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Comparing the effectiveness of interventions to improve ventilation behavior in primary schools

Abstract Poor air quality in schools has been associated with adverse health effects. Indoor air quality can be improved by increasing ventilation. The objective of this study was to compare the effectiveness of different interventions to improve ventilation behavior in primary schools. We used indoor CO_2 concentrations as an indicator. In 81 classes of 20 Dutch primary schools, we applied three different interventions: (i) a class-specific ventilation advice; (ii) the advice combined with a CO_2 warning device and (iii) the advice combined with a teaching package. The effectiveness of the interventions was tested directly after intervention and 6 weeks after intervention by measuring the CO_2 concentrations and comparison with a control group (iv). Before intervention, the CO_2 concentration exceeded 1000 ppm for 64% of the school day. The class-specific ventilation advice without further support appeared an ineffective tool to improve ventilation behavior. The advice in combination with a CO_2 warning device or the teaching package proved effective tools and resulted in lower indoor CO_2 concentrations when compared with the control group. Ventilation was significantly improved, but CO_2 concentrations still exceeded 1000 ppm for more than 40% of the school day. Hence, until ventilation facilities are upgraded, the CO_2 warning device and the teaching package are useful low-cost tools.

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Practical Implications

To improve ventilation behavior and indoor air quality in schools, CO_2 warning device and teaching package combined with a class-specific ventilation advice, are effective tools, while giving the ventilation advice solely, is not effective. Although ventilation is significantly improved through behavioral change, the ventilation rate is still insufficient to maintain good air quality during the full school day. Therefore, the improvement of the ventilation facilities is recommended. Hence, until ventilation facilities in schools are upgraded, the CO_2 warning device and the teaching package are useful low-cost tools to improve current indoor air quality.

Introduction

In the past 10 years, the attention for indoor air quality (IAQ) in schools has grown. Changes in building design, such as increased air tightness and the use of synthetic building materials, provide indoor environments in which contaminants are readily produced and may build up to much higher concentrations than outside (Jones, 1999). In addition, occupants of a room produce pollutants such as carbon dioxide (CO_2), moisture, bio-effluents and dust. It has been found that low ventilation rates (below 10 l/s per person) are associated with adverse health effects like communicable respiratory illnesses, sick building syndrome symptoms and respiratory allergies and asthma (Baek et al., 1997; Fox et al., 2003; Godish and Spengler, 1996; Seppanen and Fisk, 2004; Smedje and Norback, 2000; Wargocki et al., 2002). Ventilation is also strongly associated with comfort (perceived air quality) and reduction of short-term sick leave (Wargocki et al., 2002) and may reduce the airborne transmission of viruses (Myatt et al., 2004).

Indoor environments in schools are of particular public concern because children are generally more susceptible to environmental pollutants than adults, because of their higher breathing volume relative to body weight and because their tissues and organs are actively growing (Faustman et al., 2000; Landrigan, 1998). Furthermore, children spend a significant amount of time in schools. Next to these direct health effects, several studies have indicated associations between ventilation in schools and student performance (Gids et al., 2007; Mendell and Heath, 2005; Shaughnessy et al., 2006; Shendell et al., 2004; Wargocki et al., 2002). The adverse environmental effects of insufficient ventilation on health, learning and performance of students in schools could have both immediate and lifelong consequences (Mendell and Heath, 2005).

In occupied classrooms, the CO_2 concentration can be used as an indicator of the ventilation rate per occupant and the removal of pollutants in the air. Von Pettenkofer stated already in 1858 that CO_2 itself was not important, but that it was an indicator of the amount of other noxious substances produced by man. He reported that air was not fit for breathing if the CO_2 concentration (with man as the source) was above 1000 ppm (Pettenkofer, 1858). Measured indoor air concentrations of CO_2, produced by human respiration, have been used worldwide as an indicator of inadequate ventilation in schools (Shendell et al., 2004).

Many classrooms in schools of European and North American countries are not adequately ventilated (Boerstra et al., 2006; Daisey et al., 2003; Dijken et al., 2006). To improve the IAQ, the school building often needs radical adaptation regarding ventilation facilities. In practice, this is not always feasible. As an alternative, the ventilation behavior of the occupants can be improved. However, little is known about the effectiveness of different measures to improve ventilation behavior in schools (Carrer et al., 2002).

