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Prediction of Indoor Air Quality in a School Building Using Risk Model

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PREDICTION OF INDOOR AIR QUALITY IN A SCHOOL BUILDING USING RISK MODEL

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Abstract: *In recent past many studies demonstrated that outdoor air pollutant concentrations are having significant impact on indoor air quality of the naturally ventilated buildings. In this study an attempt has been made to demonstrate the impact of outdoor vehicular pollutant concentrations on indoor air quality of the naturally ventilated building- Kendriya Vidyalaya School located at CLRI campus. The indoor CO and PM concentrations have been monitored using IAQ monitor and GRIM dust monitor respectively. The measured CO and PM_{10} concentrations in the class room ranged between 0 to 0.54ppm and 71.6 to 175.4 µg/m^3, respectively.*
The RISK model developed by US EPA (Sparks, 2002) has also been used to predict indoor air quality of the school room using outdoor pollutant concentrations and building ventilation characteristics as input to the model. The CALINE4 model (Dana et al., 1998) has been used to predict the outdoor CO and PM concentrations resulting from vehicular sources. The results showed that the indoor CO and PM_{10} concentrations are increased with the increase in traffic flow on the adjacent SP road.

Keywords: *Indoor air quality; RISK; school; carbon monoxide; particulate matter.*

INTRODUCTION

The quality of indoor environment reflects on the health, comfort and productivity of individuals in the buildings. The World Health Organization (WHO) have estimated that as many as 30% of new buildings in the developed world may have problems leading to occupant complaints and illness which can lead to loss of productivity and even absence from work. The combined effect on productivity, absence from work and staff turnover is likely to have a considerable economic impact. The main reason for lack of awareness of the indoor air quality (IAQ) problems is due to the fact that the effects of indoor air pollution are mostly chronic and not directly and immediately life threatening. However, exposing to toxic

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pollutants such as volatile organic compounds (VOCs) can cause respiratory diseases and cancer. In recent past many studies have demonstrated that outdoor air pollutants are having significant impact on indoor air quality of the naturally ventilated buildings. Several studies indicated that indoor air pollutant concentrations are often higher than that of outdoor concentrations (Sung et al, 1997, Chaloulakou and Mavroidis, 2001). Recently, WHO has assessed the contribution of a range of risk factors to the burden of disease. It revealed that indoor air pollution as the eighth most important risk factor and responsible for 2.7% of the global burden of disease. It also states that 2.4 million people die each year from diseases directly attributable to air pollution; with 1.5 million of these deaths attributable to indoor air pollution. Comparative risk studies performed by the United States Environmental Protection Agency (USEPA) ranked IAQ have one of the top five environmental risks to public health. In developing countries, indoor smoke is responsible for an estimated 3.7% of the overall disease burden. In India, it is estimated that about half a million women and children die per year due to indoor air pollution (Smith, 2000).

In general, indoor air pollutants concentrations depend on number of factors such as type of sources and emission rates, air exchange rate, the penetration of outdoor pollutants in to the indoor environment and the pollutant sink or removal rate. Indoor to outdoor ratios (I/O) would help to identify the sources of indoor air pollution and hence to develop effective methods to reduce the health risks associated with indoor air pollution. I/O ratio>1 implies the major sources of pollutants are indoor and I/O<1 means the predominance of outdoor sources.

