Case Study: Environmental quality in classrooms of south of Chile.

Carbon dioxide concentration levels and satisfaction polls

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ABSTRACT: The indoor air quality (IAQ) and thermal comfort in public buildings and residential is relevant when their rooms are in use. However, to date it is not regulated nor controlled in Chile, despite the consequences of poor IAQ due to high concentrations of CO2 on learning, concentration, productivity and health.
Satisfaction polls were conducted between users and environmental variables were monitored in two schools located in the South of Chile (latitudes 45°23'71''S and 47°115'11''S). This article conveys the current IAQ conditions of one classroom in each school, and contrasting them with international standards and recommendations. Finally, and considering the Chilean regulations, some guidelines on the improvement of IAQ which are applicable to the design process of education buildings will be provided. This study is a preliminary approach to the field of actual environmental conditions in which children study and gives ground to new research onto their regulation.
Keywords: Indoor Air Quality (IAQ), Carbon dioxide (CO_2), Ventilation.

THEORETICAL FRAMEWORK

Human beings issue exhaust gases as a result of breathing where we find carbon dioxide. This gas is widely used as the indicator of air quality in facilities with high density of occupants due to its easy measurement and direct relation with respect to other existing exhaust gases [1, 9]. While some pollutants give signs of discomfort upon exceeding certain admissible limits, others give no alert symptoms and could be very dangerous for the human being as in the case of carbon monoxide. The most useful way of controlling concentration of gases and keeping them within comfortable and healthy limits is through ventilation.

Environmental quality and comfort is closely related to the consumption of energy even more in climatized buildings where renewals of vitiated air for a clean or exterior one are mechanically regulated. In turn, in the case of naturally ventilated facilities, control of ventilation is more complex, as it is restrained to outdoor conditions and air quality, which could be polluted, out of comfort temperature and endanger comfort of users or be highly variable.
Ventilation in classrooms of Chilean schools is in natural form, and it is not controlled or supervised [10, 11]. This takes higher relevance in buildings sited in geographical zones with extreme environmental conditions where the loss of heat is avoided mostly by sacrificing air quality.
However, mechanical ventilation is not always the solution to ventilation problems and bad indoor air quality as risks implied, such as suffering from the Sick Building Syndrome (SBS) in schools or educational facilities is high. This is because when related to small children and weaker health risks of contagion and complications are higher. Scholar absenteeism is a problem that has repercussions on the whole society, because a sick child demands special treatments and cares passing through a health system that is overworked in winter seasons, and this also implies work absenteeism by the caregiver in addition to all what is implied therewith.

NATIONAL REGULATION

There are certain design recommendations including one ventilation item of school facilities. In addition, Chilean legislation requires minimum temperatures of 12°C for Primary and Secondary Education, through heating systems with evacuation of gases outside [11]. On the other hand, ventilation should be natural, with a minimum of openings corresponding to 8% of the inner classroom surface, and it is necessary to comply with a minimum area of 1.1 m2/student and 3 m3/studnt as minimum air volume so that, according to this, keep a proper ventilation. As a result of the above stated and in addition to other requirements classrooms are designed in Chile; however, in the practice there is no supervision or control of effectively maintaining proper ventilation. In turn, the law of safety in work places goes beyond this [10] It requires a minimum air volume of 10 m3/h per person in facilities naturally ventilated and in cases of active facilities, 20 m3/h· per person or 6 changes of air per hour (ach).

INTERNATIONAL REGULATION

A large number of countries have defined indicators and admissible limit values of a good air quality and the way in which they are controlled. Most of them uses carbon dioxide as indicator, but in addition of measuring the concentration of this gas, they control the ventilation rate of facilities per occupant, which ranges 4 to 10 l/s per individual of fresh or clean air estimating certain conditions of the outdoor air and generation rate of carbon dioxide according to the metabolic activity of the body.

The limit of 1,000 ppm of CO_2 derived from the study of the German Max von Pettenkofer in the year 1858, defining the higher acceptable limit of the first standards on indoor ventilation [14] has been used internationally. Regulations defining CO2 concentration for indoor air (IDA) classification were not conducted but until the year 2008 upon which it was applied in most standards such as the UNE EN 13,779 - 2008 "Ventilation of non-residential buildings"[16] (Table 1).

