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Indoor Air Quality Improvement in a School Building in Delhi

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Abstract

In this case study we measured the indoor air quality and analyzed the performance of ventilation and air conditioning system in school campus where each building has a mechanical ventilation system. The following reviews and studies were made: review of existing documents and maintenance practices, technical review of ventilation systems and air flow measurements, indoor air quality measurements, and walk-through audit of all spaces. An online User Satisfaction Survey was carried out among school staff. Room air particulate levels were too high and therefore air filtration needed to be improved and all buildings needed to be properly over-pressurized. All ventilation system components (including air handling unit rooms) needed to be functional and clean. Target was set to reduce indoor air particulate matter $PM_{2.5}$ (2.5 µg/m3 and smaller) level to be 70% below ambient air level, to remove traffic emissions (gases) from supply air and improve the cooling in classrooms. Proposed improvements were piloted in one of the buildings. Ambient Air Purifier units were installed into the outdoor air intake. Entire ductwork was cleaned. New filters were installed to air handling units. Ductwork was balanced to ensure positive pressure in all classrooms. After the pilot project the indoor air quality was measured and compared with ambient air measurements. During the first measurement period, ambient air $PM_{2.5}$ level was 142 µg/m3 and in the classrooms 95% less i.e. 7 µg/m3.

Keywords - Indoor Air Quality, School refurbishment, Case study, Air filtration

1. Introduction

Millions of people die each year from air pollution and indoor air pollution is the second highest killer in India. Respirable Suspended Particulate Matter (RSPM) is the main ambient and indoor air pollutant in India [1]. Between 2005 and 2010, the death rate rose by 4% worldwide and by 12% in India. Cost of air pollution to society in 2010 was estimated at US$ 0.5 trillion in India according to a study by the Organization for

Economic Co-Operation and Development (OECD) [2]. This is in average INR 100,000 per family - as much as the average annual income of an Indian family.

According Central Pollution Control Board's (CPCB) database [3] that includes RSPM data of 124 Indian cities, 123 cities has the $PM_{2.5}$ annual average level above WHO Air Quality Guideline level (10 µg/m^3) [4] and 119 cities are above Air Quality Guideline level (50 µg/ m^3) in PM_{10}. The highest $PM_{2.5}$ annual average value is in Delhi being 153 µg/ m^3) and highest PM_{10} level in Gwalior being 329 µg/m^3.

The International Agency for Research on Cancer (IARC) and WHO concluded in 2013 that ultra-fine particulate matter is carcinogenic to humans [5]. WHO Indoor Air Quality Guideline [4] states that $PM_{2.5}$ level of 35 µg/m^3 is already associated with about the 15% higher long-term mortality risk. Latest research shows across India, that as many as 400,000 premature deaths per year could be prevented if the WHO standards were met. If no action is taken to bring down the current $PM_{2.5}$ levels, deaths from air pollution would increase by 20% to 30% in India [6].

Main sources of particulate matter are vehicle emissions, household cooking (especially cooking with biomass and frying based cooking), thermal power plants, biomass burning, construction work and various industrial processes. In addition to RSPM, there are host of other pollutants that contribute towards deterioration of the ambient air quality. In many areas, Ozone (O_3), Sulphur dioxide (SO_2) and Nitrogen dioxide (NO_2) levels are also reported to be significantly high as compared to internationally practiced norms and guidelines. These pollutants are emitted through various industrial processes as-well-as through combustion of Sulphur containing fuel such as coal and petroleum products. They also get produced in the polluted river water and open sewage systems. [7]

There are several international schools in Delhi, where air quality has become a major concern among parents and teachers. As both the teachers and the families comes from the different parts of the World, their awareness of health impacts of the air pollution is higher than among the local families. However, also local schools should focus on air quality issues as 43.5% of public school children in Delhi already have either the reduced lung capacity or asthma [8].

2. Background of the Case Study Project

In this project we focused on the indoor air quality improvement in a one of the largest international school campuses in Delhi. The school campus consists of 10 school buildings and 3 residential buildings. It is located in the embassy area, where there are less traffic locally and lots of greenery around.

