintain classroom thermal comfort rather than relying on mechanical ventilation or air conditioning (MoE, 2022).

Heating systems still exist in most classrooms to ensure 'fit-for-purpose' learning spaces in the cooler seasons. These may include radiators or underfloor heating. It is worth noting that while air conditioning is not standard in NZ classrooms, as in some other countries, some schools have installed inverter heat pumps for cooling to help regulate temperatures during particularly hot periods (Stuff, 2020).

School window opening behaviour would vary depending on the climate in the school's region. Generally, in warmer regions such as the north of the North Island, windows are expected to be open during the school day to allow for natural ventilation and cooling. In cooler regions, such as the south of the South Island, windows may be closed for much of the year due to colder temperatures. As such, an aspect worth noting are the reasons for the window operations. Are they in response to indoor temperature, outdoor temperature, temperature differences, humidity levels, noise or some other stimulus?

However, as mentioned previously, the MoE prefers naturally ventilated buildings. It may be likely that many schools throughout New Zealand have systems in place to encourage window-opening behaviour for natural ventilation. These systems could include window locks that allow windows to be partially opened for ventilation whilst adhering to the safety aspects (to prevent falling out of windows) or instructions to staff and students on when and how to open windows for optimal ventilation.

The COVID-19 pandemic has also brought increased attention to the importance of ventilation in indoor spaces, including schools. In response, the NZMoE has guided schools on ensuring proper classroom ventilation, which included recommendations on window-opening behaviour (MoE, 2021). One initiative introduced at this school was Aranet 4, a wireless environmental monitoring system. This system is designed to measure and monitor various environmental parameters in indoor spaces, including temperature, humidity, CO_2 levels, and atmospheric pressure. The data is collected, allowing users to monitor environmental conditions in real time. Posters were circulated to the school from the MoE, discussed at school meetings and then displayed in classrooms. Parents picking up their children after school were able to interact with these posters as well.

2.1 NZ Classroom design ventilation requirements

Most New Zealand schools are designed (following the Ministry of Education Design Quality Standard Guidelines) to be naturally ventilated, using openable windows. All classrooms must meet the ventilation rates required in the New Zealand Building Code Clause G4 Ventilation and cited standard NZS 4303:1990 (Building Performance, 2023).

The Code requires the "net openable area of windows in a classroom to be no less than 5% of the combined habitable floor area to achieve sufficient ventilation" (Building Performance, 2023). Ministry of Education's Property Management Handbook, which guides schools on property management, “all rooms where people are working, learning or teaching should be provided with adequate natural or mechanical ventilation, and the room should be maintained at a comfortable temperature and humidity level” (Ministry of Education, 2019, p. 22).

Although classrooms are designed to code, there is no end-user operational or systems requirement to open windows.

A survey undertaken in 40 Auckland (zone 1) primary schools in the winter of 2015 showed that only 40% of teachers open windows when they teach (Gully, 2015; Liaw, 2015). This figure dropped to 15% in a survey of 33 teachers from nine schools located in three NZ regions, namely Christchurch (N=4) (zone 5), Dunedin (N=3) (zone 5) and Hawke’s Bay (N=2) (zone 2) (Unpublished data, 2018).

Limited information is available in NZ relating to the window-opening behaviour of teachers and whether classrooms are adequately ventilated.

3 METHODOLOGY

This section of the paper outlines the methods and procedures used to conduct the pilot study. It will provide information on the research methods used, how the data was collected and how the data was analysed.

3.1 Sample selection

Convenience sampling was used. At the time of this study, there were five French-English bilingual schools in NZ. Three are in Auckland, one in Wellington and one in Christchurch. The reason for selecting French-English schools was to support the second part of the study. In the second stage of the study, the research will evaluate the impact that IEQ (carbon dioxide and thermal comfort levels) have on the cognitive abilities of primary school children. Bilingual individuals often demonstrate enhanced cognitive flexibility. Therefore, conducting research in schools that offer bilingual programmes in academic subjects in more than one language is a significant advantage. One school in Auckland opted out of the study, and the second was not a primary school. As the researcher was in Auckland, the third school was automatically selected as the pilot study. The study will be rolled out to other regions later.

3.2 School climate

The school is in a suburb in the North Shore area of Auckland. According to the Köppen-Geiger climate classification system, Birkdale has a Cfb climate (Peel et al., 2007). This means it has a warm-summer Mediterranean climate, with an average temperature above 10°C in the coldest month and no significant dry season. The average annual temperature in this suburb is around 15.6°C, with temperatures ranging from 10°C in winter to 22°C in summer. The area receives moderate rainfall throughout the year, with an average annual precipitation of approximately 1,231 mm (NIWA, 2023). The first week of observation studies were undertaken from 20th to 27th March 2023 (Autumn).

