Evaluation of the Indoor Air Pollution in Schools Related to CO_2 Concentration

CAMELIA GAVRILA[1]*, ANDREEA VARTIRES[1], ANDREI DAMIAN[1]

[1] CAMBI Research Center, Technical University of Civil Engineering of Bucharest, 66, Pache Protopopescu Blvd, 021414, Bucharest, Romania

The paper describes a mathematical model aiming to predict Indoor Air Quality (IAQ) inside schools. According to the World Health Organization, these educational facilities have needed more attention in the latest years than before, because of the increasing rate of pulmonary problems undergone by young children. The prediction method and the analysis of the results were validated using real data measured in three schools located in Bucharest. The study uses measured indoor and outdoor CO_2, temperature and humidity values, CO_2 being the gas used most frequently as a marker of the human presence indoors. The statistical analysis for assessing indoor air quality is based on multiple logistic regressions. One main conclusion of the study is that accurately measured CO_2 values indoors represent the most important influence factor in the IAQ analysis report. The results showed that mathematical models which have the capacity to accurately describe the correlations between CO_2 values inside, CO_2 values outside and indoor air quality are excellent instruments for analysis and interpretation of experimental data as well.

Keywords: indoor air quality, CO_2 concentrations, multiple logistic regressions

To reduce the air pollution which may lead to adverse impact upon public health it is important to comply with national and international legislation which provides for thresholds for concentrations of pollutants [1, 2].

The main objectives of the paper are to outline the Indoor Air Quality (IAQ) problems that Romanian schools are confronted with, as well as to find a mathematical correlation between the indoor and the outdoor air quality. For this purpose, an experimental monitoring campaign held in three Romanian schools during spring 2014 has been initiated and performed, which showed that maximum threshold values for indoor CO_2 concentrations were exceeded by far. The schools included in the project were High schools Ion Neculce and Nicolae Iorga, along with secondary School no.179.

The study is important since, in the last 10 years, the indoor air quality in kindergartens and schools has become a major concern in many developed countries, due to several respiratory problems observed for a number of children, during the school year. These problems could vary from simple ones (bronchitis, coryza) to more complex (wheezing, frequent cough) and even to serious diseases (asthma) and are generally caused by the insufficient ventilation of the indoor spaces where pupils follow their educational program for many hours. Numerous epidemiological studies have outlined a poor indoor air quality in schools worldwide [3 - 6].

On the other hand, other authors showed a direct dependence between the learning performance of pupils and the indoor air quality or the thermal comfort [7, 8]. Other researchers [9-12] had shown the connection between the specific ventilation airflow delivered into a classroom (expressed in $m^3/(h*pupil)$) and the learning performance, as presented in figure1. It could be noticed that, for a specific airflow lower than 15 $m^3/(h*pupil)$, the learning performance (RP) decreases dramatically while, reversely, for airflows exceeding 36 $m^3/h*pupil$, RP is stabilized at an acceptable value (fig.1).

Before starting-up the investigation, we tried to understand why this type of environments has such a major influence on children's health.

Kindergartens and schools are characterized by an important occupation density, defined as the ratio between the number of pupils and the floor area in use. This also involves the effect of heat, humidity and CO_2 emissions in the indoor air, as well as bio-effluents (body odours). In addition, some building materials, pieces of furniture (wooden chairs, blackboard) could be responsible for specific emissions of formaldehyde (HCHO), Volatile

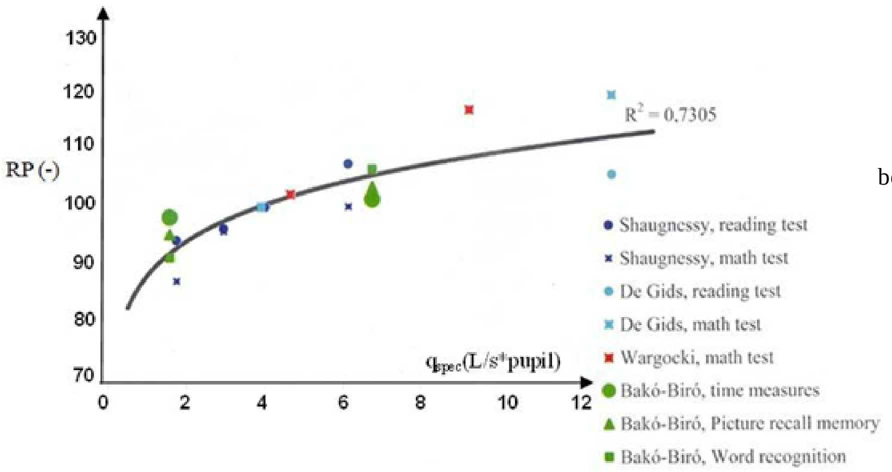

Fig. 1. Graphic display of the dependence between the learning performance, RP and the specific ventilation airflow delivered to a classroom, q_{spec} [13]

* email: cgavrila2014@gmail.com

Organic Compounds (VOC's) or other not-so-well known gaseous species [14]. According to these assumptions, it becomes clearly that a good ventilation of school classes is mandatory to ensure a good children's health. This observation should be extrapolated to other educational spaces, such as sport halls, locker rooms, laboratories or workshops.