Indoor air quality assessment in school buildings

Air quality at classrooms is of special concern since children are susceptible to poor air quality, and indoor air problems can be subtle and do not always produce easily recognizable impacts on health and wellbeing. Failure to prevent indoor air pollution can increase the chance of long-term and short-term health problems for students and staff; reduce in productivity of teachers; and degrade the student learning environment and comfort. Norback et al., (1990) were studied the relationship between VOCs, respirable dust, and personal factors to prevalence and incidence of sick building syndrome (SBS) in six primary schools. This study showed that the average CO_2 concentrations in all study sites were greater than 800ppm and indicated inadequate ventilation. Gusten and Strindehag (1995) were demonstrated that outdoor pollutant sources play a major role in affecting the IAQ of the school building. The other important factors influencing the school building IAQ is the extent of human activities (number of students, length of lessons, breaks) and the surrounding environment. Lee and Chang (2000) choose five classrooms in Hong Kong, air-conditioned or ceiling fans ventilated, for investigation of indoor and outdoor air quality. Parameters such as temperature, relative humidity (RH), CO_2, sulphur dioxide (SO_2), nitric oxide (NO), nitrogen dioxide (NO_2), respirable particulate matter (PM_{10}), formaldehyde (HCHO), and total bacteria counts were monitored at indoors and outdoors simultaneously. The average respirable particulate matter concentrations were higher than the Hong Kong standard, and the maximum indoor PM_{10} level exceeded 1000 $\mu g/m^3$. Indoor CO_2 concentrations often exceeded 1000 ppm in air-conditioning and ceiling fan classrooms, indicating inadequate ventilation. Chaloulakou and Mavroidis (2002) were carried out a field study to investigate the internal and external CO concentration levels of a public school building in Athens, Greece.

Indoor air quality models

Indoor air quality models (IAQM) are being widely used for the predicting indoor air pollution levels, taking into account the type of microenvironment and its configuration. Numerous IAQ models have been developed over the last twenty years with various degrees of complexity and applicability ranges from simple regression models to more demanding computational fluid dynamic techniques. In 1991, Hayes developed an IAQ model to evaluate ozone measurements from ten different microenvironments and 56 different population sub groups. The model results were in good agreement with the indoor ozone concentration measurements. The ratio between measured and predicted daily maximum indoor concentration ranges between 0.88 and 1.23. Marr et al., (1998) applied a simplified model to predict CO concentrations within a residential building room and a garage. The model results were used as input to a model predicting COHb levels in human blood. Bouhambra et al., (2000) performed measurements to determine indoor benzene levels in 26 residential houses in Kuwait, and found that time-averaged indoor concentrations varied linearly with outdoor concentrations, in accordance with a mass-balance based IAQ model. Dimitroulopouloua and Ashmoreb (2006) were developed a probabilistic model (INDAIR) to predict air pollutant concentration in home environments in the UK. The modeled frequency distributions of 24 h mean values showed 95 percentile concentrations that were typically twice the mean concentrations in no-source scenarios, and 3–4 times the mean concentration during emission peaks.

RISK model description

RISK (Sparks, 2002) is a multi-room model based on an earlier models, INDOOR and EXPOSURE developed by the Indoor Environment Management Branch of U.S. EPA's National Risk Management Research Laboratory to allow calculation of individual exposure to indoor air pollutants generated from various sources inside the building. The model runs in the MS-Windows operating environment and is calculated using a risk calculation framework developed by Naugle and Pierson (1991). The model provides a wide range of graphical and tabular output of the results of the calculations which includes summary of risk and exposure concentrations that are provided in tabular form. The tabular output is also supplemented by graphs of concentration and exposure versus time.

In case of school building located close to highways, vehicular emissions are the main source of indoor air pollution. In the past, few monitoring studies have been carried out to understand indoor-outdoor relationship of airborne pollutants at public and school buildings. Further, mathematical models have also been used in many studies to understand the temporal and spatial distribution of the indoor air pollutants in mechanically and naturally ventilated buildings. However, in India limited studies have been made to develop indoor-outdoor relationships. In the present work, an attempt has been made to understand the indoor-outdoor relationship of particulate matter and carbon monoxide concentrations in a naturally ventilated school building.