Table 1: Classification of facilities according to the UNE EN standard 13,779 – 2008.
(*) CO_2 Indexes in ppm correspond to the difference on the environmental level of the place. Source: Own elaboration.

Indoor air classification for non residential buildings. IDA	Quality	Applications	CO2 (ppm)*
1	Optimal	Hospitals, labs, nurseries, among others.	+ 350
2	Good	Offices, residential buildings, classrooms, among others	+ 500
3	Medium	Commercial buildings, cinemas, restaurants, gyms, among others.	+ 800
4	Low	It should never be applied.	+ 1200

According to the ASHRAE 62/2010 [3] reference, CO_2 production by an individual who performs sedentary activities is 0.31 l/min, and requires 7.5 l/min as ventilation rate in order to keep a good air quality and CO_2 levels below 700 ppm over the outdoor air concentration. Oxygen consumption is 0.36 l/min, however, oxygen reduction is insignificant when comparing it to the CO_2 generation for one same activity, there lies the higher need to dilute CO_2 before increasing oxygen. According to the ASHRAE 62 standard, acceptable air is considered if the CO_2 concentration is lower than 700ppm above outdoor CO2 concentration to all inhabited facilities measured without use restrain. In turn, the UNE 13,779 as well as the last version of the ASHRAE 62/2010 classifies them according to the use. Specifically, in the case of classrooms, it recommends to keep difference of CO_2 concentration below 500ppm between indoors and outdoors.

Table 2: Other international references and standards referred to air quality and ventilation. Source: Own elaboration.

Standard	Quality	CO_2
ASHRAE 62/ 2001	Acceptable	<1000ppm of indoor air. Considering there is between 300-400ppm of CO2 outdoors.
ASHRAE 62/2006 and ASHRAE 62/ 2007	Acceptable	Lower than 700 ppm above the outdoor CO2 concentration. This value is considered to keep a good air quality in facilities with individuals inside to avoid bad odors or feeling of vitiated air.
DIN in 13779: 2007–09 (DIN 2007–09).	IDA 1 IDA 2 IDA 3 IDA 4	Air quality requirement in accordance with the facility.

CO2 Exposure Limits used abroad:

- USA:
  - 5,000ppm (PEL – OSHA, NIOSH and ACGIH)
  - 5,000 ppm and 30.000ppm in 15 min. maximum (NIOSH)
- Spain:
  - 5,000 ppm for daily exposures of 8 hours and a limit value for short exposures of 15 minutes of 15,000 ppm (LEP-VLA, from INSHT [Instituto Nacional de Seguridad e Higiene en el Trabajo - *National Institute of Labor Safety and Hygiene*]).
- OMS:
  - Reference values: 500-2200 ppm.

- Belgium: 5,000ppm

Acceptable levels of other gases present in the atmosphere according to the United States Environmental Protection Agency (USEPA):

- CO: 9-25ppm
- Particulate matter (MP_{10}): 150µg/m3
- Ozone: 0.08ppm

These limits are collected by primary standards of the Chilean air quality in order to set parameters and acceptable limits.

USERS PERCEPTION POLLS

"One person is comfortable when he/she can observe and feel a phenomenon without being worried or feeling uncomfortable"[5]. Thus, it is possible to talk about thermal, acoustic and luminous comfort as variables of the environmental comfort. If some of the factors affecting user's comfort increases above certain limits a negative stress in the body is generated in the long-term which can caused diverse associated physical and psychological.

During the monitoring, satisfaction polls with the environment were also applied to all students of the classroom, and they were also asked if they found air quality acceptable during classes.

STUDY CASE: CLASSROOMS IN EXTREME SOUTH OF CHILE.

From the project developed by a technological consortium coordinated by the Instituto de la Construcción de Chile *[Construction Institute of Chile]* during the years 2010-2011, 10 buildings were monitored in 5 regions throughout the country. Among the 10 buildings measured, the data compiled during winter in 2 schools were used in this analysis. Classrooms monitored (hereinafter, School 1 and School 2) are located in the extreme south of Chile, latitudes 45°23'71''S and 47°115'11''S specifically. This zone is characterized for being cold, humidity and rainy during most part of the year with a maximum mean temperature in cold months ranging between 4.6°C and 9.3°C associated to a low thermal oscillation.

