Evaluation of the ventilation situation in Dutch schools using the QuickScan method.

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Abstract.
The COVID19 pandemic has brought especially the health aspect to the forefront and the need to improve ventilation in Dutch schools. To assess the ventilation in schools during the pandemic, the QuickScan method was developed by a large National consortium called 'Masterplan Ventilatie'. The method contains a list of instructions for users to quickly evaluate the quality of ventilation. As part of this study, 25 TU Eindhoven bachelor students were provided with the QuickScan documentation and children and teacher questionnaires were added to assess the ventilation systems, each in a different Dutch school. These results have been used to identify the possibilities and limitations of the QuickScan method and provide information on the current ventilation status in the investigated schools. Firstly, administrative (i.e., information gathering and reporting) and functional (i.e., measurements and data analysis) groups of steps are distinguished. Secondly, scoring criteria are defined to rate each individual step of the QuickScan performed by the students. The questionnaires pointed at uncomfortable winter conditions, limited possibilities for ventilation control, poor air quality, and inadequate cleanliness for schools. The measurements show that 50% of the schools, which indicated maximum CO_2 levels during occupancy, recorded levels above 1200 ppm. About 67% of the studies, which reported the ventilation capacity for the worst or winter operating conditions, recorded insufficient ventilation. The balanced mechanical ventilation system rated better based on the teacher questionnaires while the children questionnaires indicated no preference for a specific ventilation system. The QuickScan evaluation highlighted that 100% of the studies achieved at least 60% completion for the administrative steps and only 52% of the studies achieved at least 60% completion for the functional steps. This study is the first to apply the QuickScan method, report results, and provide an approach to evaluate and suggest improvements to the QuickScan method.

Keywords. Schools, Ventilation, Materplan Ventilatie, QuickScan method, Evaluation.
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1. Introduction

Schools have a typical indoor environment where there is high occupancy throughout the year. If they are not properly ventilated it can lead to increase in CO_2 concentration and other pollutants which come from both indoor and outdoor non treated sources. There are many sources of such pollutants and there is a complex interplay which can impact the child wellbeing [1]. A bad indoor environment can significantly impact the health and the learning capacity of children [2]. Most schools in the Netherlands are financed and controlled by the government. Budgets generally are limited, and policy implementation can take time as they must be applied throughout the Netherlands. There are still many classrooms in the Netherlands today that rely on natural ventilation to meet their fresh air needs. This becomes a challenge especially during winter when the temperatures are too low. The windows are then kept closed to avoid thermal comfort problems. This in turn leads to an increase in indoor pollutants. A recent study in 54 classrooms at 21 schools in the Netherlands found out that measures to improve air quality conditions in classrooms are needed [3]. As a result of the COVID-19 pandemic, the issue of ventilation in Dutch schools has been brought to the forefront and there is an urgent call for action also by the government. The Landelijk Coördinatieteam Ventilatie in Scholen (LCVS) was incorporated to assess the situation in schools and found that at

least 2194 school buildings still need to assess their ventilation systems to check whether they match the relevant standards or not [4]. With this urgent need in mind, the Masterplan Ventilatie – Quickscan COVID-19, 2020 [4] was devised by a consortium of TVVL, Binnenklimaat Nederland, ISSO and VCCN. The method entails a list of instructions that the user can follow for a fast-track assessment of the ventilation in a (Dutch) school.

However, the QuickScan method is new and has not been tested before. Therefore, an assessment based on its actual application in the field is beneficial to check its current effectiveness and shortcomings. To get an assessment of the QuickScan and the status of Dutch schools, TU Eindhoven (TU/e) students conducted field studies in schools. Keeping this in mind, the primary objectives of this study are formulated as follows:

1. To find the status of ventilation in Dutch schools using the QuickScan method

2. To evaluate the QuickScan method

2. Method

To achieve the objectives of this study, the following steps were followed. As a first step, students from TU/e conducted studies in schools using the QuickScan method and questionnaires. The results from these QuickScan studies and questionnaires are used to firstly prepare a summary of the current situation in schools. Secondly, the studies are used for an assessment of the QuickScan based on a rating criterion developed to evaluate the QuickScan method.