The aim of the present study was to determine the effectiveness of different measures to improve ventilation behavior in primary schools, using the change in indoor CO_2 concentrations after intervention as an indicator. Three different measures to improve ventilation behavior were compared with a control group:

- a class-specific ventilation advice;
- a class-specific ventilation advice in combination with a CO_2 warning device; and
- a class-specific ventilation advice in combination with a teaching package.

The measures were tested in 81 classrooms from 20 Dutch primary schools. The effectiveness of the measures was evaluated directly after intervention and 6 weeks later. The results are discussed within the context of improving IAQ in primary schools.

Methods

Selected classrooms

We selected 81 classes spread over 20 schools from a total of 1100 primary schools in the working area of five Regional Public Health Services in the south of the Netherlands. The intervention with the teaching package was carried out in schools in the city of Breda, while the other interventions and the control measurements were carried out over the whole south of the Netherlands. The schools were randomly selected until we identified sufficient classes fulfilling the following criteria:

- all schools were located at a distance of at least 400 m from highways to prevent that traffic density affects the ventilation behavior via noise disturbance;
- schools with renovations planned during the measurement period were excluded, because building activities may affect the ventilation behavior or may cause withdrawal from the study;
- only classes with natural unforced ventilation facilities were included (e.g., windows, ventilation grids), so the airflow was depending on the ventilation behavior;
- the ventilation capacity of the classrooms must be sufficient for the number of occupants present, even in the winter season. Furthermore, to avoid draft and cold in the classrooms, especially in the winter season, the ventilation facilities must be located at least at 1.80 m height;
- for homogeneity, only classes with pupils aged 7–10 years were selected; and
- only one type of intervention per school was conducted to minimize the influence of classes with other interventions.

The average number of pupils in a classroom was 25 with a standard deviation (s.d.) of four. The mean ventilation demand per classroom, based on NEN 1089 (NEN, 1986), was 518 m^3/h (s.d. 75 m^3/h). The mean volume of the classrooms was 177 m^3 (s.d. 36 m^3) with a mean volume per person of 7.0 m^3 (s.d. 1.5 m^3). The mean area of the classrooms was 55.9 m^2 (s.d. 6.6 m^2) with a mean area per person of 2.2 m^2 (s.d. 0.4 m^2). The mean indoor temperature was 20.3°C (s.d. 1.2°C) and the mean relative humidity was 45% (s.d. 6.4%).

Interventions

The first intervention group received the class-specific ventilation advice (n = 20 classes). The second group received the CO_2 warning device for 1 week, in addition to the class-specific ventilation advice (n = 20 classes). The third group received the teaching package for 1 week in addition to the class-specific ventilation advice (n = 21 classes). The fourth group was the control group, which received no intervention (n = 20 classes).

Measurement strategy

The CO_2 concentration and the ventilation behavior were recorded for three separate monitoring weeks: first, the starting situation was recorded (T_0) 2–3 weeks before intervention. The short-term effect was recorded directly after intervention (T_1) and the longer-term effect was recorded 6 weeks after intervention (T_2). During these monitoring weeks, the indoor CO_2 concentration, temperature and humidity were measured every 3 min, and the teachers were asked to register their ventilation behavior in a ventilation journal, i.e., when and which ventilation facilities were open and closed. In addition, in monitoring week T_0, a checklist was used to survey the class-specific situation. Furthermore, after the monitoring week T_1, all teachers except the control group were asked to fill out a questionnaire to elicit their opinion about the interventions. The questionnaire contained questions to determine whether the different tools were used by the teachers and whether they found the tools useful. Additionally, the experiences were discussed with the teachers at the end of the experiment (T_2). This gave qualitative information on the approach. Figure 1 shows an overview of the measurement strategy.

Measurement periods

Because of a limited number of CO_2 measurement devices, the experiment was conducted over two independent periods in the winter of 2004/2005. From October to December 2004, 24 classes were monitored and from January to March 2005, another 57 classes were monitored. The intervention groups were monitored in both periods, except the group that received the teaching package, which was only recorded in the second period.

