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Ventilation by the Windows in Classrooms: A Case Study

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SYNOPSIS

Four classrooms of two secondary schools located around Lyon in France have been monitored. The objectives are to analyse the quality of the indoor air and the thermal comfort and also the behaviour of the occupants towards opening of the windows.

This paper briefly describes the context and the nature of the monitoring campaign, and presents the results of the measurements with direct interpretation of the ventilation needs. Then, we try to make a statistical analysis of the influencing factors that lead to the opening of the windows, but our study is limited because of the small number of collected data.

Results from this study show that allowable CO2 levels are overpassed several times in a school day. The presence of a mechanical ventilation system leads to lower peaks but the fresh airflow is too small to prevent an indoor confining, that is also revealed by the aerobiological analysis. These measurements confirm a certain ill-being of the surveyed people, not in relation with thermal comfort. This feeling leads people to open windows provided that outdoor conditions are favourable (temperature, wind speed, noise, outside odours, ...).

1.0 CONTEXT OF THE STUDY

French regulation for schools does not impose that the buildings are equipped with a mechanical ventilation system except for some classrooms devoted to the physical sciences. Opening of the windows is supposed to be sufficient to insure the recommended hygienic airflows. To have a better knowledge of the practical use of the windows and the resulting indoor air quality inside classrooms, a first monitoring campaign has been undertaken by the Laboratory for the Building Sciences (ENTPE/LASH) in collaboration with a team from the technical network of the French Ministry of Public Works (CETE Lyon) and the laboratory of hygiene of the Lyon city.

The chosen sample of buildings is small for this first prospective study: two buildings, a first one with a mechanical ventilation system, a second one with natural ventilation by the windows. Two similar classrooms are monitored for each building on a weekly basis. This study could be extended to other buildings in the future.

1.1 Description of the monitoring

Measurements in the buildings include [1]:

- duration of the opening of each windows within a 2 minutes time step
- indoor temperature and relative humidity every 3 minutes (Vaisala)
- CO2 concentrations every 4 minutes in one classroom (Dräger Multiwarn IND equipment), or hourly averaged in second classroom (IR spectrometer Cosma Beryl100)

Ambient climate (wind, solar radiation, outdoor temperature) was recorded on the ENTPE site (between 5 and 10 km from the studied buildings).

These measurements were done during winter time : 10th-19th February 1993 for first school and 10th-24th March 1993 for second school. Unfortunately weather was particularly warm during the monitoring of the second school.

Aerobiological samples were taken several times during the monitoring. The biocollector is Joubert one, with 3 different media boxes: tryptone soja gelose, Baird-Parker, and Sabouraud [2].

1.2 Survey to the occupants

The measurements were coupled with a survey to the teachers of each school by questionnaires, and a few interviews to the occupants of the studied classrooms.

Questions were relative to the general well-being inside classrooms, with more directed questions about thermal comfort, air quality (or "feeling of suffocation"), building equipments knowledge and other factors that could influence the openings of the windows (noise, wind, sun...).

We try also to have an idea of the teachers' habits towards windows opening and closing.

The high return level of the questionnaires (50%) show the teachers' interest for their working environment.

2 RESULTS FROM THE MONITORING

Here are given some direct results about comfort level inside classrooms, that were got from the monitoring.

2.1 Air quality

The measured carbon monoxide concentration inside classrooms are very low (less than 4 ppm), without any risk for the occupants' health.

Conclusion is not the same for carbon dioxide; very high concentrations can be reached in both schools, with maximum of 7000 ppm in the school without any ventilation system (figure 1a). This level is much higher than the 800-1500 desirable values for indoor air quality [3]. In the building equipped with a mechanical ventilation system, the peaks are lower, with maximum of 3500 ppm after 3 hours of occupancy (figure 1b).