2.1 Field studies using the QuickScan Method

In total 25 schools of Lucas Onderwijs, were studied by 25 TU/e students. The students gathered important information from field visits during the period of November and December 2020 and compiled a report each with detailed analysis of the school ventilation as per the QuickScan. The year of construction of the schools varied from 1892 to 2006 and almost all schools were in and around the Hague, the Netherlands. Out of the total 25 studied, 19 schools were primary schools with children ages between 4 and 12 years, and the other 6 schools were Secondary schools with children ages between 12 and 18 years. The different ventilation systems (Types) and their percentage out of the total 25 schools studied are:

A (40%): Natural inlet and Natural exhaust
B (4%): Mechanical inlet and Natural exhaust
C (40%): Natural inlet and Mechanical exhaust
D (16%): Mechanical inlet and Mechanical exhaust

It is to be noted that some of the systems assigned as type A could be type C, in cases where there is a Mechanical exhaust provided in the corridor which can also exhaust the classroom airflow via the vents provided in the door or by door opening. However, for this study this detail is not considered. The QuickScan method consists of 3 main steps: A-Preparation, B-On the spot investigation, C-Analysis. A detailed description of each step can be found in [4].

2.2 Teacher and Student Questionnaires

In addition to the QuickScan, the TU/e students were provided with questionnaires for both school children and teachers to obtain their perception of the ventilation. Both the children and teacher questionnaires are based on a 7-point rating scale. The teacher questionnaires were more elaborate with 28 questions (indicators) about various aspects relating to the classroom air quality, thermal comfort, health, cleanliness, winter and summer conditions, and ventilation controllability. The children questionnaires were less extensive with 7 questions (indicators) about the winter and summer thermal comfort and air quality. The children questionnaires were filled in almost all cases by the children from the classroom where measurements were conducted. To get more responses, the teacher questionnaires were filled in by teachers from the same and different classrooms when possible. The questionnaires were filled in anonymously.

2.3 Assessment of the QuickScan Method

An important aim of this report is to assess the QuickScan method. The QuickScan steps [4] are divided into an administrative part, which is about information gathering and reporting, and a functional part, which is about measurements and data analysis, for ease of assessment. The QuickScan identifies steps by a capital alphabet and number, e.g. A1, however, for ease of identification of each important step or sub-step, additional letters and numbers are added in this study, refer **Tab. 1.** Step C 2 (a) [iii] is an addition made for this study. The assessment of the Quickscan method will be made by giving each of the student reports a score with respect to the administrative steps and functional steps of the QuickScan. The distribution of the scores for correctly performing each step is mentioned for both the administrative and functional steps in **Tab. 1**. Based on the scores, an overview of how correctly the school assessments were preformed according to the QuickScan will be determined. The errors that were encountered will also be reported and its significance will be discussed. Based on this, suggestions for improving the QuickScan method will be proposed.

An additional remark is that there are cases where the scoring of a step is dependent on a previous step. For e.g., if there is no CO_2 measurement reported (B 5 (c) [i]|), then all the points for the rest of the steps related to using CO_2 data are also lost. Moreover, there are cases where the step cannot be evaluated as it is not applicable for the study. For e.g., if there were no vents present in the classroom,

the steps for information collection and vent capacity determination will become redundant and, for such steps, full points are provided in the assessment. The same is the case for a ventilation system type D, where capacity determination via windows and vents is not necessary and hence the relevant steps are marked with full points for these cases.

Tab. 1: Rating criteria for the Administrative and Functional steps of the QuickScan method

