Achieving suitable airflow rate in New Zealand classrooms: a CFD approach to inform on potential retrofitting solutions.

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ABSTRACT

During the COVID-19 pandemic, besides sanitising, masking, and increasing social distancing, opening classroom windows was the NZ Ministry of Education's main requirement for reopening schools. However, a pre-COVID-19 survey showed that only a third of the NZ teachers opened windows during teaching time. Achieving a suitable ventilation level could not rely on humans to open windows. Heating, Ventilation, and Air Conditioning (HVAC) systems are not affordable for most NZ schools. Consequently, an alternative and affordable ventilation method that could be retrofitted is needed to increase the airflow rate. In this project, we investigated the benefit of using trickle ventilators with connection (or not) to extraction fans in three NZ locations (Auckland, Wellington and Dunedin). The computational fluid dynamic (CFD) approach allowed us to test different scenarios for ventilation performances, such as single-sided trickle ventilators versus cross-ventilation scenarios, modelling with or without extractor fans. We carried out an aeraulic simulation of the airflows to visualise the trajectory of the flows and check the air velocity and temperature in the classroom volume where the students are located. The results for the Wellington case study (no extractor fan used) showed a suitable airflow rate in summer when the trickle ventilators were fully open. However, the trickle ventilators' effective area was reduced in winter, and insufficient air entered the classroom. In addition, despite good air mixing assisted by the inverter heat pump use in winter, there were still a few areas where the air was not well-mixed. These areas experiencing a lower mixing rate could create some "CO_2 pockets", reducing the extraction of pollutants or viruses. Acknowledging COVID-19 and its lasting impacts on NZ schools and families, we must better prepare for future learning disruptions. By investigating different cases simulated by CFD software, we compared different scenarios to improve ventilation performance in the classroom. Following the CFD project, we plan to deploy some sensors to monitor the temperature, relative humidity and CO_2 in Auckland, Wellington and Dunedin classrooms and validate our modelling findings. This study will assist the NZ Ministry of Education retrofit classrooms for a healthy environment.

KEYWORDS

Computational Fluid Dynamic (CFD), IAQ, ventilation, occupied primary schools

1 INTRODUCTION

Children spend the second largest proportion of their time at school. Half of the school stock in New Zealand (NZ) was built before 1970, and nearly all classrooms depend entirely on natural ventilation via open windows. This dependence on occupants for airing does not always guarantee an adequate ventilation rate. Surveys showed that only 30% of NZ teachers open windows during teaching time (Gully, 2015; Liaw, 2015; Boulic, 2019). In addition, classrooms have a higher density of occupants than most other building types. Due to the high density of occupants and reliance on natural ventilation, providing an acceptable ventilation rate during the winter in the school environment could be challenging.

A lack of ventilation will increase pollutants and moisture levels in the classroom (Sadrizadeh, 2022). It is also well established that a poorly ventilated classroom will favour the transmission of viruses like SARS-CoV-2, even if social distancing is respected (Correiaxc, 2020; Dai, 2020). The literature shows some associations between moderate levels of heat stress and CO_2 in classrooms and children's cognitive performance (Palacios Temprano, 2020).

As NZ teachers seldom open windows, there is a need to find an alternative solution to assist them in airing in the classrooms. Smart ventilation could assist in providing more ventilation in the classroom when needed (Guyot 2018). In a previous study, we tested trickle ventilators connected to extraction fans in an Australian apartment. The results showed trickle ventilators connected to an extraction fan (continuous extraction) could be a classroom ventilation option (Boulic, 2023).

Our approach will use Computational Fluid Dynamics (CFD) to evaluate three ventilation configurations for winter and summer across three NZ locations. We will first test the performance of cross ventilation (airflow enters the classroom through the trickle ventilators) with no extractor fan. The results from this first configuration are presented in this paper. Our second and third tests will evaluate the ventilation performance under a continuous extraction regime (8 litres per second per child, NZS 4303:1990) with the air entering the classroom either from one or both sides. Our study aims to investigate the airflow velocity, temperature distribution and ventilation efficiency in winter and summer seasons.

2 MATERIALS AND METHODS

2.1 Description of the classroom and ventilation strategies

Case study locations

The rationale for selecting these three locations (Auckland, Wellington and Dunedin) is the large temperature and wind gradients across the three NZ cities. Auckland is exposed to a subtropical climate with warm, humid summers and mild winters (Chappell, 2013). Wellington region experiences stronger winds than other parts of New Zealand (Chappell, 2014). Dunedin, located in the southern part of the South Island, is characterised by cool coastal breezes (Macara 2015). Figure 1 shows the locations of these three cities (Auckland, Wellington and Dunedin).