METHODOLOGY

Study area:
Figure.1 describes the study region. For the present study a naturally ventilated room in Kendriya Vidyalaya school building located at Central Leather Research Institute (CLRI),

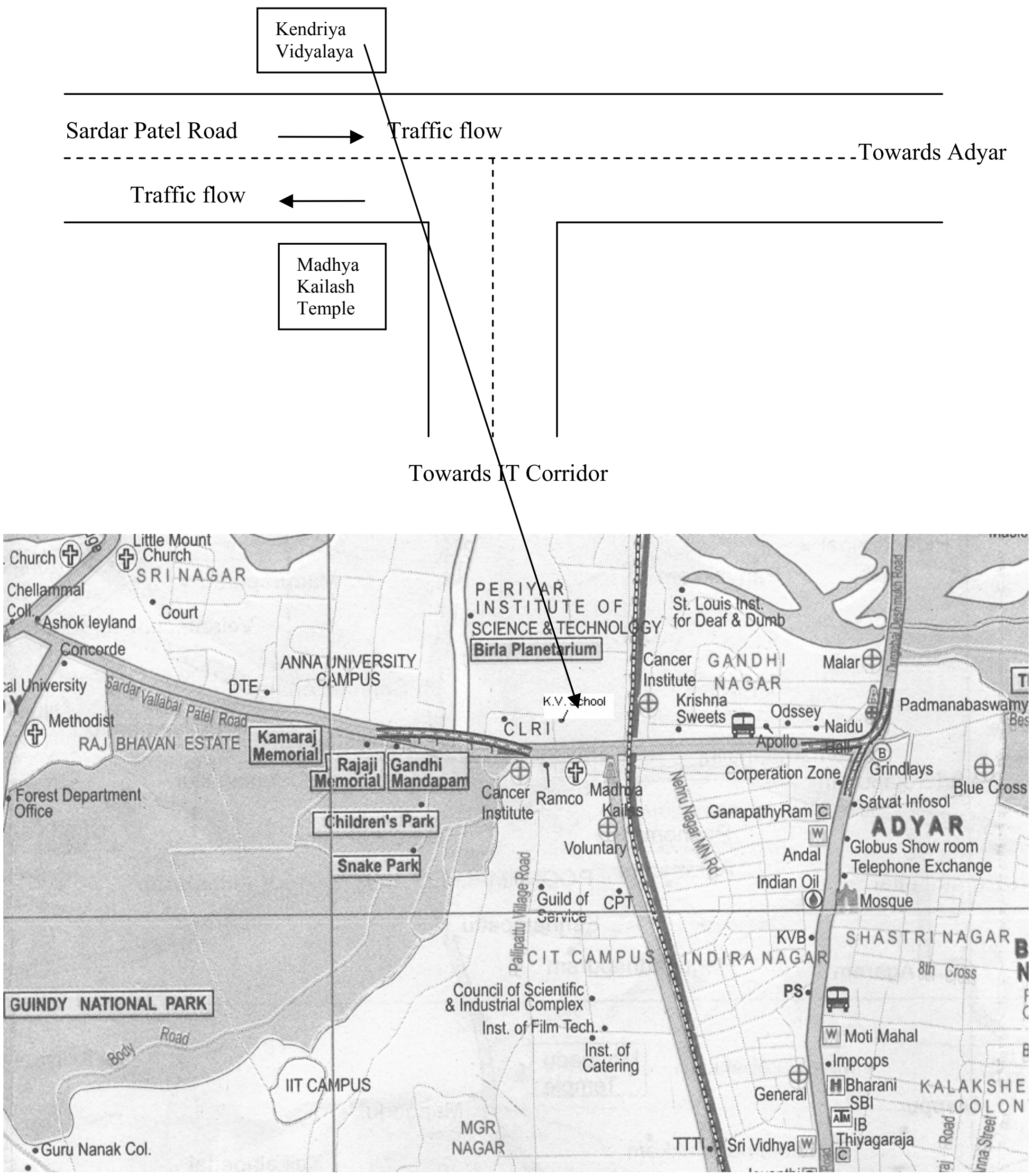

Fig. 1. Location of Kendriya Vidyalya School Building.

Chennai has been selected. This room is adjacent to an urban road (Sardar Patel road) having heavy traffic flow. The study site is located within a 100m from Madhya Khailash traffic junction. The School has strength of nearly 1000 students and offers education from pre-school to 12th class in two different buildings. The study room is in the primary block (from 5th to 12th class) located in the first floor of the building which has two windows facing towards the road, three other windows always closed. The entry to the room is through single door having dimension of 2.1 x 1.2 m. The size of the room is 7x 6.5x 3 m.

