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Effects of COVID-19 measures on ventilation in secondary schools in the Netherlands

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Background. During the COVID-19 pandemic, the importance of ventilation for ensuring occupants' health was widely stressed, especially for densely occupied places such as schools (Ding *et al*, 2022). Correspondingly, new protocols of ventilation were implemented in school buildings among many countries and regions. In the Netherlands, school classrooms were first required to keep the windows and doors open, and later after a national lockdown more stringent measures such as reducing student occupancy were introduced. Previous studies have already shown that the ventilation in a large portion of school classrooms did not meet the requirement (National Ventilation Coordination Team, 2020). However, what are the actual effects of the COVID-19 measures on ventilation in school classrooms remains unclear.

Aims. This study aims to investigate 1) the ventilation sufficiency, and 2) the ventilation-related effects of temporary pandemic control and prevention measures in school classrooms under the COVID-19 pandemic.

Methods. A field study was conducted among 31 classrooms of 11 Dutch secondary schools. Fifteen (48%) of the 31 classrooms only use natural ventilation, three (10%) have mechanical air supply, three (10%) have mechanical air exhaust, and 10 (32%) have both mechanical air supply and exhaust. All the classrooms have openable windows, most of which are top-hung or side-hung windows, and can be opened to an angle of 30°-45°. During the time when this survey was conducted, windows and doors were often kept opened during the occupied lessons. Therefore, natural ventilation should also be considered present inside the classrooms that have mechanical ventilation.

All the schools were visited before and after a national lockdown (December 2020-Febrary 2021), i.e. during both October-December 2020 (pre-lockdown) and March-June 2021 (post-lockdown). Each visit lasted for one school day, during which the indoor and outdoor CO_2 concentration were continuously monitored, namely inside the classrooms (at the center of both the front and back walls) and at the entrance/courtyard of the schools, using HOBO® CO_2 loggers (model: MX1102A). Occupied teaching hours and numbers of student occupants were recorded for each classroom.

The ventilation rate per person (VR_p, l/s/p) in the classrooms was calculated accordingly based on the steady-state method (Zhang *et al*., 2022). VR_p was then assessed according to the Dutch Fresh School guidelines (Netherlands Enterprise Agency, 2021) and Dutch Building Decree (Ministry of the Interior and Kingdom Relations, 2012). The difference in VR_p between pre- and post- lockdown periods was examined through Wilcoxon signed-rank tests. Generalized estimating equations (GEE) analysis with linear function was used to identify the association between VR_p and student occupancy, number of opened windows, number of opened doors, and pre- and post-lockdown visits (Ding *et al*., 2023).

Results. The results of VR_p are presented in **Figure 1**. Before lockdown, the average occupancy in the classrooms was 17 students. VR_p ranged from 4.6 to 241.5 l/s/p, with an average of 21.8 l/s/p. In 13%, 45%, and 65% of the classrooms, VR_p did not meet the *acceptable* (6 l/s/p), *good*

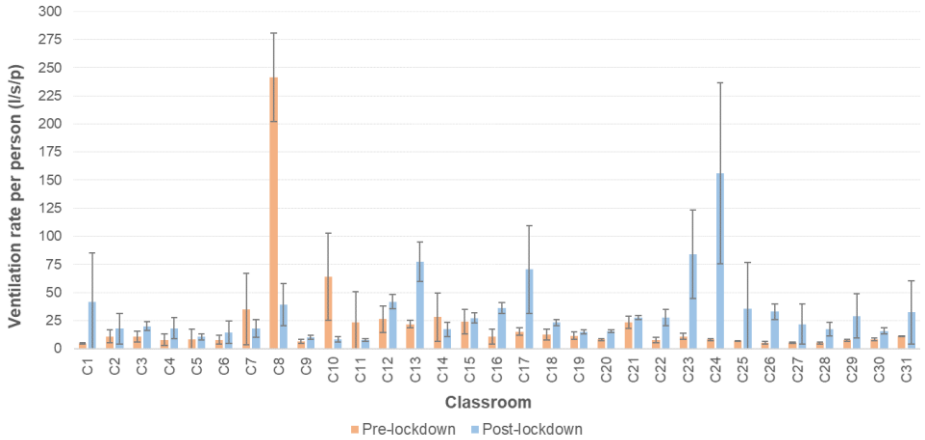
(8.5 l/s/p), and *very good* (12 l/s/p) level of the Dutch Fresh School guidelines, respectively. Besides, VR_p in 45% of the classrooms did not fulfill the requirement of the Dutch Building Decree (8.5 l/s/p). After lockdown, the average occupancy in the classrooms decreased to 10 students. VR_p ranged from 7.4 l/s/p to 155.8 l/s/p, with an average of 32.5 l/s/p. VR_p in all classrooms exceeded the *acceptable* level of the Dutch Fresh School guidelines, yet was still lower than the *good* and *very good* level in 6% and 13% of the classrooms, respectively. Also, VR_p in 6% of the classrooms did not fulfill the requirement of the Dutch Building Decree. For the Wilcoxon signed-rank tests, VR_p was significantly higher after lockdown than before lockdown ($P = 0.005$). For the GEE analysis, VR_p only had a significant association with the student occupancy in the classrooms ($P < 0.001$), with an estimated exponentiated β of 0.938 (95% CI: 0.915-0.963).

Conclusions. According to the Dutch Fresh School guidelines and Dutch Building Decree, before lockdown when the classrooms were used under normal occupancy, the ventilation rate per person in many classrooms was unsatisfying (some even unacceptable), even with windows and doors kept open. After lockdown, the ventilation rate per person increased significantly, yet it was mainly due to the reduction in student occupancy, rather than any changes in the operation of windows and doors. While opening windows and doors cannot achieve the required ventilation at all times, reducing occupancy might not be a feasible solution in the short term. Hence, more controllable and flexible ways for improving ventilation in school classrooms are needed.

Keywords. Classroom, ventilation, indoor air quality, children, COVID-19 pandemic.

Figure 1

Ventilation rate per person in the classrooms before and after lockdown.



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