QuickScan step Number	QuickScan steps in brief	Total Points	Rating method	Part
A 1 (a)	Preparation: Ventilation system	9	All Points lost if not reported	Administrative
A 1 (b)	Preparation: Year of construction	9		
A 1 (c)	Preparation: Floor plan	9		
A 1 (d)	Preparation: Pictures	9		
B 2	On the spot: Determine measurement method	9		
B 4 (a)	On the spot: Occupancy & age	9		
B 4 (b)	On the spot: Classroom details	9		
B 4 (c)	On the spot: Ventilation devices	9		
B 4 (d)	On the spot: Classroom marked on school map	9		
C 3 (a)	Assessment for each Building: Tabulate the results	9		
C 3 (b) [i]	Assessment for each Building: Action points mentioned	5		
C 3 (b) [ii]	Assessment for each Building: Action points selected from the provided list	5		
Maximum score		100		
B 5(a)	On the spot: Information for capacity determination via windows as per NEN 8087:2001 [5]	10	All Points lost if not reported. 5 points lost for incorrect data collected.	Functional
B 5(b)	On the spot: Information for Capacity determination via Vents as per NEN 8087:2001 [5]	10		
B 5 (c) [i]	CO_2 measurement reported	8	All Points lost if not reported	
B 5 (c) [ii]	CO_2 measurement reported during occupancy	8		
C 1 [i]	Determine the test values for Ventilation rate	8		
C 1 [ii]	Determine the test values for CO_2 levels	8		
C 2 (a) [i]	Analyse the measurement data: Capacity determination via vents	8		
C 2 (a) [ii]	Analyse the measurement data: Capacity determination via windows	8		
C 2 (a) [iii]	Analyse the measurement data: Worst case considered (*extra step added for this study*)	8		
C 2 (b) [i]	Analyse the CO_2 measurement data: Report 98th percentile	8		
C 2 (b) [ii]	Analyse the CO_2 measurement data: Correct the value for design occupancy (only if there are at least 5 less people compared to design occupancy)	8		
C 2 (b) [iii]	Analyse the CO_2 measurement data: Asses if it was a representative measurement day (KNMI [6])	8		
Maximum Score		100		

3. Results

3.1 Results from Field Studies & Questionnaires

When available, only the maximum CO_2 levels measured during occupancy have been reported in **Tab. 2**. Nine studies reported the ventilation capacity via the vents and windows for the worst-case or winter operating conditions for ventilation types A and C. The ventilation capacity computed using NEN 8087:2001 [5] for the windows and vents did not meet the requirements for 6 out of these 9 schools.

Tab. 2: Summary of Results about the maximum CO_2

School Number	Max CO_2 levels (ppm)	Occupancy during measurement
2	1356	no information
10	904	17
12	1250	no information
14	1150	21
17	1434	29
19	869	19
22	1320	25
24	1193	31

The results from the Children Questionnaires were analysed using box plots with the rating for each indicator on the y axis and the School number on the x axis. A student questionnaire box plot example for one indicator (TS1) out of the total 7 is shown in **Fig. 1**. The data from 21 schools which were available are presented in the box plots with the red line representing the median, the box representing the 2nd and 3rd quartile and the end of the box to the whiskers (in black) representing the 1st and the 4th quartiles respectively. The small back circles represent the outliers. The different ventilation systems are also marked in the plots on the x axis between brackets. The indicators are graded such that the highest values represent a comfortable situation, and a lower score represents an uncomfortable situation. For school number 15 and 22 only the median values were available.

The results from the teacher questionnaires for 21 schools whose data was available, are presented in **Fig. 2**. The data per school is not presented as the number of teachers filling the questionnaires were insufficient, and only one in some cases. To remove subjectivity, the data from all the schools is plotted in a bar graph to give a general assessment of the school ventilation perception by the teachers for the investigated schools. Similar to the children questionnaires, the lower values represent an uncomfortable situation, and a high value represents a comfortable situation. The x axis represents the different indicators investigated, 28 in total. Additionally, in colour, the results are plotted per ventilation system A, C and D. Eighteen teachers filled in the questionnaires for type A schools, 34 for type C schools and 11 for type D schools. Only the median values are presented.