The PM and CO concentrations have been monitored inside the school room for two days. IAQ was monitored at the study site using Gas Probe instrument. The GasProbe IAQ simultaneously and continuously monitors four parameters namely carbon monoxide (CO), carbon dioxide (CO_2), relative humidity (RH), and temperature (T). Instantaneous readings are displayed on an alphanumeric LCD. The IAQ measurements have been made at the site on two days, i.e., 10th and 11th June 2008 for an duration of 8 hours each day (the duration for which the school remains open during a day) using the GasProbe instrument. The concentrations of PM_{10}, $PM_{2.5}$ and PM_1 have been monitored at the school building using the Environmental Dust Monitor (GRIMM environmental dust monitor 107). Grimm dust monitors are small portable instruments designed to provide continuous number and mass size distributions of particulate matter suspended in the ambient air. The Grimm dust monitor samples air at 1.2 lit/min into a light scattering optical particle counter, with a lower cut-off at 0.25 µm. The sampling inlet is placed at 1.5 m above the floor level. The PTFE-Teflon Filter, 47 mm diameter, 0.2 micron size is being used for PM sampling. The instrument records the concentrations every minute for 24 hours.

Outdoor concentrations at school were predicted by using CALINE 4 software for the same indoor monitoring period. CALINE4 is a simple line source model developed using Gaussian plume dispersion equation. The user defines the proposed roadway geometry, worst-case meteorological parameters, anticipated traffic volumes, and receptor positions. The user must also define CO and PM_{10} emission factors for each roadway link. The traffic flow data collected at SP road has been used for estimating CO and PM_{10} source emission rates. The output given by the model is: predicted concentrations at the receptor depending on the meteorological data i.e., wind direction, wind speed and temperature. The important meteorological parameters have been obtained from Indian meteorological department. The CALINE4 model predicted outdoor concentrations were then used as input to the RISK model along with building dimensions and air exchange rate for naturally ventilated building as per ASHRAE guidelines (7.5ACH) to calculate indoor concentrations.

RESULTS AND DISCUSSIONS

Figure 2 presents the variation of measured carbon monoxide concentrations in the classroom. The CO concentration in the class room was in the range of 0 to 0.54 ppm. Two CO peaks were observed in the class room corresponding to the morning and the evening peak traffic flows. These values of CO are not exceeding the threshold value recommended by WHO (9 ppm for eight hours).