Each building has a mechanical ventilation system with cooling. The typical system consists of air handling unit (AHU) located inside an air handling unit room. Air handling unit is supplying the cooled air into the classrooms or apartments via ducts. The return air path is ceiling void and corridors. Fresh air intake is via a duct from the façade into the air handling unit room. Outdoor air volume is controlled by a damper in the end of the duct. Some of the classrooms and apartments have the additional fan coil units for local cooling. All air handling units had either EU2 or EU4 filters.

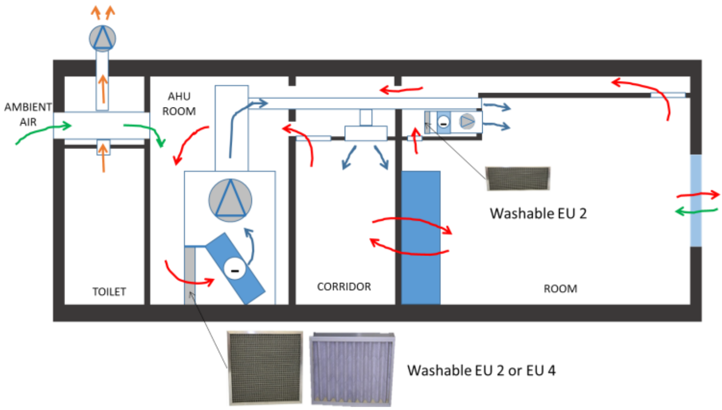

Fig. 1 A typical Air Handling Unit both in the school and residential buildings.

Delhi Pollution Control Board (DPCB) have been measuring the ambient air quality already during the many years nearby the school campus. The main ambient air quality problem has been the very high ultra-fine particulate ($PM_{2.5}$) levels; as annual average was 153 µg/m^3 in 2012 (WHO long term target is 10 µg/m^3) and peak load conditions can go above 1000 µg/m^3 based on the DPCB.

School wanted to address increased concerns with indoor air quality (IAQ) as it is related to staff and student health. But they were not clear what all need to be done to ensure good air quality inside the buildings. Room air purifiers had been tested but the air quality results were not good and also the high maintenance was an issue. Lots of plants had already been located in school premises to purify air, but mechanical ventilation system had not been addressed.

3. Method to Improve Indoor Air Quality in School Campus

In order to improve indoor air quality (IAQ) in school campus, we first had to understand the current performance of ventilation systems in each building, the current maintenance practices and the current IAQ & user satisfaction. In the second phase the recommended solution was designed and piloted in one of the buildings and then later the same concept with some improvements were executed in all buildings in the campus. The project had therefore three major phases:

- Phase 1: Indoor Air Quality and Ventilation System Performance Study:
    - Maintenance review;
    - User satisfaction survey;
    - IAQ measurements;
    - Ventilation system performance audit;
    - Walk-through audit of spaces.
- Phase 2: Pilot project to improve IAQ in one of the school buildings:
    - Set targets for IAQ;
    - Design the selected retrofit option;
    - Implementation of required retrofit, repair and maintenance activities;
    - Independent third party validation.
- Phase 3: Retrofit of entire school campus:
    - Evaluate the results of the pilot project;
    - Re-design of the system;
    - Implementation and validation of results.

In this paper we focus on the phases 1 and 2 mainly i.e. how the performance was evaluated, which where the major findings, what was the solution to improve the IAQ and what kind of results were achieved after pilot project.

4. Indoor Air Quality and Ventilation System Performance Study

In the first phase we reviewed all buildings in the school campus. We reviewed the maintenance practices, we conducted the user satisfaction survey, we measured the indoor air quality (IAQ) parameters in various locations in each building, and we studied the ventilation system operation and based on that we recommended improvements for maintenance practices as well as retrofitting and balancing the ventilation system.

