Design and analysis of Air purifier

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Abstract - *Air purifiers are increasingly used to improve indoor air quality and promote healthy living and working environments. In this study, we designed and analyzed an air purifier for a standard office space using a combination of literature survey, market research, software tools, and simulation techniques. We conducted a comprehensive search and screening of research papers related to various aspects of air purification, ventilation, design of air filter and narrowed down our focus to the specific domain of air purifier design and analysis. We used Solidworks software to design the air purifier and conducted CFD analysis using ANSYS Fluent to gain a better understanding of the airflow, removal, and capture of dust, pollen, and other airborne contaminants. Our results showed that the designed air purifier based on best possible filter selection was effective in removing pollutants from indoor air, with a suggested standard air purifier capacity for a standard office space and residential bedrooms. The simulation results were validated by comparison with analytical solutions. Our study highlights the importance of air purifiers in maintaining healthy indoor air and provides insights into their design and analysis along with the filter design.*

Key Words: Air purifier, Indoor air quality, Design, analysis, Solidworks, CFD, ANSYS Fluent, Simulation, pollutants, Office space, clean air delivery rate.

1.INTRODUCTION

Air purifiers are devices designed to improve the quality of indoor air by removing pollutants, such as dust, smoke, allergens, and other harmful particles. The air quality in indoor spaces, such as homes, offices, schools, and hospitals, can have a significant impact on the health and well-being of the occupants. Poor indoor air quality can lead to a range of health problems, including allergies, asthma, respiratory illnesses, and even cancer.

Air purifiers have become increasingly popular in recent years, as people become more aware of the importance of maintaining healthy indoor air. With the rise of air pollution levels, natural disasters, and pandemics, air purifiers have become an essential tool in ensuring that indoor air is safe and healthy.

The significance of air purifiers is particularly evident in areas with high levels of outdoor pollution, such as cities and industrial areas. In these areas, the use of air purifiers can help to reduce the harmful effects of pollution on human health, particularly among vulnerable populations such as children, the elderly, and those with pre-existing health conditions.

In addition, air purifiers are also important in workplaces, where the quality of indoor air can have a significant impact on productivity, absenteeism, and employee health. For example, in office spaces, air purifiers can help to reduce the spread of germs and viruses, particularly during flu season.

2.PROPOSED METHODOLOGY:

1) The project was initiated with the selection of air-purifiers as the topic of research.
2) A comprehensive search and screening of research papers related to various aspects of air-purification were conducted, including performance evaluation, ventilation, applications, and emerging technologies.
3) The analyzed research papers were discussed in the research work.
4) The team narrowed down their focus to the specific domain of air purifier design and analysis to check effectiveness and suggest a standard air purifier capacity with best possible filter selection along with ventilation and heat treatment study for a standard office space .
5) Solidworks software was utilized to design the air purifier, taking into account market research and available air purifier models.
6) CFD analysis was conducted using ANSYS Fluent to gain a better understanding of the airflow, removal, and capture of dust, pollen, and other airborne contaminants.
7) The results obtained from the CFD simulations were validated by comparison with analytical solutions.

3.CONSTRUCTION AND PERFORMANCE OF AIR PURIFIER

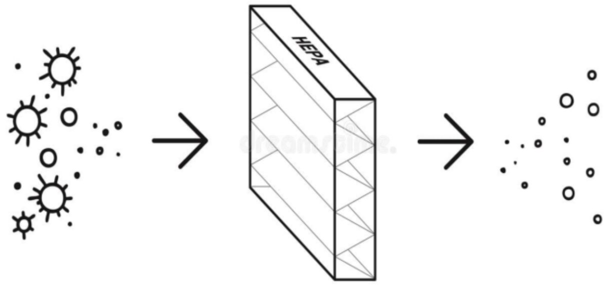

Fig -1: HEPA Filter

Air Purifier's function is to reduce, remove or prevent the Contaminants present in air. Hence, all these functions are performed by filter. Hence, Filter is the most essential component of AP. There has been evolution in the filters and hence the classification of filter is discussed. To improve the performance of Air purifier we need to be keen on the selection of the filter and filtration process, i.e., air purification technique.

3.1.Types Of Inside Air Filtration Technique-

Capture type is based on separation, prevention, removal of contaminants present in air and **Reactive type** includes reaction which involves some kind of transformation to the contaminants of air, i.e., ionization, catalysis , oxidation etc.