In these schools, during 1 week in winter season and 1 week during summer season CO_2 concentrations were measured among other environmental parameters with intervals of 10 minutes between measurements. From these data, only those corresponding to the hours of use of these facilities were selected.

Both schools have a central heating system through hot water with firewood-operated boiler, reason why there are no products resulting from combustion inside classrooms and, in consequence, exhaust gas predominating indoors is carbon dioxide.

RESULTS AND ANALYSIS

The classroom monitored of the Gabriela Mistral School located in the city of Aysén (School 1) has a surface of 55.32 m^2 and a capacity for 45 students equivalent to 1.23 m^2/student; and the classroom of the Teniente Merino School located in Cochrane (School 2) has a surface of 1.16 m^2/student complying with the requirements provided by the General Ordinance of Urbanism and Construction. For both classrooms the hours of use correspond to full day, namely, from 8:00 to 18:00 hrs.

Air-tightness tests (UNE-EN 13,829) [17] were conducted by the CITEC investigation center of the Universidad del Bío-Bío using the standardized equipment Blower Door. Tests showed indexes of air renewal within the expected for educational facilities, which are detailed below.

Table 3: Results of pressurization tests, number of air renewals. Source: Own elaboration from reports of the Test of CITEC UBB for the INNOVA/CORFO No. 09 CN 14-5706 project.

Infiltration Coefficients [1/h]	Result n4	Result n50 (classification)
School 1	1.58	7.78
School 2	1.22	4.15

The RT 2005 reference of France recommends a value of 6.5 air renewals at 50 Pa (n50) or 1.2 at 4Pa for educational facilities. In general, it is advisable to not exceed 10 renewals per hour at 50Pa.

However, these air changes by infiltration through the envelope are insufficient if the target is to keep a good indoor air quality, where CO_2 levels are extremely high; in consequence, it should be necessary to incorporate additional ventilation.

CO2 concentration in the monitored classroom of School 1 during winter season showed 2,075ppm in average during class hours with a maximum of 4,847ppm, exceeding the 0.3% per air volume. The same happens in the classroom of School 2, where the average concentration was 1,385 ppm with a maximum of 3,890 ppm (Figure 1 and 2). It is likely that during the time when these carbon dioxide concentration levels were reached children have shown symptoms such as numbness and feelings of vitiated air [7], which was confirmed in polls applied to teachers of schools. Finally, break periods are not enough to improve conditions and lower concentrations to acceptable levels, or else ventilation of classrooms is not appropriate.

During class hours of School 1, indoor temperature was maintained at about 12°C out of what is indicated in the Chilean regulation, and the result of the energy demand of the building during the monitoring week was 330.75KW/m^2.
On the other hand, School 2 submitted average indoor temperatures of 15°C, and energy demand of the building during that week was 220.5KW/m^2.

Results of measurements according to the UNE EN standard 13,779 – 2008:

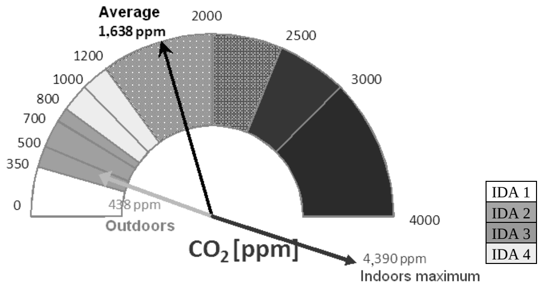

Figure 1: CO2 values obtained from monitoring in classroom of School 1. Acceptable limit of 1,000ppm is exceeded 4.8 times.
Source: Own elaboration, data obtained from the INNOVA/CORFO No. 09 CN 14-5706 project.

Values shown below for classroom of School 2 are slightly lower than for School 1.

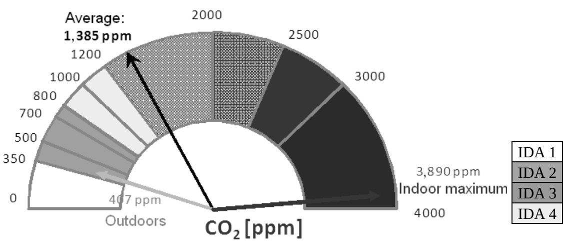

Figure 2: CO2 values obtained from monitoring in School 2, in Cochrane. The internationally allowed limit is exceeded 3.9 times.
Source: Own elaboration, data obtained from the INNOVA/CORFO No. 09 CN 14-5706 project.