In order to control the complexity of this scientific field, the proper understanding of its background physical mechanisms, as well as the ability to evaluate their behaviour appear to be two essential factors. Moreover, these mechanisms include the effects of individual, as well as random variation. Essentially they are uncertain; the uncertainties involved render an overall understanding hard to achieve and reasoning a daunting task. Models capturing these processes and methods using these models are thus called for to support decision making in real-life practice [15, 16]. Statistical methods were considered appropriate in such situations because we intended to draw reasonably valid conclusions from limited amounts of data, for which significant differences were also often blurred by experimental imprecision. On the other hand, the human mind excels at finding patterns and relationships and tends to generalize too much [17 - 19].

Experimental part

Materials and methods

In many cases, the goal of scientific research is to assign relationships between sets of variables and logistic regression using statistical analytical methods in the study of these types of relationships [20]. Usually, the goal of regression is to describe the analytical importance of a dependent variable y as a function of a number of predictor variables. Logistic regression is usually applied to a dichotomous random variable, Y, which can be 1 with probability π and 0 with probability $(1 - \pi)$.

$$\Pr(Y = y) = \pi^{y}(1-\pi)^{1-y}, \quad y = 0.1 \qquad (1)$$

Logistic regression analysis assumes that the relationship between π_i and covariance value x_i is described by the logistic function:

$$\pi_i = \frac{1}{1 + exp[-(\beta_0 + \beta_1 x_i)]}, \quad i = 1,2,...,n \qquad (2)$$

The model previously used for simple logistics can be easily generalized at the multiple regression analysis and expressed as:

$$\pi_i = \frac{1}{1 + exp\left[-\left(\beta_0 + \sum_{j=1}^{k}\beta_j x_{ji}\right)\right]}, \quad i = 1,2,...,n \qquad (3)$$

or, equivalently:

$$ln\frac{\pi_i}{1-\pi_i} = \beta_0 + \sum_{j=1}^{k}\beta_j x_{ji} \qquad (4)$$

This leads to the probability function:

$$L = \prod_{i=1}^{n}\frac{\left[\exp\left(\beta_0 + \sum_{j=1}^{k}\beta_j x_{ji}\right)\right]^{y_i}}{1 + \exp\left(\beta_0 + \sum_{j=1}^{k}\beta_j x_{ji}\right)}, \quad y_i = 0.1 \qquad (5)$$

Usually the statistical packages provide the statistics that measure the usefulness of the model [21], such as the Cox & Snell R^2 and the Nagelkerke R^2.

The experimental campaign performed during spring 2014 had as main goal the evaluation of the Indoor Air Quality for three classrooms being part of educational buildings located in Bucharest, the capital city of Romania and a very polluted town. These buildings are the following:

- Secondary School no.179, located in the Quarter 1 of Bucharest
- High-School Nicolae Iorga, located in the Quarter 1 of Bucharest, and
- College Ion Neculce, located in the Quarter 1 of Bucharest.

The buildings have been completely refurbished during the last two years, and the old wooden-framed windows have been replaced by energy-efficient double glazed windows with PVC joinery. As a result, it is expected that the natural ventilation of the classrooms by outdoor air infiltrations through the building's old joinery would drastically decrease with the increasing of the façade air tightness. During the experiment, four parameters were monitored: the indoor air temperature, the relative humidity of the indoor air, the indoor CO_2 concentration and the outdoor CO_2 concentration. As a result, the thermal comfort and the Indoor Air Quality for the three classrooms could be investigated. All the parameters investigated during the experiment: temperature, relative humidity and CO_2 concentrations were measured using portable gauges connected to multiport data-loggers for data acquisition.

Each of the three classrooms investigated had one wall exposed to the outdoor environment and all three were occupied by a variable number of pupils during the experiments (25 to 30), according to the timetable that included 10-min breaks for every 50 min of teaching courses. During these breaks, most pupils got out the classes and the professors opened the windows for natural ventilation (airing).