Normally, reactive types of Air Purifiers can cause some problem of smell, odor due to chemical reaction & hence causes unnecessary pollution. Therefore, Capture type of Air Purifiers are preferred over reactive type Air Purifiers .

3.2.Types Of Capture Filters-

1. Mechanical filter (HEPA - high efficiency particulate air)
2. Electrostatic Precipitator (ESP ionizer)
3. Hybrid

Mechanical filter consists of prefilter, fan & casing and the purification process is diffusion. Its efficiency is affected by fan speed, filter material characteristic and structure of Air purifier i.e., coverage area etc. Mainly porous fibrous material is preferred as filter.

ESP uses high voltage electrode & Collecting electrode and electricity is generated, by creating electrostatic field. In the presence of electrostatic fields contaminants are ionized and with collision, they continue the chain of ionization. Due to influence of electric field forces, charged particles flow in direction of electric field & are collected on collecting electrode. Hence electrodes need to be charged or maintained to improve functionality. However, this process generate smell with ozone generation that process may hamper IAQ.

Hybrid AP combines static electricity with filtration. In which, ESP removes gases contaminants and Mechanical filter removes other contaminants. HEPA filter, a fibrous material with ionizer has been taken in the purification system that we have taken for analysis. The efficiency for good HEPA is about 99.97%. Along with these 2 filters, two Pre-filters are placed at front & back as they remove Contaminants > PM 2.5 easily and can be replaced at low cost or can be maintained or cleaned very easily.

4.DESIGN AND CAD:

4.1.Objective Of Design :

The main objective of using design or CAD software in the research paper on air purifiers is to create a prototype that meets the desired specifications and is capable of efficiently removing airborne contaminants. CAD software is used to design the air purifier, considering market research and available air purifier models.

4.2.Selection Of Software:

In this project, Solidworks software was chosen for designing the air purifier due to its versatility and user-friendliness. Solidworks offers a wide range of design tools that allow for efficient creation and modification of 3D models. It also offers advanced simulation capabilities that enable the researchers to evaluate the design and make informed decisions. The availability of a vast library of pre-built parts and models in Solidworks reduces design time and increases productivity. Additionally, Solidworks is widely used in various industries, making it an ideal choice for designing an air purifier that can be manufactured at scale.

4.3.Components Of Air Purifier:

The following are the components of air purifier.

1) Casing
2) Set of 4 Filter
   (i) pre–Air Filter
   (ii) 2 x HEPA Filter
   (iii) Activated Carbon Air Filter

4.3.1. Casing

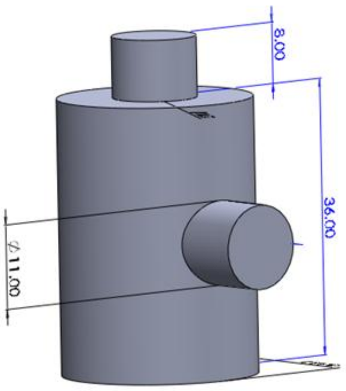

Fig -2: Volume of Body casing with inlet and outlet pipe

4.3.2. 4x Filter

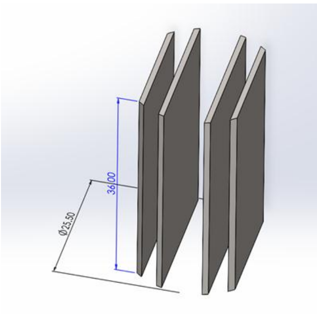

Fig -3: Isometric view of filter

4.3.3. Final Assembly of Air Purifier

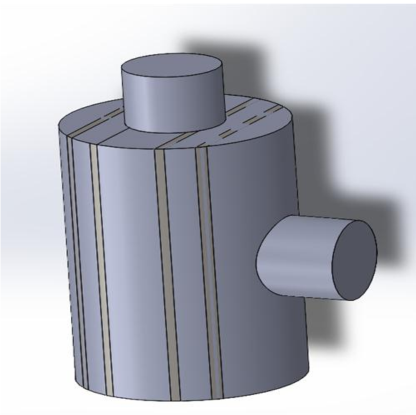

Fig -4: Isometric view of air purifier

5.SIMULATION:

5.1.Objective Of The Simulation :-

The design of the air purifier is done using American Micronic air purifier , the required dimensions for the purpose of design are obtained based on referring to it . Also, parameters of the air flow are determined using the analytical method. To compare the results, we require a software CAD model which will imitate the process of air flow and the capture of dust particles by the filter.

