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A Study of Wind Patterns as a Function of Ventilator Geometry

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Abstract

This paper investigates the effect of ventilator geometry on wind patterns within a model building. Computer based simulations were conducted with fixed parameters such as temperature, pressure, and room size. The ventilator position was varied, and the resulting wind speeds and wind patterns were measured for two inlet scenarios: inlet from window and inlet from the ventilator. These findings suggest that the optimal ventilator position depends on the desired airflow direction and the inlet location. When maximizing wind speed is the primary goal and air enters through the window, positioning the ventilator directly in line with the window is recommended. However, when the inlet is the ventilator itself, the position has less impact on wind speed, and other factors such as noise reduction or aesthetics may become more important considerations. Key findings from the simulations have been reported in this paper. Future research could explore the influence of additional factors such as building layout, and external wind conditions on airflow patterns within buildings.

Keywords
Wind Energy, Simulation and Modeling, Venturi Effect, Computer Aided Design, Environmental Science.

1. Introduction
Wind energy has a lot of potential in today's "energy hungry" living. Certain geometries allow for wind speed amplification because of the built-in "Venturi Effect". This study explores the effects of ventilator geometry and ventilator position on the wind speed and wind patterns in a model structure.

2. Literature Review
Wind Energy at COP28: COP28 offers a chance for climate leaders to enhance ambition and implementation for a more climate-resilient world. GWEC at COP28 was determined to triple the global renewable energy capacity by 2030 for a 1.5°C pathway, targeting 3-4 times increase in annual wind energy installations by the end of the decade. They aimed for wind to generate one-fifth of global electricity by 2030 and one-third by 2050.

The energy and industrial sectors, responsible for 58% of 2019's net emissions, require a decisive shift. A global 2030 target signals the urgency for unprecedented renewables deployment to limit global warming to 1.5°C. Scaling up utility-scale wind energy offers economic benefits and supports climate goals. To achieve this by 2030, governments should commit to concrete plans reflected in updated NDCs by 2023, collaborate to accelerate permitting schemes, and develop grid action plans. Grid systems must be upgraded for efficient integration of renewable energy, and supply chains need government-supported reviews for sustainability.

Despite wind and solar being cost-effective, market challenges hinder the industry. Evolving market and policy frameworks, integrating long-term price signals, and incentivizing high-CAPEX investments are essential. The wind industry's expansion should align with national environmental and biodiversity strategies. Collaboration between governments, industry, and civil society is crucial for permitting schemes and unlocking private sector input for a successful global energy transition.

3. Methods
A 7mx5mx5m room was selected as a model building for study. A ventilator, of size 0.7mx1m, was placed on the top, and its position was varied to study the resulting wind speed and wind patterns. The size of the window is 2mx3m.This is shown in Figure 1 below. Two situations were considered: inlet from the ventilator, and inlet from the window.

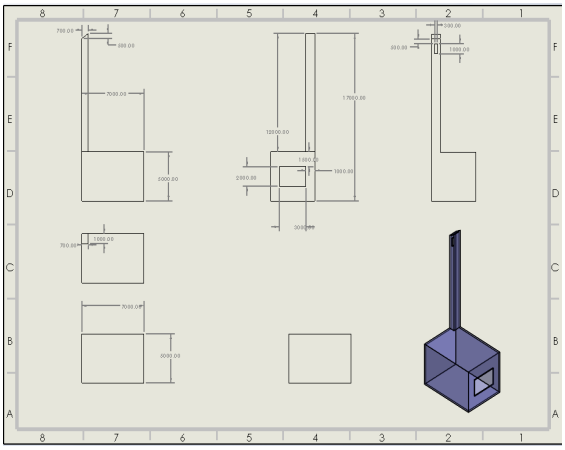

Figure 1. Model structure used to simulate the resulting wind patterns

4. Data Collection

The structure is modeled using SOLIDWORKS, and extensive simulations of the wind patterns have been performed using FloXpress. The effect on wind speed because of changing selected parameters of the structure have been studied. Selected cases of interest have been reported under the Results section.

