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Investigating the Effect of an Open Window vs. A Closed Window on the Concentrations of Suspended Particulate Matter in the Indoors with respect to the Outdoors

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ABSTRACT

Background: A study was conducted in New Delhi during peak winter to investigate the impact of open versus closed windows on indoor levels of PM2.5 and PM10, given the high ambient air pollution levels during this time.

Purpose: The aim was to determine whether opening windows affected indoor concentrations of PM2.5 and PM10, despite the prevailing belief that outdoor air quality significantly influences indoor air quality.

Method: A PM2.5 and PM10 air quality meter was used near a window at a single location for 10 days, with measurements taken nine times daily during working hours. The experiment involved alternating between open and closed window conditions to observe any significant changes.

Result: Contrary to expectations, opening or closing windows did not substantially alter indoor PM2.5 and PM10 levels. The study indicated that outdoor air might not significantly contribute to indoor particulate matter, suggesting minimal diffusion through open windows.

Conclusion: The findings suggest that isolation measures alone may not effectively reduce indoor PM2.5 and PM10 levels, as outdoor sources do not significantly influence indoor air quality even when windows are opened.

1. Introduction

In this paper, a study is performed to see the effect of a closed window vs. an open window on the particulate matter concentration in the indoors. There are multiple studies present which try to correlate the indoor and outdoor particulate matter, but the results in the various studies did not always present a conclusive answer. This study in particular focuses on a micro-environment with a single window to see the difference in the concentrations of the particulate matter. Over a period of ten days, during the working hours, the readings have been recorded and analysed and discussed. Conclusions have been drawn from these results and have been reported in this study.

2. Literature Study

The COVID 19 pandemic has led to a push by HVAC institutions to increase dilution ventilation in spaces. This has a direct impact on reducing the concentration of the aerosolized suspended droplets containing pathogens, which spread through the airborne route (Atkinson, 2009; Escombe *et al.*, 2007; Wilson, 2007; Xu *et al.*, 2022). Dilution ventilation can be achieved in naturally ventilated buildings as well as mechanically ventilated buildings. In naturally ventilated buildings, the opening of windows has been the most suggested method of achieving dilution ventilation (Francisco *et al.*, 2020; Guo *et al.*, 2021). In mechanically ventilated buildings, the one having central air conditioner plant with Air Handling Units (AHUs), dilution ventilation can be achieved by increasing the fresh air supply through dampers in the AHUs, though the quantification of the amount of the fresh air intake possible depends on the design of the air conditioning system. As far as opening the windows is concerned, there must be a mechanism to prevent the entry of unwanted elements inside the space. These include noise, insects, street animals, dust, and air pollution. In most metro cities in the developing world, cities have an ambient air pollution problem (Gardiner, 2019; Rizwan *et al.*, 2013). This problem is more acute with respect to the presence of suspended particulate matter in the air. Suspended particle matter is classified and measured

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as PM 2.5 and PM 10. The crucial is PM 2.5 which is an indication of the size. It means the aerodynamic diameter of these particles released during combustion is below 2.5 microns. These particles, especially PM 2.5, are a leading cause of lung diseases in the population of the country (Rizwan *et al*., 2013). Researchers across the world have tried to find out the relation between the outdoor suspended particle levels and the indoor particle levels (Liu & Zhang, 2019; Goyal & Kumar, 2013; Meng *et al.,* 2005; Morawska *et al.,* 2001; Patterson & Eatough, 2000; Wang *et al.,* 2016). Therefore, the main goal of this study is to investigate the impact of window opening in naturally ventilated rooms on indoor particulate matter levels relative to outdoor levels. It also aims to assess whether closing windows effectively isolates indoor environments from outdoor particulate matter effects. Furthermore, the study explores the feasibility of using window closure as a strategy to combat air pollution.

3. Methodology

The experiments were conducted to determine the relationship between Indoor Air Quality (IAQ) and Outdoor Ambient Air Quality with respect to the levels of airborne particulate matter. The tests focused on measuring suspended particulate matter of two kinds: PM2.5 and PM10. TVOC and HCO measurements were also recorded, but it was observed that their levels remained constant throughout the duration of the test. Hence, for the purpose of these experiments, these recordings have not been tabulated and show no significant rise or fall.