5.2.Selection Of Software :-

There are a number of software available in the market which allow the simulation of the airflow . Namely , Autodesk CFD , Simscale , Ansys Fluent , Open FOAM , Simcenter , Paraview etc. Among all these software we used Ansys fluent . The main reason for selection of Ansys Fluent was the amount of community help and tutorials available in the market about the same.

5.3.Process Of Simulation :-

The simulation of the air purifier has to be done in number of stages :-

a. Importing the geometry:

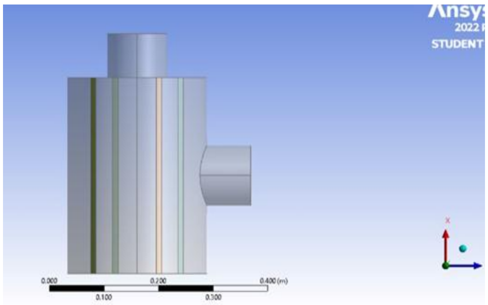

Fig -5: Modelling of air purifier in Ansys Fluent

The geometry which is created using the Solidworks software is imported in order to conduct further analysis on it.

b. Meshing of the Air Purifier:

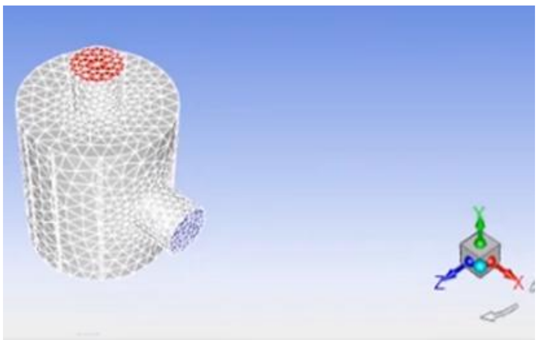

Fig -6: Meshing of model

In this step the geometry is divided into finite numbers of elements in order to obtain an approximate solution.

c. Setting up of the boundary conditions:

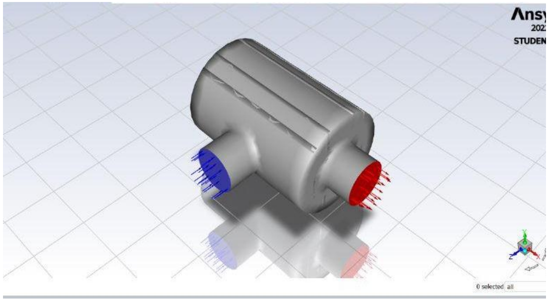

Fig -7: Boundary condition of Air purifier

The following assumptions of boundary conditions are made –

- Laminar viscous flow
- Suitable values of viscous resistance for the porous filter material
- inlet velocity magnitude
- outlet intensity and hydraulic diameter

d. Solution:

For the above boundary conditions the solution is obtained for 1000 iterations.

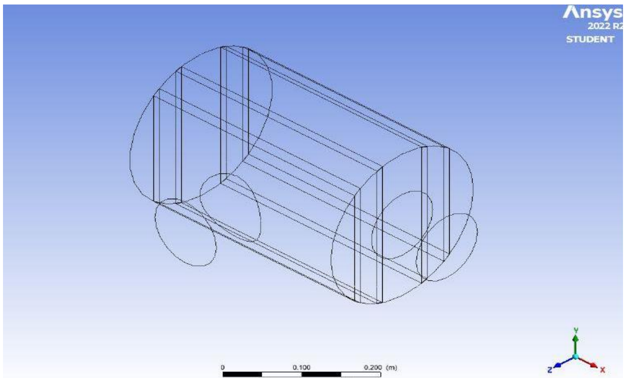

Fig -8: Initial condition before running iteration

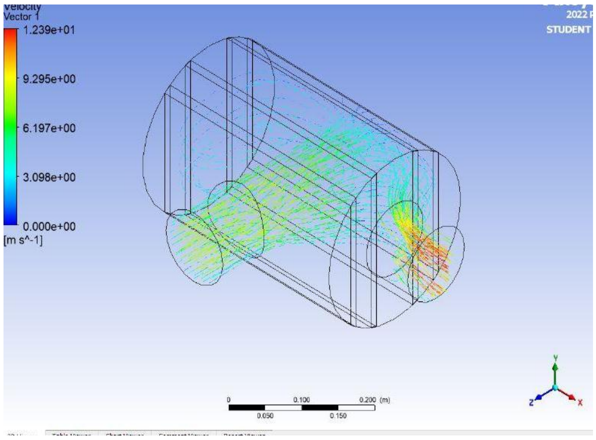

Fig -9: After running iteration

e. Obtaining the results :- The results in the form of a graph obtained are –

- Continuity
- Outlet air flow rate
- Outlet Mass flow rate
- Outlet Volume flow rate
- Permeability