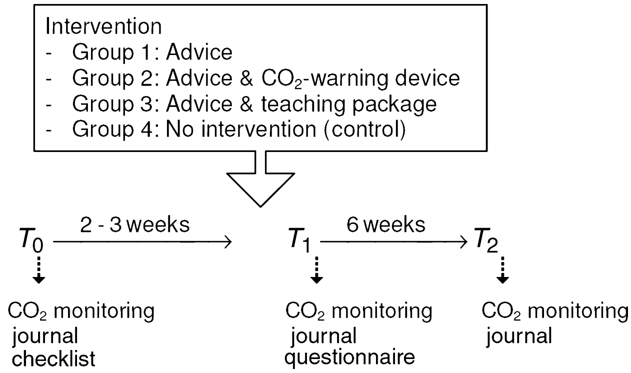

Fig. 1 Measurement strategy

Class-specific ventilation advice

The class-specific ventilation advice was based on the assessment of the starting situation and on two Dutch standards for ventilation in schools to prevent odor annoyance. These standards were:

- the Dutch standard for ventilation in school buildings, NEN 1089, which prescribes a minimum ventilation rate of 5.5 l/s per child and 10 l/s per adult (NEN, 1986); and
- the guideline for ventilation in schools of the Dutch Public Health Services, which prescribes a guideline value of 1200 ppm for the CO_2 concentration (LCM, 2002).

The starting situation in the schools was studied by means of a checklist, the ventilation journal and measurements of CO_2, temperature and relative humidity. The checklist was used to gather information about ventilation facilities, furnishing of the classroom, school timetables and the number of pupils. The teachers were asked to register their ventilation behavior in a ventilation journal, i.e., when and which ventilation facilities were opened and closed during the monitoring week. Based on the information gathered so far and on the ventilation standards, the teachers received an advice which described in detail how the ventilation facilities in that specific classroom should operate. This advice consisted of a written advice, an oral presentation and a 'ventilation card'. In the oral presentation, the CO_2 concentration over the day was shown in a graph, and the advice and the need for ventilation was explained. The 'ventilation card' was a plasticized colored A5 paper with the class-specific key ventilation instructions, which could be placed on the teacher's desk.

CO_2 warning device

The CO_2 warning device, studied by Doorn and Wouters-Van Buggenum (2004), is a measuring instrument with display and a red light-emitting diode (LED) which turns on when the CO_2 concentration exceeds 1200 ppm. This informed the teacher and the pupils when the CO_2 concentration was too high according to the Dutch Guideline. The CO_2 warning device consisted of an Atal ATV-8002 Single Beam Absorption Infrared Diffusion Sample Method CO_2 sensor with ABC-Logic™ that enables the CO_2 sensor to automatically calibrate itself once installed in the field (Atal, 2004). Before usage the devices were calibrated using directly introduced calibration gases. The CO_2 concentrations were measured with an accuracy of ± 75 ppm, and a range of 0–5000 ppm (Atal, 2006).

Teaching package

In their daily routine, teachers may not ventilate the classroom on a regular basis. We hypothesized that ventilation could be improved by involving the pupils. To facilitate this, we developed a teaching package for the teachers and their pupils. The teaching package 'Outdoor air, come in and play!' was specifically developed for this study for pupils of 7–10 years old. The teaching package consisted of three lessons and in each lesson a different theme was discussed with the help of a cartoon character called 'Outdoor air'. The first theme, 'Moisture in the air & Ventilation', described a regular school situation with the occurrence of moisture in the air, emitted from the skin and the lungs. It explained that continuous ventilation was needed to remove the moisture from the classroom. Although more pollutants in the classroom are of importance, moisture was used to simplify the situation for the pupils. The second theme, 'Dirt in the air & Airing of the classroom', described that more pollutants, like glues or paints, were emitted into the air during handicraft lessons. Furthermore, it explained that extra ventilation of short duration, like airing, was needed to remove those extra pollutants from the classroom. The third theme, 'Dust mite & Cleaning', described the need for a clean school environment, for example to avoid the growth of dust mites. Again, the situation was simplified for the pupils, and the dust mite was used as an example.