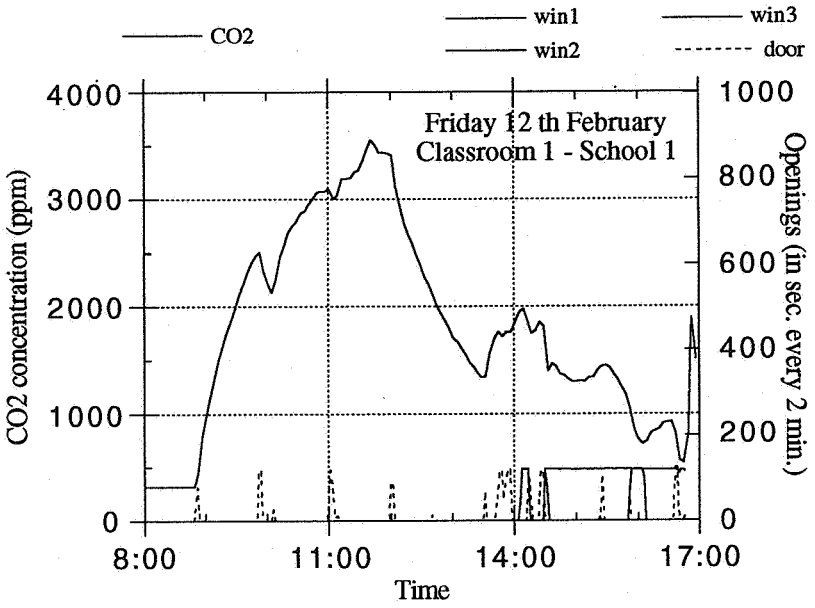
The CO2 level of 1500 ppm is overpassed during 66% of occupancy time for first school and 74% for second one.

The aerobiological analysis also reveals quite an important environmental bacteria and fungi flora load because of students' activities (table 1), but no pathogenic germ was found [2].

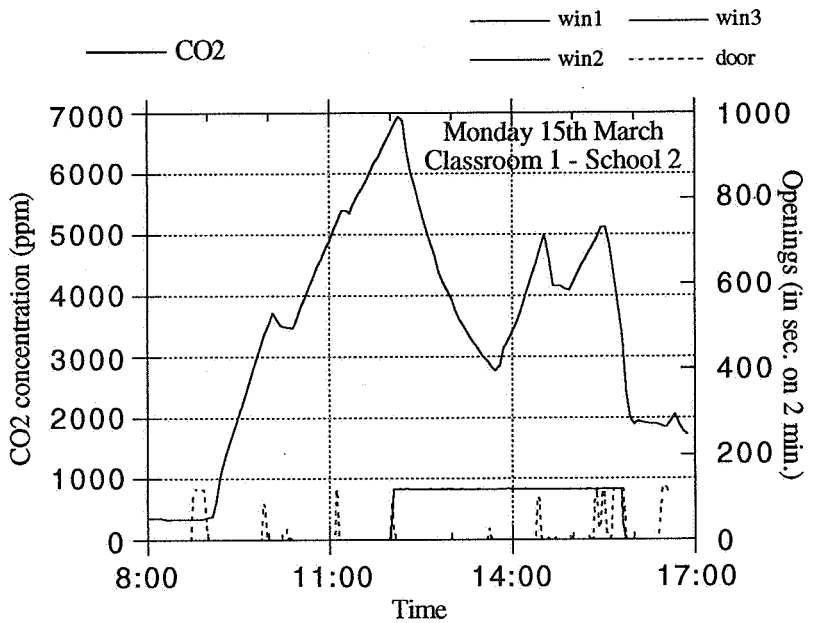
School	Bacteria		Staphylocoques		Fungi	
1	201	207	19	12	E(*)	27
2	192	118	23	29	32	34

(*) The counting was not possible because of Mucor colonies

Table 1 : Counting of the colony forming units (CFU) per 0.5 m3, after 6 days (2 samples each classroom during occupancy).



a)



b)

Figure 1 : CO2 measurement and openings duration during one class day

2.2 Thermal comfort

The couples (temperature, humidity) are in great majority inside the relative comfort zone (-0.5 < PMV < 0.5) defined for a clothes resistance of 1.5 clo and a metabolism of 1 Met [4]. Only a few periods get outside this zone during the occupancy periods (PPD>17% for temperature between 24 and 25°C). This result is valid for both schools during the monitoring.