5. Results and Discussion

Wind Patterns are presented in Figure 2.

Window to Chimney

- CASE A

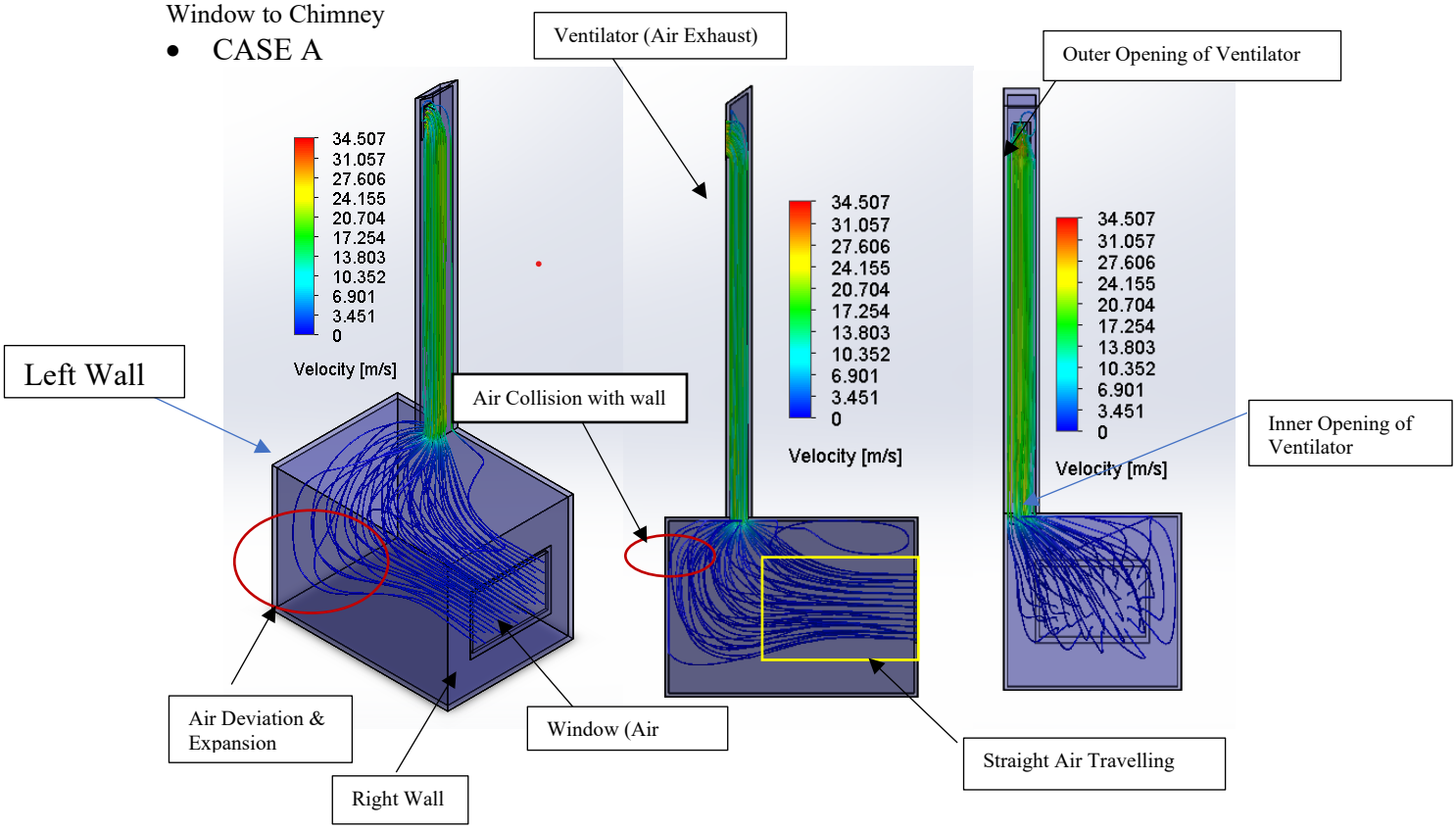

Figure 1. 1m from left wall

5.1. Discussion

In the above analysis, when the ventilator is positioned 1m from the left wall and a window is placed at the center of the right wall as shown in Figure 2, As indicated in the table above, the window has a cross section area of 3m*3m, while the ventilator has a cross section area of 0.7m*1m. By maintaining a lower pressure at the ventilator end compared to the window opening, we observed certain findings, which are detailed in Table 1. Specifically, the wind speed at the centroid of the ventilator opening increased from zero to 34.507 m/s when air was allowed to circulate into the room through the window and exit through the ventilator. Undoubtedly, the rapid velocity at that location can be attributed to the venturi effect, as the opening of the venturi has a smaller cross-sectional area compared to the window. As observed in the above scenario, the density of air layers is significantly lower near the window opening and even lower near the left wall. This is because the air has more time and space to expand in that area. On the other hand, at the ventilator, the air density increases as it moves upwards. However, the air speed reaches its maximum when it tries to escape from the room through the ventilator opening, where the cross section is the smallest. It is interesting to observe the movement of air layers within a room. The upper layers, located near the ceiling and closer to the ventilator, have a higher likelihood of maintaining a straight path. This is due to the support they receive from the ceiling and the lower layers. As a result, these upper layers tend to enter the ventilator more quickly and consistently. The air layers on the right side of the window are confined by the right wall and the layers on their left, causing them to follow a straight path and enter the ventilator sooner. However, the layers located on the lower side and opposite to the ventilator opening near the left wall or on the left side of the window tend to deviate from a straight

path and circulate within the room due to their support on only one side. Due to this, these layers require additional time to reach the ventilator opening. It is worth noting that when the ventilator is positioned near a window, specifically 1m from the left wall, the speed should be increased. However, it has been observed that the gap between the ventilator and the left wall allows for additional circulation of air. As the air collides with the wall, it then moves upwards, resulting in a decrease in the overall air density within the ventilator. The different layers do not enter the ventilator simultaneously, causing the air density to not reach its maximum level. As a result, the overall speed at the outer opening of the ventilator is limited to a velocity of 34.507 m/s.