The IAQ measurements were recorded in the library of a naturally ventilated institutional building in the Jasola industrial area of South Delhi. The library is a south-facing room on the 2nd floor of the four-storeyed building, facing a busy road. The Air Quality Monitor (hereafter called the AQ Monitor) was placed at a fixed location in the room- at a distance of 500 mm from the openable window and at a height of 700 mm from the floor. The make of the AQ Monitor used for the purpose of this experiment is AX-8016, which can measure PM2.5 and PM10 levels in a range of 0-999 microgram/meter3.

Readings were taken daily over a period of ten working days. Measurements were recorded at intervals of one hour over the operational hours of the building i.e., from 08:00 to 16:00 hours. The days in which these recordings were made were from 14th December 2021 to 29th December 2021. This is also the time period when the air pollution in Delhi is at its peak due to various external factors, which are beyond the scope of this study. The variable in the experiment was the status of the operable fixed-glass pane window in the room. Experiments were recorded with four distinct statuses of window:

- Window open for the whole duration of the test, i.e., 08:00 to 16:00.
- Window closed for the whole duration of the test, i.e., 08:00 to 16:00.
- Window opened from 08:00 to 12:00 and closed thereafter till 16:00.
- Window closed from 08:00 to 12:00 and opened thereafter till 16:00.

Parallel to the measurements from the AQ Monitor, recordings were also tracked from the Air Quality Monitoring Station at Okhla Phase-2. This is the nearest government facility for real time monitoring of ambient air quality, and falls under the purview of the Delhi Pollution Control Committee, Government of N.C.T. of Delhi. The data is available as open-access on their website. Readings were tracked from this dataset simultaneously with the indoor AQ Monitor measurements.

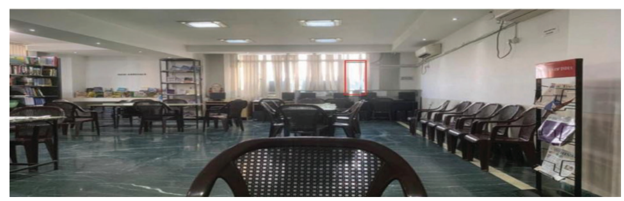

Figure 1: The interior of the library where the study was performed. (Highlighted in Red)

4. Results

The first observation is that in a naturally ventilated building, indoor air quality is a direct derivative of the outdoor ambient air quality, including the concentrations of suspended particulate matter. Table 1 shows the measurements recorded during the experiment, which reflect this relationship. This relationship was observed irrespective of the status of operable fixed-glass pane window.

Table 1: Tabulation of the Results: Levels of PM 2.5 in the indoors-measured and outdoor levels taken from the nearest Air quality station.

Time	PM 2.5 Indoor	PM 2.5 Outdoor	PM 10 Indoor	PM 10 Outdoor	Windows
Day 1 – 14/12/2021					
08:00	66	300	73	471	Open
09:00	–	365	–	566	Open
10:00	50	311	56	652	Open
11:00	50	–	56	–	Open
12:00	40	–	44	–	Open
13:00	37	145	41	228	Open

