Title:

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.

Authors:

1. Ar. Raja Singh*, Research Scholar, Department of Architecture, School of Planning and Architecture, New Delhi 110002.
Assistant Professor, Periyar School of Architecture, Jasola, New Delhi 110025.
2. Ar. Tushar Mondal, Faculty, Periyar School of Architecture, Jasola, New Delhi 110025.
3. Prof. Dr. Anil Dewan, Professor and Head, Department of Architecture, School of Planning and Architecture, New Delhi 110002.

*corresponding author; email: rajaphd@spa.ac.in

Abstract

A study was conducted to see the effect of an opened window vs. a closed window in New Delhi in peak winters. This is the time when the $PM_{2.5}$ and PM_{10} concentrations are the highest in the ambient air due to various external factors. A $PM_{2.5}$ and PM_{10} air quality meter was used at a singular location near the window for 10 days with 9 readings taken during the daily working hours. Contrary to the possible conjectural belief, it was found that the window opened or closed did not have a substantial effect on the concentrations of the indoor levels of $PM_{2.5}$ and PM_{10}. The results showed 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 the reducing the indoor levels. This study was reconfirmed with options where the windows were opened and then closed and vice-versa. In all cases, the effect of the outdoor was not visible. To curb indoor particulate matter levels, isolation is not the solution.

(200 words)

Keywords: Indoor Air Pollution, Suspended Particulate Matter, Windows operability, Indoor Air Quality, Indoors vs. Outdoors.

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 microenvironment 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.

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 et al., 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(CPWD, 2017; Francisco et al., 2020; Guo et al., 2021; Indian Society of Heating, refrigeration and Air Conditioning Engineers, 2020). In mechanically ventilated buildings, the one having central air conditioner plant with Air Handling units, 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 to the inside of 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, 2020; 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 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(Cong Liu, 2019; Goyal & Kumar, 2013; Meng et al., 2005; Morawska et al., 2001; Patterson & Eatough, 2000; Wang et al., 2016). 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 ultrafine 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 recirculated air on the inside(Singh & Dewan, 2020). In this case, use of openable window has been recommended along with a functioning split air conditioner(CPWD, 2017; Guo et al., 2021; Indian Society of Heating, refrigeration and Air Conditioning Engineers, 2020).

Aim/Objective

Experiments conducted were aimed at answering the following research questions:

1. What is the effect of window opening in a naturally ventilated room on the levels of indoor particulate matter in relation to the outdoor particulate matter?
2. Does closing the window isolate the indoor from the effect of outdoor suspended particulate matter? Is closing of windows a viable solution to tackle air pollution?

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 focussed 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.

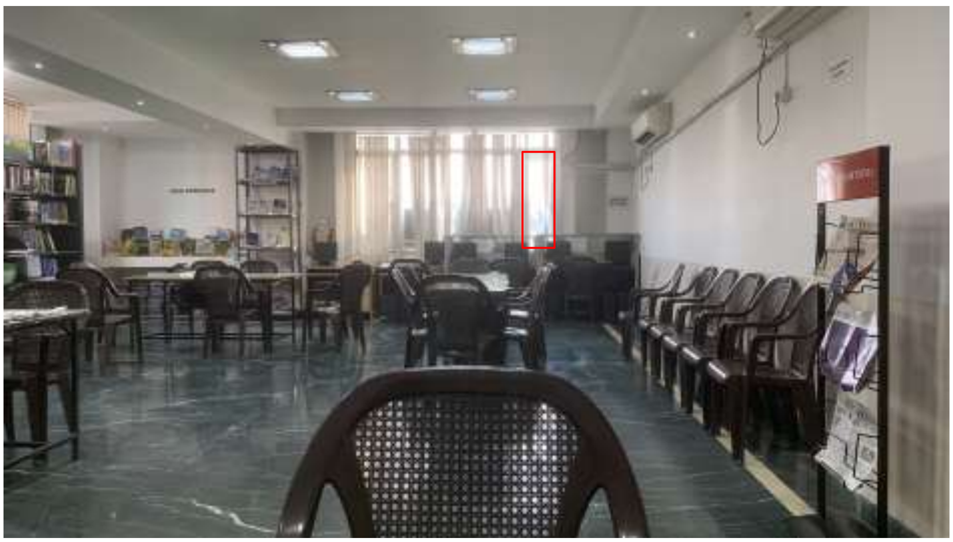

Figure 1: The interior of the library where the study was performed. Note the Highlighted Window which was opened (in red)

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(Delhi Pollution Control Committee, n.d.). The data is available as open-access on their website. Readings were tracked from this dataset simultaneously with the indoor AQ Monitor measurements.