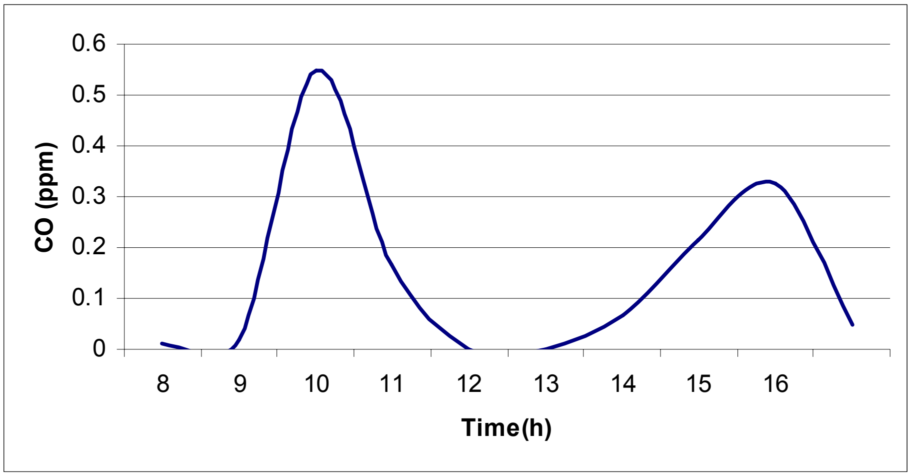

Fig. 2. CO concentrations inside school building

The Figure 3 shows measured PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ concentrations in the school room. The maximum PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ concentrations at the site were 175.4µg/m^3, 54.55µg/m^3, and 30.71µg/m^3, respectively, while the minimum concentration values at this site for respective sizes were 71.6µg/m^3, 28.2µg/m^3, and 15.4µg/m^3. The indoor PM concentrations were also following a similar trend as that of CO concentrations. Two peaks were observed in the indoor PM concentrations corresponding to the peak traffic flow. The 1 hour average PM_{10} concentrations are higher than the 24 hour average national ambient air quality standards (NAAQS) (100 µg/m^3) during peak hours and during lean traffic flow, it is close to 100 µg/m^3. The hourly average $PM_{2.5}$ concentrations are well below the NAAQS.

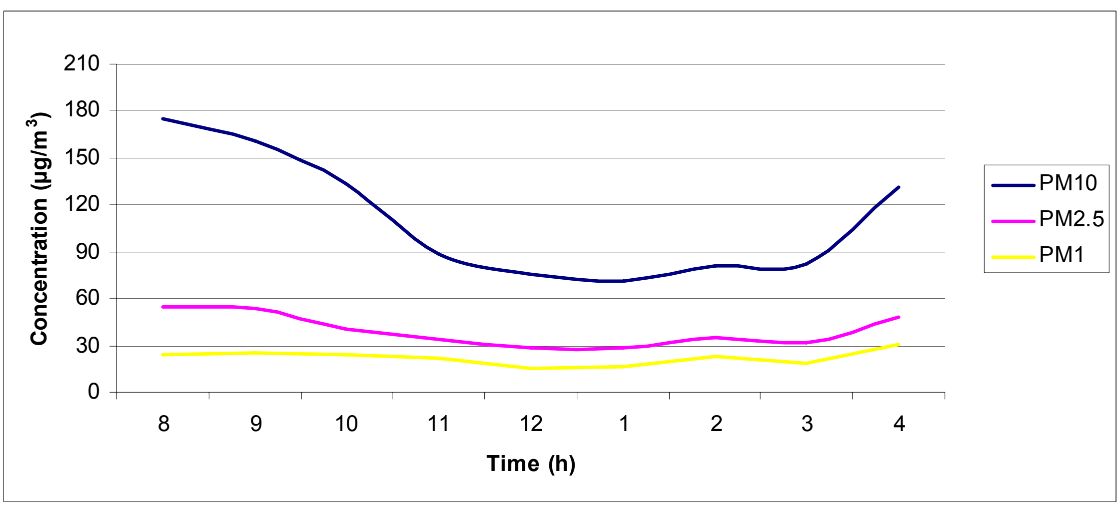

Fig. 3. Particulate matter concentrations inside school building

The outdoor CO concentrations predicted by CALINE4 and indoor CO concentrations predicted by the RISK model were presented along with the measured indoor CO concentration in Figure 4. The maximum predicted value at out side the school room is 2.4ppm, while CO value predicted by RISK model inside the school room is 2.1ppm. The measured CO value inside school building was lower than the predicted value. Hence, the RISK model was over predicting the CO concentration inside the classroom.