- CASE B

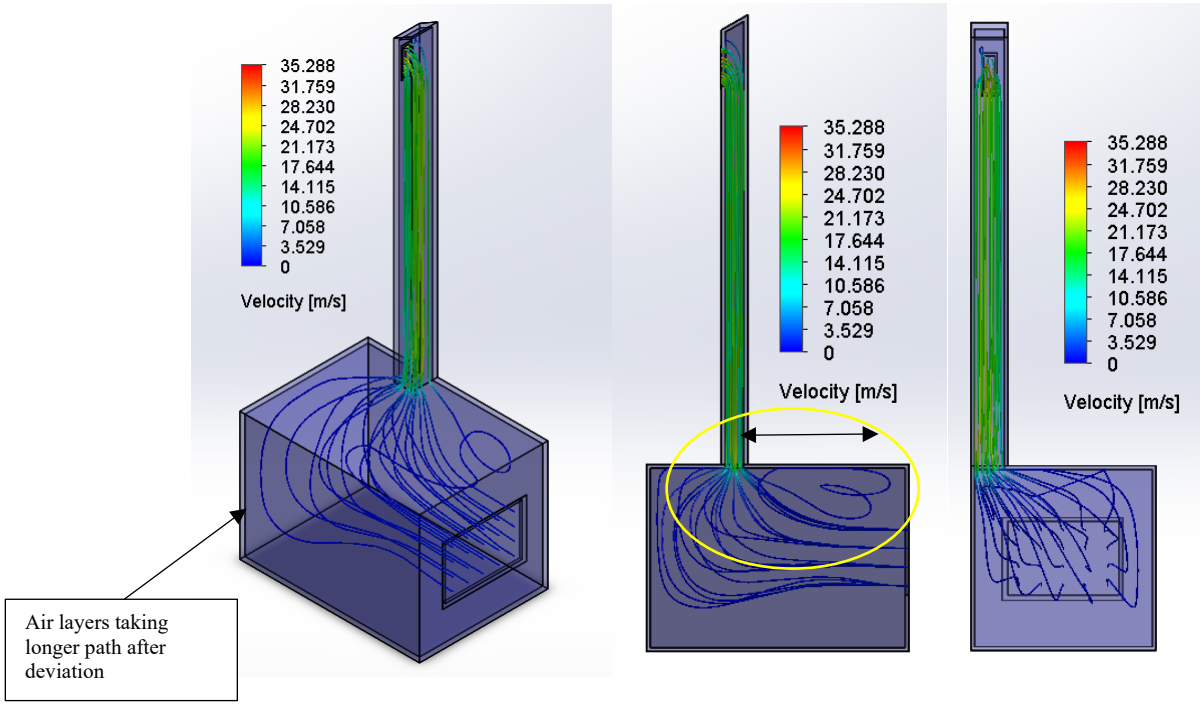

Figure 2. 2m from left wall

As discussed earlier, the speed of air is influenced by the path it takes and the support it receives from surrounding layers, such as room walls or other layers. In this scenario, it is evident that the distance between the ventilator and the left wall, opposite to the window wall, is greater compared to the previous case. This allows for more opportunities for the air layers to expand and deviate from a straight path into the ventilator. However, the most crucial factor in this situation is the proximity of the ventilator to the inlet window, as shown in Figure 3. This directly affects the air density in the ventilator, as the time it takes to enter or the path distance is reduced. This plays a significant role in enhancing the speed of the air. Similar to a previous occurrence in case1, the layers on the left side of the window lack support on the left, causing them to take a longer route to reach the ventilator opening. This results in a decrease in air density in the ventilator. This results in a significant waste of time, as well as the added inconvenience of traveling long distances through thin air layers, which decreases air density and reduces speed to 35.288 m/s instead of reaching its maximum potential.

- CASE C (Figure 4)