14:00	29	155	32	239	Open
15:00	26	130	29	213	Open
16:00	28	123	31	223	Open
Day 2 – 15–12–2021					
08:00	47	233	47	313	Close
09:00	53	241	59	389	Close
10:00	55	246	61	395	Close
11:00	55	239	61	351	Close
12:00	48	194	53	296	Close
13:00	45	156	50	237	Close
14:00	36	149	40	254	Close
15:00	27	111	30	191	Close
16:00	22	107	24	168	Close
Day 3 – 17/12/2021					
08:00	47	197	52	301	Close
09:00	–	194	–	321	Close
10:00	–	173	–	343	Close
11:00	29	132	32	228	Close
12:00	26	85	28	212	Close
13:00	18	80	20	207	Close
14:00	18	74	20	190	Open
15:00	15	69	16	175	Open
16:00	15	68	16	153	Open
Day 4 – 20/12/2021					
08:00	35	186	39	272	Open
09:00	42	180	47	304	Open
10:00	34	174	38	453	Open
11:00	30	133	33	248	Open
12:00	30	127	33	229	Open
13:00	24	116	26	224	Open
14:00	22	94	24	194	Open
15:00	21	106	23	212	Open
16:00	22	94	24	191	Open
Day 5 – 22–12–2021					
8:00	–	–	–	–	–
9:00	78	432	87	648	Open
10:00	73	407	81	637	Open
11:00	76	302	85	423	Open
12:00	69	307	77	477	Open
13:00	66	183	73	287	Open
14:00	32	173	35	287	Open
15:00	26	96	29	183	Open
16:00	37	100	41	196	Open
Day 6 – 23–12–2021					
08:00	60	428	68	621	Close
09:00	101	467	113	692	Close
10:00	104	473	116	737	Close
11:00	79	337	88	537	Close
12:00	71	255	79	399	Close
13:00	61	221	68	365	Close
14:00	52	229	58	362	Close
15:00	50	228	58	372	Close
16:00	50	216	57	378	Close
Day 7 – 24–12–2021					
08:00	67	334	75	490	Close
09:00	75	383	84	610	Close
10:00	71	305	79	434	Close
11:00	64	280	71	427	Close
12:00	42	265	47	417	Close
13:00	35	212	39	321	Open
14:00	31	171	34	263	Open
15:00	28	155	31	255	Open
16:00	30	162	33	284	Open
Day 8 – 27–12–2021					
08:00	21	172	23	241	Open
09:00	29	155	32	229	Open
10:00	25	139	28	195	Open
11:00	21	116	23	182	Open
12:00	9	81	11	119	Open
13:00	13	84	14	138	Close
14:00	11	86	12	136	Close
15:00	8	79	8	129	Close
16:00	9	74	10	130	Close
Day 9 – 28–12–2021					
08:00	19	197	21	287	Open
09:00	37	215	41	321	Open
10:00	39	259	43	404	Open
11:00	41	245	45	444	Open

12:00	47	216	52	383	Open
13:00	47	239	52	406	Open
14:00	40	224	43	345	Open
15:00	31	151	34	212	Open
16:00	21	124	23	177	Open
Day 10 – 29−12−2021					
08:00	16	174	17	234	Close
09:00	53	190	59	271	Close
10:00	45	212	50	300	Close
11:00	47	229	52	331	Close
12:00	43	174	48	261	Close
13:00	36	155	40	238	Close
14:00	25	102	28	183	Close
15:00	7	48	7	117	Close
16:00	9	38	10	105	Close

As observed during the experiment, the general ambient air quality trend shows that the concentrations of both PM2.5 and PM10 peak around 10:00-11:00 hours and decline over the duration of the day, with the lowest concentrations recorded around 15:00-16:00 hours. This trend also reflects itself in the IAQ recordings, shown in Figure 2 and Figure 3. The concentrations gradually decline over the operational hours to their lowest recordings around 16:00 hours, subject to operating conditions of the building and stable weather conditions. An initial spike in the values was seen between 08:00-09:00 hours every day, which was attributed to the initial change in state of the room as the authors entered the room. This trend is seen across regardless of the statuses of the operable fixed-glass pane window i.e. whether they were opened or they were closed.

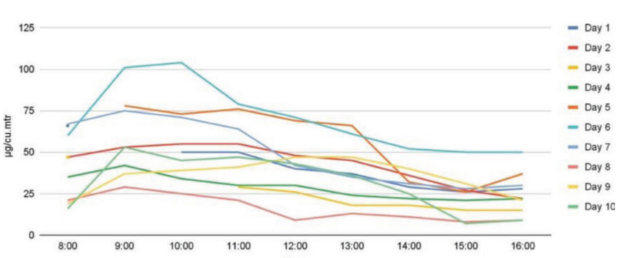

Figure 2: Aggregate PM 2.5 Levels.

