Investigations On Parameters For Analysing Effectiveness Of An Air Purification System

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Abstract - **Pollution has turn out to be a part of our day to day activities due to modernisation and unsustainability issues, therefore degrading place for stay in and making it a hell for our future generations. With or without our understanding constantly heading towards to a time, when everyones live turn out to be a point of starvation. Owing to indoor air pollution children are deadliest victims and air as an essential element, stays uncontrollable not like other pollutions. All humans cannot easily visualise indoor air pollution except it gets mentioned on our medicals reports. Investigation on parameters associated with air purification system methodology begins with analyzing various trends in indoor air pollution via facts available, continuing mitigation measures, and finalizing a measure which needs concentration and feasible are carried out. It is observed that filtration is a measure that desires to be integrated with various innovations in the related field. In this paper, all required and desired parameters and methods available are focused and summarised for development of better air purification system.**

***keywords* - Air Purifier, Indoor Air Pollution**

I. INTRODUCTION

As mankind progresses their desire for comfort increases. This need for comfort is fulfilled by designing and developing modern shelters, vehicles, fuel-burning stoves, air conditioners, refrigerators also many other types of equipment for comfort.

This development comes at the price of environmental pollution which comes as a by-product of vehicles, construction of buildings, fuel-burning for cooking, smoking cigarettes and development of industries, etc. This pollution leads to adverse health effects like respiratory illness, decreased lung function, development of diseases like asthma, etc. US Environment Protection Agency (EPA) positioned Indoor Air Quality among the top five concerns related to public health.

Indoor air quality is specially related to occupant's health and comfort. Poor indoor quality can trigger health problems like asthma and allergies also many diseases related to eyes, lungs, nose, and skin. Indoor air quality is not only related to health but comfort also.

Sick Building Syndrome (SBS) is a clinical situation where humans suffer from illness caused due to breathing poor indoor air quality. It consists of a number of symptoms that occur to the occupants residing in the household for a very long time, or different indoor areas like office and school. Poor indoor air quality can decrease the overall performance of office work by 69%. Indoor air pollution is additionally linked to acute respiratory infections, which are the leading cause of global mortality in kids 5 years old or younger (Bruce, Perez-Padilla and Albalak 2000; Duflo, Greenstone and Hanna 2008).

WHO reports that due the household air pollution caused by the inefficient use of solid fuels and kerosene for cooking around 3.8 million people a year die prematurely from illness attributable pollution. The effects of indoor air pollutants range from short term effects throat and eye irritation to cancer and long-term effects on respiratory disease.

In a report published in 2019 by the state of global air by the Boston-based health effects institute, independent global health, and air pollution research organization, due the household air pollution an estimate of 846 million people in India were in threat of poor health effects. That's 60% of the country's population.

Table 1: Air quality standards by various organisation

IAQ parameters	INDOOR AIR QUALITY STANDARDS				
	EPA	ASHRAE	WHO	OSHA	INAQS
CO	9 ppm (8 hr)	9 ppm (8 hours)	10 mg/m3	50 ppm (8 hours)	2 mg/m3(8 hours)
CO2	–	1000 ppm	–	5000 ppm	-
PM 10	150 μg/m3		50 μg/m3	15 mg/m3	100 μg/m3
PM 2.5	65 μg/m3	–	25 μg/m3	5 mg/m3	60 μg/m3
SO2	140 ppb	–	20 μg/m3	5 ppm (8 hours)	80 μg/m3
NO2	53 ppb (annual)	–	40 μg/m3 (Annual)	5 ppm (8 hours)	80 μg/m3
			200 μg/m3 (1 hour)		
NH3	-	-	-	-	400 μg/m3
Ozone					100 μg/m3(8 hours)
Lead					1μg/m3
Temperature	-	22.8 to 26.1 °C	–	–	-
Humidity	-	30 % to 65 %	–	–	-

EPA: United States Environmental Protection Agency
ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers
WHO: World Health Organization
OSHA: Occupational Safety and Health Administration
INAQS: Indian National Air Quality Standard