3.3 School building

The school has a roll of approximately 160 (personal communication from school administrator, 20 March 2023) students across teaching years 1 to 6. Students in these years are typically of ages 5 through 11 years old. At this school, students learn in mixed-aged classes i.e., Years 1 & 2, 3 & 4 and 5 & 6.

The school, as indicated in Figure 2, is located on an arterial road designed to handle high traffic volumes in a suburban environment. However, the main body of the school is set back from the road, and the classrooms used (identified with red X) are setback even further. Thus, the road noise is significantly diminished. To protect the privacy and anonymise data, the classrooms were named using the format "S0R1". The first alpha number represents the school (S0), and the second the classroom number (R1). For the pilot study, this will be S0R1 – S0R7. Initially, six classrooms with identical sizes were identified for the study. After a term break, mould was discovered in one classroom (S0R3). Those students were relocated to the library (S0R7). The school building is a single-storey light timbre-framed structure which is naturally ventilated (Fig 3, Fig 4 and Fig 5).

Figure 2: Site map of school and arterial road. (Source: Google Maps, 2023)
(Red X identify the six studied classrooms)

All classrooms are on the ground floor with north-facing external doors exiting onto the playground. Cross ventilation can be achieved as there are windows on both the front (North) and back (South) walls. Table 2 details the design of the windows for the classrooms and library. The design and number of doors and windows are the same in the five classrooms, so only the details of one classroom and the library have been outlined.

Table 2: An overview of the window features of the classroom and library and their controls.

		Window Design					**Window Operation**
	Area (m^2)	WA[1] (m^2)	NW[2]	Window Type	MW[3]	Ventilation	
Classrooms (S0R1 – S0R6)	66	3.36	1	Louvre (North)	Above head height	Double-sided at 2 levels + louvre opening	Manually with handle
		7.20	6	Side-hung outward opening (North)	0.64		Manually
		2.50	4	Top-hung outward opening (South)	1.50		Manually with handle
Library (S0R7)	175	3.36	1	Louvre (North)	Above head height	Double-sided at 2 levels + louvre opening	Manually with handle
		3.60	3	Side-hung outward opening (North)	0.64		Manually
		4.90	6	Top-hung outward opening (South)	1.00		Manually
		2.50	4	Top-hung outward opening (South)	1.50		Manually

1 = Total window area (m^2) in each classroom
2 = Number of windows
3 = Minimum height of windowsill (m)

Figure 3: Design of windows in S0R2 and five other classrooms.

Figure 4: External door and windows for S0R2 (North) and Top-hung windows for S0R1 and S0R2 (South). Same design for five other classrooms.

Figure 5: Louvre window and external double doors for Library/S0R7 (North)

3.4 Data acquisition

Visual observations
Three days of visual observations were conducted to ascertain the physical characteristics of the door/window open/closed status during the school day. The lead author appreciates that three days of a week is not sufficient to establish a comprehensive understanding of normal behaviour. However, due to teaching limitations throughout the semester, this was the only timeframe available. The week in March was selected as it included a day in which one class

was away on a fieldtrip. This would provide insight into how the classroom would be managed.

An observation form was developed to obtain information on the door/window open status at 20-minute intervals. By conducting these observational studies, the researcher was able to confirm the following:

- Functionality – how individuals interact with the space and whether the classrooms were in use or vacant.
- User functionality – by observing the use of space, it will be possible to identify if areas are meeting the ‘fit-for-purpose’ goal. Changes on how to improve can then be identified.
- Digital data – visual observations can provide valuable context and interpretation of the data supplied by monitoring systems, helping identify issues, validate data and improve the overall effectiveness of the monitoring system.

Visual observations were conducted to provide a general overview of the space and identify explanatory predictors influencing operations on windows and external doors. The lead author recorded the reasons for operations and the frequency through visual observations and teacher comments (Table 3).