After the themes were discussed, three tasks were assigned to the pupils. The 'ventilation controller' had to make sure that the ventilation facilities were used in the regular school situation. The 'airing controller' had to make sure that during and after handicraft lessons extra windows were opened. The 'blackboard wiper' had to wipe the blackboard at the end of the day with a wet cloth to remove chalk dust from the classroom. Wiping of the blackboard is not related to ventilation, but this task underlined the need for a clean school environment. It was the first teaching package in the Netherlands that puts the children in charge of the ventilation, airing and cleaning of the classroom. For each assignment a badge was handed out. The classes were allowed to keep the badges, to encourage the development of a ventilation routine.

Analysis

Of the CO_2 concentrations, measured every 3 min during every monitoring week, only the measurements taken during the school day were evaluated. As a result, about 500 measurements of each classroom were evaluated per monitored school week.

The CO_2 measurements were depicted in a graph and classified according the EN 13779 classification of indoor air (CEN, 2004). This standard, describes the classification for ventilation in non-residential buildings. It is based on the outdoor air supply and the corresponding difference between indoor and outdoor CO_2 concentration. The classification is shown in Table 1.

The evaluation of the effectiveness of the tools was based on the average CO_2 concentrations ($CO_2|_{AVG}$). The $CO_2|_{AVG}$ was the arithmetic mean of the CO_2 measurements, calculated for each classroom and for each monitored week separately. The short-term effect was expressed as the paired difference in average CO_2 concentrations between the starting situation and the situation directly after the advice: $CO_2|_{AVG}$ (ΔT_1). The effect on the longer term was expressed as the paired difference in average CO_2 concentration between the starting situation and the situation 6 weeks after the advice: $CO_2|_{AVG}$ (ΔT_2). The $CO_2|_{AVG}$ (ΔT_1) and $CO_2|_{AVG}$ (ΔT_2) were calculated per classroom.

The data analyses were performed using SPSS software package 14.0 (SPSS Inc., Chicago, IL, USA). We decided to correct for the number of classes in the two measurement periods because of the following reasons:

- weather conditions are likely to influence both ventilation behavior and the diffusion of the outdoor and indoor air; and
- in the first measurement period, the temperature in the T_2 monitoring week was lower than in the T_0 and T_1 monitoring week, whereas in the second measurement period, the temperature in the T_1 monitoring week was lower than in the T_0 and T_2 monitoring week (Figure 2; WeerOnline, 2005).

Table 1 EN 13779 classification of indoor air (IDA)

Category	Rate of outdoor air in a non-smoking area (l/s per person)	ΔC^a CO_2 (ppm)	Indoor CO_2^b (ppm)
IDA 1	>15	<400	<800
IDA 2	10–15	400–600	800–1000
IDA 3	6–10	600–1000	1000–1400
IDA 4	<6	>1000	<1400

IDA, indoor air.
[a]Difference between indoor and outdoor CO_2 concentration.
[b]Based on typical outdoor CO_2 concentration of 400 ppm (CEN, 2004; RIVM, 2004).

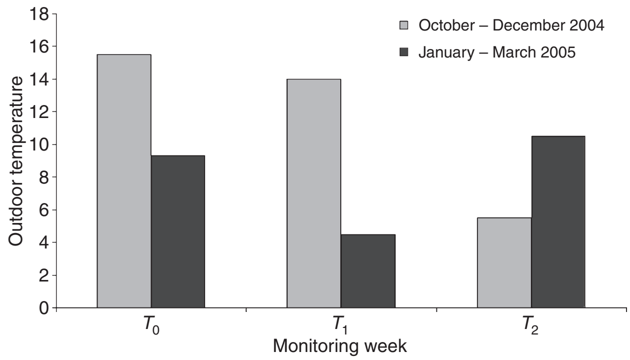

Fig. 2 Outdoor temperature (°C) in study area per measurement period and monitoring week

To assess the effectiveness of the tools on short and longer term, we used the General Linear Model Univariate Analysis of Variance, with the measurement period as random factor. For multiple comparisons between the different interventions groups we used the commonly applied Bonferroni confidence interval (CI) adjustment to reduce the probability that the null hypothesis is unjustly rejected (Abdi, 2007).

