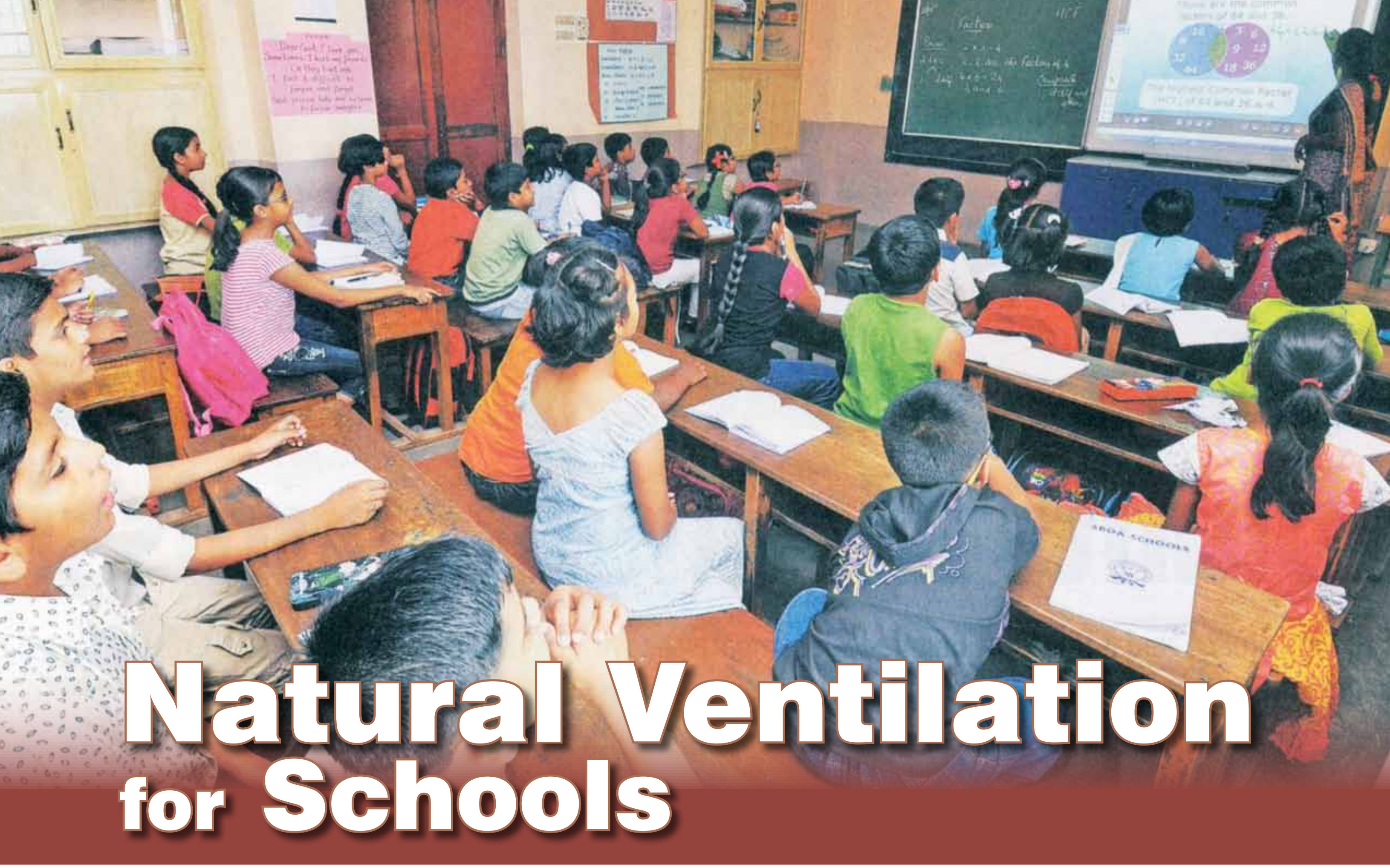

Natural Ventilation for Schools

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Abstract

The problem of indoor air quality (IAQ) in schools is usually associated with high occupancy levels and poorly designed, maintained or operated air-conditioning and mechanical ventilation (ACMV) systems or uncontrolled naturally ventilated systems. Schools in Indian cities are mostly naturally ventilated and are located near road sides. Therefore, outdoor air pollution levels may have significant influence on indoor pollution levels subject to meteorological conditions and location and design of openings in schools. To understand the problems of IAQ in schools, an audit can be adopted to establish the IAQ profile vis-a-vis the requirements so that remedial measures can be taken to solve the IAQ problems and for IAQ management.