Figure 1: Location of the three cities (Auckland, Wellington and Dunedin) selected for the modelling

Modelled classroom building

Figure 2 shows the 3D model of the two-classroom building imported into the CFD program. This 160.4 m² floor building comprises two identical classrooms of 80.2 m² each (11.3 m x 7.1

m), an average area for NZ primary schools (MOE, 2024). The building has a mono-pitch skillion roof (ceiling height between 2.7 m and 3.5 m) and is made of Metra Wall™ (panels constructed from NZ pine wood fibre and resin with a 640 kg/m^3 density, BRANZ, 2021). A NZ building company (Builtsmart, Huntly, NZ) uses this plan to deliver prefabricated classrooms to the NZ Ministry of Education.

Figure 2 shows that the building comprises two identical classrooms side by side (mirror). This design allowed us to run two CFD simulations (summer and winter) simultaneously, display the differences on the same graph, and explore more case studies in a shorter time due to the high computing needs to conduct CFD simulations. The classroom furniture is distributed as in a typical NZ classroom. Each classroom has five tables with five students (25 total). The NZ median class size is 25 students (PPTA, 2024). The building faces the north (south hemisphere) for optimal solar gain during the school day (9 am – 3 pm). Each classroom has four windows (thermally broken aluminium frame and double glazed, U_w = 2.0 W/m^2.K) and one door.

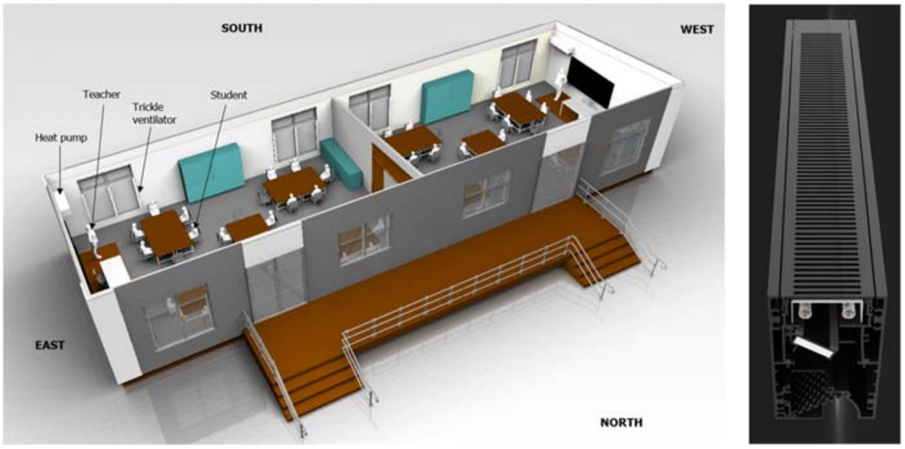


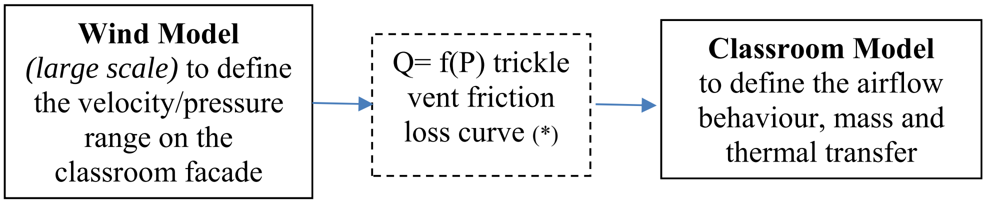
Figure 2: The 3D model of the two-classroom building imported into the CFD program (left) and the trickle ventilator (APL Ventient SCW-SH1500) installed vertically on the classroom windows (right).

Ventilation system

The original classroom relies on occupants to open windows for airing. In our study, we installed three vertical trickle ventilators (Figure 2, right) on each of the four windows (one trickle ventilator on each jamb and one on the mullion), making twelve trickle ventilators per classroom. All twelve trickle ventilators are the same size (1500 mm by 55 mm with a 64.4 cm^2 effective open area when fully open). The trickle ventilator incorporates a passive wind dampener to manage water ingress and draughts associated with high wind gusts and a filter for coarse particles. The trickle ventilator has an acoustic treatment to mitigate the effects of outside noise. Discussions with a few NZ teachers reported that outside noise was a significant factor that prevented teachers from opening windows during teaching (Tookey L, 2024, personal communication). This trickle ventilator includes a shape memory alloy adapting the opening to external temperature (fully open above 18°C and one-third open under 12°C external temperature). A fan extractor will be installed on the classroom ceiling to assist with ventilation and test the impact of continuous ventilation on CO_2 levels. The fan flow rate (749 m^3/h) follows the NZS 4303:1990 minimum requirements of 8 litres per second per child/teacher, assuming 25 children and one teacher per classroom. This fan is rated 42dB(A) at 3 m and suits the learning environment. The air will enter the classroom via the trickle ventilators and be extracted via the ceiling fan extractor. As there are twelve trickle ventilators per classroom, we assumed each ventilator would have a mean airflow of 17.3 L/s (equivalent to 62.4 m^3/h).