Results

Questionnaire and ventilation journals

The response to the questionnaire was high (95%). The teachers were mainly positive about the different tools. The CO_2 warning device was considered useful by 95% of the respondents, and they pointed out that they watched closely if the LED turned on. The class-specific ventilation advice was considered useful by 80% of the respondents. The teaching package was considered useful by two-thirds of the respondents, and they pointed out that, because of the allocation of tasks, they were reminded of ventilation by the pupils. Five percent thought the teaching package was too difficult for the pupils of 7–8 years old. The oral presentation of the ventilation advice was considered useful by 60% of the respondents. Negative judgments were often explained by complaints of draft or cold. In addition, two-thirds of the teachers mentioned they followed the advice only partially, mainly because of this discomfort. Most teachers indicated that they failed to accurately register their ventilation in the ventilation journals. This was confirmed by visual inspection of the journals, i.e., the majority showed considerable data gaps and irregular registration patterns. It was therefore decided not to include these data in the interpretation of the results.

CO_2 concentration

To visualize the IAQ, CO_2 measurements are classified according to the EN 13779 classification of indoor air (IDA) (CEN, 2004), and depicted in Figure 3a–c. In the starting situation (T_0), the curves of the different groups were comparable and the CO_2 concentrations exceeded the level of 1000 ppm (IDA 2) for about 65% of the school day. Directly after the advice (T_1), the level of 1000 ppm was exceeded for the shortest time of the school day in the group with the CO_2 warning device (38%), followed by the group with solely the advice (55%), the group with the teaching package (58%), and the control group (63%). Six weeks after the advice (T_2), the CO_2 concentration exceeded the level of 1000 ppm for the shortest time of the school day in the group with the teaching package (40%), followed by the group with the CO_2 warning device (57%), the group with solely the advice (62%), and the control group (69%).

The evaluation of the effectiveness of the tools was based on the average CO_2 concentrations ($CO_2|_{AVG}$), calculated for each classroom and each monitoring week. The means and the corresponding 95% CI of the average CO_2 concentrations $CO_2|_{AVG}$ are presented in Table 2. In the starting situation (T_0), the average CO_2 concentrations did not significantly differ between the groups ($P = 0.378$).

To assess the effectiveness of the tools on short and longer term, the improvement in average CO_2 concentration was calculated for each classroom for the short term: $CO_2|_{AVG}$ (ΔT_1); and for the longer term: $CO_2|_{AVG}$ (ΔT_2). The short-term improvement $CO_2|_{AVG}$ (ΔT_1) was significantly different from 'zero' in all three intervention groups compared with the starting situation. The largest improvement on the short term was achieved by giving a class-specific ventilation advice combined with a CO_2 warning device. A pairwise comparison with Bonferroni correction, showed that the advice combined with the CO_2 warning device was better than the control group ($P < 0.001$), the group with solely the advice ($P < 0.01$), and the group with the advice combined with the teaching package ($P < 0.05$).

On the longer term, the improvement decreased for the CO_2 warning device and for the advice solely. On the other hand, the improvement for the teaching package increased. On the longer term, the largest improvement was achieved by giving a class-specific ventilation advice combined with either the CO_2 warning device, or the teaching package. The improvements in these groups were significantly higher compared with the control group (Bonferroni, $P < 0.01$). On the longer term, the intervention group which received solely the advice did not differ from the control group.