Introduction

Schools provide a major indoor environment for children apart from their homes as they spend 6-8 hours per day and at least 1100 hours per year in a school *(Leickly, 2003)*. IAQ in a school, therefore, can have a substantial impact on the health of children. The American Academy of Pediatrics has identified children as the more sensitive group of population towards exposure to any pollutant, and having lower immunity towards them *(AAP, 2003)*. A growing body of evidence proves the consequences to children's health from lead, mercury, environmental tobacco smoke (ETS), and pesticides. These hazards and more may be part of their daily indoor air environment. Recognizing the large number of hours spent indoors, children are considered at risk from poor IAQ.

IAQ studies on schools show that more than 50% of school going children have some kind of allergy, like asthma. The most predominant causes identified are insufficient ventilation, high occupancy levels and poor cleaning and maintenance practices (*Tippayawong et al., 2009; Goyal and Khare, 2009*). Besides, occupancy density is high (1.8–2.4m^2/person) in school classrooms compared to offices (10m^2/person). The higher occupancy level results in very large values of internal heat sources (approximately 5 kW) and larger internal emissions of body odors, water vapor and CO_2 levels (*Besler and Besler,*

About the Authors

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2000; Ellis, 2003). Higher occupancy also increases proximity among occupants and may help airborne and contagious viruses to spread.

Due to higher level of occupancy, ventilation problems are most commonly observed in school and institutional buildings (*Brennan, 1991; Turk, 1993*). Insufficient ventilation conditions in schools aggravate the results of high occupancy. As a result, youngsters are exposed to extreme environmental conditions in terms of high pollutant concentration levels and adverse thermal comfort parameters for prolonged time, and develop symptoms of allergy and asthma. Other important factors that influence air quality in schools are the intensity of occupant activities in the school premises and the building design (e.g. window openings and door-ways).

Sufficient evidence is available from past studies suggesting the association between ventilation rates, IAQ, sick building syndrome symptoms and student performance (*Mendell and Heath, 2005*). High ventilation rates are required at spaces of high occupant density in order to provide adequate IAQ. In case of mechanically ventilated or centrally air conditioned (HVAC) school buildings, it may cause significant energy losses. Therefore, it is indeed required to develop a performance-based energy code and ventilation code for schools to establish deemed- to-satisfy solutions.

The Chartered Institution of Building Services Engineers, UK recommends a minimum fresh air supply rate of 8 l/s per person for non-smoking adults in offices and the same value for occupants in schools. The American Society of Heating, Refrigerating and Air-conditioning Engineers recommends fresh air supply rates of 10 l/s per person and 8 l/s per person for general office accommodation and school classrooms, respectively.

In developing countries like India, most of the school buildings are naturally ventilated, where outdoor air infiltration shows a significant impact on IAQ, which makes it essential to study the IAQ in a naturally ventilated school building. The frequency of health symptoms among students in *air-conditioned classrooms was higher* than those in naturally ventilated classrooms *(Koo et al., 1997)*. In warm and moderate climates, the large internal heat sources usually found in school buildings prevent achieving thermal comfort without active cooling in summer, but are not sufficient to eliminate the need for heating in winter. Commonly used air conditioners do not improve IAQ, whereas natural ventilation induces uncontrolled energy losses.

When pollutant concentration in school air increases, the health of children is jeopardized and frequent complaints are made by staff and children. Such school buildings are labeled as "sick school buildings" and health complaints of occupants in such buildings are known as "sick building syndrome (SBS)". A number of factors as mentioned previously in this article may contribute to increase in indoor air pollutant concentration in schools. Among all, ventilation systems may largely be responsible for SBS (*Morey and Shattuck, 1989*).

The assessment of the status of IAQ in schools and institutional buildings is important as occupants spend varying periods of time in such premises. The importance of good IAQ in schools is strongly promoted by the US Environmental Protection Agency (USEPA), as results of their studies show 2-5 times higher pollution levels inside school premises as compared to outside, which can have serious consequences on the students' learning environment, comfort, attendance, short and long term health problems and productivity due to discomfort (*ISIAQ, 2000*).