2.2 Conceptual framework

Figure 3 shows our two-step process. The first step, the "Wind Model", defines the velocity range on the input face of the trickle ventilators for the main wind direction. The "Wind Model" results will be implemented in the second step, the "Classroom Model". The velocity profile obtained in the "Wind Model" will be combined with the "Fan Q/P equation" to define the airflow behaviour in the classroom. The "Wind Model" is a steady-state model, while the "Classroom Model" will be a transient model simulated over 90 minutes (average teaching period at the primary school level).



(*) Trickle vent friction loss formula for our configuration is $Q = 97.7\ (\Delta P/9.8)^{0.53}$

Figure 3: Conceptual framework of the CFD simulations

2.3 Wind boundary conditions

We implemented the wind data (meteorological station data measured at 10 m high) in the “Wind Model” for the three selected locations (Grey Lynn for Auckland, Wellington Airport/Lyall Bay for Wellington, and Forbury for Dunedin). Figure 4 shows the monthly wind direction in Auckland (top), Wellington (middle) and Dunedin (bottom). For Auckland, the January 2014 - March 2024 data was averaged. For Wellington, the June 2004 - March 2024 data was averaged. For Dunedin, the January 2014 to March 2024 data was averaged. We selected one month in summer (January) and one month in winter (July) in NZ (south hemisphere) for our CFD simulations.

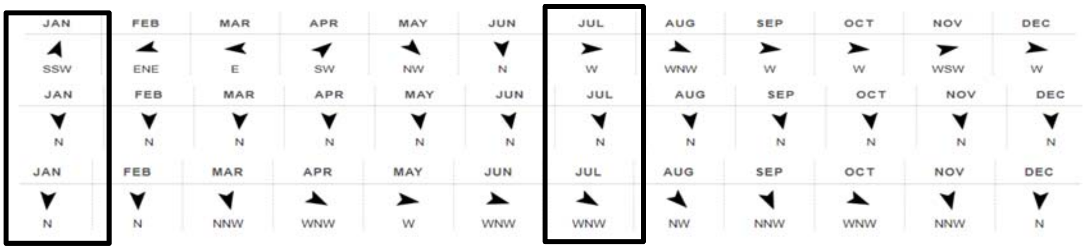


Figure 4: Dominant wind direction in Auckland Grey Lynn (top), Wellington Lyall Bay (middle) and Dunedin St Clair/Forbury Park (bottom) (Source Windfinder.com)

In Auckland, the wind predominates from the South/South-West during January (summer) and the West during July (winter). In Wellington, the wind predominates from the North during January (summer) and North during July (winter). In Dunedin, the wind predominates from the North during January (summer) and the West/North-West in July (winter).

Table 1 presents the averaged wind velocity and temperatures over the summer and winter. The wind velocity is twice as high for Wellington than Auckland and Dunedin for winter. In a subtropical climate, Auckland experiences higher temperatures than Wellington and Dunedin. In winter, Dunedin, located in the southern part of the South Island, is characterised by cool coastal breezes. These three cities show a significant gradient of temperature and wind that should cover most NZ locations.

Table 1: Average wind speed (m/s) and temperatures for Auckland, Wellington and Dunedin in summer and winter (Source: Windfinder.com and Weatherspark.com)

	Season	Auckland (Grey Lynn)	Wellington (Airport)	Dunedin (Forbury)
Average wind speed (m/s)	Summer	3.6	6	6
	Winter	2.8	7.2	3.3
Average temperature (°C)	Summer	23.0	19.0	19.0
	Winter	9.0	7.0	5.0

Heat sources and heat transfer

The preliminary simulation did not consider solar gain from the north-facing glazing surfaces but considered the heat gain from the children (100 W) and the teacher (157 W), as stated in Gao (2023). The heat loss for walls (88.6 W/K), windows (116.5 W/K), roof (21 W/K), and floor (50.3 W/K) were provided by the prefab module designer. In addition, one wall-mounted inverter heat pump (Mitsubishi DXK33) was used only in winter to heat the room. Consequently, we expect a higher air mixing effect in winter than in summer, which will help de-stratify the air that tends to make thermal layers (entering cold air and staying at the bottom of the classroom).