A. Maintenance Review

We reviewed existing maintenance documents and practices. The maintenance practices in principle were well organized, however there were some problems with implementation mainly due to lack of knowledge of operation and maintenance (O&M) staff. Operation of all technical systems were followed daily in Building Management System (BMS) and key performance parameters were recorded daily. Operation review of each equipment was done every month using a checklist. Filters were washed once a month. IAQ measurements (CO_2, CO, VOC and O_3) were done 2 times a day in selected spaces. Based on them, CO_2 levels were high in some of the classrooms, other parameters were in limit values. Particulate Matter was not part of the daily measurement schedule. Energy consumption was measured building by building and the annual energy use was varying from 50-80 kWh/m^2 in older school buildings to 150-200 kWh/m^2 in apartments and the newest school buildings.

B. User Satisfaction Survey

We carried out the user satisfaction survey among the staff. The Indoor environmental quality user survey was localized to Indian conditions. The survey consisted on three major elements: perceived indoor environmental quality (based on the CBE Berkeley questionnaire), users' awareness of air quality problems in Delhi and user's Building Related Health Symptoms (based on the Orebro MM40 questionnaire).

The first part measured the perceived indoor environmental quality and covers the following areas: Thermal comfort, Indoor air quality, Lighting and daylight, Acoustic conditions and Cleanliness.

Survey results shows that the Indoor Air Quality (60% dissatisfied) and Thermal Comfort (40% dissatisfied) are the two major areas creating dissatisfaction among the users.

All the staff members were aware of Air Quality issues in Delhi. Internet had been the major information source (32%) followed by newspaper (15%) and colleagues & friends (14% & 13%), respectively. Only 23% of staff members were using breathing masks and 63% used air purifiers at home. 49% of staff considered that air quality will affect their length of stay at Delhi.

The user's health symptoms were compared with Orebro international data base (MM40). The only symptom that stands out is cough which may be due to high level of particulates and irritants in the respiratory system.

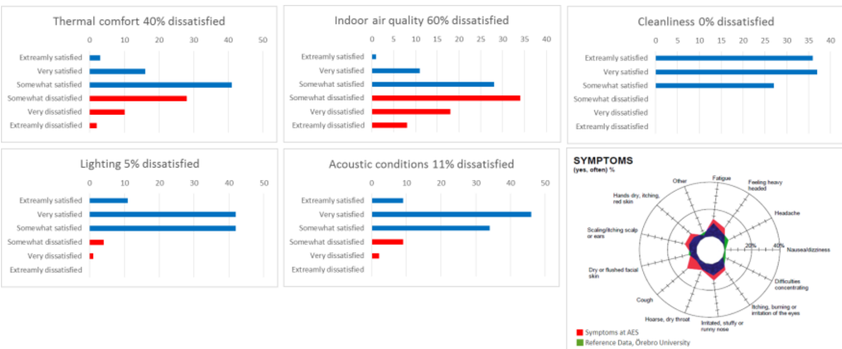

Fig. 2 Results of user satisfaction survey.

C. IAQ Measurements

We measured temperature, relative humidity, CO_2 and particulate matter in several locations in each building. Temperature was mainly comfortable in all those spaces, where either fan coil units were operating or ventilation was proper. High temperature and CO_2 were problems in the rooms where there was no sufficient ventilation. Relative humidity was mainly below 65%, however during the measurements the outdoor air was very dry.

The biggest IAQ problem was the high ultra-fine particulate matter ($PM_{2.5}$) levels. They were very high everywhere, sometimes even higher than in the outdoor air, especially near the doors and in the spaces with several printers and copy machines. The PM_5 levels were between 100 and 200 µg/m3 during the measurement both in indoor air and outdoor air, much higher than standard level and the ventilation system was not able to reduce the level.

Table 1. Air quality and thermal comfort measurements in the pilot building during the audit. In two locations the particulate matter was higher than ambient and in two other locations it was only slightly less than ambient air level. The acceptable reduction level was 70% reduction and it was reached only in one location.