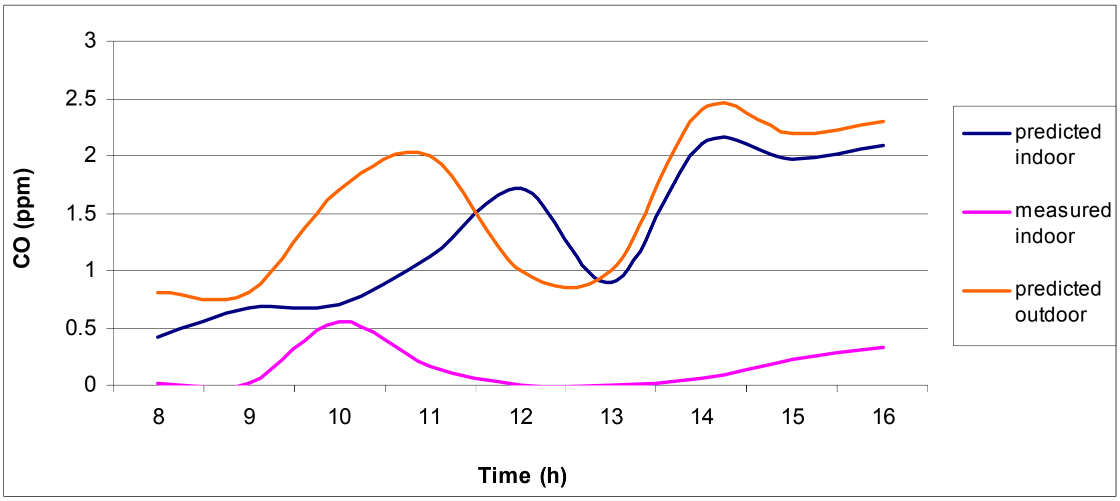

Fig. 4. CO concentrations in school building room

The indoor PM concentrations predicted RISK model along with the measured indoor PM concentrations are presented in Figure 5. Two peaks were observed in indoor concentrations

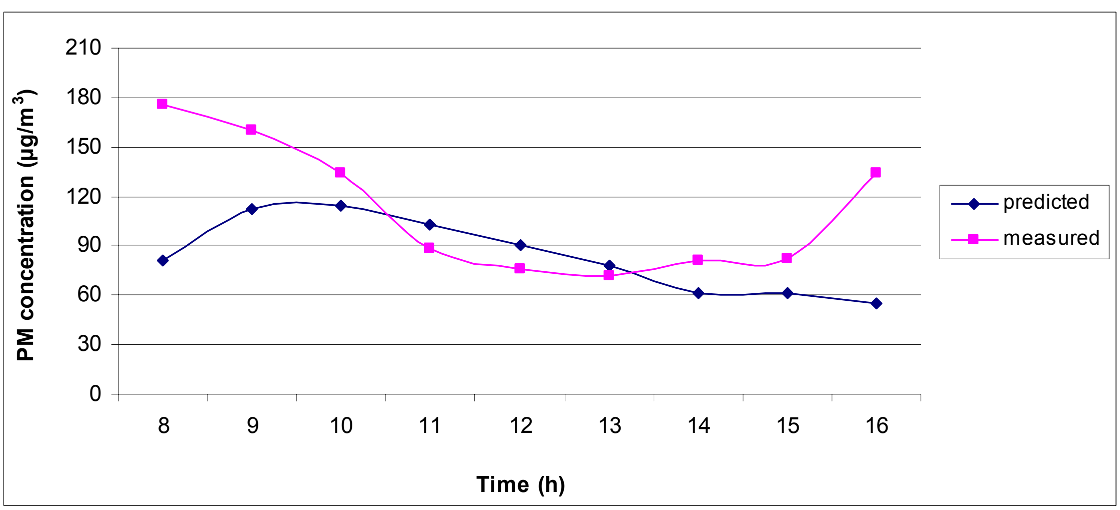

Fig. 5. Comparison of measured and predicted PM concentrations in school building

corresponding to the peak traffic flow. Further, it was observed that the measured indoor peak concentrations were higher than the predicted PM concentrations. This may be due to under prediction of outdoor PM_{10} concentrations by the CALINE 4 model.

The performance of RISK model was evaluated using statistical indicators such as mean, standard deviation, mean bias error and degree of agreement. Table 1 summarizes the performance statistics of RISK model. The mean value of the predicted PM concentration (83.97µg/m^3) was lower than the observed mean (111.08µg/m^3). Where as the predicted CO mean value (1.29ppm) was higher than observed value (0.15ppm). It indicates that the RISK model was under predicting PM concentration and over predicting the CO concentration inside the classroom. The mean bias error values also indicate under prediction of PM concentration and over prediction of CO concentration. The standard deviation of the PM predictions was lower than the observed ones, where as the standard deviation of CO prediction was higher than the observed ones. This explains that the RISK model was able to reproduce the CO and PM variations in the class room with reasonable accuracy. The da value explains that the PM predictions made by the RISK model are 65% error free, while for CO predictions it is 15%.