Therefore, there is a need for IAQ management programs for schools. IAQ audit system can be adopted in schools to identify the problems, their causes and effects on occupants and to establish complete IAQ profile of the school building so that the remedial measures can be taken. IAQ investigation in buildings is a cycle of information collection, hypothesis formation and hypothesis testing. The goal of the investigation is to understand the IAQ problem well enough to solve it. Notably, many IAQ problems have more than one cause and may respond to or require several engineering corrective action designs. Accordingly, remedial measures can be taken to solve the identified IAQ problems.

This article presents the case study of a naturally ventilated school building in a metro city near a heavy traffic urban road, and the details of IAQ audit methodology and its application in schools and institutional building types. The results may provide more comprehensive and useful information to building owners and facility managers for better management of the air quality in buildings.

IAQ in Naturally Ventilated school near urban roadway – a case study

A study of indoor–outdoor Respirable Suspended Particulate Matter (RSPM) of PM^*_{10}, $PM_{2.5}$ and $PM_{1.0}$ size, oxides of sulfur (SOx), nitrogen dioxide (NO_2), carbon monoxide (CO) and carbon dioxide (CO_2) concentration monitoring along with meteorological parameters, including temperature, relative humidity (RH), pressure, wind speed and direction, ventilation and traffic parameters including its type and volume, has been carried out in classrooms of a naturally ventilated school building located near an urban roadway in Delhi (*Goyal and Khare, 2009; Goyal and Khare 2010*). *Figures 1* and *2* show the three–storied rectangular naturally ventilated school building with four blocks and a total

Figure 1: Three storied, rectangular, naturally ventilated school building

* PMx is particulate matter of size less than or equal to x micron.

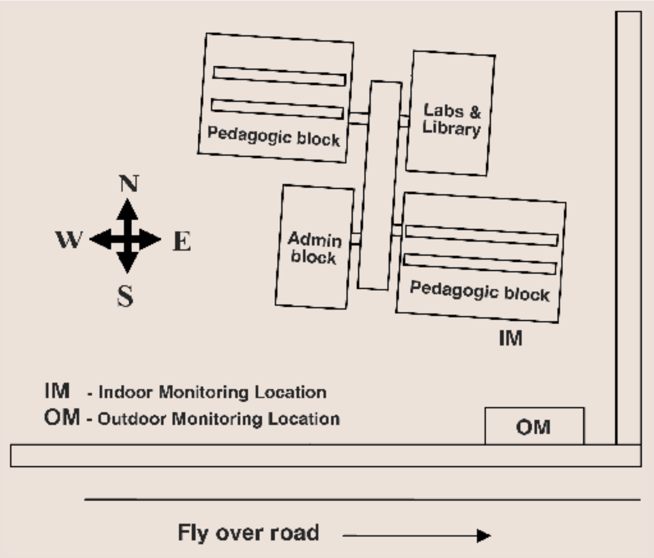

Figure 2: Line diagram of the school building

height of 14 m, located in close proximity to a road with heavy traffic and surrounded by commercial and residential area. The two larger blocks (rectangular in shape) are used for classroom activities (pedagogic blocks), one small block (towards roadside and flyover) is used for administrative activities and the other small block (towards service road) is used for laboratory and library activities. The pedagogic blocks consist of two symmetric rows of classrooms embracing in corridors, which is the most common design all over the world for school buildings.

The results of the study indicate that RSPM concentrations in classroom exceed the permissible limits during all monitoring hours of week days and weekends in all seasons, and may cause potential health hazards to occupants, when exposed. Indoor–outdoor ratio (I/O) for sizes of particulates is higher than 1, which implies that the building envelop does not provide protection from outdoor pollutants. Daily six- hour average concentrations of outdoor PM_{10}. $PM_{2.5}$ and $PM_{1.0}$ during summer week days were found to be 162.4μ/m^3, 37.7μ/m^3 and 27.9 μ/m^3 respectively, with 20 percent reduction during weekends. During winters, the daily six-hour average concentrations of outdoor PM_{10}. $PM_{2.5}$ and $PM_{1.0}$ were 531.1μ/m^3, 244.7 μ/m^3 and 221.7μ/m^3 respectively, with 34 percent reduction during weekends.