II. LITERATURE SURVEY

Research institutes and manufacturing industries across the world have done a lot of research. To get clean and purified air these days, indoor air technology mostly uses two kinds of technologies: Seizure (Capture) type and Reactive type. The capture type filters remove the impurities from the air by filtration and adsorption, which lets clean air pass through, leaving pollutants on the filter. The gaseous pollutants in the air are mainly removed by reaction type principle by ionization or chemical reaction. Generally used chemical reaction mechanisms are photocatalysis, UV germicidal technology, plasma, and ozone oxidation. Also, there are three universal capture air-cleaning techniques: Mechanical filtration, electrostatic precipitator (ESP), and hybrid air purifiers [1].

Two German brothers Klaus Hammes and Manfred Hammes in the year 1963, invented the first air purification system. They used a fiberglass pad and attached it small magnets to the air outlet of a residential oil oven, and the Hammes brothers were able to filter soot (dust) from the air, which boosted the quality of air in residences in Germany. The main components of mechanical filtration are fans and dust collecting filters. The fan in the air purifier draws the polluted air inside it, and particulate particles are get filtered by diffusion, interception, impact, or inertial force [2].

According to Oh H.J. et al. (2014), the filters for filtering PM2.5 are generally made up of High-efficiency particulate filters (HEPA: High-Efficiency Particulate Air), and the material used for it is ultrafine synthetic fiber or glass fiber. In the 1940s, to assist soldiers and lab workers involved in the Manhattan project, High-efficiency particulate air filter (HEPA) was invented to avoid the ill effects of radioactive matter. Nowadays, HEPA filters are widely used in food industries, pharmaceutical industries, as well as nuclear industries. [3]

According to Park et. Al (2017), Glass fiber, and quartz fiber are mostly used as central components of HEPA. The most important feature of this material for partial collection is a high efficiency, but the resistance is too much. The particulates are deposited on filter first and then deposited on a filter surface[4]. A study by Jessica L. Rice et.al (2018) mentioned that the more prolonged use of mechanical filter leads to clogging of the filter. As the particulate matter continues to deposit on the filter, the resistance to air also increases, which makes the fan to consume more energy. Additionally, this might lead to the escape of contaminants from the filter, and the filters are needed to replace with a new one after a certain period to get better efficiency[5].

In the case of Electrostatic precipitation (ESP), suspended particles from air are removed by using electrostatic force. An ESP contains discharge electrodes and collecting plates, by using corona discharge ions and electrons are produced. These ions attach to suspended solid particles, which are then stuck to either positive or negative polar plate[6]. In 2017 Shao et al. mentioned that the ESP air cleaner does not need to replace the filter regularly like a mechanical filter that needed to replace time to time. The ESP filter can be recycled by cleaning it after turning OFF the power [7]

Mostly electrostatic air cleaners remove particulate matter and gaseous contaminants like NO_x. The economy and filtration efficiency is improved by combining the ESP technique with another filtration mechanism in a Hybrid air purifier. According to Wongaree et al., 2016 the fibrous filters in which collect charged particles do not require HEPA because the filtration efficiency increases as charged particles charge the fiber filter material [8], but these ESP cleaners may generate secondary pollutant like ozone gas.

The physical and chemical adsorption is the primary mechanism which most of the air purifiers in the market often use to remove harmful gases or VOCs, such as formaldehyde, SO_2, NO_x, benzene, and toluene in the air (Xiao et al., 2018)[9]. The main advantage of this is whatever the concentration of pollutants, the sorption effect can be decent, and speed is fast. However, the adsorption material is needed to be replaced once it is saturated.

In 1989 NASA discovered that indoor plants could absorb harmful toxins from the air. Dr. Wolverton from NASA has developed a prototype in which contaminated air is passed through plant root bed via three embedded manifold tubes and traps the VOCs by the mixture of activated carbon and shale pebbles. The adsorb VOCs then convert to food sources for a plant by microbes formed by the root system of plants[10].