	PM_5	**CO_2**	**Temperature**	**Relative Humidity**
	Difference between indoors and ambient	(ppm)	(°C)	(%)
Office	56% (higher than ambient)	510	24.9	47.7
Library	-79%	1259	22.8	54.2
Classroom 1	311%	637	25	55
Classroom 2	-23%	551	23.8	52.3
Classroom 3	-7%	563	24	51.4

D. Ventilation System Performance Audit

During the ventilation system performance review we measured air flow rates in each air handling unit and pressure loss across each component (filters, cooling coil and fan). Air flow rates in all air handling units were below design value. The current filtration G3+G4 was not sufficient to remove RSPM. The pressure loss across the filter section was very low, about 40-100 Pa only, indicating the poor quality of current G4 filters. This was confirmed with visual inspection – there were lots of damaged filters and due to the regular washing, the filter media had worn out.

Fig. 3 There were lots of problems with current ventilation system operation and filtration.

Based on the pressure difference evaluations between various rooms (measurements and smoke demonstrations), most of the classrooms were not in positive pressure, as designed, and some of the rooms did not have air supply at all. Ducts were dirty as they had never been cleaned since buildings were constructed. Some fan motors were not working and belts were damaged. Loose mineral wool was found inside the ducts near the air handling unit. Many air handling unit rooms were also used as a storage room.

E. Walk-through Audit of the Building

During the walk-through audit, the following observations were made. Most of the rooms were under pressurized i.e. ambient air come directly into the room from windows & doors. Due to the lack of ventilation in many classrooms, doors and windows were kept open. In library there were strong odour but source was not found. In many ceiling tiles there were water damages (dark spots), however there was no smell of mould and in very few places mould was found. Room dust was not found except in air handling unit rooms. Carpets were mainly clean, no smell. Plants' leafs were clean from dust but soil mould was found in many places.

F. Main Recommendations

The following recommendations were made to improve IAQ and system performance in the school campus. Room air particulate and CO_2 levels as well as temperature were too high. To improve air quality, ambient air and AHU filtration needs to be improved, buildings needs to be properly over-pressurized to avoid ambient air from entering indoors via windows and doors and each room to have the sufficient amount of supply air.

Maintenance and operation of ventilation system needs to be improved. HVAC-system components (including AHU rooms) need to be maintained at a high standard. Operation and maintenance personnel need additional training to better manage the operation of ventilation and air conditioning system in each building. Regular 3rd party inspection of indoor air quality and HVAC-system operation is required.

5. Pilot Project to Improve IAQ in One of the School Buildings

A. Target Setting

The target for improvement project was set in terms of indoor air quality. The main target was to reduce indoor air particulate matter $PM_{2.5}$ level to be 70% below ambient air level. Simultaneously, traffic emissions (NO_2, SO_2, O_3) shall be removed from the supply air and cooling needs to be improved in classrooms by ensuring high enough ventilation rates and balancing the ductwork properly.

B. Selection and Design of the Retrofit Options

The selected solution consists of retrofitting an ambient air purifier into each AHU room, repairing and cleaning the ventilation system, balancing the ductwork and improving the system maintenance.

Ambient Air Purifier (AAP) is a fan-filter unit that cleans the outdoor air before it is supplied into the AHU room. Building has 9 AHU rooms, so 9 AAP units were designed in sizes between 250 – 1,000 l/s. Each unit was designed to supply 1.5 l/s,m^2 of fresh air (15% of the total air handling unit air volume), which gives the air exchange efficiency of 2 air changes per hour. Each unit has a place for four filters: washable G4 filter, F9 fine filter, chemical filter and M6 post-chemical filter. This shall give the filtration efficiency that is more than 99% for $PM_{2.5}$, 100% for PM_{10} and remove gases from outdoor air.

Other options would have been to retrofit the air handling units with new, improved filters or installing the room air purifiers into each room. In terms of investment and maintenance cost, the chosen solution was the cheapest.