Table 1. Performance statistics of RISK model.

Pollutant	$\overline{O}$	$\overline{P}$	σo	σp	MBE	da
PM (µg/m^3)	111.08	83.97	38.62	21.12	-27.11	0.65
CO (ppm)	0.15	1.29	0.18	0.63	1.14	0.15

CONCLUSIONS

In the present study the indoor-outdoor pollution relationship in a naturally ventilated class room has been studied. The particulate matter (PM) and carbon monoxide (CO) concentrations have been measured for two days in Kendriya Vidyalaya school building located at CLRI campus. The measured CO and PM_{10} concentrations in the class room have been varied between 0 to 0.54 ppm and 71.6 to175.4 µg/m^3, respectively. Two CO and PM peaks have been observed in the class room corresponding to the morning and the evening peak traffic flows.

The EPA- RISK model has been used to predict indoor CO and PM concentrations using the outdoor CO and PM concentrations predicted by CALINE4 model. The study reveals that the indoor PM and CO concentrations are dependent on outdoor vehicular pollutant concentrations. This study also demonstrates that the ambient air pollutants can have significant impact on indoor air quality of the naturally ventilated buildings located close to urban roadway.

REFERENCES

Bouhambra, W.S., Elkilani, A.S. and Abdul-Raheem, M.Y. 2000. Analysis of indoor concentrations of benzene using an airquality model. *Archives of Environmental Health* 55 (3), 201–209.

Dana L. Coe, Douglas S. Eisinger, Jeffrey D. Prouty and Tom Kear. 1998. User's Guide For Cl4: A User-Friendly Interface For The Caline 4 Model for Transportation Project Impact Assessments User's Guide.

Dimitroulopoulou, C., Ashmor, M.R., Hill, M.T.R., Byrne, M.A., and Kinnersley, R., 2006. "INDAIR: A probabilistic model of indoor air pollution in UK homes", *Atmospheric Environment*, 40, 6362–6379.

Chaloulakou, A. and Mavroidis, I. 2001, Comparison of indoor and outdoor concentrations of CO at a public school. Evaluation of an indoor air quality model, *Atmospheric Environment* 36 (2002) 1769–1781.

Gusten, J. and Strindehag O. 1995. Experiences of measures taken to improve the air quality in schools. *Air Infiltration Review*, 16 (3), 5-8.

Hayes, S.R. 1991. Use of an Indoor Air Quality Model (IAQM) to Estimate Indoor Ozone Levels. *Journal of Air and Waste Management Association*. 41:161-170.

Lee, S.C. and Chang M. 2000. Indoor and outdoor air quality investigation at schools in Hong Kong, *Chemosphere* 41, 109-113.

Marr, L.C., Morrison, G.C., Nazaroff, W.W., and Harley R.A.,1998. Reducing the risk of accidental death due to vehicle related carbon monoxide poisoning. *Journal of the Air and Waste Management Association* 48, 899.

Norback D., Torgen M. and Edling, C. 1990. Volatile organic compounds, respirable dust and personal factors related to prevalence and incidence of sick building syndrome in primary schools, *British Journal of Industrial Medicine* , 47, 733-741.

Sparks L.E. 2002, Indoor air quality model for windows-risk (version 1.5) *user manual*.

Smith, K.R. 2000. "Inaugural Article: National burden of disease in India from indoor air pollution", *Proceedings of the National Academy of Sciences*, 97, 13286-13293.

Sung-Ok Baek Yoon-Shin Kim and Roger Perry 1997. Indoor air quality in homes, offices and restaurants in Korean urban areas—indoor/outdoor relationships, *Atmospheric Environment*, 31, 4, 529-544.

World Health Report 2002.