W. J. Fisk (2013) researched particle filtration in non-industrial buildings such as homes, schools, offices and concluded that "Particle filtration can be modestly effective in reducing adverse allergy and asthma outcomes, particularly in homes with pets"[11]. In 2005 David Berry et.al tested commonly available air purifiers to analyze the effect of air purifier on indoor to outdoor particulate concentration ratio in a residential environment and found that these air cleaners may have the capability to remove pollutant from the actual residential air[12]. Also, to enhance indoor air quality Vijayan et.al (2015) suggested air purifiers as one of the best strategies to improve indoor air quality[13].

III. EXPERIMENTAL SETUP

For air cleaner performance measurement, the experiments should be conducted in a closed chamber. The room dimensions should be approximately a total volume of 70 m3 free space exists. The room doesn't have any force ventilation or fresh air supply source except doors and windows that can be opened. The room should be maintained at a condition of 20 to 30 ^{0}C temperature and 40% to 50 % relative humidity.

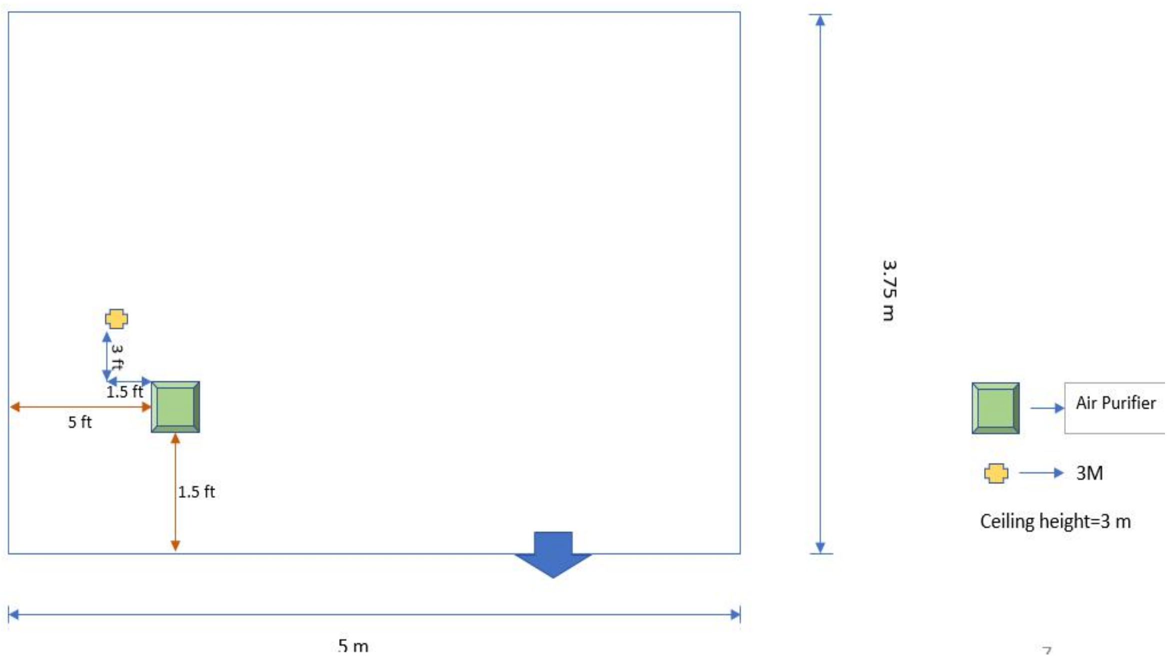

Figure: Instrument Setup

IV. METHODOLOGY & EXPERIMENTATION

The essential air cleaner performance characteristics critical to IAQ (indoor air quality) are Particle removal efficiency, emission, and by-product formation, Clean air delivery rate, change in performance of filter with age, Energy consumption.
From the user's viewpoint, there are specific performance characteristics of air cleaner that are of interest.