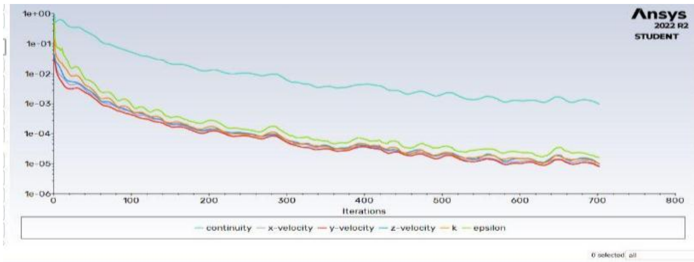

Fig -10: Plot of results

6.ANALYTICAL CALCULATION:

Fig -11: Multistage air filtration

6.1.Specifications:

1. Coverage area(CA): 300 sq.ft
2. Ceiling height(h): 10 ft

Normally, residential buildings have ceiling height of 9 to 11 ft in Mumbai.

3. Air changes per hour (ACH) : 3.5

ASHRAE recommends selecting ACH of 3 to 4, hence selecting the average value.

4. This AP efficiency is 99.97% as it filters 99.97% of dust, bacteria, odor & contaminants.
5. Multistage filtration is installed in the system consisting of Pre-filter, HEPA, ionizer and activated charcoal filter.
6. Power: 30W
7. Weight: 2.9 kg
8. Clean air delivery rate(CADR): 275 m^3/h
9. Dimensions: D25.5 x W25.5 x H36 cubic centimeters

Material: ABS

10. Efficiency: 99.97%
11. Color: Ivory & Grey
12. Control method: Touch
13. Model: AMI-AP2-30Dx

6.2.Calculations:

Dimension of bedroom: 20 x 15 x 10 cubic ft.
CADR is clean air delivery rate i.e., since the purifier filters the contaminants and impurities present in air and air at outlet or discharge is pure and clean. Hence the term CADR is used as a parameter to measure performance of the purification system.

CADR = (ACH x CA x H)/60
= (3.5 x 300 x 10)/60
= 175 cubic ft/min (1 ft is equivalent to 0.305 m)
= 175 x (0.305^3) x 60
= 274.3466 cubic m/h

CADR = Area at outlet x Velocity at outlet (diameter at outlet is 0.11m, outlet is circular in shape, V is velocity at outlet)

CADR = (3.142x d x d)/4 x V
274.3466 = (3.142 x 0.11 x 0.11)/4 x V
V = 8.019 m/s

The value of V is in range with the simulation results. Hence results are verified. Since the results are verified, we also need to define the accuracy of the solution and for that purpose we need to calculate the percentage error. If the percentage error is less than 5% i.e., 5% deflection from the actual values then the results will be accurate.
% error = (Actual - Calculated)/Actual x 100
Here, calculated value of CADR IS 274.3466 m^3/h and actual value is 275 m^3/h (specifications)
% error = (275-274.3466)/275 x 100
= 0.237596 %
The percentage error is under control i.e., <5%. Hence results are satisfactory.

7.VENTILATION AND HEAT TREATMENT

7.1.External Factors Affecting Air Purifier Performance :

Since the purpose of installation of Air Purifier is to free the air from contaminants or to keep the system free from contaminated air. Ventilation is the process of exchange of air in which fresh air is brought inside the system and expelling the contaminated air outside. Doing ventilation at regular intervals ensures the proper working and efficiency of the Air Purifier. This also leads to increase of intervals of maintenance and removal of filters and thus reducing the overall cost. Improving ventilation efficiency and performance further improves the performance and efficiency of Air Purifier. Hence, natural ventilation and PAC (Portable air conditioners) combined yields better results than the individual Air Purifier installation.

Another thing which came to our notice with regards to Air Purification is the presence of harmful contaminants in air. It's very similar to polluted or contaminated water problem which is solved by boiling the water as the contaminants lose their functionality at the high temperature. The thing which brought this to our attention was that air as well as water both are very essential for human life to sustain. Hence, we studied and analyzed the feasibility and process of heat treatment of air and its limitations.