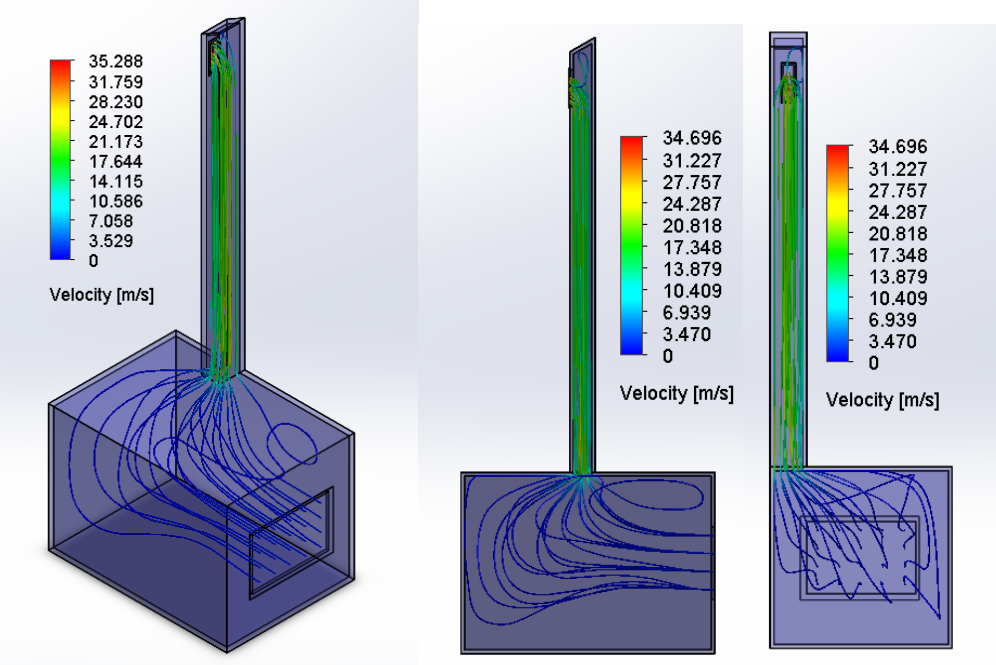

Figure 4. 3m from left wall

When the distance between the left wall and ventilator was increased to 3m, which is higher than in previous cases, it was expected that the speed would increase as the distance between the window and the ventilator decreased. However, it was surprising to observe that the speed at the outer opening, which previously depended solely on the air density in the ventilator, appeared to be influenced by another factor. This crucial element is the entering air that moves directly into the room or attempts to do so with some initial speed. In the analysis, this speed is assumed to be zero, although in reality it is not zero, but rather considered to be zero relative to the velocity at the outer opening of the ventilator. This optimal velocity aims to remove the surrounding air layers from the opening of the ventilator. As a result, there is increased time consumption and a longer route for most layers to enter the ventilator, leading to greater air expansion. Consequently, the overall speed is reduced to 34.696 m/s.

5.1.1 SWAPPING

Previously, the window was used for incoming air and the ventilator served as an outlet. However, at the moment, the inlet is sourced from the ventilator while the window serves as the exhaust. The remaining pressure conditions were also reversed, resulting in a lower pressure at the window compared to the ventilator. An analysis is conducted on the air pattern and wind speed at nine different positions in the past.