- Particle removal efficiency
- Pressure drop
- Clean air delivery rate
- Energy consumption
- Amount of sound generated

MATERIALS AND METHODS

A. Particle Removal Efficiency

Generally, filtration efficiency is measured by counting particle concentration at upstream and downstream of filter and estimated by,

- $Particle\ Removal\ Efficiency\ (\eta) = \frac{Particle\ Trapped}{Particle\ Upstream} \times 100$ (1)

In our case, we cannot use this method since we're conducting a test in a room where output air effect or mix with the input air because of recirculation of air the filtered air may pass through the filters again. Efficiency can thus be calculated by setting a ground data and then running the instrument for some time and comparing the change in PM concentration from the initial values.

For particle removal efficiency, other methodologies like ANSI/AHAM AC-1, JEM 1467, and other CADR measuring methods involve background data collection, which provides the general information about particle concentration, temperature, and relative humidity of test room and changes in them as time varies. The background data also helps in calculating the natural decay rate of particles. For particle decay rate with air cleaner, the door and windows of the room were kept open for about 10 min to let the outside air inside the room as ambient air was used as target aerosol in the room after that air purifier is allowed to run with keeping room closed. The monitoring is done with the help of EVM-3 3M, which shows the real-time data of temperature, humidity, and concentration of Particulate matter. 3M monitor work on the principle of light scattering sensors.

B. Pressure Drop

The concern of indoor air quality issues has led to the increased use of more effective air filters. The drawback of using a more effective air filter is that they have high flow resistance to the airflow. Thus, increased resistance produces a higher pressure drop across the filter.

This higher-pressure drop leads to increased air bypass or increased fan power consumption to maintain the airflow rate. This pressure drop keeps increasing as the filter gets dirty. The pressure drop across the filter is measured with the help of a differential pressure gauge.

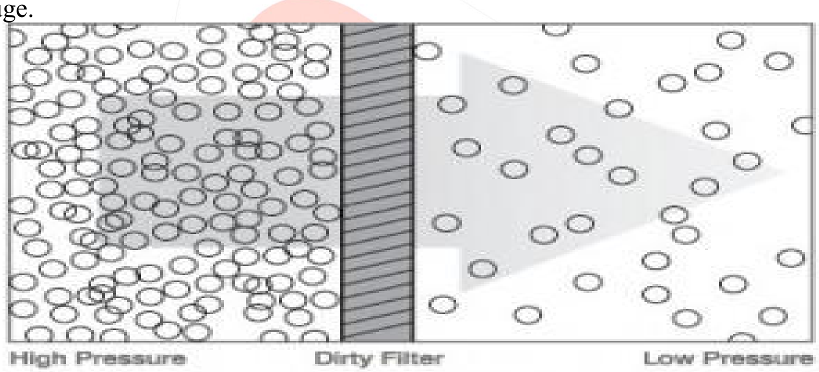

Fig – 4.1 – Pressure drop across the filter

C. Clean Air Delivery Rate

The cleaning Effectiveness of Air purifiers is mostly quantified by Clean Air Delivery Rate (CADR) as a universal metric. To get CADR value, the initial and final particle concentration is measured without the air cleaner. Then again, the same test is repeated with turning the air purifier ON. The decay rates K are determined by measured particle decay concentration C_t and initial particle concentration C_0.

$$CADR = V\,(K_{AC} - K_n) \quad (2)$$

Where K_{AC} is Particle decay rate constant in min^{-1}

Kn is Natural decay rate constant in min^{-1}

V is Volume of testing room in m^3

The airflow rate(Q) is measured at five different points on orifice by using an anemometer, and then the average of all those points gives the airflow rate of the fan. The product of particle removal efficiency and airflow rate gives CADR for air purifiers.

CADR= Particle removal Efficiency × Volumetric Airflow Rate (3)

D. Electrical Power Consumption

Energy consumption is the parameter directly related to the economy of an air purifier. Three major components of life cycle costing formula are initial investment and maintenance, energy consumption and disposal. The cost breakdown on the basis of operational characteristics shown in the figure.