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					
8:00	66	300	73	471	Open
9:00	-	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					
8:00	47	233	47	313	Closed
9:00	53	241	59	389	Closed
10:00	55	246	61	395	Closed
11:00	55	239	61	351	Closed
12:00	48	194	53	296	Closed
13:00	45	156	50	237	Closed
14:00	36	149	40	254	Closed
15:00	27	111	30	191	Closed
16:00	22	107	24	168	Closed
Day 3 - 17/12/2021					
8:00	47	197	52	301	Close
9:00	-	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					
8:00	35	186	39	272	Open
9:00	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					
8:00	60	428	68	621	Closed
9:00	101	467	113	692	Closed
10:00	104	473	116	737	Closed
11:00	79	337	88	537	Closed
12:00	71	255	79	399	Closed
13:00	61	221	68	365	Closed
14:00	52	229	58	362	Closed
15:00	50	228	58	372	Closed
16:00	50	216	57	378	Closed
Day 7 - 24/12/2021					
8:00	67	334	75	490	Closed
9:00	75	383	84	610	Closed
10:00	71	305	79	434	Closed
11:00	64	280	71	427	Closed
12:00	42	265	47	417	Closed
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					

8:00	21	172	23	241	Open
9:00	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	Closed
14:00	11	86	12	136	Closed
15:00	8	79	8	129	Closed
16:00	9	74	10	130	Closed

Day 9 - 28/12/2021					
8:00	19	197	21	287	Open
9:00	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					
8:00	16	174	17	234	Closed
9:00	53	190	59	271	Closed
10:00	45	212	50	300	Closed
11:00	47	229	52	331	Closed
12:00	43	174	48	261	Closed
13:00	36	155	40	238	Closed
14:00	25	102	28	183	Closed
15:00	7	48	7	117	Closed
16:00	9	38	10	105	Closed

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 1 and Figure 2. 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.