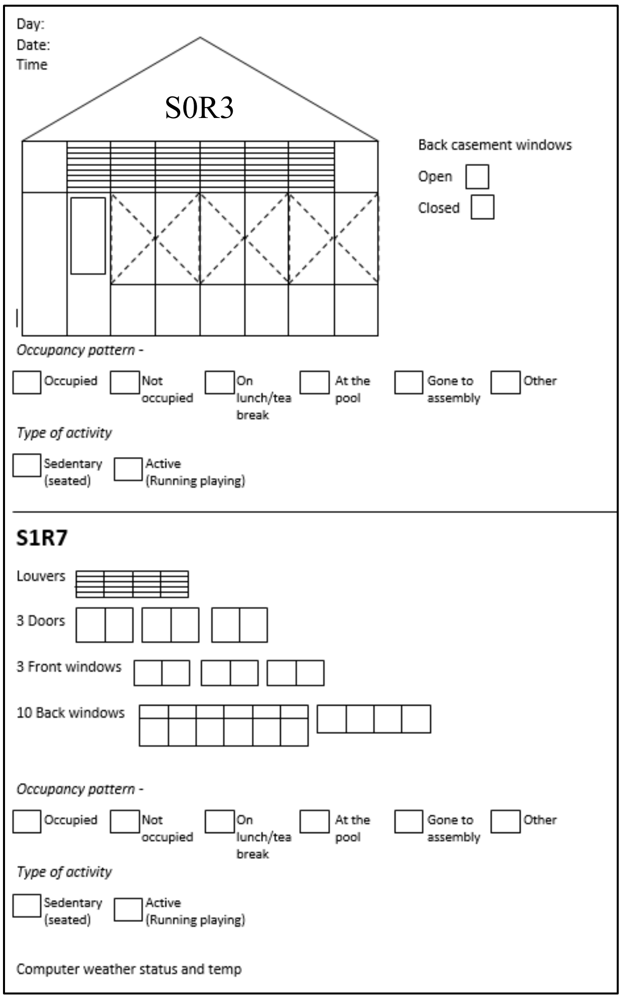

Table 3: Observation form for occupancy patterns and window opening behaviour.

To avoid disruption, the reasons for opening/closing operations were classified into general categories such as occupancy patterns, IEQ or external factors such as noise, which were obvious to observe without asking questions and intervening. In cases where the cause was unclear, the lead author would ask what the window operation was at the end of the teaching period.

Time management and weather conditions were some challenges associated with the visual observations. Due to time restrictions, the lead author could not conduct a week-long observation study; thus, the study had to be broken up over a few weeks. This was further exacerbated by a Cyclone and severe flooding, which led to school closures.

Teacher information
Before the commencement of the observational studies, the lead author was informed by two of the teachers that the students manage the opening/closing of the windows during the day based on the teacher's requests.

Window/door sensors
Window/door sensors, which incorporate Bluetooth LE5.0 technology and internal magnetic sensors, were installed on the window frame (Figure 6). Due to financial limitations, these sensors could only be installed in three classrooms. It was decided to install them in the classrooms which would form part of the second phase of the research study.

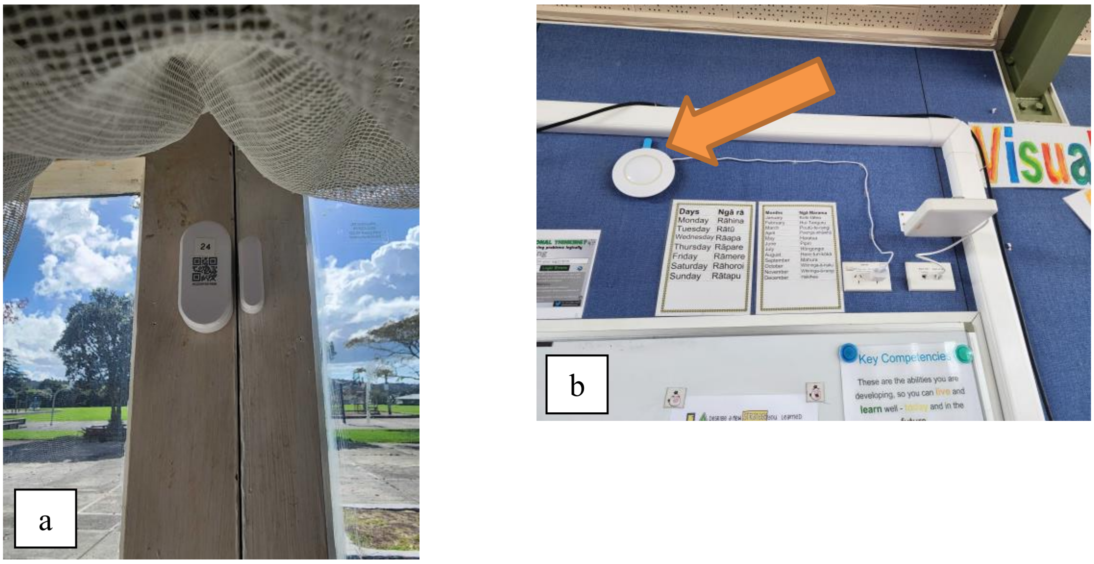

Figure 6: Placement of window sensor (a) on window frame and data logger connected to sensor through Bluetooth monitoring system (b).

These sensors assist the researcher in understanding window/door-opening behaviour by providing data on when and how often window/doors are opened and closed. The internal magnetic sensors in the sensor detect changes in the magnetic field when a window/door is opened or closed. This data is transmitted via Bluetooth LE5.0 technology to a centralised data logger (Figure 6b) as highlighted by the orange arrow.