2.4 CFD modelling approach

The general equations used in this CFD simulation can be found in Versteeg et al. (2007). These equations are based on the mass, energy, and momentum conservation laws. The CFD modelling was undertaken using a commercial CFD software, scSTREAM (Cradle CFD part of Hexagon Manufacturing Intelligence, Hexagon AB Group, Sweden).

Turbulence models

CFD employs turbulence models to simulate fluid motion and the appearance of eddies. These turbulence models are specific to different situations, and a significant research effort has been dedicated to their development (Stevanovic, 2009). In ventilation studies, air turbulence is usually described using the Reynolds-Averaged-Navier-Stokes (RANS) equations (Yakhot, 1986; Lu et al., 2019). Derived from the RANS equations, several models have been developed, like the ReNormalization Group (RNG) K-epsilon turbulence model. This model is commonly used for airflow simulation to study building cross-ventilation and agrees well with experimental data (K. Kosutova et al., 2019).

Computational grid and convergence criteria

scSTREAM has a finite volume discretisation scheme. The computational grid is a structured hexahedral mesh defined following CFD good practices (Sørensen et al. 2003). A sensitivity analysis was run after refining the volumes where considerable pressure or velocity gradients were expected, and then the grid convergence was obtained. The solver convergence was assessed by meeting residual error convergence criteria (10^{-6} level). The final mesh includes 8 million nodes for the models described.

2.5 Scenarios considered

Occupants, activities, and carbon dioxide generation rate

Figure 2 shows that each classroom is occupied by 25 children (10 years old) and one teacher (female, 40 years old). The occupants are undertaking light activities (MET 1.5). Table 2 shows the two occupant categories' CO_2 generation rate (L/s).

Table 2: Carbon dioxide generation rate (L/s) at MET 1.5: sitting tasks, light effort (Persily et al., 2017)

Occupants	Generation rate (L/s) at MET 1.5
Female (40 years old)	0.0045
Child (10 years old)	0.0037

In our study, we assume that the CO_2 is generated at a constant rate. The CFD simulation keeps the outside CO_2 background level constant (0 ppm). The results will be increased by 419.3 ppm, the current outside CO_2 level in NZ (NIWA, 2024).

In our modelling, we considered three case studies:

Case study 1 - Cross ventilation without extraction fan: The airflow enters the classroom through the six trickle ventilators due to the difference in pressure between the outside and inside compartments (extractor fan disabled). This scenario is valid as most NZ classrooms lack extraction fans. For this case study, we expect the pressure difference between the inside and outside will usually not provide enough airflow to achieve the recommended 8 litres per second per child (NZS 4303: 1990).

Case study 2 - single-side ventilation with extraction fan: The fan Q/P curve controls the extracted airflow. Under a continuous extraction regime (8 litres per second per child/teacher – 749 m^3/h for the 26 occupants), the air flowing through the six trickle ventilators (north-facing windows only) will be influenced by the dynamic pressure applied due to the wind force on the classroom facade.

Case study 3 - double-side ventilation with extraction fan: The fan curve controls the extracted airflow. Under a continuous extraction regime (8 litres per second per child/teacher – 749 m^3/h for the 26 occupants), the air flows through the 12 trickle ventilators (north and south facade).

3 RESULTS AND DISCUSSION

3.1 Wellington Wind Model (Summer case): wind velocity on the classroom facade

Figure 5 shows a large-scale model for the Wellington school during summer. The dimensions of the Wind model are defined considering the building height (4.5 m) and the surface blockage on the plane perpendicular to the wind direction (200 m width (44H) and 50 m height (11H), 8 million nodes). On the windward side of the building (the north-facing side in our simulation), the velocity ranges from 0 to 8.0 m/s, with a reference input velocity of 6 m/s at 10 m (Table 1). A similar profile will be observed for the Dunedin classroom; both sites have a dominant northern wind with an average wind velocity of 6 m/s at 10m (Table 1).