Discussion

The influence of three different tools on CO_2 concentrations in classrooms was compared with background

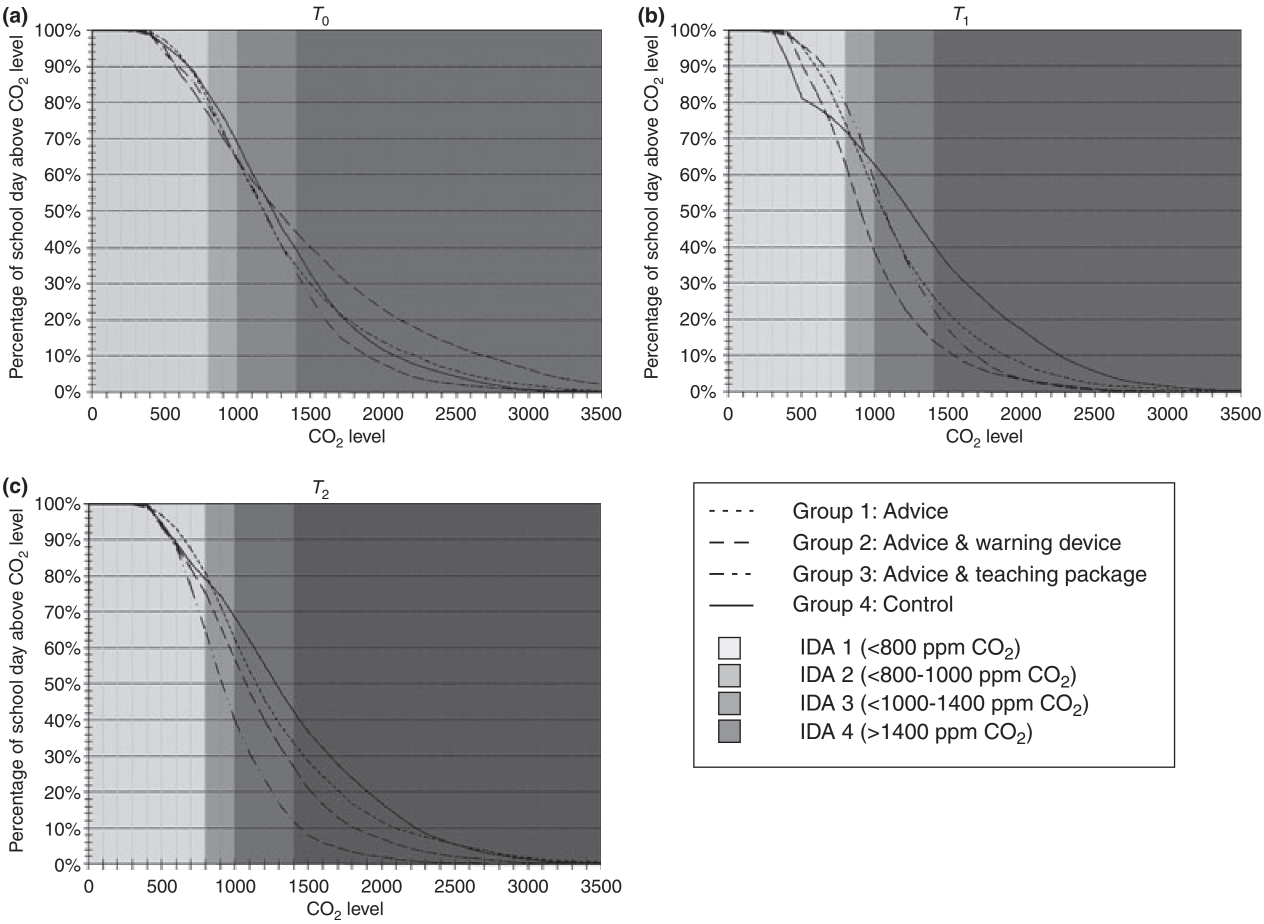

Fig. 3 Percentage of CO_2 measurements during the school day, classified according to EN 13779 classification of indoor air (IDA) on T_0 (a), T_1 (b), and T_2 (c), assuming a background CO_2 concentration of 400 ppm (CEN, 2004; RIVM, 2004)

Table 2 Average CO_2 concentrations in ppm ($CO_2|_{AVG}$), tested with GLM Univariate ANOVA with correction for the random factor measurement period