By analysing this data, the researcher may gain insight into window/door opening behaviour, such as the frequency and duration of the window/door opening and the time of day when the window/doors are most often opened.

Some of the challenges associated with installing the sensors were related to the time management of the lead author and the logistics of working after hours at the school. The school was available for a limited time after hours because the classrooms were used for after-school workshops and community group events. Another issue was the actual construction of the window/door frame. The sensors are sensitive to rattles and frames that are not flush. Alternative fixing methods had to be developed.

Indoor Air Quality monitors

A team of researchers from Massey University, collaborating with NIWA, developed a low-cost monitoring platform, SKOMOBO (Figure 7). SKOMOBO stands for SKOol MOnitoring BOx, specifically adapted for the learning environment. Several units have been installed in the pilot study school (S0R1 – S0R3). However, as previously mentioned the students in S0R3 were moved to S0R7 due to the identification of mould. At the time of writing this paper, SKOMOBO units had not been installed in S0R7.

Figure 7a shows the pre-fieldwork co-location testing to check for data drift in the monitoring platform (SKOMOBO). The large orange arrow in Figure 7b point to a SKOMOBO monitoring platform installed in either S0R0/S0R1.

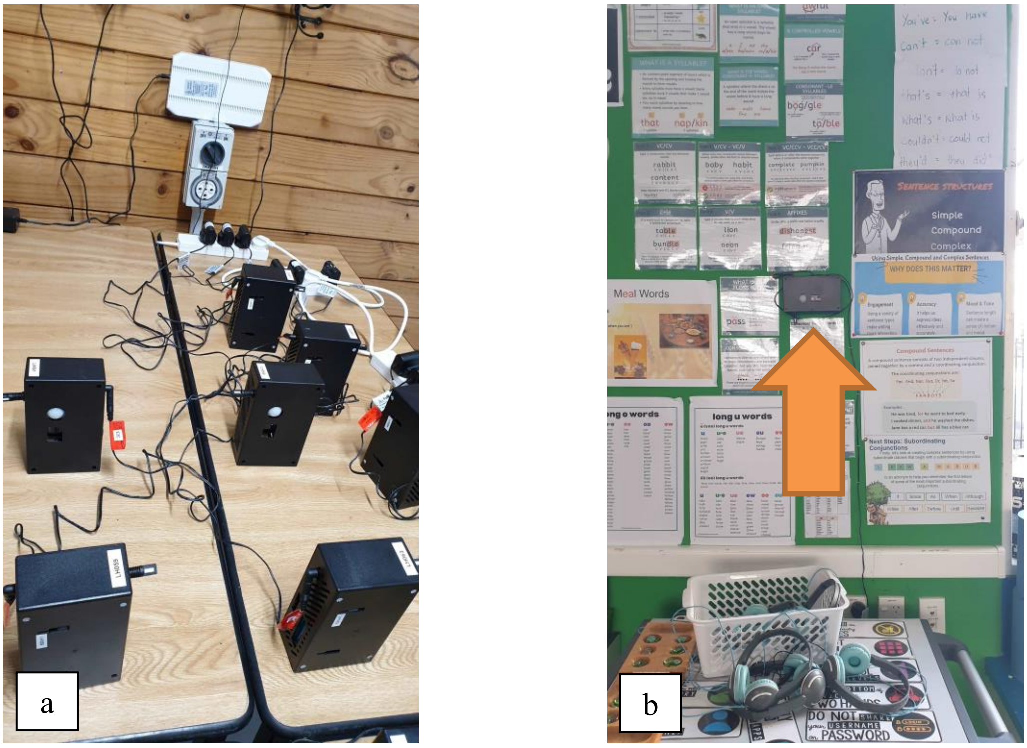

Figure 7: Pre-fieldwork co-location monitoring device at the lab (a) and Skomobo placed on the classroom wall (b)

Using a combination of the window/door sensors with the IEQ monitors it will be possible to identify periods of low ventilation, and increased carbon dioxide concentration levels, which could negatively impact on student health, learning and cognition. This data analysis forms part of the next phase of the study.

Environmental measurements
External environmental variables impacting window operations were recorded at 3-hourly intervals. This data was obtained from The National Climate Database (CLIFLO), utilising the local weather station-based in Albany North Shore (NIWA Cliflow database, 2023).

4 RESULTS

Table 4 shows the descriptive statistics of the indoor and outdoor variables over the three-day observation period. The maximum carbon dioxide (CO_2) level recorded in a classroom was 1000 ppm. The maximum indoor temperature was 26.9 °C, so this is not unexpected for an end of March (Autumn) reading. The average (across the three classrooms) CO_2 reading for the observation period was 508.6 ppm. There was a spike in the CO_2 reading for S0R2 on Day 1, the maximum (1000 ppm). The lead author assumes this is from the extra window operations made due to noise created by the swimming classes. The pool is located directed behind S0R2. This was confirmed after a conversation with the teacher (personal communication with teacher, 20th March 2023).