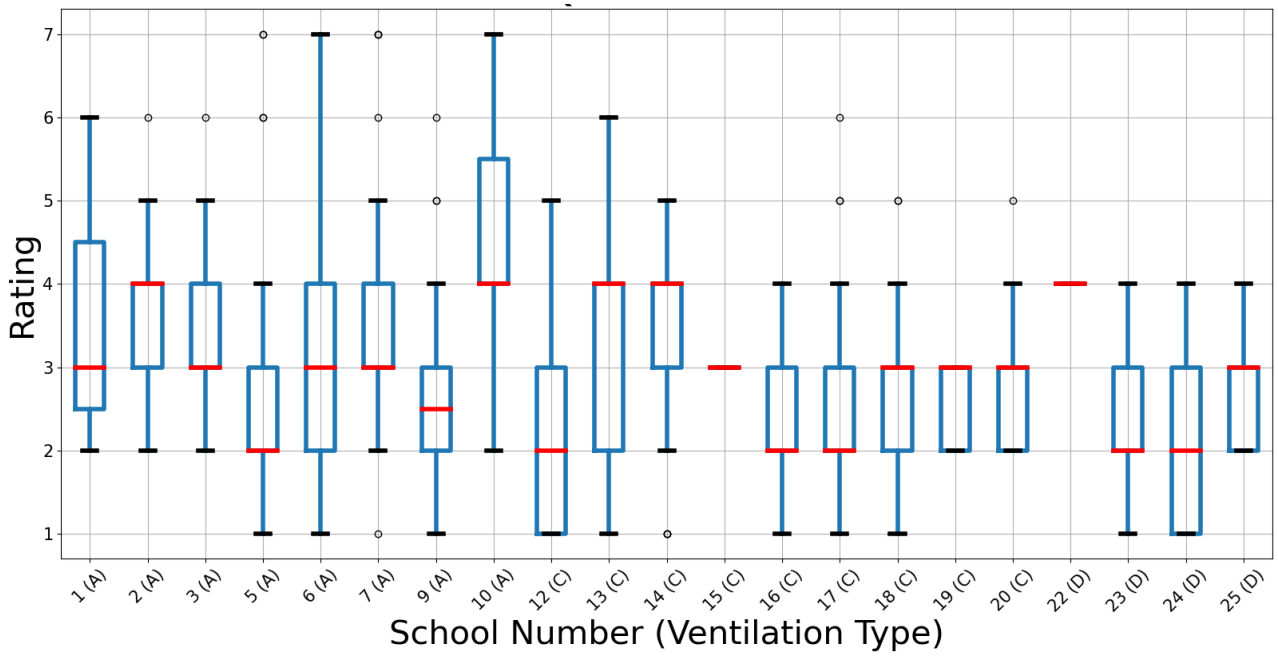

Fig. 1: Results from the Children questionnaires: Temperature Summer (TS1) – Rating 1 = Too Hot, Rating 4 = Not warm and not cold; Rating 7 = Too Cold. Ventilation types are added in brackets adjacent to the school number