Under these conditions, the indoor CO_2 concentration profiles are dependent on the classroom's ventilation mode (sealed facades with windows closed during teaching hours and windows opened during breaks).

According to standard I5/2010 [22], the IAQ category could be evaluated by the difference ΔC_{CO2} between the indoor CO_2 concentration (CO_2_VI) and the outdoor CO_2 concentration (CO_2_VO):

$$\Delta C_{CO2} = CO_2\_VI - CO_2\_VO \text{ (ppm)} \qquad (6)$$

Table 1 shows the connection between the four IAQ classrooms and the values of ΔC_{CO2}.

From equation (6) and table 1 it could be stated that the IAQ class is directly dependent on the variable ΔC_{CO2} and, consequently, this variable should be called, from now on, the *IAQ* parameter.

IAQ class name	Description	ΔC_{CO2} (ppm)	By default
IDA 1	High-level IAQ	< 400	350
IDA 2	Middle-level IAQ	400-600	500
IDA 3	Moderate-level IAQ	600-1000	800
IDA 4	Weak-level IAQ	>1000	1200

Table 1
CLASSES OF IAQ ACCORDING TO I5/2010 STANDARD [22]

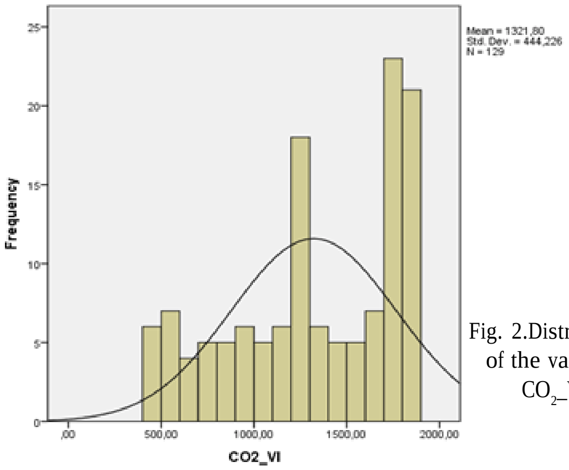

Fig. 2.Distribution of the variable CO_2_VI

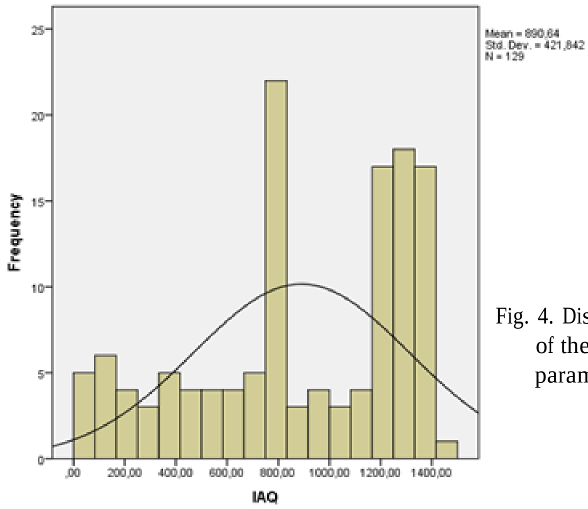

Fig. 4. Distribution of the IAQ parameter

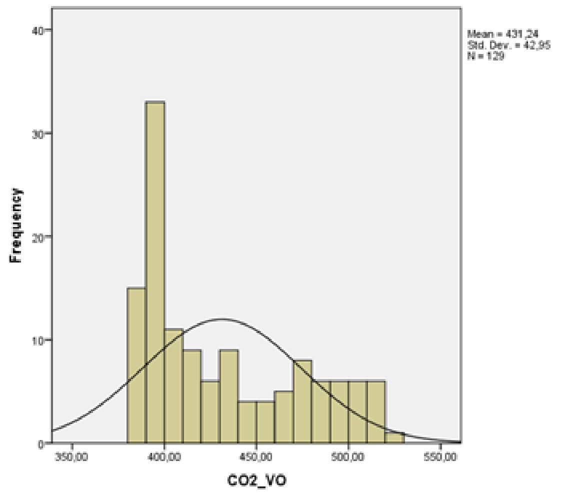

Fig.3. Distribution of the variable CO_2_VO

Table 2

CORRELATIONS OBTAINED BY APPLYING LOGISTIC REGRESSION ANALYSIS

		IAQ	CO_2_VI	CO_2_VO
IAQ	Pearson Correlation	1	0.996**	0.484**
	Sig. (2-tailed)	0.000	0.000	0.000
CO2_VI	Pearson Correlation	0.996**	1	0.156
	Sig. (2-tailed)	0.000		0.210
CO2_VO	Pearson Correlation	0.484**	0.156	1
	Sig. (2-tailed)	0.000	0.210	
**. Correlation is significant at the 0.01 level (2-tailed).				