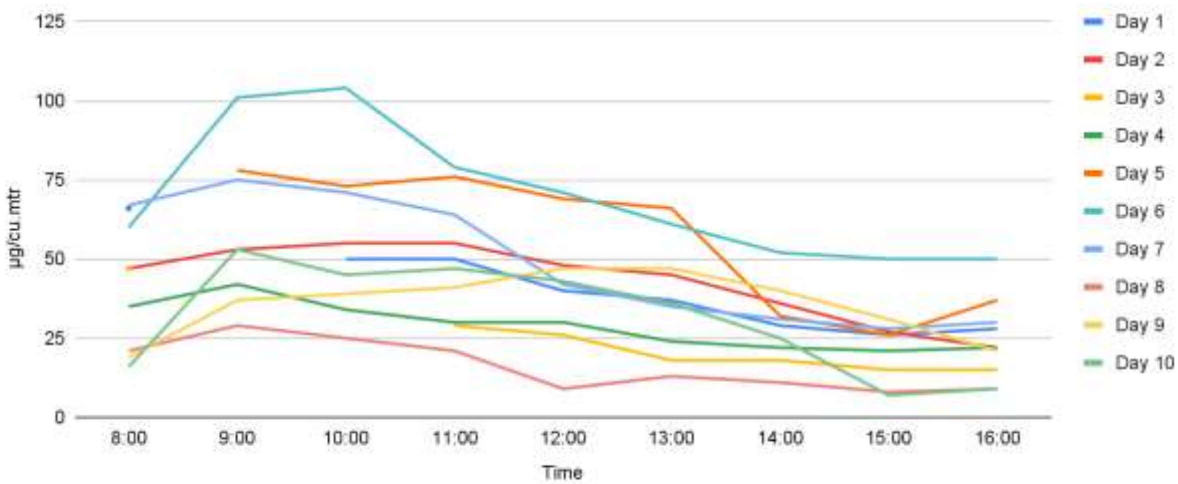

Figure 2: Aggregate PM 2.5 Levels

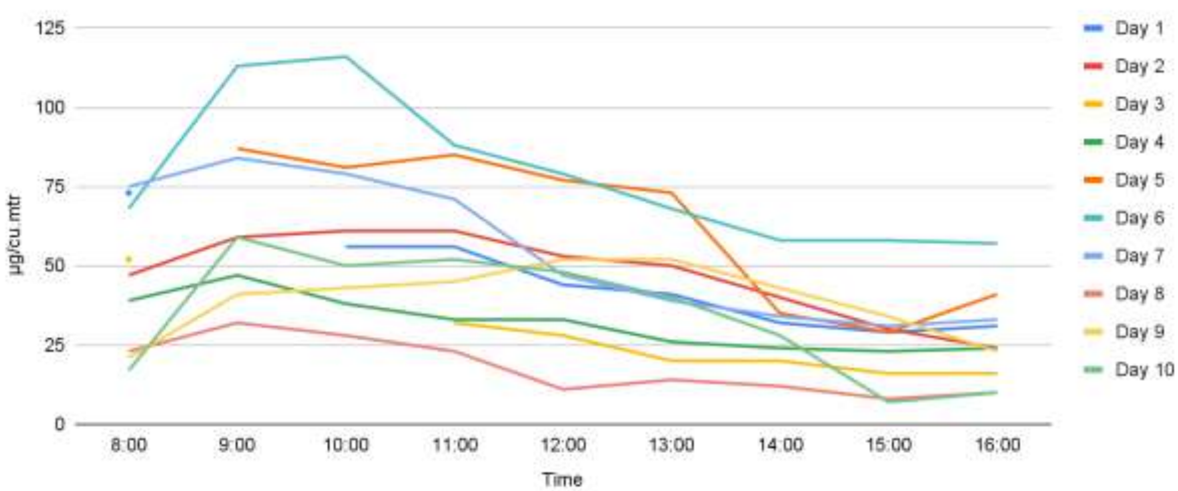

Figure 3: Aggregate Indoor PM 10 levels

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

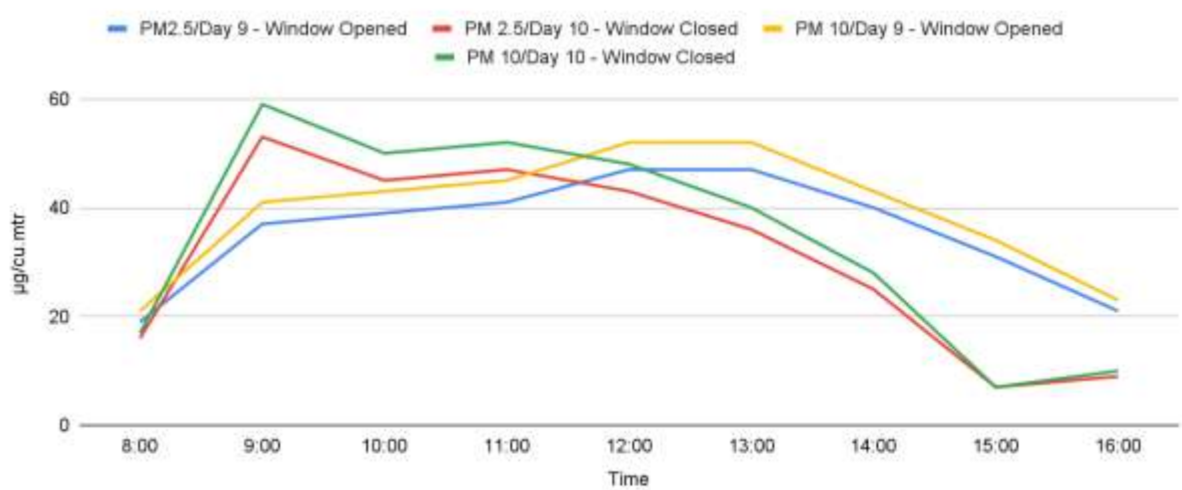

Figure 5: Indoor Particulate Matter Levels for Opened and Closed Window Status

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.