	1. Advice mean (95% BI)	2. Advice and CO_2 warning device mean (95% BI)	3. Advice and teaching package mean (95% BI)	4. Control group mean (95% BI)	*P*-value[a]
Estimated means					
$CO_2|_{AVG}$ (T_0)	1286 (1134–1437)	1438 (1287–1590)	1271 (1122–1420)	1298 (1146–1450)	
$CO_2|_{AVG}$ (T_1)	1139 (1017–1261)	960 (838–1082)	1124 (1001–1246)	1346 (1224–1468)	
$CO_2|_{AVG}$ (T_2)	1249 (1117–1380)	1140 (1006–1275)	980 (848–1113)	1383 (1249–1517)	
Estimated paired improvements					
$CO_2|_{AVG}$ (ΔT_1)	147 (11–283)	478 (343–614)[b,c]	171 (31–312)	−47 (−183–88)	0.000
$CO_2|_{AVG}$ (ΔT_2)	37 (−105–179)	275 (130–420)[b]	277 (130–424)[b]	−93 (−238–52)	0.001

[a]General Linear Model Univariate Analysis of Variance.
[b]Statistically significant different from group 4. Control (Bonferroni adjustment for pairwise comparisons).
[c]Statistically significant different from group 1. Advice (Bonferroni adjustment for pairwise comparisons).

variations in a control group. On the short term, the largest improvement in CO_2 concentration was achieved by giving a class-specific ventilation advice combined with a CO_2 warning device. This was followed by the advice combined with the teaching package and the advice solely. On the longer term, only the improvement for the teaching package further increased. The largest improvement on the longer term was achieved by giving a class-specific ventilation advice combined with either the CO_2 warning device, or the teaching package. We also assessed the relative improvement and draw the same conclusions from those results. We will now discuss these results in more detail.

The intervention group with the teaching package was located in the city of Breda while the other three groups were distributed more or less homogeneously over the southern part of the Netherlands. However, we do not expect that this different localization of the intervention groups influenced our results because: (i) the weather conditions in the different study areas were similar (WeerOnline, 2005), and (ii) the criteria for school selection resulted in comparable schools (see Methods section).

In case buildings are located near highways or busy local roads, ventilation may increase the indoor concentrations of outdoor pollutants (Baek et al., 1997; Daisey et al., 1994; Perry and Gee, 1994; Yocom, 1982). Furthermore, traffic can cause noise nuisance and therefore may discourage ventilation behavior. However, we do not expect that traffic had a large influence on the ventilation behavior and CO_2 concentrations in the class rooms of our case study because the schools were located on a distance of over 400 m from highways and the majority of the schools (17 out of 20) were not situated near busy local roads.

Opening windows during the winter period may cause draft and cold and in this way it may affect indoor thermal climate. To avoid draft and cold, teachers may have reduced ventilation. Hence, in a warmer part of the year, the ventilation conditions are generally better, further improving the effectiveness of the instruments evaluated in our study. It should be stressed, however, that our results are representative for the temperate climate in the Netherlands which may not be applicable to classrooms in colder climates.

The relatively small improvement on the short term for the teaching package could be explained by the fact that the measurements on short term directly started after the teachers received the teaching package, but it took three to four lessons to go through it. This meant that the first days of this monitoring week, the teaching package was not fully used yet. Therefore, the short-term effect of the teaching package was probably underestimated.

The influence on CO_2 concentrations in classrooms of three different tools was studied on short term and on a longer term of 6 weeks. In this period, the influence of the tools decreased after removal of the tools, except for the teaching package. The effects on long term, for example after 1 year, are not studied yet. We expect the influence to decrease further on long term. However, continuous use of the tools may reduce decrease on long term. Grimsrud et al. (2006) already showed that the use of continuous monitoring without display could make a significant improvement in IAQ. In our experiment, the CO_2 warning device was present in the classroom for only 1 week. In this week the CO_2 concentrations decreased, but when the CO_2 warning device was removed the CO_2 concentrations increased again. In the case of the teaching package, the package was removed, but the badges remained in the classrooms, and the CO_2 concentrations did not increase. Correspondingly, we expect the improvement in CO_2 concentrations to last longer, if the CO_2 warning device is present in the classroom continuously. Nonetheless, one important condition would be that the placing of a CO_2 warning device should be accompanied with a description of the problem and an introductory interpretation of the data. Because the teaching package 'Outdoor air, come in and play!' can be used as problem description, we recommend to offer these tools together, combined with a complementary introduction on the interpretation of the CO_2 data. Further study on (i) the effects of the combined approach, (ii) the effects of continuous use of the tools, and (iii) the effects on long term, would be recommendable.