The indoor PM_{10} concentrations reduce by 67 percent during weekends in summers, and 46 percent during winters with daily six-hour average concentrations of 410.64μ/m^3 during summers and 1181.54μ/m^3 during winters, which are 10 to 15 times higher than the prescribed standards and limits. The concentration of other pollutants indoor as well as outdoor was within the standards, therefore not considered for discussion in this article. Further, a significant influence of meteorological parameters, ventilation rate and of traffic was observed on I/O ratio of RSPM. It was observed that indoor RSPM concentrations decrease with increase in ventilation rate. The maximum average value of ventilation rate in summers was 102.98 cfm/ person, when all the windows were open and fans were running; whereas, in winters, the minimum mean ventilation rate was 26.9 cfm/ person, when windows were closed and fans were off. Therefore, the indoor concentration of RSPM in winters was 4-5 times higher than in summers. Additionally, the higher I/O for PM_{10} also indicated the presence of its indoor sources in classroom and their indoor concentrations were strongly influenced by activities of occupants during week days. *Figures 3a* and *3b* show a typical classrooms in Indian conditions with and without occupants.

The RSPM concentrations outdoors show decreasing trend from 8:0 a.m. to 2:0 p.m. as the day proceeded and temperature increased. Therefore, the RSPM concentration outdoors showed a reverse trend with increase in temperature of the day, and positive correlation with RH. However, the indoor RSPM concentrations could not show a clear trend with meteorological parameters due to predominance of the effect of intense occupant activities inside the classrooms.

Therefore, the results of this case study and many other studies available in literature indicate that RSPM levels in indoor environment have become a cause of concern, since an association between its exposure and adverse health effects has been

Figure 3a. Typical Indian classroom in a naturally ventilated school (without occupants)

Figure 3b: Typical Indian classroom in a naturally ventilated school (with occupants)

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demonstrated by a number of epidemiological and clinical studies. Its indoor levels are influenced by many parameters as mentioned in the case study. Therefore, there is a need to investigate these parameters and their association with different pollutant types and their levels using a systematic and robust methodology. IAQ audit can add one dimension to IAQ investigations for such school and institutional buildings, where occupancy and ventilation are the key factors for deciding the IAQ.

IAQ Audit

An IAQ audit is a systematic approach, which involves the survey and inspection; identification and measurement of various indicator parameters; evaluation; corrective actions to be taken and finally the recommendations to the building owner/manager for IAQ management. The schematic flow of IAQ audit methodology to be followed in schools is proposed in *Figure 4*.

The proposed methodology may be applicable to all types of buildings, i.e. institutional and schools, office complexes, hotels and resorts, hospitals and health care centers and, of course, residential complexes. However, the parameters of measurement change depending upon the building type, ventilation type, sources of pollutants identified and building usage. The IAQ audit methodology involves various stages of investigation as follows:

The **preliminary stage** involves a walk-through inspection of problem areas to collect the information on four of the basic factors that influence indoor air quality: occupants, ventilation system (natural/ HVAC), contaminant/pollutant pathways, and contaminant/pollutant sources, which help in establishing the hypothesis, which could possibly explain the IAQ problem of the selected school type. A checklist information of the ventilation system operation and hygiene, air intake location, sources of contaminants, building drainage, roof and interior inspection, maintenance, combustion appliances, room area and volume, special facilities, space usage and other factors are to be prepared. Feedback from children as well as the staff is also to be recorded for concerns involving occupant exposure. All collected information at this stage is considered, to determine the quantity and locations of required sampling points, a crucial task for the suitable planning of the measuring campaign as there should not be any disturbance in routine classroom activities while monitoring/sampling program is being conducted.

The **sampling stage** involves comprehensive data collection, which is based on a sampling strategy that understands how the building operates, the nature of complaints of children and staff, and a plan for interpreting the results. It involves monitoring of physical indicators, which include temperature, relative humidity, air exchange rate, ventilation effectiveness and age of air; chemical indicators, mainly carbon dioxide, carbon monoxide, RSPM, formaldehyde (HCHO) and total volatile organic compounds (TVOCs); biological indicators, which are bacteria, fungi and Legionella; and ventilation parameters. This stage of IAQ audit tests the hypothesis developed in Phase I through actual site specific IAQ monitoring.

The **evaluation stage** includes the quality-assured analysis of sampled/monitored data and its comparison with standards/ regulations/ specified limits. In India, standards/ limits for various monitored parameters have not yet been prescribed for schools. Therefore, comparison could be made with existing WHO and USEPA standards for the time being, following certain assumptions. Further, quantification/scoring of subjective questionnaire data using statistical techniques/ tools can be performed. Finally, the sources of IAQ problems are identified with the help of an integral correlation between all the indicators measured and information acquired, and their implications are identified on quality of indoor air and receptors.