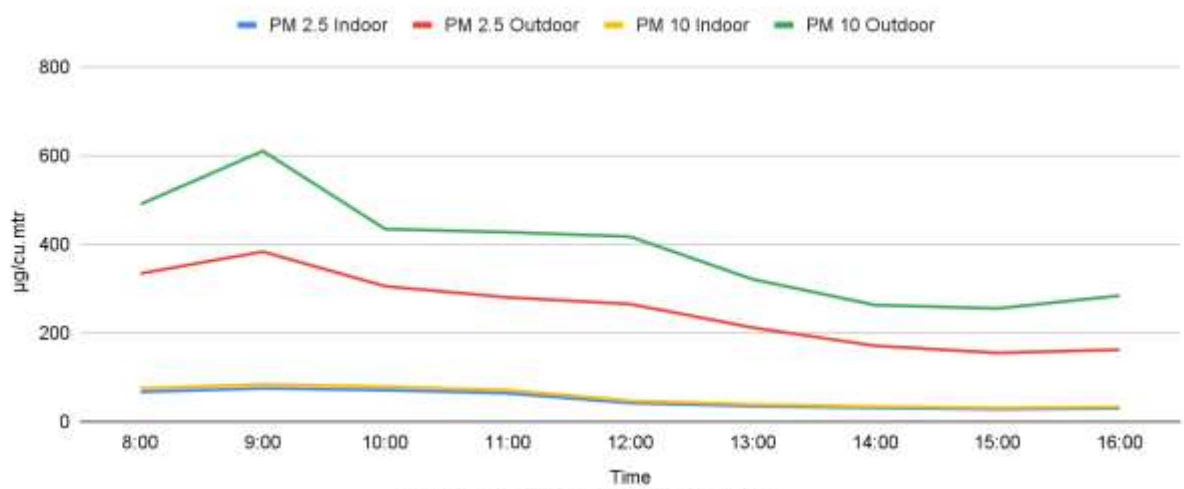

Figure 6: Particulate Matter Levels on Day 7

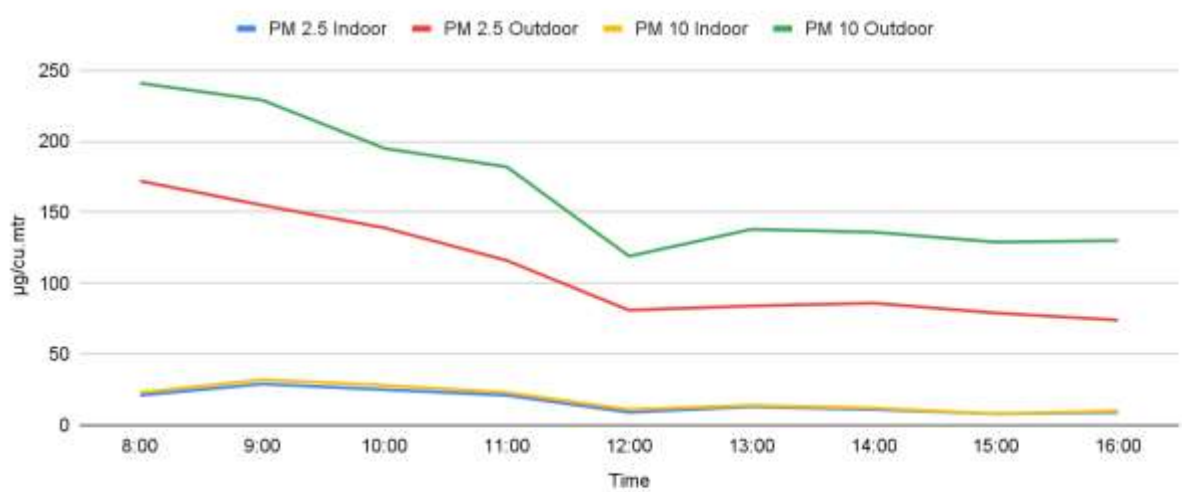

Figure 7: Particulate Matter Levels on Day 8- The Rainfall Day.

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 the 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.

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 the reducing the indoor levels, which may be contrary to popular belief. Closing the window, may play a very marginal role in 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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Declaration

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CASRAI CRediT based role of authors in the development of this manuscript:

The authors RS and TM were responsible together for Writing-original draft, Data Curation, investigation, and project administration.

Author RS was responsible for Conceptualization, Methodology, Resources (instruments) and Writing-review and editing.

Author TM was responsible for Visualization, Formal Analysis.

Author AD was responsible for Supervision

ORCID ID:
RS: 0000-0002-3203-1755
TM: 0000-0001-8108-176X

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