Results and discussions

The purpose of this study is to develop a mathematical model that gives a prediction of Air Quality in Schools, namely, to find if it complies or not with the standards required by law.

The model is created from real data, collected from High school Neculce regarding the temperature, the humidity, the CO_2 values inside and CO_2 values outside, as well as the Indoor Air Quality (IAQ) parameter.

In view of logarithmic regression use, a preliminary analysis of the dependent variable and predictors is required, in order to test if: this variable doesn't follow a normal distribution, the Hessian matrix doesn't have singularities and there is no co-linearity between predictors (the presence of a correlation between predictors has a negative impact on the prediction itself). Because the indoor temperature and the indoor CO_2 concentration are strongly correlated (Pearson Correlation=0.853), we have excluded the temperature from the model. In addition, if we consider the indoor humidity as model predictor, unexpected singularities in the Hessian matrix are encountered.

Using the data mentioned above the following parameters where taken into account: CO_2 values inside - *CO_2_VI*, CO_2 values outside - *CO_2_VO* and Indoor Air Quality – *IAQ*.

The data were processed using the IBM-SPSS (Statistical Package for the Social Sciences)-Trial version 20.0.0 (www.spss.ie/software/index.html) [23]. In order to determine which mathematical tools we could apply we first studied the repartition of these parameters, represented in figures 2-4, to check whether or not the variables are normally distributed.

Since the variables are not normally distributed, we propose the use of logistic regression. The logistic regression model focuses on the relation between a set of independent variables and a dependent variable (in this case, the indoor air quality *IAQ*). In this study were considered the independent variables *CO_2_VI* and *CO_2_VO* and the dependent variable *IAQ* (multiple regressions). Table 2 presents the correlations between variables. It shows that the correlation (0.996) between *CO_2_VI* and *IAQ* is greater than correlation (0.477) between *CO_{22}_VO* and *IAQ* which means that the CO_2 values inside have a higher influence on the quality of air inside than the CO_{22} values outside.

By using equations (3) – (5) the coefficients presented in table 3 were obtained, thereby giving the following logistic regression equation:

$$\ln(ODDS\_quality) = 21.395 - 2.902 * (CO_2\_VI) + 8.492 * (CO_2\_VO) \quad (7)$$

where *ODDS_quality* represents the ratio between the quality of the compliant air and the non-compliant air.

Thus, if the CO_2 values inside, and CO_2 values outside respectively are known, P(%) it can be presumed that the air

Table 3

VARIABLES OF THE LOGISTIC REGRESSION EQUATION

IAQ[a]	B	Std. Error	Wald	df	Sig.
Intercept	21.395	1.998	0.000	1	0.094
CO2_VI	-2.902	1.915	2.296	1	0.030
CO2_VO	8.492	3.760	5.102	1	0.024

Table 4
EXAMPLES WITH THE DATA FROM HIGH SCHOOL NECULCE, DAY 1

CO_2_VI	CO_2_VO	*ln(ODDS_quality)*	P [%]
592	398	1681	94
940	392	619	83
1232	467	409	74

inside schools will comply with its quality standards (IAQ<1000ppm) (table 4). This model offered good results with reference to the compliant indoor air quality case (correct in proportion of 94%), as well as in the non-compliant air quality case (91%).

Table 5
PSEUDO R^2 COEFFICIENT

Cox and Snell	1.000
Nagelkerke	1.000
McFadden	0.941

Table 6
VALIDATION OF THE MODEL USING DATA FROM BUCHAREST CITY

School	CO_2_VI	CO_2_VO	P computed [%]	P measured [%]
School 179	664	348	99	98
	1448	523	61	59
	2325	498	38	36
High school "Iorga"	869	421	90	92
	942	435	89	86
	1132	423	69	72
High school "Neculce", day 2	594	412	99	99
	832	424	94	94
	1103	497	90	90

P - The probability of air quality inside the school to comply with the standards required by law

The Cox and Snell coefficient pseudo R^2 was approaching 1, as shown in table 5, thereby indicating a very good correlation between the model and the actual data.

The values obtained indicate a very good prediction. The performance of the proposed method can therefore be verified for three schools in Bucharest city, as illustrated in table 6.