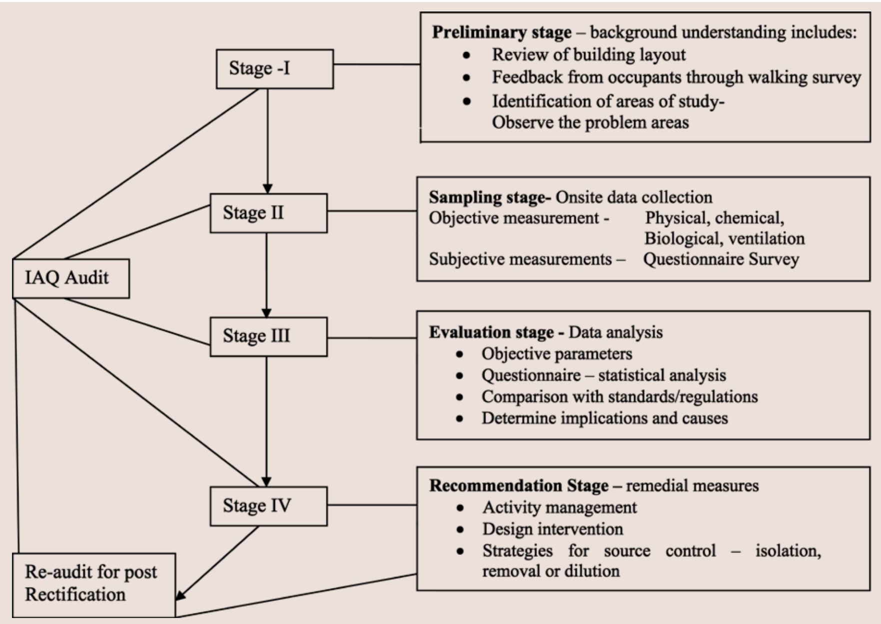

Figure 4: IAQ audit methodology for schools

The **recommendation stage** involves the review of the hypothesis developed in stage I and comparing it with the results of stages II and III. Accordingly, a set of corrective actions can be recommended for IAQ management. A detailed engineering design program including the abatement costs and alternative is also prepared to actually implement the corrective action designs. However, suggesting changes in building design is not feasible in most of the cases, therefore some strategies for source control can be suggested.

Finally, re-auditing can be performed after implementation of control strategies and remedial measures post rectification.

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Highlights of the Case Study

During the walkthrough stage, it was observed that the school does not follow a daily wet wiping routine, which results in resuspension and resettlement of dust particles after dry sweeping, especially 10 microns and lower sizes, into the classroom environment.

During the evaluation stage it was observed that while ventilation conditions in the classrooms during summers were up to the desired level, in winters they usually worsened due to closing of windows and ventilators. It was also observed that indoor concentrations of PM_{10} and $PM_{2.5}$ are largely influenced by indoor activities and their level of intensity rather than their outdoor concentrations and other influencing factors, i.e. meteorology, traffic etc. However, the indoor $PM_{1.0}$ concentrations are completely influenced by their outdoor concentration levels. There were no indoor sources of $PM_{1.0}$ particles (smoking and cooking are not allowed in school premises).

Finally, in the recommendation stage, planting of more trees was suggested in the school premises near window openings of classrooms so that penetration and infiltration of outdoor pollutants can be minimized. Regular practice of wet wiping after the classroom hours to remove the settled dust from classrooms was also recommended.

Conclusions & Recommendations

The results of the case study indicate that air pollutant concentrations inside the school classrooms may reach much higher levels beyond prescribed limits/standards. Other influencing parameters, such as ventilation conditions, occupant density and intensity of their activities, outdoor as well as indoor sources, and meteorological conditions may aggravate the problem of IAQ inside schools, which ultimately affect the health and performance of the children and staff. Therefore, there is a need to go for IAQ assessment and investigation in school and institutional buildings to identify the problems so that corrective measures can be suggested to the school owners/authorities. IAQ auditing can play a significant role in abating and solving the problems of such buildings. An important precaution that needs to be taken while conducting IAQ investigations in schools/institutional buildings is to determine the usage time of classrooms/ lecture theatres by occupants when comparing the sampling results with standards/ limits. It is not advisable to use the time weighted average (TWA) for comparison unless the occupants are exposed to 8-hr period as in case of office buildings. Generally, in schools, the exposure duration is 4-6 hours. Currently, there is no established standard for exposure limit of 2, 4 and 6 hr period. In that scenario, the short term exposure limits (STEL) can serve as a guide when occupants are exposed to less than 8 hr but more than a 15 min period.