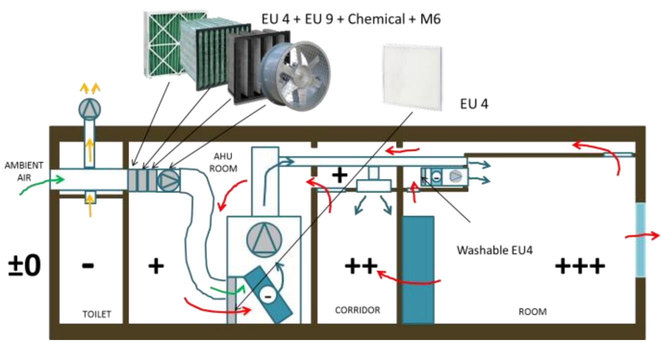

Fig. 4 The ambient air purifier is installed to clean the air before supplied into the air handling unit room.

C. Implementation of required retrofit, repair and maintenance activities;

The ventilation system required lots of small repairs and maintenance activities. All air handling unit rooms were cleaned and sealed properly. New G4 filters were installed to all air handling units. Some ductwork modifications were done. All loose mineral wool surfaces were covered inside the air handling units and ducts. Ducts and diffusers were vacuum cleaned.

As there was no updated ventilation system drawings, the ductwork was audited and new drawings were created. After installing the Ambient Air Purifier units, some new balancing dampers were installed and all ductworks were balanced in order to have sufficient ventilation and to maintain positive pressure in all classrooms against outdoor air and other spaces.

D. Independent third party validation.

After the pilot project the indoor air quality was measured and compared with ambient air quality as the target was set relative to that. It is difficult also to compare to the results before retrofit as the ambient air pollution levels are very different in different days. During the measurement period, the ambient air $PM_{2.5}$ level was 142 $\mu g/m^3$ and in the classrooms 7 $\mu g/m^3$. This is 95% less than ambient air level. Also SO_2, NO_x and O_3 levels were below detectable limit.

However the similar building which had not been refurbished yet, $PM_{2.5}$ was 21 $\mu g/m^3$. CO_2 readings were showing that refurbished building had proper ventilation with the CO_2 level of 450 ppm whereas in the other building the CO_2 level was 3050 ppm. It did not have any outdoor air ventilation and that kept the $PM_{2.5}$ in reasonable low level.

6. Changes Required to Retrofit the Entire School Campus

After few months of experience in the pilot building, we found out that the life cycle of F9 fine filters were much shorter than expected. Some of the filters were chocked with dust already after 6-8 weeks of use. After evaluating the situation, we found two reasons for that. Firstly, the pre-filtration was not sufficient enough in ambient air purifiers and therefore too much dust accumulated into the fine filter surface. Secondly, when the pre-filters were washed, they were installed back to the system when they were still wet. This made the fine filter to operate in too moist condition and the accumulated dust created a solid film to the filter surface. Due to this the pressure loss of fine filter increased above 500 Pa just in few weeks.

Therefore we added another coarse filter M5 between G4 and F9 filters to the rest of the buildings at the school campus in order to improve coarse dust filtration. This increased the life cycle of the more expensive fine filter. We also advised the maintenance team to keep the ambient air purifier units switched off until the filters are dry in case they want to wash them.

7. Conclusion and Discussion

This case study shows that indoor air quality can be improved a lot even in the most polluted cities in the world by designing and maintaining the ventilation system properly and separate, high maintenance room air purifiers are not necessarily required. In this case the ambient air purifiers were installed, but the same result in terms of IAQ could have been achieved by retrofitting existing air handling units with similar set of filters and new EC fans. However, this would have meant higher filtration and energy cost, as the improved filtration would have been needed for the total air volume. Now the higher pressure loss impacts only 15% of the air and also the number of filters to be changed annually is less.

This case study proves, that as long as the main pollution source is the outdoor air, good IAQ can be achieved by just properly cleaning the outdoor air before supplying it into a building. However, this concept requires properly balanced ductwork in order to keep all spaces in a positive pressure.

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