Table 4: Descriptive statistics of indoor and outdoor variables.

		S0R1 (SKOMOBO)			S0R2 (SKOMOBO)			Outdoor variables		
		Temp (°C)	RH (%)	CO2 (ppm)	Temp (°C)	RH (%)	CO2 (ppm)	T_{out} (°C)	Rhout (%)	Wind Speed (km/hr)
Minimum	Day 1 (9am -3pm)	19.2	54.4	410	19.5	48.1	410	14.8	58.0	1.4
	Day 2 (9am -3pm)	17.7	52.3	405	17.8	48.0	417	13.9	54.0	1.0
	Day 3 (9am -3pm)	21.1	58.6	417.0	21.7	56.9	414.0	17.9	69.0	1.1
Maximum	Day 1 (9am -3pm)	23.9	70.6	904	26.9	66.8	1000	21.8	96.0	5.0
	Day 2 (9am -3pm)	21.9	66.4	631	24.8	63.3	769	19.4	84.0	8.3
	Day 3 (9am -3pm)	24.9	75.6	701.0	25.8	72.8	718.0	21.2	94.0	6.5
Mean	Day 1 (9am -3pm)	22.2	61.3	480.5	24.2	57.2	608.5	19.1	70.7	3.7
	Day 2 (9am -3pm)	20.6	56.5	468.5	22.3	53.7	454.3	17.4	64.0	5.6
	Day 3 (9am -3pm)	23.1	68.0	525.1	23.5	65.4	515.0	20.1	79.7	3.7

Figure 8 illustrates outdoor variable conditions at 3-hourly intervals. Over the three days, no rain was recorded. On the last day there was low lying cloud, and rain was experienced in the neighbourhood, thus increasing the humidity levels at the start of Day 3. The temperatures rose steadily from day two through day three. The wind speed remained below 10km/hr.

Figure 9 details the number of window operations. Window operations are described as the number of times the windows are opened/closed during each school day (09:00 – 15:00), over the 3-day observation study. No operations occurred in S0R2 on the second day as the class was on a field trip. The windows in S0R4 and S0R5 were never opened so have not been included in Figure 9.

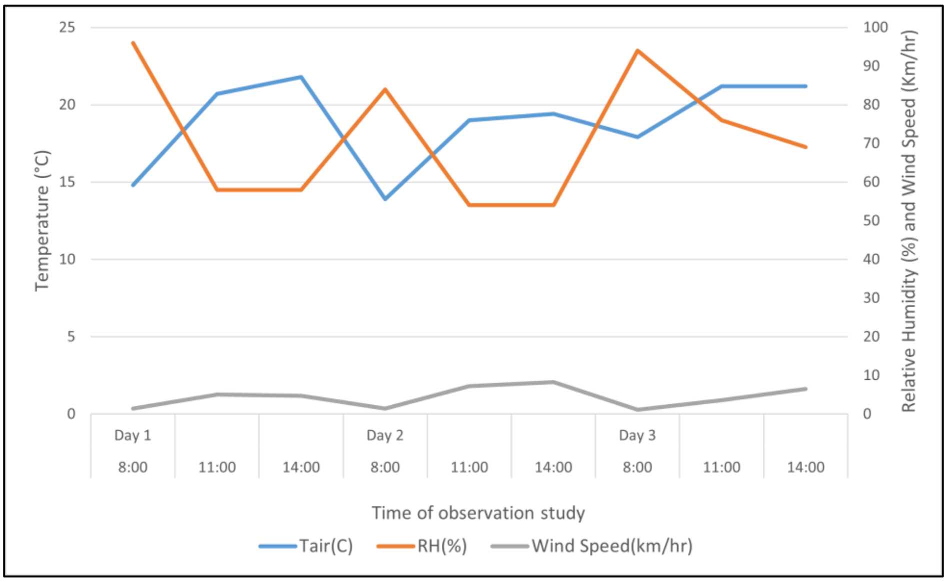

Figure 8: Three-hourly readings of outdoor environmental conditions over observation study.