Although the IAQ in general and many different factors influencing IAQ, were studied frequently, tools or programs to improve IAQ were studied less (Carrer et al., 2002). Moglia et al. (2006) conducted a survey on IAQ practices in schools. They showed that 42% of the schools in the USA have an IAQ management program, and emphasized that this appeared to be a valuable factor in improving the learning environment for school children. The focus in the programs studied was on management programs for school officers in general. The CO_2 warning device and the teaching package might be used in addition to such IAQ programs.

Besides management programs, a visual ventilation guiding device (VVGD) was developed for instant estimation of IAQ (Weis et al., 2006). The VVGD differed from the CO_2 warning device as it measures the concentrations of volatile organic compounds (VOCs). This makes the VVGD particularly valuable in situations when building materials are the main source of pollutants. However, in situations when occupants are the main source of pollutants, like in schools, the CO_2 warning device would be more appropriate to use.

After this study was conducted, the output of the CO_2 warning device has been adapted and the output is displayed similar to a traffic light. In the general settings, this 'traffic light' flashes (i) green when the indoor CO_2 concentrations are below 800 ppm; (ii) orange when the indoor CO_2 concentrations are between 800 and 1400 ppm; (iii) red when the indoor CO_2 concentrations are above 1400 ppm, conform the European classification EN 13779 (CEN, 2004). This more user-friendly CO_2 warning device is now also commercially available (http://www.atal.nl).

Before intervention, the CO_2 concentration exceeded the level of 1000 ppm (IDA 2) for about 65% of the school day. This finding is in accordance with earlier studies in schools in the Netherlands and in European and North American countries (Boerstra et al., 2006; Daisey et al., 2003; Dijken et al., 2006). Although an improvement in ventilation behavior and CO_2 concentration was achieved, the ventilation was still insufficient to maintain good air quality during the full school day. In order for a person to perform a given behavior, the following must be present: (i) strong positive intentions or commitment, (ii) no environmental barriers that make it impossible to perform the behavior, and (iii) the skills necessary to perform the behavior (Gielen and Sleet, 2003). Although the three tools consider the positive intention and the skills, insufficient or inappropriate ventilation facilities may form a barrier that makes it impossible to perform the behavior (factor 2). Therefore, to improve IAQ the focus should not only be on the ventilation behavior, but improvement of the ventilation facilities is also recommended. This was emphasized by the results of the questionnaire, which elicited that cold and draft were important reasons not to use the available ventilation facilities, like windows and ventilation grids. However, until the ventilation facilities are upgraded, the CO_2 warning device and the teaching package are useful tools to improve ventilation and current IAQ in schools.

Conclusions

Three different tools were compared in our study. We showed that:

- before intervention the CO_2 concentration exceeded the limit of 1000 ppm (IDA 2) for about 65% of the school day;
- the CO_2 warning device and the teaching package appeared to be effective tools to improve ventilation behavior and IAQ, while giving class-specific ventilation advice without any supporting means appeared ineffective;
- ventilation is significantly improved through behavioral change. Nevertheless, the CO_2 concentrations still exceeded the level of 1000 ppm for more than 40% of the school day. Therefore, improvement of the ventilation facilities is also recommended. Hence, until the ventilation facilities are upgraded, the CO_2 warning device and the teaching package are useful low-cost tools to improve ventilation behavior and current IAQ.

It should be stressed that our results are related to classrooms with natural ventilation in a temperate climate zone. These findings may not be applicable to classrooms with mechanical ventilation or to classrooms in colder climates.

We recommend further study on (i) the effectiveness of the 'traffic light' combined with the teaching package and an introductory interpretation of the data; (ii) the effectiveness of continuous use of the recommended tools; and (iii) the effectiveness on long term (e.g., after 1 year).

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