2.3 Openings of the windows

Table 2 gives how many times one window has been opened during occupancy period. The daily duration is quite different between the two classrooms in the first school, according to different habits of the teachers .

School	Classroom	Average nb of openings /day	Average duration of opening	Average duration of 1 opening
1	1	2.5	65 minutes	26 minutes
	2	2.2	26 minutes	12 minutes
2	1	2.7	304 minutes	114 minutes
	2	2.3	243 minutes	108 minutes

Table 2 : Daily statistics about openings duration

Daily opening duration is important in the first school (up to 65 minutes) despite the ventilation system. It is much more large in the second school (up to 5 hours), as teachers used to opening the windows after one hour class and keep them open all morning long. Unfortunately, it is difficult to interpret these openings in terms of larger needs for fresh air because the weather was warmer during the second monitoring period, that could influence people.

2.4 Occupants' point of view

The number of returned questionnaires which is 18 for first school and 20 for second one is enough to allow a representative analysis. Table 3 gives the recorded answers (in percents) about thermal comfort and feeling of suffocation.

Table 3 : Comfort feeling from the teachers answers

% answers	School 1	School 2
Thermal comfort		
Neutral	89	85
Too hot	11	5
Too cold	0	10
No answer	0	0
Feeling of suffocation		
Yes	28	70
No	72	25

These figures confirm previous conclusions from the physical measurements during monitoring, that is a satisfactory temperature level during winter time for both schools. The feeling of suffocation in the second school (without mechanical ventilation system), that nearly does not exist in first school, can be linked to higher levels of relative humidity and CO2 concentration.

About windows openings, the answers do not allow to estimate properly the number and the duration of the openings. However, they show that some teachers never open the windows during winter in the first school when most of them at least open for a 20 minutes duration in second school.

Table 4 shows that the reasons for the openings are the same in both schools with 80% of the answers directed towards air quality. Reasons for closing the windows are also the same, to come back to a comfortable temperature and to dampen the outside noise.

Table 4 : Main reasons to open / close the windows

% answers	School 1	School 2
To get a comfortable temperature	17	17
To disperse bad smell	44	42
To have fresh air get in	36	41
To come back to a comfortable t°	37	25
To dampen outside noise	33	36
Because weather has changed	18	14

In the second school, 50% of the surveyed people know that the building has no mechanical ventilation system et 40% say that it is not acceptable. In the first school, 2 teachers say that the ventilation is not satisfatory and 9 teachers say it works well.

2.5 Summary

The measurements have shown that there are some problems of air quality in both schools (high CO2 concentrations, body odours...) which the occupants are sensitive to. The resulting "feeling of suffocation" in the building without ventilation system has no link with thermal comfort, that seems satisfactory.

3 VENTILATION EFFICIENCY

At the arrival of N students in a classroom, the CO2 concentration increases because of the metabolic production according to equation (1) :

$$V\frac{dc}{dt} = nV(c_o - c) + Np \qquad (1)$$

where
V is the volume of the room [m3]
$c(t)$ is the CO2 concentration [g/m3]
n is the air change per hour [vol/h]
co is the CO2 concentration of fresh air [g/m3]
p is the metabolic CO2 production [p = 32 g/h/pers.]