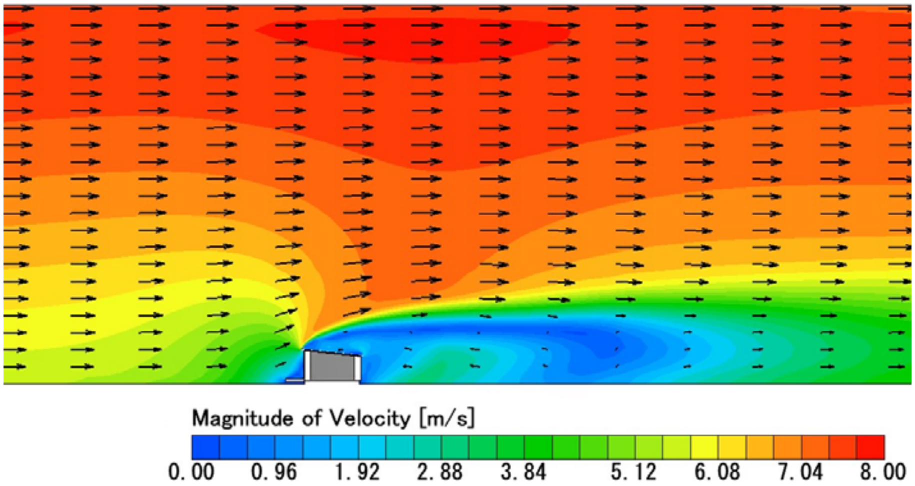


Figure 5: Wind velocity on the Wellington classroom façade in summer

Figure 5 shows a 2 m/s velocity near the windows where the trickle ventilators are located. The five additional simulations were undertaken (three locations/two seasons in total), and the pressure results are reported in Table 3.

Table 3 reports the pressure applied to the trickle ventilators and the flow rate entering the trickle vents. These results were obtained by averaging ten points along the length of each of the six trickle ventilators on the dominant wind facade (average of 60 values).

	Auckland summer	**Auckland** winter	**Dunedin** summer	**Dunedin** winter	**Wellington** summer	**Wellington** winter
Pressure applied to the facade [Pa]						
North facade	-5.83	-3.07	22.0	-0.88	22.00	31.23
South facade	3.14	-2.85	-5.84	-3.88	-5.84	-8.88
ΔP/2	4.49	0.11	13.92	1.50	13.92	20.05
Flow Rate [m^3/h]						
Flow rate deduced for each trickle ventilator	64.6	9.1	117.7	36.1	117.7	142.8
Total flow rate per classroom (*input from six trickle ventilators fully open*)	387.5	54.7	706.0	216.6	706.0	856.8
Percentage of achievement (*749 m^3/h recommended level*)	52%	7%	94%	29%	94%	114%

Table 3 Mean dynamic pressures and corresponding flow rates applied to the trickle ventilators

Table 3 shows lower pressures applied to the Auckland classroom facades than in Dunedin and Wellington. As expected, Wellington showed higher pressures for both summer and winter than Auckland and Dunedin.

NZS4303:1990 recommends 8 litres per second per child. Assuming 25 children and one teacher per classroom, the minimum air flow rate is 749 m^3/h to ventilate the classroom and keep the CO_2 level below 1000 ppm. Table 3 (last row) shows the achievement percentage across the six trickle ventilators (assuming the trickle ventilators fully open).

For the Auckland classroom, 52% and 7% of the recommended air flow rates were achieved in summer and winter, respectively. Regarding Dunedin's results, the airflow was almost sufficient

(94%) in the summer season. However, only 29% of the recommended flow rate entered the classroom in winter. For the Wellington case study, the airflow rate was close to the recommended level for summer (94%) and exceeded the recommended level in winter (114%).

The air enters at 19°C and 7°C in summer and winter, respectively (Table 1). We expect the summer airflow profiles through the trickle ventilators for the air at 19 ◦C (same temperature as room temperature) will follow a 45° angle. In contrast, the winter airflow profiles through the trickle ventilators for the air at 7°C (intake temperature is 12°C cooler than the 19°C room temperature) should quickly fall to the floor (Boulic, 2023). They could create discomfort for children sitting close to the windows.

It should be noted that these winter results were simulated with the trickle ventilators fully open. However, this assumption is only valid when the outside temperature is above 18°C, which was not the case in winter. The trickle ventilator will be only a third open when the outside temperature is below 12°C. So, the winter achievement should be divided by three. In summary, Wellington and Dunedin could achieve the recommended ventilation rate only in summer when using the trickle ventilators without a fan extractor. None of the three winter simulations achieved the recommended level of ventilation (effective open area reduced to a third of the full opening).