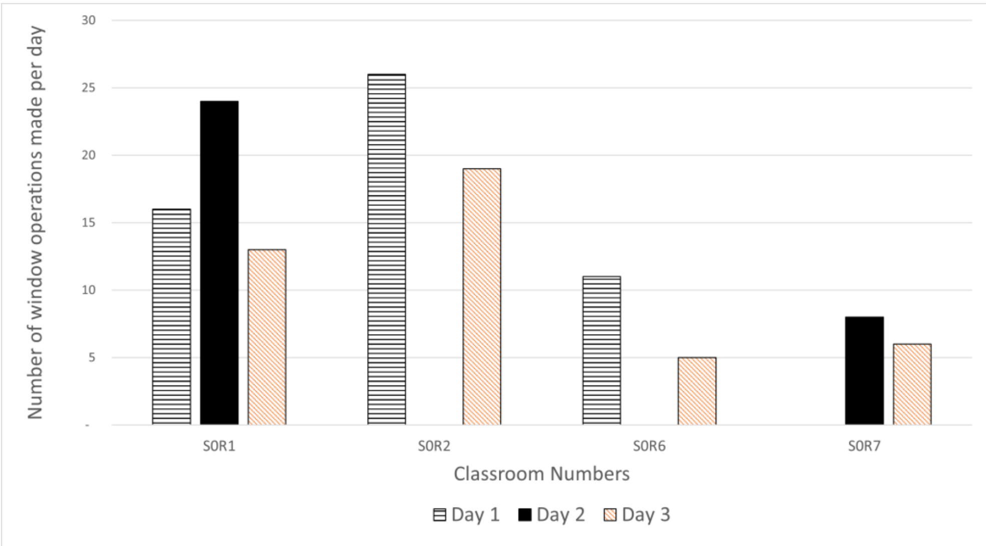

Figure 9: Number of window operations made per day over observation study.

Figure 10 shows the reasons for window operations (window opening and closing). 43% of window operations usually occurred upon teachers' arrival (usually around 8:30 am) and before students arrived in the classroom. 38% of operations occurred because of IEQ. 10% of operations (window closures) occurred due to noise. S0R2 closes the windows when the Year 1 and Year 2 students are in the pool due to increased noise.

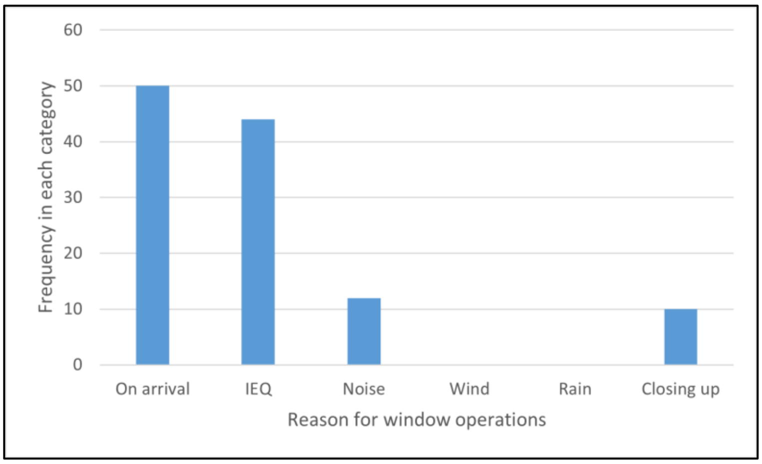

Figure 10: Reasons for window operations based on visual observations.

The caretaker opened the external doors prior to the teacher's arrival. These doors were kept open during the school's operating hours. On no occasion were windows opened by the caretaker before the teachers and students' arrival. Teachers opened their windows upon arrival. Once the windows were open, they would be kept open unless disturbing factors such as noise, rain, cold temperature or unwanted wind made them close the windows. This suggests that opening or closing windows depended on occupancy patterns (upon arrival and departure) and environmental variables. Not all window operations followed this logic; however, this closely represents the scenario in most of the classrooms in this study.

Figure 11 represents the percentage of window area that was open in each classroom for each day over the observation study period. This is based on the number of windows openable in each classroom and operations per hour.

