

**INDOOR AIR QUALITY IN CLASSROOMS OF A  
NATURALLY VENTILATED SCHOOL BUILDING NEAR  
AN URBAN ROADWAY**

by

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Submitted

In fulfillment of the requirements of the degree of Doctor of Philosophy

to the



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## WORK IS WORSHIP

*Basavanna, 12<sup>TH</sup> Century*

कर्मण्येवाधिकारस्ते मा फलेशु कदाचन ।  
मा कर्मफलहेतुर्भूर्मा ते संगोऽस्त्वकर्मणि ॥

*karmany evādhikāras te  
mā phalesu kadācana  
mā karma - phala-hetur bhur  
mā te sango 'sto akarmani*

*You have a right to perform your prescribed duty,  
but you are not entitled to the fruits of action.  
Never consider yourself the cause of the result of your activities,  
and never be attached to not doing your duty.*

**BHAGAVAD-GITĀ (II-47)**

*Dedicated to*

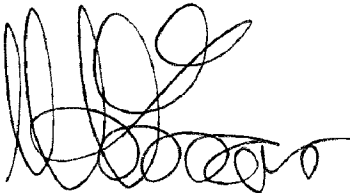
*My Parents*

*and*

*My Beloved Daughter HEMANYA*

## CERTIFICATE

This is to certify that the thesis entitled “**Indoor Air Quality in Classrooms of a Naturally Ventilated School Building Near an Urban Roadway**” being submitted by **Ms. Radha Goyal**, has been prepared under my supervision in conformity with the rules and regulations of the **Indian Institute of Technology Delhi**. I further certify that the thesis has attained a standard required for the award of a degree of **Doctor of Philosophy** of the institute. This work, or any part thereof, has not been submitted elsewhere for the award of any other degree or diploma.



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January, 2009

  
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## ABSTRACT

Urban schools in India are mostly naturally ventilated and are located in close proximity to heavy traffic density roadways. As a result, such school buildings are exposed to significant concentrations of outdoor pollutants. In addition, indoor sources and occupants activities/movements also contribute significantly to indoor pollutants. Under these conditions, children in these schools spend at least a third of their time indoors. Subsequently, they may develop potential health related problems when exposed to such indoor environments. The aim of present research is to evaluate indoor air quality (IAQ) in classrooms of naturally ventilated urban school buildings located near to the urban roadways. The indoor air quality has been investigated comprehensively by monitoring and sampling relevant pollutants, viz. suspended particulate matter, respirable suspended particulate matter ( $PM_{10}$ ,  $PM_{2.5}$  and  $PM_{1.0}$ ), carbon monoxide, sulphur dioxide, and nitrogen dioxides indoor and outdoor. Besides, other influencing parameters viz. ventilation characteristics, indoor activities (including opening and closing of the windows/doors/ventilators), cleaning practices, occupant's activities, micrometeorology (e.g. wind speed and direction, indoor/outdoor temperature and rH) and traffic volume and traffic type have either been observed or measured/ estimated. Exploratory data analysis concludes that particulates concentrations are always exceeding their prescribed limits/standards irrespective of seasons, weekday- weekends and hours of the day. However, there is substantial reduction in particulate concentrations during weekends, and in non-winter periods. Similarly, I/O is greater than unity irrespective of the seasons, and weekday- weekends. Higher I/O for suspended particulate matter and  $PM_{10}$  during weekdays infer the presence of their indoor sources. Similarly, for  $PM_{2.5}$  and  $PM_1$ ,  $I/O \approx$

1, indicates that the school building envelope is highly permeable and does not provide any protection from outdoor sources of these pollutants. No indoor sources exist for  $PM_{2.5}$  and  $PM_{1.0}$  as school premises are non-smoking area and cooking is not permitted.

Ambient temperature and rH and ventilation and traffic parameters show significant linear relationships with respirable particulate concentration values irrespective of seasonal and weekday-weekends variations. However, in the case of indoor  $PM_{10}$  concentrations during start and closing hours of the school and recess times, no linear relationships exist. Indoor concentrations of carbon monoxide, sulphur dioxide, and nitrogen dioxides during weekdays and weekends remain below permissible limits in both non-winter and winter periods. Their primary sources are outdoor traffic exhaust emissions.

Further, mass-balance based IAQ models for  $PM_{10}$ ,  $PM_{2.5}$  and  $PM_1$  developed for critical winter periods, predict indoor concentrations with reasonable accuracy. However,  $NVIAQM_{pm10}$  and  $NVIAQM_{pm2.5}$  exhibit a tendency to under predict indoor particulate concentrations at the start of the school hour. A newly introduced proportionality constant,  $R_c$  coupled with deposition term in  $NVIAQM_{pm10}$  and  $NVIAQM_{pm2.5}$  improves the performance of these models with its values in certain range. The  $d$  and NMSE statistics of the model performance describe satisfactory agreement between predicted and observed respirable particulate concentrations indoor in both weekdays and weekends. IAQ models are found to be least sensitive to mixing factor,  $k$  but sensitive to  $R_c$ .

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