Building Bulletin 101 (BB101, 2006) recommend trickle ventilators with a minimum effective area of 0.192 m^2 to satisfy the classroom ventilation requirement in the case of single-sided ventilation. This is five times the effective area we used in our study (0.04 m^2 with six trickle ventilators fully open). Still, we had a case of double-sided ventilation, which should be more efficient than single-sided ventilation. A study carried out in a Wellington school over four days in late summer (March 2022) showed that more than five air changes per hour (twice higher than the recommended ventilation rate) were achieved with approximately 1.5 m^2 effective window opening in a cross-ventilation setting and under a wind velocity between 1.2 m/s and 3.5 m/s (Aniebietabasi et al. 2022). The size of the effective area of the trickle ventilator is important, and in our case study 1, it was insufficient in winter (lower effective area) and with low wind velocity. The wind velocity (creating the pressure difference) also impacts the ventilation rate. Cornaro et al. (2013) reported a higher ventilation rate with a 3.2 m/s average wind velocity entering the trickle ventilators than a lower 1.3 m/s wind average velocity. In our Case Study 1, a velocity of 2.0 m/s (Wellington summer) provided around 94% of the recommended level with the trickle ventilator fully open. The literature supports our results that wind velocity combined with a large effective area of trickle ventilators (at least 0.05 m^2) will be needed to achieve the recommended ventilation rate when no extraction fan is used (BB101, 2006; Biler, 2018). In summary, we demonstrated that achieving a suitable air flow rate in a classroom environment with the sole operation of trickle vents (no extraction fan) was not possible in winter but was close to the requirement (94%) in the summer season for Dunedin and Wellington. An extraction fan connected to the trickle ventilators will be tested in Case Study 2 and Case Study 3.

3.2 Wellington classroom CFD model during winter and summer.

Airflow path and ventilation efficiency - no usage of the extractor fan (Case Study 1).

In Case Study 1, the airflow enters the classroom through the trickle ventilators due to the difference in pressure between the outside and inside compartments (extractor fan disabled). The building comprises two identical classrooms. This will allow us to run two CFD simulations (winter and summer) simultaneously. Figure 6 shows the airflow path for the classroom located in Wellington during winter (left) and summer (right). The dominant wind was North for both summer (January) and winter (July), as reported in Figure 4.

In winter, the inverter heat pump (Mitsubishi DXK33) is operated to keep the classroom in the thermal comfort zone (20°C ± 2°C). The inverter heat pump is not operated for cooling during the summer season. In Figure 6 (left), the inverter heat pump created the green streamlines.

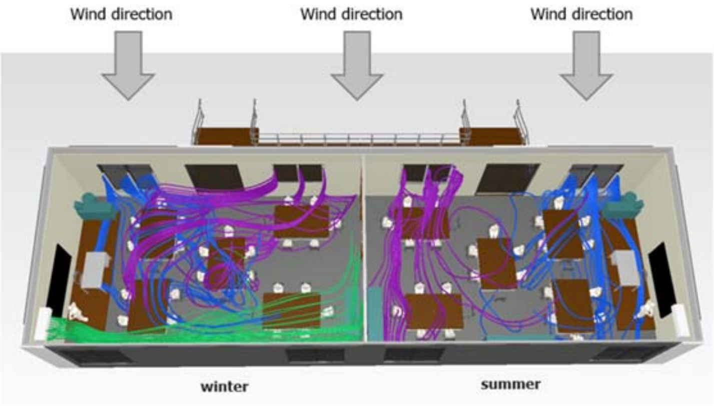


Figure 6: Air streamlines for the air entering from the North facade (cross ventilation)

For the summer case, we can notice fewer streamlines around the middle table (Figure 6, right). This result is expected as the middle table is not aligned with the trickle ventilator axis. Figure 6 shows that the inverter heat pump contributes to the winter air mixing in the classroom (the heat pump is not used in summer for cooling). The air streamlines are more disturbed during the winter case than the summer case. We can also notice that the furniture located in the left top corner (winter) and in the right top corner (summer) disturbed the streamlines.

Figure 7 shows the magnitudes of the velocity (m/s). Figure 7 (left) shows two seasons' positions on the vertical axis (air column). Figure 7 (right) shows the velocity plan 1.5 m from the floor, representing the children's breathing zone.