7.2.Proposed Solution-

Presence of contaminants like dust, pollen, and bacteria are the prime reasons for poor air quality. As we all know, these contaminants cannot survive when temperature is higher than 100°C as in the case of boiling water. Hence, air heat treatment is also an air disinfection approach. As mentioned in the calculations below, the same heat required for air and water to 100°C makes this method considerable. Sometimes, heating may require too much energy which results in an increase in expenditure. Continuous heat recovery from air already heated during the disinfection process hence energy & cost efficient. The process involves inactivation i.e., losing functionality of contaminants. Hence using kinetics equation of half-life.

The inactivation rate of virus in aerosol follows equation:

$C = C_0 . e^{-kt^n}$
Where ,
k α T
k α UV radiation
C – concentration of active virus at time t
C_0 – initial concentration of virus at time t=0
K – inactivation rate factor (min^{-1})
n – decay rate (0.5)

Experimentally at 20°C and 50%RH, half-life is 274 for the virus and Relative Humidity (RH) depends on the virus. The proposed solution is to heat above 50°C, where viruses lose their functionality.

Different methods of air purification / disinfestation are:

- UV radiation
- filtration
- ventilation
- photocatalysis

7.3.What Makes The Heating Feasible?

Human consumption of air (daily basis) = 14 kg
Human consumption of water (daily basis) = 3 kg
Energy required to heat to 100°C
For water,

$$Q = C_{water} M_{water} \Delta T$$
$$= 4.20\times3\times(100-20) = 1008 \text{ KJ}$$

For air,

$$Q = C_{air} M_{air} \Delta T$$
$$= 1\times14\times(100-20) = 1120 \text{ KJ}$$

Where,
C -Specific heat (KJ/KgK)
M -mass (kg)
T – temp difference (k)
Q - required for air and water is almost equal hence it is feasible to heat

7.4.How To Make Heat Treatment More Economic:-

It is required to set up a continuous heat recovery system due to:

- Reduce the cost of energy input
- Outlet air temperature reduction from system

Cost of thermal disinfection of air:-
Cost = R×0.31110.9
Where
R – cost of electric energy per KWh
0.9 - efficiency of conversion electrical to thermal energy
0.311 - equivalent of 1120 KJ

Out considering cost & efficiency of conversion, cost can be reduced by cheaper heat source (heat recovery used) i.e., heat exchanger(HE). Efficiency(h) of HE depends on:- Maximum heating temperature and the Exposure time.

However, heat treatment of air disinfestation cannot solve the problem of smell and odor in air and also it makes the air purification system bulky due to use of heat exchanger . Hence before adoption of this method we need to do more research and improve this method. However, this is an excellent area to be focused in future for the purpose of innovating the air purification process.

8. RESULTS AND DISCUSSIONS:

Table -1: Comparison of results

Sr. no.	Parameter	Analytical values	CFD simulation values or specification value
1	CADR (clean air delivery rate)	274.34 m^3/h	275 m^3/h
2	Velocity at outlet	8.019 m/s	9.29s m/s

The present study was conducted to design and analyse an air purifier for a standard office space using a combination of literature survey, market research, software tools, and simulation techniques. The air purifier was designed using Solidworks software, taking into account market research and available air purifier models. Capture filters were used for filtration, and the velocity of the air purifier was found to be in the range of 8-9 m/s.

To validate the simulation results, we compared them with analytical solutions. The results of the simulation and analytical solutions matched well, indicating the accuracy of the simulation technique. The clean air delivery rate (CADR) of the air purifier was found to be in the range of 250-300 m^3/h, which is within the acceptable range for an air purifier to be effective.

Our study also highlighted the importance of natural ventilation and portable air conditioners (PAC) for maintaining healthy indoor air quality. The recommended ventilation should allow for the natural flow of air into the space and should be combined with PAC to provide optimal filtration. Additionally, our study showed that heat treatment above 50°C is necessary to remove all airborne contaminants effectively.

In conclusion, our designed air purifier based on the best possible filter selection was effective in removing pollutants from indoor air, with a suggested standard air purifier capacity for a standard office space and residential bedrooms. Our study provides insights into the design and analysis of air purifiers, including filter design and recommendations for natural ventilation and heat treatment, to maintain healthy indoor air.

9. CONCLUSIONS:

This study highlights the importance of air purifiers in maintaining healthy indoor air quality. The designed air purifier is based on the best possible filter selection which was effective in removing pollutants from indoor air, capacity selection , ventilation and heat treatment suggestions . The insights gained from this study can be useful for designing and implementing effective air purifiers in indoor environments to promote healthy living and working environments.

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