Carbon dioxide can be seen as a good tracer gas to measure air change per hour of the studied classrooms. If air change per hour is constant during times t_1 and t_2 n can be estimated with sampled values of $c(t)$ using a mathematical solver (we suppose that the volume is well mixed and the c measurement is representative):

$$c(t_2) = c(t_1)e^{-n(t_2-t_1)} + (1 - e^{-n(t_2-t_1)})(c_o + \frac{Np}{nV}) \qquad (2)$$

Outside concentration co is supposed to be equal to the concentration inside classroom at early morning, before arrival of the occupants; Values between 280 ppm and 340 ppm are found for first school and between 340 and 470 ppm for second school.

In the first school, the calculated air change per hour varies between 1.5 and 2.0 that is a volume of less than 10 m3/h per person. Following French regulation, it is required that 15 m3/h/pers of fresh air is supplied in classrooms. A simulation shows that the limit of 1500 ppm would not be exceeded with this rate.

In the second school, the calculated air change per hour when windows are closed is located between 0.3 and 0.6 that means that less than 3 m3/h of fresh air are supplied per person. Opening of the windows can induce air flows as large as 3 ACH during the monitored period. The hygienic air flow per person is then effectively provided.

4 INFLUENT FACTORS ON WINDOWS OPENINGS

One of the objectives of the study is to analyse efficiency of windows openings to maintain air quality inside classrooms. As the windows are not automatically moved, it is necessary to study the occupants' behaviour towards the windows. When, why, how do they open windows ?

4.1 Time for the openings

Teachers used to opening between two classes. 70% of the openings correspond with breaks, while closings can occur at any time This could mean that the teacher (which is most of the time the first person involved in the opening process) either is not bothered by discomfort feeling during his class, or his attention prevents him to be sensitive to it.

4.2 Effect of indoor climate

In order to better understand if there are specific reasons involving people to open the windows (or doors) of the classroom, the influence of various factors is analysed from the recorded measurements: CO2 concentration, indoor temperature, relative humidity

For each of the 68 recorded openings the corresponding values of these factors (when available) are gathered in a data base for statistical analysis. The following questions were looked at for each of this factor:

Is there a limit beyond that the opening is systematic ?
Is there a limit below that the opening is prohibited ?
Is the frequency of the openings dependent on the value of the factor ?

4.2.1 Influence of indoor temperature

Figure 2 plots the number of openings and closings in each temperature interval between 17 and 26°C, compared to the total number of measurements in the same interval when the room is occupied. There is a slight increase of the openings frequency when temperature is greater than 23°C, but there is no upper limit that leads people to systematically open one window. However, very few openings occur when temperature is below 21°C, while more closings happen.

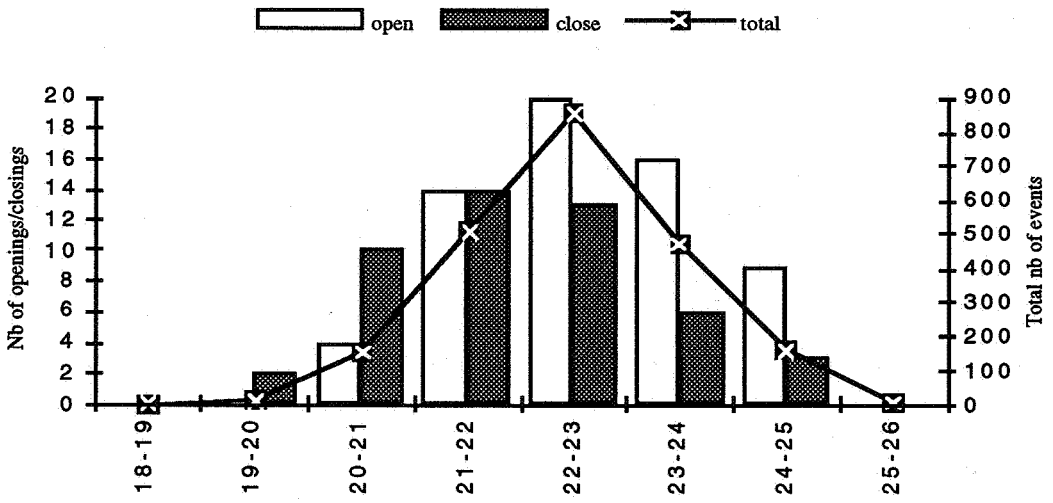


Figure 2 : Frequency of the openings/closings in a temperature range (°C).