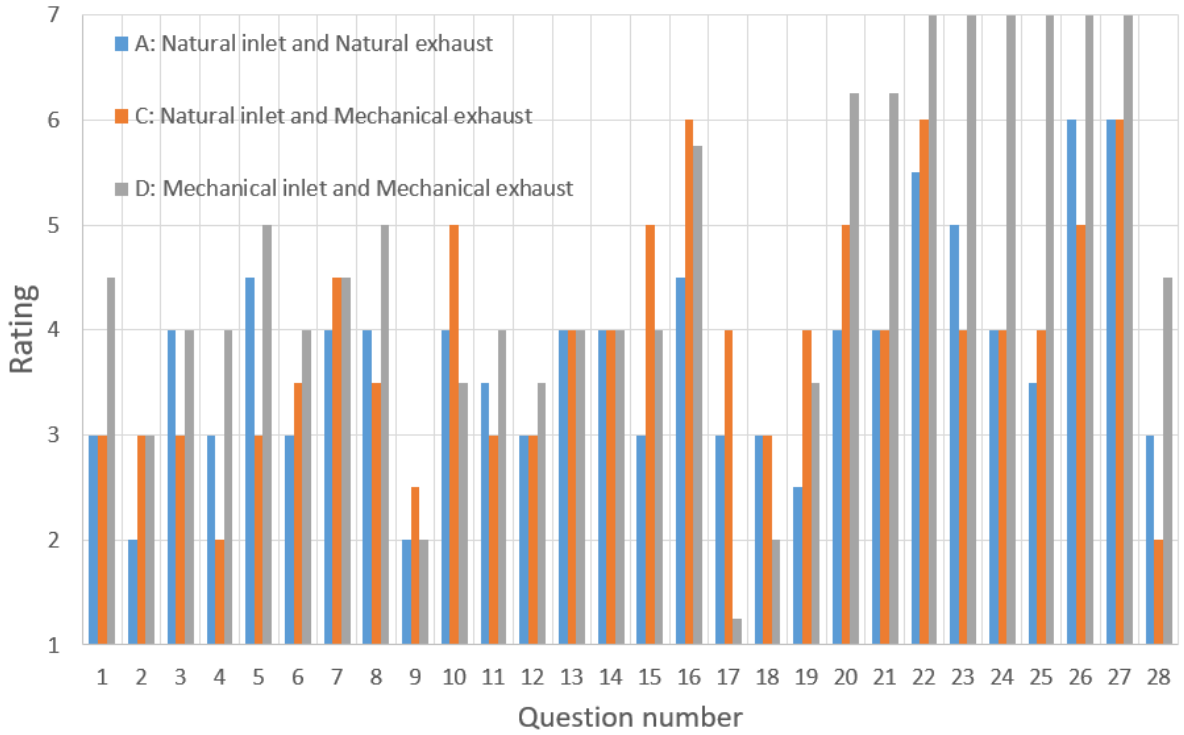

Fig. 2: The results of the teacher questionnaires with the median values presented as per different ventilation system types – **1/8.** Winter/Summer temperature - Uncomfortable (1), Comfortable (7); **2/9.** Winter/Summer temperature - Too Cold (1/7), Too hot (7/1); **3/10.** Winter/Summer temperature - Varying (1), Stable (7); **4/11.** Winter/Summer Air Quality - Dry (1), Moist (7); **5/12.** Winter/Summer Air Quality – Not Fresh (1), Fresh (7); **6/13.** Winter/Summer Air Quality – Uncomfortable (1), Comfortable (7); **7/14.** Winter/Summer Air Quality – Stinky (1), No Smell (7); **15.** Draft – Very much (1), None (7); **16.** Noise - Very much (1), None (7); **17.** Temperature Controllability - None (1), Complete (7); **18.** Ventilation Controllability - None (1), Complete (7); **19.** General Experience – Cold (1), Hot (7); **20.** Headache – A lot (1), Little (7); **21.** Drowsiness– A lot (1), Little (7); **22.** Trouble breathing – A lot (1), Little (7); **23.** Dry eyes – A lot (1), Little (7); **24.** Children Headache – A lot (1), Little (7); **25.** Children Drowsiness– A lot (1), Little (7); **26.** Children Trouble breathing – A lot (1), Little (7); **27.** Children Dry eyes – A lot (1), Little (7); **28.** Cleanliness – Unsatisfactory (1), Satisfactory(7); (in bold the question numbers to which the description applies)

3.2 Results from the QuickScan evaluation

A summary of ratings given for both the Functional and Administrative aspects in terms of percentage is shown in **Tab. 3.** The summary is based on the rating criteria presented in **Tab. 1.**

Tab. 3: Percentage of studies that were completed as per the Rating definition for both Administrative and Functional steps

Rating definition	% Completion	Admin. part (% studies meeting rating)	Functional part (% studies meeting rating)
complete and correct	100	0	0
partly	80 - 99	60	4
partly with some mistakes	60 - 79	40	48
partly with several mistakes	40 - 59	0	36
incomplete and insufficiently	0 - 39	0	12

The error prone steps are displayed in terms of the percentage of studies encountering this error in **Tab 4.** Only steps where at least 40% of the studies encountered an error are mentioned.

Tab 4: QuickScan error prone steps in terms of % of studies encountering error (>40% of studies)

Step number	% Studies	Part
B 2	40	Administrative
C 3 (a)	80	
C 3 (b) [ii]	100	
B 5 (c) [i]	44	Functional
B 5 (c) [ii]	68	
C 1 [i]	68	
C 1 [ii]	68	
C 2.a [iii]	44	
C 2.b [i]	72	
C 2.b [ii]	64	
C 2.b [iii]	96	

4. Discussion

4.1 Status of School ventilation

The natural ventilation capacity computed from the windows and vents as per NEN 8087:2001 is variable based on the number of windows opened or closed and their opening area (partially or fully open). The best-case scenario is all the windows and vents staying fully open. The worst case, which generally occurs during winter, is almost all windows closed or partially closed. It was found from the study that the ventilation is insufficient for 67% (6 out of 9) of the cases when considering the worst-case scenario of window and vent operation. A worst-case assessment with windows and vents closed was not explicitly stated in the QuickScan, but is important to be noted, because in winter most schools with natural supply of fresh air have a high chance of being operated in this worst-case scenario.