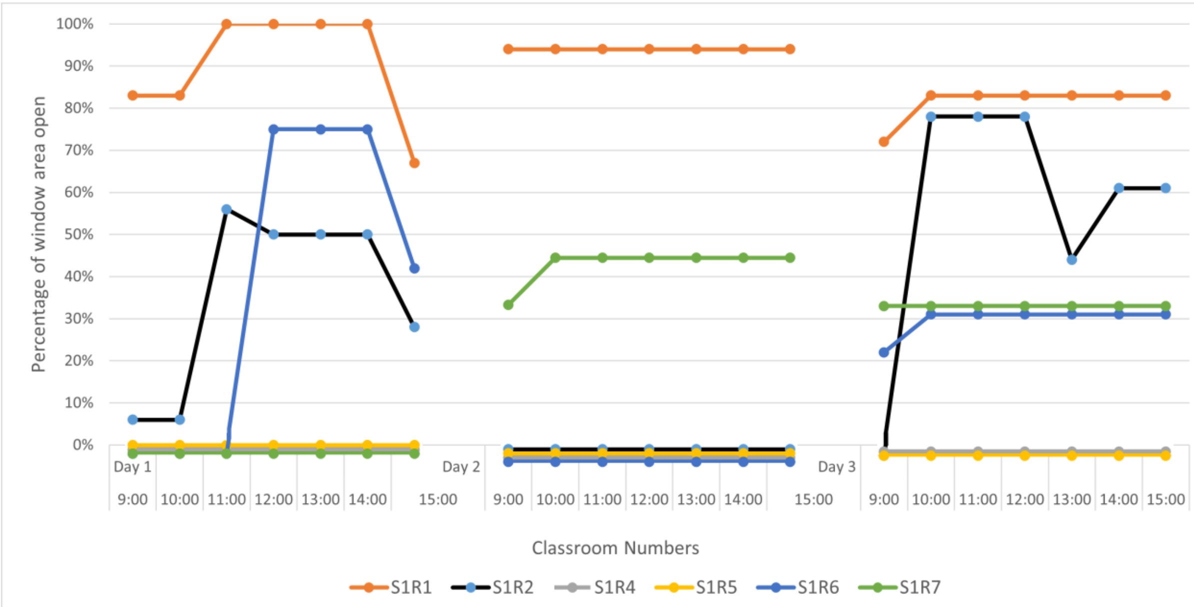

Figure 11: Percentage of window area that is open over the school day (by class) during the observation study.

The front north-facing door was open for each classroom over the three days. In classrooms S0R1 and S0R2, the teachers, consistently keep their windows open, creating well-ventilated classrooms. The windows in S0R4 are never opened. S0R5 is combined with S0R6 (flexible teaching space with sliding partition wall). This partition wall was open throughout the observation period. Most of the teaching occurred in S0R6. The window and door usage could be more consistent in these two classrooms. This may be a result of the team teaching that occurs in this venue. This is something the lead author will investigate further.

A Spearman correlation between window open area (WOA m^2) and environmental variables was conducted to determine a more detailed analysis of window operations in response to IAQ. Visual observations showed that 38% of the windows were operated due to IAQ; therefore, environmental measured variables, including Temp, Humid (%), CO_2 (ppm), T_{out}, RH_{out} (%), and Wind Speed, were tested against WOA (m^2). The instances of operations unrelated to environmental variables from the observations (closing windows at the end of the school day) were excluded from the analysis. Table 5 shows the results of the Spearman correlation.

Table 5: Correlation and regression values between WOA (m^2) and environmental variables

Correlation/Regression of WOA with …	**Temp (°C)**	**Humid (%)**	**CO_2 (ppm)**	T_{out}(°C)	**RH_{out} (%)**	**Wind Speed (km/hr)**
R_s value	0.758	-0.341	-0.613	0.893	-0.494	0.479
P values	0.018 [a]	0.370	0.079	0.001 [a]	0.177	0.192

[a] Correlation is significant (2-tailed)

Results of the Spearman correlation in Table 5 show that outdoor temperature (Spearman correlation coefficients = 0.001, $P < 0.001$) and indoor temperature (Spearman correlation coefficients = 0.018, $P < 0.001$) have the most robust relationship with WOA (m^2). Window area opening (m^2) does not correlate with outdoor windspeed. Results of the Spearman correlation in Table 5 show that WOA (m^2) negatively correlates to CO_2 and internal and external humidity levels.

5 CONCLUSIONS

The duration of time that external doors and windows are kept open will have an impact on the IEQ and ventilation in a classroom. It is interesting to note the extreme differences in practice in window opening behaviour between S0R1/S0R2 and S0R4. One would anticipate this behaviour prior to COVID-19. However, this behaviour seems unusual after the circulation of MoE guidance documents relating to window/door opening best practices.

Also, it is interesting to note the different teacher behaviour in the same school. All teachers are receiving the same information and guidance from the principal, yet their window opening behaviours are quite different.

The analysis of Spearman's correlation coefficients revealed significant relationships between the variables under investigation. A strong positive correlation was found between Variable A (window openable area) and Variable B (internal classroom temperature) ($\rho = 0.758$, $p < 0.018$), indicating a robust and consistent association between these two factors. Additionally, Variable C (Relative Humidity) exhibited a negative correlation with Variable A ($\rho = -0.341$, $p = 0.370$), suggesting an inverse relationship between these variables. Furthermore, Variable D (Carbon dioxide ppm) also exhibited a negative correlation with Variable A ($\rho = -0.613$, p

= 0.079), suggesting an inverse relationship between these variables. However, Variable E (Outdoor temperature) also exhibited strong positive correlation Variable A ($\rho = 0.893$, $p = 0.001$).

These findings demonstrate the presence of statistically significant associations between the variables A, B and E, reinforcing the hypotheses proposed in this study. The strength and direction of the correlations provide valuable insights into the relationships among the factors examined.