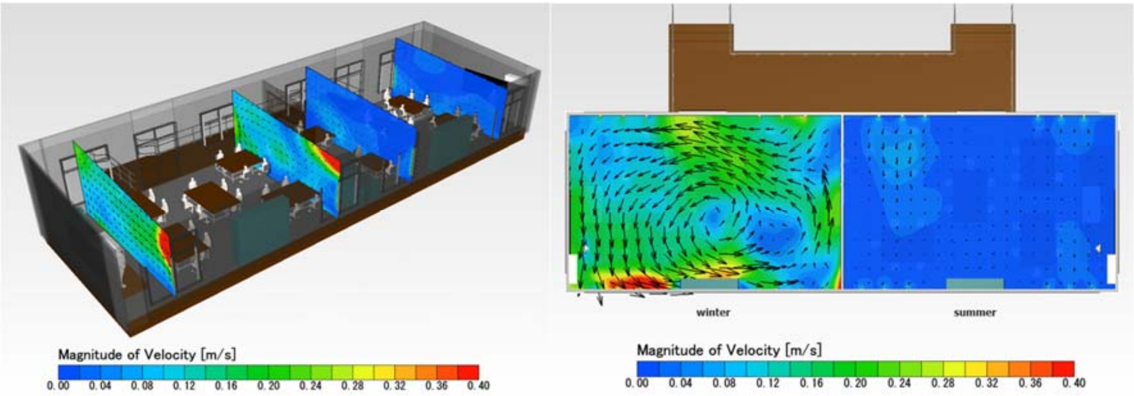


Figure 7: Magnitude of the velocity (left, vertical plan; right, 1.5 m from the floor)

Figure 7 confirms that the inverter heat pump contributes to air mixing during winter. The air moves at a velocity of 0.20 m/s in the centre of the room during the winter season. In contrast, the classroom has a much lower air velocity (0.05 m/s) during the summertime (lower buoyancy due to a lower difference in inside/outside temperatures). Despite the good mixing of air (0.20 m/s) in most parts of the classroom (inverter heat pump), we can notice a few areas with lower air velocity (0.05 m/s). These areas experiencing a lower mixing rate could create some “CO$_2$

pockets" (Boulic, 2023). This hypothesis will be confirmed by our model investigating the impact of the airflow on the CO_2 concentration generated by the occupants.

Temperature distribution - no usage of the extractor fan (Case Study 1).

Figure 8 shows the temperature distribution (°C). Figure 8 (left) shows two seasons' positions on the vertical axis (air column). Figure 8 (part) shows the temperature distribution 1.5 m from the floor (children's breathing zone). In winter, the input temperature is 7°C, while the summer input temperature is 19°C (Table 1).

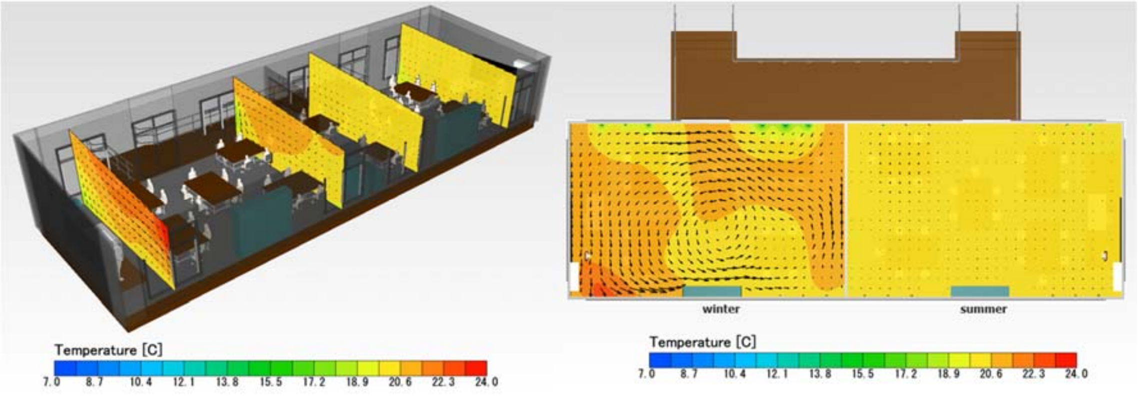


Figure 8: Temperature distribution (left, vertical plan; right, at 1.5 m from the floor)

Figure 8 (left) shows the winter case's temperature gradient from floor to ceiling and homogenous temperature distribution (well-mixed column) during the summer. A ceiling fan could be installed to homogenise the classroom air volume, mainly during winter (destratification).

Figure 8 (right) shows the cold air (7°C) entering the classroom through the six trickle ventilators for winter (blue spots). We need to confirm that intake air, which is 12°C cooler than the 19°C room temperature, will not create discomfort for children sitting close to the windows. This cold air trajectory is expected to be unidirectional downwards from the trickle ventilators (due to the temperature difference).

The trickle ventilators are equipped with a shape memory alloy spring, which will change the opening to external temperature (fully open above 18°C and one-third open under 12°C external temperature). Therefore, with an outside temperature of 7°C, the incoming flow rate could be reduced from 856.8 m^3/h to 282.7 m^3/h (66 % decrease), representing only 38% of the recommended flow rate. Reducing the effective open area of the trickle vent will reduce the ventilation rate and potentially impact pollutant distribution and virus transmission.