With regards to the maximum CO_2 levels reported in **Tab. 2**, the students relied on the measurements by the CO_2 meters in the classroom which was not easily accessible during working times. However, there are some schools for which the CO_2 levels are available during occupancy. For 50% (4 out of 8) of these cases the maximum CO_2 levels are above the limit set by Frisse Scholen Class C of 1200 ppm [7]. When converting all levels reported in **Tab. 2** from current occupancy to design occupancy, more measurements could overshoot the limits of 1200 ppm. This raises concerns about the CO_2 levels, and therefore the ventilation levels, at least in the cases where measurements were reported during occupancy.

An example result from the student questionnaire is shown in **Fig. 1**. On an average, the summer temperature is perceived too hot by the children. In general children prefer lower temperatures than predicted by most used comfort models like the PMV (predictive mean vote)[8]. However, children still consider the summer temperature to be bearable in most schools. The winter temperature is perceived too cold by most children, and they find it to be very uncomfortable as well. This is a cause of concern seen in almost all the schools during winter, which can incite actions to close the windows thereby reducing the ventilation in the classroom. A note must be made that, due to the COVID-19 pandemic, schools were strongly advised to keep windows frequently open to ensure sufficient ventilation. As a result, thermal comfort was compromised as the results clearly indicate. The children do not indicate any issues with the classroom air quality.

When looking at the ratings for the 7 children questionnaire indicators for the different ventilation types, the children don't seem to prefer any one type of ventilation system. One would have expected the type C and D to perform much better than A, but it seems the children perceive all of them in the same way. In some cases, D performs even worse than A. However, the teacher questionnaire results in **Fig. 2** indicate that the ventilation type D performs better or at least equal to other types in most cases, especially for the health aspects. This gives confidence on the use of type D Mechanical ventilation systems in the schools. However, the system D scores low for the control indicators and hence, the control should be an important aspect to deal with when considering such systems.

From **Fig. 2** it can be deduced that the winter conditions, in line with the children, are noted as uncomfortable by almost all teachers and the summer temperature is assessed as very hot by almost all teachers. The air during both summer and winter is considered dry in general and in summer it is perceived as not being fresh. The teacher still has a problem about the ventilation controllability and the cleanliness is not considered adequate.

4.2 QuickScan evaluation & improvements

From **Tab. 3**, it can be observed that most studies lag with respect to the functional aspects. It can be observed that no study was completed perfectly with a score of 100. Most of the administrative steps were completed partly and the rest completed partly with some mistakes. For the functional steps most studies were completed partly with some mistakes or with several of mistakes. There were also some studies regarded insufficient. This indicates that there is a definite scope for improving the QuickScan implementation, especially with respect to the functional steps.

To better identify the causes of incompleteness of the studies, the number of errors recorded per QuickScan step is mentioned in **Tab 4**. It can be observed that certain steps are more error prone than others. To filter out the most error prone steps, only the errors reported in more than or equal to 40% of the studies are tabulated. The main improvement points for the QuickScan highlighted from the error prone steps are:

- Step B2, C3(a), C3(b)[ii], C1[i], C1[ii]: In the QuickScan, it needs to be clearly stated that the report template which is provided with the QuickScan is to be used to report the results. This makes it part of the QuickScan steps and clear to the user about how to present the data, such as, e.g., B2 or C3(a). It also creates uniformity. Special attention needs to be given to clarify to the user that there is also a list of action points that the user can choose from while preparing an action plan for the assessed school.
- Step B5(c)[i], B5(c)[ii]: The collection of equipment required for the measurements should be added in the preparation part (A) so that they are not missed during the campaign. The accuracy and other equipment details can also be specified

here. It can also be added in the preparation part (A) that special permissions need to be sought from the school for measuring during occupancy. Such measurements have the highest value.

- C2(a)[iii]: Since all windows and vents may not be open fully for naturally ventilated classrooms during winter, it is necessary to explicitly mention that the capacity determination using NEN 8087:2001 needs to be performed for the worst-case operating states. The measurement condition therefore should resemble everyday practice as much as possible.
- C2(b)[i], C2(b)[ii], C2(b)[iii]: As per the QuickScan report template [4], only the CO_2 98th percentile needs to be reported and corrected for design occupancy, if applicable. However, in the detailed descriptions (QuickScan disclosures [4]), the ventilation capacity is to be calculated from the CO_2 levels for both the measurement and design occupancy. This ventilation capacity based on CO_2 levels is not part of the conclusions and hence is not clear why the capacity is required to be derived in an alternative manner. E.g., the ventilation capacity is calculated using the NEN 8087:2011 for naturally ventilated cases and air flow measuring devices in Mechanically ventilated cases. The CO_2 based ventilation capacity calculation can be used when there is no possibility of measurement of the ventilation flowrate in the classroom. It may also serve as a check for comparing with the outcomes from the measured flowrates. However, this needs to be clarified in the QuickScan.