References

1. American Academy of Pediatrics (AAP), Committee on Environmental Health. (2003). *Pediatric Environmental Health*, Pub. Grove, IL.
2. ASHRAE Standard 62-89. (1989). "*Ventilation for acceptable indoor air quality.*" Atlanta, Georgia.
3. ASHRAE Fundamentals Handbook (2001). American Society of Heating, Refrigerating and Air-conditioning Engineers, Inc.
4. Besler GJ, Besler M. (2000). *Towards healthy microclimate of closed spaces and habitats.* Environmental Protection Engineering; 26(3), pp23–38.
5. Brennan, T, Clarkin, M, Turner, W. et al (1991). *School buildings with air exchange rates that do not meet minimum professional guidelines or codes and implications for radon control.* ASHRAE IAQ'91 Healthy Buildings, Atlanta, GA, pp. 228–9.
6. Cheong, K.W.D. & Lau, H.Y.T. (2003). *Development and application of an indoor air quality audit to an air-conditioned tertiary institutional building in the tropics.* Building and Environment, Vol. 38, pp. 605 – 616
7. Climate, vol. 3, Indoor Air '96, Japan, pp. 1027–32.
8. Ehsan, Asadi, J.J., Costa, Manuel Gameiro da Silva (2011). *Indoor air quality audit implementation in a hotel building in Portugal*. Building and Environment, (online available).
9. Ellis R. (2003). *Commissioning for indoor air quality.* Engineering Systems; 20(4), pp30.
10. Goyal Radha and Khare Mukesh (2009), *"Indoor-Outdoor Concentrations of RSPM in Classroom of a Naturally Ventilated School Building near an Urban Traffic Roadway"* Atmospheric Environment, Volume 43 (38), pp 6026-6038.
11. Goyal, R and Khare, M. (2010), *"Indoor Air Quality in Naturally Ventilated Schools"*, ISBN 978-3-639-25234-7, By VDM publisher, Germany.
12. ISIAQ, (2000). *Creation of Healthy Indoor Environment in Schools: Task Force on Schools. 'A Nordic Approach'.* Published by National Institute of Public Health, Stockholm, Sweden.
13. Koo LCL, Luk MY, MokMY, Yuen JHF, Yuen TYS. (4–5 September, 1997). *Health effects from air conditioning: epidemiologic studies on schools and offices in Hong Kong.* In: Proceedings of indoor and built environment problems in Asia at Kuala Lumpur, Malaysia.
14. Lee SC, Chang M. (1999). *Indoor air quality investigations at five classrooms.* Indoor Air, 9, pp134–8.
15. Leickly, F.E., (2003). *"Children, their school environment, and asthma".* Ann. Allergy Asthma Immunol, 90, pp.3–5.
16. Leung, Michael & Chan, Alan H.S. (2006). *Control and management of hospital indoor air quality*. Medical Science Monitoring, Vol.12(3): pp17-23
17. Lugg AB, Batty WJ. (1999). *Air quality and ventilation rates in school classrooms I: air quality monitoring.* In: Proceedings of the CIBSE: Building Service Engineering Research Technology, vol. 20(1), p. 13–21.
18. Mendell MJ, Heath GA. (2005). *Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature.* Indoor Air 15, pp.27–52.
19. Myhrvold AN, Olsen E, Lauridsen O. (1996). *Indoor environment in schools— pupils health and performance in regard to CO2 concentrations*. In: Proceedings of seventh international conference on indoor air quality and climate, July 21–26, Nagoya, Japan, vol. 4, pp.369–74.
20. Raatschen, W. (1990). *"Demand controlled ventilating system—states of the art review".* Sweden: International Energy Agency.
21. Tippayawong, N., Khuntong, P., Nitatwichit, C., Khunatorn, Y., Tantakitti, C. (2009). *Indoor/outdoor relationships of size resolved particle concentrations in naturally ventilated school environments.* Building and Environment 44, pp.188–197.
22. Tham, K.W., Sekhar, S.C. & Cheong, K.W. (1996). *Integrated indoor air quality investigation of office buildings.* Proceedings of the Seventh International conference on Indoor Air Quality and
23. Turk, B.H., Powell, G., Fisher, E. et al (1993). *Improving general indoor air quality while controlling specific pollutants in schools.*