The time in which the facility is in each class during the period analyzed is shown below.

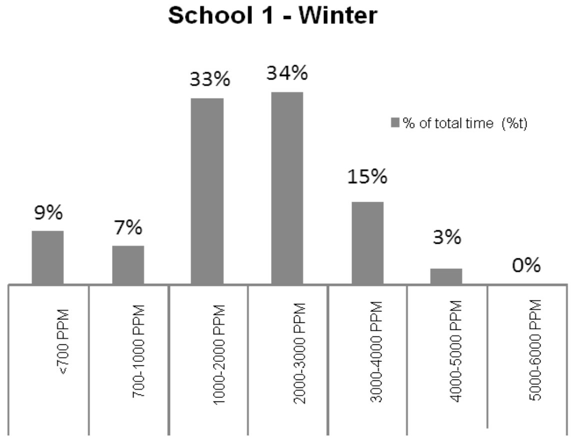

Figure 3: Distribution of CO2 concentration during 1 week of classes in School 1. Acceptable limits are exceeded 84% of the class time, and most of the time air quality is in "Bad" conditions.
Source: Own elaboration.

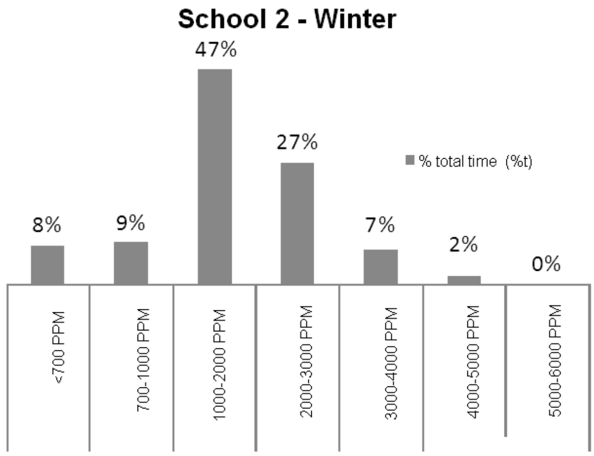

Figure 4: Distribution of CO2 concentration during 1 week of classes in School 2 and its respective qualitative scale. Only 17% of the class time the classroom shows "Good or Innocuous" indoor air quality.
Source: Own elaboration.

USER'S PERCEPTION POLLS

When asking about air quality during classes, 100% of students of School 1 answered negatively or not satisfied, making comments on the lack of ventilation and bad odors. In turn, in School 2 about 80% of Dissatisfaction was observed with air quality of the facility, although it is still an unacceptable result.

CONCLUSIONS

Two classrooms of 45 students each in 2 cities of the extreme south of Chile were monitored from the INNOVA/CORFO No. 09 CN 14-5706 project during 2 campaigns, winter and summer, taking records of physical-environmental variables every 10 minutes.

By comparing IAQ of classrooms monitored with standards of the reference and international investigations (ASHRAE 62/2010 and UNE EN 13,779), it is observed that limit concentrations are exceeded from the first 20 and 40 minutes of classes respectively, not complying with any regulation. This is mainly due to the fact that there is no adequate ventilation system, and aspect that up to this date is not required in any manner in Chile. In turn, pressurization tests shown Moderate and Tight air-tightness results for Schools 1 and 2 respectively, which is consistent to weather conditions of the zone allowing to count on a good control of heat losses, but few air renewals.

In Chile, legislation for educational facilities is prescriptive and equal to all the country without considering the existing diverse environmental conditions. It requires areas, air volumes and percentage of openings that do not ensure proper ventilation or a good air quality of classrooms during their use. It is necessary to advance so that it moves towards a social-benefit type, similar to the requirements demanded in labor facilities complying with certain air renewals per hour, and comfortable air temperature for users. It is recommended to adapt the architectonic design of schools to the environment and climatic zone starting with strategies of passive design, where you take advantage of wind direction and speed, solar gains, characteristics of materials, among others. In addition, it is essential to incorporate CO2 measurement equipment or detectors, already available in the market, that allow an alarm sound by exceeding a determined limit, and that could be implemented as ventilation management plan.

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