Overall, the observed correlations support the notion that changes in Variable A (opening of windows) are likely to impact the variations observed in Variable B (indoor temperature) and Variable D (carbon dioxide). These findings contribute to our understanding of the complex interplay between these variables and lay the foundation for further investigations in this field.

The next research phase will consider how much indoor thermal comfort (temperature and relative humidity) and indoor CO2 levels change based on window/door opening behaviour. The third phase of the research will evaluate the impact of these changes (thermal comfort and CO2 levels) on primary school students learning cognitive abilities.

6 REFERENCES

Asadi, I., Mahyuddin, N. and Shafigh, P. (2017), "A review on indoor environmental quality (IEQ) and energy consumption in building based on occupant behavior", Facilities, Vol. 35 No. 11/12, pp. 684-695. https://doi.org/10.1108/F-06-2016-0062

Barrett, P., Zhang, Y., Moffat, J., & Kobbacy, K. (2013). A holistic, multi-level analysis identifying the impact of classroom design on pupils' learning. Building and Environment, 59, 678-689. doi: 10.1016/j.buildenv.2012.09.016.

Dadvand, P., Nieuwenhuijsen, M. J., Esnaola, M., Forns, J., Basagaña, X., Alvarez-Pedrerol, M., ... & Sunyer, J. (2015). Green spaces and cognitive development in primary schoolchildren. Proceedings of the National Academy of Sciences, 112(26), 7937-7942. doi: 10.1073/pnas.1503402112.

Department of Building and Housing. (2011). Compliance Document for New Zealand Building Code - Clause G4 Ventilation. Wellington, NZ: Department of Building and Housing.

Fanger, P. O. (1982). Thermal comfort. Analysis and applications in environmental engineering. New York: McGraw-Hill.

Gully, F. (2015). Windows and Doors in Schools: A study of low-decile primary schools in Auckland (Final Year Project Report). Auckland, NZ: Massey University.

Liaw, F. (2015). Doors and Windows Needs for School (Final Year Project Report). Auckland, NZ: Massey University.

Mendell, M. J., Heath, G. A., & Doi, L. (2005). Indoor environmental factors associated with cognitive function in school children. Indoor Air, 15(Suppl. 10), 1-9. doi: 10.1111/j.1600-0668.2005.00339.x.

Ministry of Business, Innovation and Employment. (2023). Building Code Handbook: H1 Energy Efficiency [Brochure]. Retrieved from https://www.building.govt.nz/assets/Uploads/building-code-compliance/h1/h1-energy-efficiency/building-code-handbook-h1-energy-efficiency.pdf

Ministry of Education. (2017). Deciles. Retrieved from https://www.education.govt.nz/school/funding-and-financials/resourcing/operational-funding/deciles/

Ministry of Education. (2019). Funding changes to support equity in schools. Retrieved from https://www.education.govt.nz/news/funding-changes-to-support-equity-in-schools/

Ministry of Education. (2021). Ventilation and COVID-19. Retrieved from https://www.education.govt.nz/school/property/state-schools/covid-19-property-guidance/ventilation-and-covid-19/

Ministry of Education. (2022). Designing Quality Learning Spaces - Indoor Air Quality and Thermal Comfort. Wellington, NZ: New Zealand Ministry of Education.

Ministry of Education. (2023). Equity index funding summary 2023. Retrieved from https://assets.education.govt.nz/public/Documents/our-work/changes-in-education/MOE14173_Regional-Summary_Auckland_19.pdf

National Center for Education Statistics (NCES). (2019). Condition of Education 2019. U.S. Department of Education, Washington, DC. Retrieved from https://nces.ed.gov/programs/coe/pdf/coe_toc.pdf

National Institute of Water and Atmospheric Research. (2023). Retrieved from https://niwa.co.nz/education-and-training/schools/resources/climate/overview

NIWA. (2023). Cliflo Database. Retrieved from https://www.niwa.co.nz/climate/cliflo

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences, 11(5), 1633-1644. https://doi.org/10.5194/hess-11-1633-2007

Shaughnessy, R. J., Haverinen-Shaughnessy, U., Nevalainen, A., Moschandreas, D. J., & Sundell, J. (2006). A preliminary study on the association between ventilation rates in classrooms and student performance. Indoor Air, 16(6), 465-468. doi: 10.1111/j.1600-0668.2006.00450.x.

Stuff. (2020). Retrieved from https://www.stuff.co.nz/national/education/121817162/should-air-conditioning-be-standard-in-nz-classrooms

Sundstrom, E., & E. D. Nilsson. (2002). Predicting perceived control in indoor environments: The roles of environmental stimulation and attentional processes. Journal of Environmental Psychology, 22(3), 247-257. doi: 10.1006/jevp.2002.0243.