This section focused on the airflow path and the temperature distribution in the Wellington classroom for Case Study 1. We will repeat the modelling for Auckland and Dunedin and then move to Case Study 2 (continuous extraction regime of 749 m^3/h with an air intake through the six trickle ventilators) and Case Study 3 (continuous extraction regime of 749 m^3/h with an air intake through the 12 trickle ventilators).

We also plan to investigate the distribution of CO_2 in the classroom when CO_2 is used as a proxy for the ventilation rate. We will use the CO_2 generated by the classroom occupants over 90 minutes as a tracer gas. We will also investigate the potential creation of "CO_2 pockets" due to a lack of air mixing in some parts of the classroom. We will run the simulations for the three cities and the three case studies. When no extractor fan is used (Case Study 1), we expect to find a higher concentration of CO_2 in Auckland and Dunedin classrooms than in Wellington classrooms due to the lower air velocity input. We also expect to find a higher CO_2 concentration in winter than in summer due to a decrease in trickle ventilators' efficient areas. Using an extraction fan (8 litres per second per child) should reduce the CO_2 concentration to the recommended level. A Finish study shows that the cold outdoor temperature makes opening windows for airing in winter more challenging. The same study recommends a mechanical ventilation strategy and a reduced classroom density (number of children per m^2) to preserve indoor air quality in winter for cold climates (Uotila et al., 2023).

For temperate climates, a Spanish winter study (8°C to 12°C outside temperature) shows that after 10 minutes of cross ventilation (flush method), the CO_2 level decreases by 300 ppm (from 1000 ppm to 700 ppm) with a classroom temperature loss from 21.5°C to 19.5°C (Rey-Hernández, 2023).

For tropical climates, Seng Theng Ang et al. (2023) used CFD to simulate airflow and thermal comfort in a school. They showed that airing through louvres only does not sufficiently decrease the temperature, but using a windcatcher to extract the hot air through the roof provided potential chillness to the occupants. Elmualim's study (2006) supports these findings as a windcatcher system can assist in reducing indoor temperature and mitigate summertime overheating. This method could be useful for Auckland and Northland NZ classrooms located in subtropical climates.

4 LIMITATIONS AND SUGGESTIONS FOR FUTURE WORK

This study focuses on the behaviour of different ventilation scenarios for a selected average classroom. However, it should be noted that variable configurations (room geometry, position of the tables, number of children and room volume) and wind conditions could vary.

Furthermore, we neglected the infiltration rate for the building envelope, considering that they were negligible in the overall air flow trajectories.

This paper focused on the airflow path and the temperature distribution in the Wellington classroom for Case Study 1. We will repeat the modelling for Auckland and Dunedin and then move to Case Study 2 (continuous extraction regime of 8 litres per second per child with an air intake through the six trickle ventilators) and Case Study 3 (continuous extraction regime of 8 litres per second per child with an air intake through the 12 trickle ventilators).

We also plan to investigate the distribution of CO_2 in the classroom. We will use the CO_2 generated by the classroom occupants over 90 minutes as a tracer gas. The CO_2 level is used as a proxy for the air change rate following the NZS4303:1990 (ASHRAE 62: 1989) threshold. However, the classroom's CO_2 level should not be considered an overall indoor air quality indicator (Persily, 2020).

5 CONCLUSION

An appropriate ventilation rate is needed to provide children with a healthy classroom environment. Classroom occupants tend not to open windows during teaching, so an alternative solution is needed, which could retrofit existing windows and install an extraction fan.

In three NZ locations (Auckland, Wellington and Dunedin), our project investigated a suitable ventilation solution (trickle ventilators disconnected/connected to an extraction fan). This paper reported findings for the Wellington classroom with the disconnected extractor fan. This case study was selected because Wellington experiences the highest wind velocity level in NZ, so the highest pressure is applied to the classroom facade, and potentially, there should be a higher air intake. The results showed that the air was well-mixed in the classroom in summer (no temperature difference between inside and outside). Our CO_2 model must confirm that enough flow rate can be provided to the classroom in summer. However, the trickle ventilators' effective area was reduced in winter, and insufficient air entered the classroom. In addition, despite good air mixing assisted by the inverter heat pump use, there were still a few areas where the air was not well-mixed. A ceiling fan could be installed to assist in the air mixing. The literature supports our results that wind velocity (at least 2 m/s at the trickle ventilator level) combined with a large effective area of trickle ventilators (at least 0.05 m^2) will be needed to achieve the recommended ventilation rate when no extraction fan is used. It will be advised to connect the trickle ventilators to the fan extractor to increase the ventilation rate throughout the year. Following the CFD project, we will deploy sensors to monitor the temperature, relative humidity and CO_2 in Auckland, Wellington and Dunedin classrooms to validate the modelling findings.

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