4.2.2 Influence of CO2 concentration

Openings can occur at the early beginning of classes (figure 3) when CO2 level does not exceed 1000 ppm or may not occur for high levels (only one opening in the range 3500-7000 ppm which represents 15% of the recorded concentrations). 69 % of the openings occur in the range 1500-2500 ppm which is reached after 1 hour class.

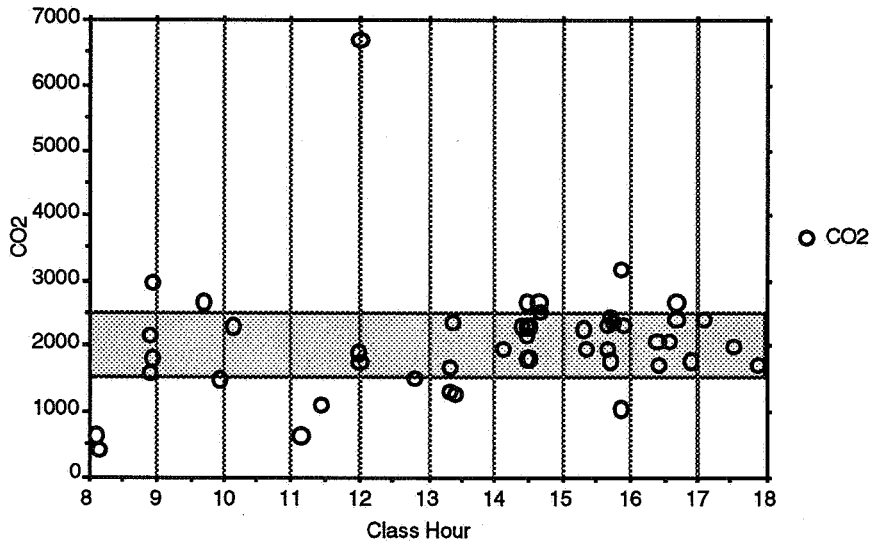


Figure 3 : CO2 concentration at the opening against time

4.2.3 Influence of relative humidity

Using the same approach, it is found that most of the openings occur when relative humidity is around 45-50% in first school or 50-55% in second school, but this factor is highly correlated to CO2 concentration because of human metabolism.

4.3 Conclusions

It is difficult to find specific factors to explain the openings. If temperature could play a significant role, showing that human body is quite sensitive to low values, it does not seem to be the case for air quality. There is no visible correlation between openings and CO2 concentrations, except that teachers open more often when CO2 level can reach 1500-2500 ppm. But this factor seems to be more sensitive at the class breaks, either when the teacher finishes his class or when he comes back to his classroom.

A lot of other factors are likely to influence windows openings and closings either from the indoor environment or the outdoor one (wind was found to be an influent factor on the closings in this study). Sociological and psychological factors [5,6] could also be analysed, but it was out of the scope of this study.

5 OVERVIEW

According to the objectives of the study, the pollution from the human presence inside classrooms was analysed thanks to some measurements and a survey to the occupants. It was demonstrated that problems exist in both studied schools. In the first building, insufficient fresh air flow was provided by the ventilation system, while in the second building, opening of the windows cannot be seen a reliable mean to prevent pollution by the human metabolism. Indeed, no direct correlation could be found between high CO2 concentration levels and frequency of the openings. The recorded openings seemed more linked to the school pace.

In the future, it seems interesting to develop this approach to a larger set of schools in order to assess effective ventilation air changes by the systems and to improve comfort inside classrooms.

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