Conclusions

Due to the fact that the purpose of this paper was to assess the IAQ, we focused on the measured values of temperature, humidity and CO_2 concentrations. In order, to evaluate the Air Quality in Schools we applied the Multiple Logistic Regression method, from which we can conclude that the model which contains the variables CO_2_VI, CO_2_VO, IAQ explains its progress. The correlations between variables are presented in table 2 and it can be noted that the CO_2 value indoors is the most important factor affecting the IAQ evaluation.

The developed model is original and can also be applied to other schools, since it has been tested with good results for the three schools mentioned above.

By using the calculation algorithm described above, a prediction model for Air Quality in Schools in Bucharest could also be developed for other cities for which we have the necessary input data.

Mathematical models which have the capacity to accurately describe the correlations between CO_2 values inside, CO_2 values outside and inside air quality are excellent instruments for analysis and interpretation of experimental data as well.

Further experimental work, that paper authors intend to start during the spring of 2015, would investigate the IAQ level related to other pollutants specific to the learning environment, such as particulate matters (PM) and ozone (O_3).

Acknowledgement: This work was supported by a grant of the Romanian National Authority for Scientific Research, CNCS, UEFISCDI, project number PN-II-PT-PCCA-2013-4-0569.

References

1. MIRCEA, I., FALUP, O., IVAN, R., IONEL, I.,Rev. Chim. (Bucharest), **66**, no. 2, 2015, p. 247.
2. National Law nr. 104/2011, for the air quality.
3. NENCIU, F., VAIREANU, D.I., Rev. Chim.. (Bucharest), **65**, no. 5, 2014, p. 565.
4. DAISEY, J. M., ANGELL, W. J., APTE, M. G., Indoor Air, 13, nr. 1, 2003, p. 53.
5. VAN DIJKEN, F.; VAN BRONSWIJK, J E M H.; SUNDELL, J., Building Research & Information, 34, nr. 5, 2006, p. 437.
6. TRAUMANN, A., TINT, P., TUULIK, V., Environmental Engineering and Management Journal, 11**,** nr. 1, 2012 p. 207.
7. BIANCHI, A., CATERINA, G., ATTAIANESE, E., Cefalee e rendimento scolastico. Valutazione del rischio e strategie di prevenzione (Cephalgies and school performance. Risk assessment and prevention strategies). Ed. Luguori (in Italian), Napoli, 2003.
8. MENDELL, M. J., HEATH, G. A., Indoor Air, 15, nr. 1, 2005 p.27.
9. BAKO-BIRO, Ventilation rates in schools and pupil's performance using computerized assessment tests, Proc. of the 11th international conference on indoor air quality and climate-Indoor Air, Copenhagen, 2008, p. 368-372.
10. DE GIDS, The effect of ventilation on the cognitive performance of pupils at a primary school, TNO Delft, the Netherlands, 2006.
11. SHAUGHNESSY, R J., HAVERINEN-SHAUGHNESSY, U., NEVALAINEN, A., MOSCHANDREAS, D., Indoor Air, 16, nr. 6, 2006, p. 465.
12. WARGOCKI, P., WYON, D., Proc. of Indoor Air conference, Beijing, China 2005, p. 368.
13. D'AMBROSIO ALFANO, F. R., BELLIA, L., REHVA Guidebook, **13**, Federation of European Heating, Ventilation and Air-conditioning Associations, 2010.
14. GIUSCA, R., COROBCEANU, V., GIUSCA, R., Environmental Engineering and Management Journal, 8, nr. 6, 2009, p. 1495.
15. FRANCIS, D., International Journal of Cardiology, 69, nr. 2, 1999, p. 185.
16. RODGERS, J.L., NICEWANDER, W.A., The American Statistician, 42, nr. 1, 1988, p. 59.
17. CARBUTT, C., Bothalia, 42, nr. 2, 2012, p. 71.
18. GAVRILA, C., SANDU, A. E., BURCHIU, E., IRECHE Journal, 5, nr. 4, p. 305.
19. TEODORESCU, N., GAVRILA, C., Statistical Data Analysis in Prostate Cancer, Proc. 10th Balkan Conference on Operational Research, Thessaloniki, **1**, 2011, p. 123.
20. CHAP, T. L.E., HOBOKEN, N.J., Introductory Biostatistics, John Wiley, New York, 2003.
21. BEWICK, V., CHEEK, L., BALL, J., Correlation and regression, Crit. Care, **7**, 2003, p. 451–459.
22. COLDA, I., Romanian regulation for ventilation and air-conditioning design, Ed. Fast Print IPCT, Bucharest, 2011.
23. IBM-SPSS (Statistical Package for the Social Sciences)-Trial version 20.0.0 (www.spss.ie/software/index.html)

Manuscript received: 31.03.2015