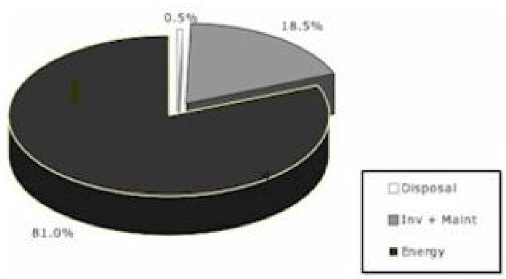

Fig -5.2- LCC

The energy consumption in filter-based air cleaners is related to the pressure drop across the filter. As the pressure drop increases fan will consume more power which will increase the costing to use it. also, a very low-pressure drop can lead to less effective filtration which lets particles roam in the air, to avoid these situations energy consumption for optimum final pressure should be calculated.

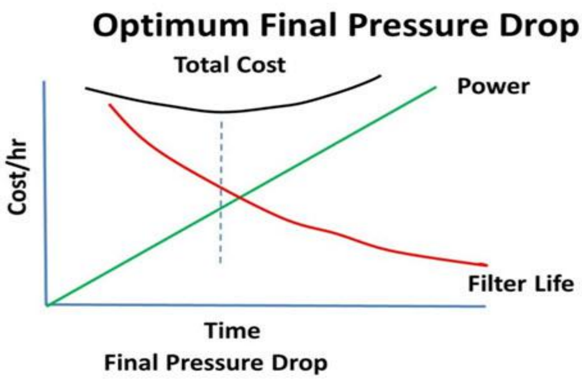

Fig – 5.3 – Optimal final pressure drop [22]

$$\text{ENERGY CONSUMPTON} = \frac{(Q * \Delta P * t)}{(\text{Fan Efficiency} * 1000)} \quad (4)$$

Where,

Energy consumption in kWh

Q is Airflow rate in m^3/s

ΔP is Average pressure drop

t is the time of operation in hours

The electrical power measurements can be conducted with the help of a single-phase multifunctional meter such as MECO EM-09. The air purifier is connected to the meter and turned ON. This instrument Measures V, A, PF, Hz, KW, KVA, KVAr, Kwh, KVAh and KVArh. The readings are being noted for 15 minutes at a 1-minute interval. Then the mean value of collected data gives the power consumed by the equipment.

E. **Noise**

Clean air by an air purifier is good and healthy for human life. But does clean air have to come at the cost of peace and quiet? Most of the air purifiers make too much noise while cleaning air which is not acceptable for comfort and peace which we want. The noise comes from it measured in dB(A) which should be minimum as possible.

Following table shows the noise level of different things in dB(A)

Table -2 – Noise level chart

Sr. No.	OBJECTS	dB(A)
1	A threshold of human hearing	0
2	Rusting leaves	10
3	Very quiet air purifier	15
4	Whispering	20
5	Good air purifier on low setting	32
6	Typical air purifier on low speed	36
7	Fridge	50
8	Normal conversation	60
9	Dishwasher	50-70
10	Small orchestra	72

11	Vacuum cleaner	80
12	Lawn mover	90

Noise level greater than 50 dB(A) makes normal conversation difficult.

V. RESULTS AND DISCUSSIONS

A number of effectiveness analysis techniques have been studied. Most of the investigators utilised only few of the parameters including clean air delivery rate and particle removal efficiency. But to achieve all desirable factors that users ask are studied and research methods to measure all required parameters for optimal effectiveness analysis of an air purifier are described here.

The simplest approach to this analysis is measure every parameter in same environmental condition. By doing this we can achieve better results with minimum chances of getting error. Also, the system should be less noisy.

One most important parameter for analysing air purifiers is CADR. CADR is very difficult to measure without having proper experimental setup and a close chamber with maintained environmental condition. Also, maximum particle removal efficiency and minimum power consumption holds important aspects for air purifier better performance.

Generally, purpose of an effectiveness analysis is to determine only particle removal rate. But in this paper, authors tried to cover all desired parameters and methods to evaluate purifier performance.

VI. CONCLUSION

Based on study and investigations, following conclusions are made. Important parameters are identified for development of air purification system, indicates very useful for improving indoor air quality. Observations for airflow shows that airflow rate of air-cleaner is adequate to clean air in that room. Power consumption rate is an important parameter for energy efficiency of the purification system.

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