Some other suggestions for improvement for the QuickScan implementation are as follows:

- Communication with schools: CO_2 sensor data, if available, can be requested from each school for a longer period. The measurement team can request selection of a classroom based on their preferences.

- Capacity determination from windows and vents as per NEN 8087:2001: The capacity determination using NEN 8087:2001 does not consider the actual indoor and outdoor conditions which are the main drivers of the flow through windows and vents. The pressure difference across the window plays an important part in determining the flowrate [9][8]. Moreover, using a constant value for the discharge coefficient for different cases leads to an inaccurate prediction of window airflow capacity [9]. The velocity can also vary considerably across the vent cross section and is also highly unsteady with a lot of fluctuations [10]. However, according to NEN 8087:2001 a constant air velocity is assumed throughout the vent. This can lead to inaccurate (too positive) estimates of the airflow computed through vents as well. Therefore, it should be explicitly mentioned that the QuickScan is only for a preliminary evaluation and cannot guarantee proper natural ventilation in the classroom even if the results meet the requirement. CO_2-measurement data can give a first impression whether the natural ventilation is working properly.

- Capacity determination from vents and windows for type C ventilation system: The ventilation flowrate for type C cannot be only computed by the capacity determination from windows and vents as per NEN 8087:2001, because there is also a mechanical exhaust which is the main driver of the ventilation. The computation of the ventilation flowrate for type C needs to be clarified, possibly it can be measured directly from the exhaust grille.

- Questionnaires: The QuickScan currently does not have a perception evaluation and it is recommended to include that using questionnaires. Moreover, the QuickScan currently misses measurements to assess thermal comfort in the schools, which can also be addressed using questionnaires. This method allows for additional information on the ventilation when measurements are not easy to perform.

4.3 Limitations of the study

The main assumptions and limitations of this study are:

- It is assumed that the students used the QuickScan excel tool properly for all computations, especially for the ventilation rates from windows and vents.
- The students did not have their own CO_2 or flow measuring equipment. Because of this some steps could not be fully performed.
- There are some QuickScan steps excluded from the evaluation as they could not be performed by the students because of logistic or accessibility issues. Hence, the

final evaluation method is intended to highlight the areas of improvement rather than providing a final rating for the QuickScan.

- The QuickScan assessment has a subjective component and is mainly intended to identify possible sources of errors when trying to use the QuickScan method.
- It is assumed that the students interpreted and clearly understood the intent of the QuickScan and reported all the results correctly. Since Scans are not necessarily performed by professionals, it is assumed to provide for a good representation of potential users of the QuickScan.

5. Conclusions

The idea of the QuickScan is to make a fast-track assessment of the ventilation in Dutch schools. Therefore, it must be as minimally ambiguous as possible with clear instructions that anyone can follow. By considering the students who are not subject experts, the QuickScan method was tested for a critical case. The QuickScan method was evaluated by dividing it into an administrative and functional part. It was found that the administrative part has a better chance of completion as compared to the functional part. Based on the evaluation results, the QuickScan steps that have a higher risk of not being completed have been identified. Based on the identified error prone steps, concrete improvements for the QuickScan have been suggested.

50% of the studies reported maximum CO_2 levels during classroom occupancy above the limit of 1200 ppm. Out of all studies that reported the ventilation capacity for the worst case or winter operation (type A & C ventilation system), 67% reported insufficient ventilation. The questionnaires were not part of the QuickScan but were specially used for this study. The questionnaires pointed at uncomfortable winter conditions, limited possibilities for ventilation control, poor air quality, and inadequate cleanliness for schools. The results give confidence in using Mechanical ventilation systems in schools instead of naturally ventilated systems. The questionnaires have proved to be a valuable addition to the QuickScan.

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Data Access Statement

The datasets generated during and/or analysed during the current study are not publicly available *because they are provided by a company and has to be kept private owing to privacy and security concerns* but are/will be available if *the concerned parties contact us and explain the reason for the data requirement, but the final decision lies with the company and access cannot always be guaranteed.*