The second observation was that within the trend of suspended particulate matter over the duration of operational hours as discussed above, there were further important sub trends. In the situation where the window had been kept open across the working hours, the indoor airborne particulate matter levels were lower when compared to the case where the window was closed the whole day. This was subject to similar levels of outdoor ambient airborne particulate matter levels. Figure 3 and Figure 4 show a comparison of two such observations during the experiment. The comparisons were made from days with similar levels of outdoor ambient particulate matter levels (Day 2 vs. Day 4 and Day 9 vs. Day 10). This sub trend was witnessed even when the outdoor ambient particulate matter levels were marginally higher on the day with open windows as compared to the days with closed windows.

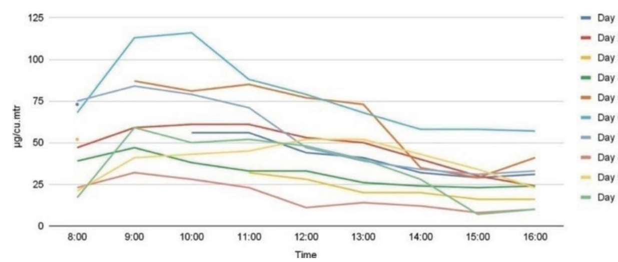

Figure 3: Aggregate Indoor PM 10 levels.

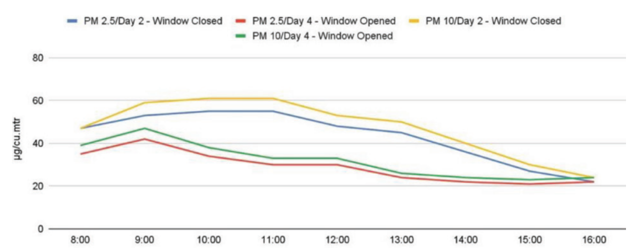

Figure 4: Indoor Particulate Matter Levels for Opened and Closed Window Status.

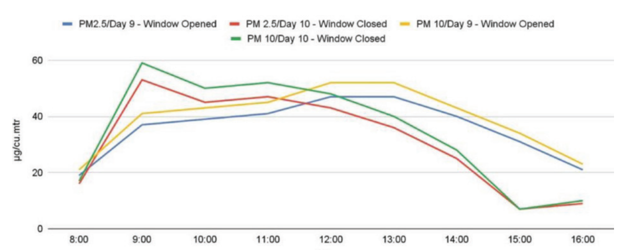

Figure 5: Indoor Particulate Matter Levels for Opened and Closed Window Status.

The third observation was related to the effect of ambient weather conditions on indoor air quality. It was observed that precipitation, rain in case of the experiment, drastically reduced outdoor ambient airborne particulate matter levels. This drop was directly reflected in indoor airborne particulate matter levels, with reductions in both PM 2.5 and PM 10 levels and can be observed in Table 1 above. There was rainfall on Day 8 of the experiment.

A minor fourth observation was also made regarding the relationship between outdoor ambient particulate matter levels and indoor airborne particulate matter levels.

Although, as mentioned in the first observation, indoor airborne particulate matter level is a direct derivative of outdoor ambient particulate matter level, the trend shown in the measurements suggests that indoor airborne particulate matter levels simply follow the general trend and do not exhibit drastic peaks and drops as seen in outdoor ambient particulate matter levels throughout the operational hours of the building. Figure 5 and Figure 6 depict two days selected within the experiment, clearly exhibiting this trend.

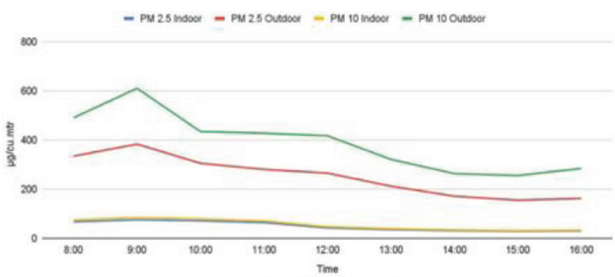

Figure 6: Particulate Matter Levels on Day 7.

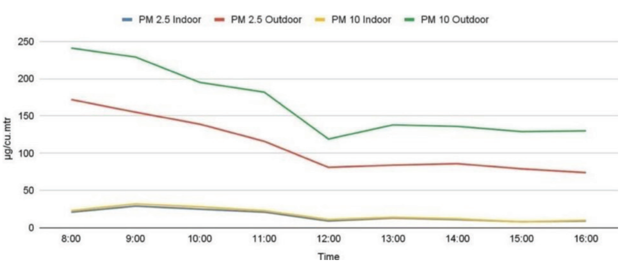

Figure 7: Particulate Matter Levels on Day 8- The Rainfall Day.

5. Discussion

As explained in the first observation above, the relationship between indoor airborne particulate matter level and outdoor ambient particulate matter level was seen irrespective of the status of operable fixed-glass pane window, contradicting a conjecture that keeping all the windows and doors closed will prevent substantial levels of PM 2.5 and PM 10. Another pertinent fact is observed in the second observation. The indoor airborne particulate matter levels were lower in case of an open window rather than in a completely closed room. This implies that the rate of dissipation of indoor airborne particulate matter to the outside under natural ventilation is faster than the rate of deposit of outdoor ambient suspended matter to the indoors by ventilation. Thus, it can be inferred that while the status of operable window plays a minor role in the improvement of indoor air quality, allowing natural ventilation by opening windows, though sounding counter-intuitive, has a positive effect on improving indoor air quality when strictly talking about suspended particulate matter concentrations in the indoor.

Such opening of window, as suggested by various HVAC institutions across the world, may also be helpful in the reduction of infection due to dilution ventilation that may be possible by such opening of the windows. This is in line with the various studies that have been taken place around the world. The isolation of the indoor from the outdoor, even by closing the windows seems to not fully prevent concentration of PM 2.5 to be present in the indoors. In one study, the Brownian Diffusion was said to be an important mechanism for ultra-fine particles that have penetrated from the outdoors towards the indoors. The study done in China also reiterated that closed windows can only play a very weak role in the decline of indoor PM 2.5 concentrations (Wang *et al.*, 2016). It is also worth noting that there were indoor sources of pollutants and that the indoor levels can be substantially higher than the outdoor PM 2.5 concentrations (Meng *et al.*, 2005). Even though the outdoor PM 2.5 can be the source of the indoor concentrations, the direct entry through window openings may not likely be the cause. Diffusional flow through cracks and fissures may be the source of infiltration. In such cases, having hermetically sealed buildings may not be the solution as they may ill perform in case of prevention of airborne infection spread which can be easily achieved by opening the windows. This problem is all the more aggravated when there is a use of split air conditioners in such spaces with sealed windows and re-circulated air on the inside (Singh & Dewan, 2020). In this case, use of open-able window has been recommended along with a functioning split air conditioner (Guo *et al.*, 2021).

6. Conclusion

To conclude, it must be reiterated that opening of the windows does not substantially affect the levels of the indoors with respect to the levels of PM 2.5 and PM 10 in the outdoors. Outdoors may provide the source of the particulate matter in the indoor, but due to diffusive effect, open windows play a key role in reducing the indoor levels, which may be contrary to the popular belief. Closing the window, may play a very marginal role in creating any isolation between the indoor and the outdoor. High concentrations of PM 2.5 and PM 10 in the indoors due to outdoors cannot be reduced by closing of the operable windows.

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Author Contribution

The authors Raja Singh and Tushar Mondal were responsible together for writing-original draft, data curation, investigation, and project administration. Author Raja Singh was responsible for conceptualization, methodology, resources (instruments), and writing-review and editing. Author Tushar Mondal was responsible for visualization and formal Analysis. Author Anil Dewan was responsible for supervision.

Conflict of Interest

The authors declare no conflict of interest.

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