- CASE D

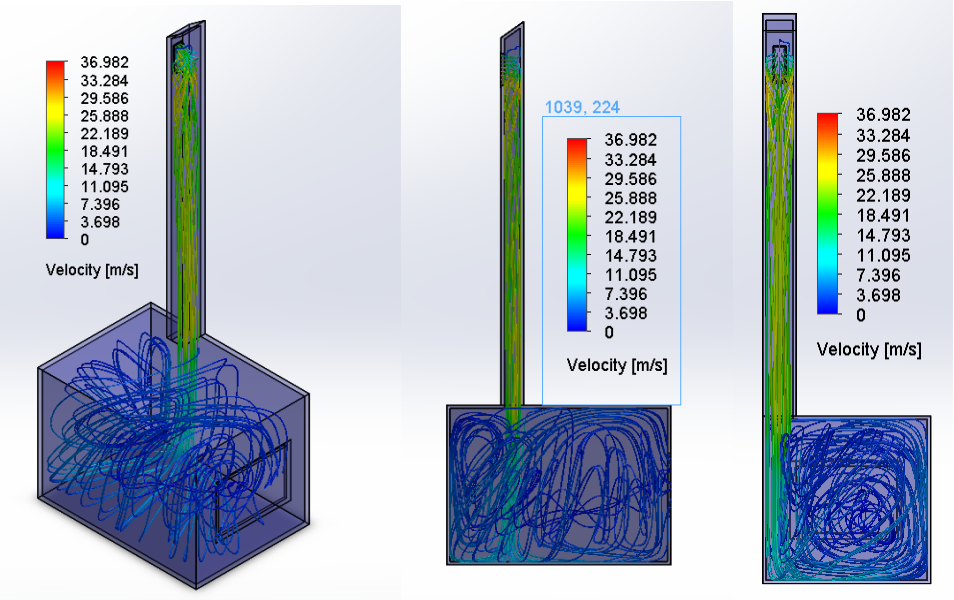

Figure 53. 1m from left wall

Upon the introduction of air through the upper opening, noticeable fluctuations in speed were observed, accompanied by the formation of an air pattern within the room. Upon entering the ventilator, the air speed was at its highest, reaching 36.982 m/s. Throughout the process, there were fluctuations in speed, indicated by color-coded variations of red, yellow, and green. The overall speed ranged from 36.982 m/s to 22.189 m/s. These variations are considered normal due to the natural variations in air density within the ventilator. It's fascinating to observe the pattern that emerges when the air is released from the ventilator and enters the room. The air in the room expanded throughout the space after being struck. The air, having circulated throughout the entire room, attempted to exit through the designated exhaust, which in this scenario happens to be a window. As shown in the Figure 5 mentioned earlier, the air loses its velocity almost completely after hitting the floor but continues to circulate throughout the room. This type of geometry is applicable in situations where the velocity of air is not a significant factor, but rather the resulting circulating pattern it generates. Additionally, there is a lack of air concentration only at the lower right corner.

- CASE E

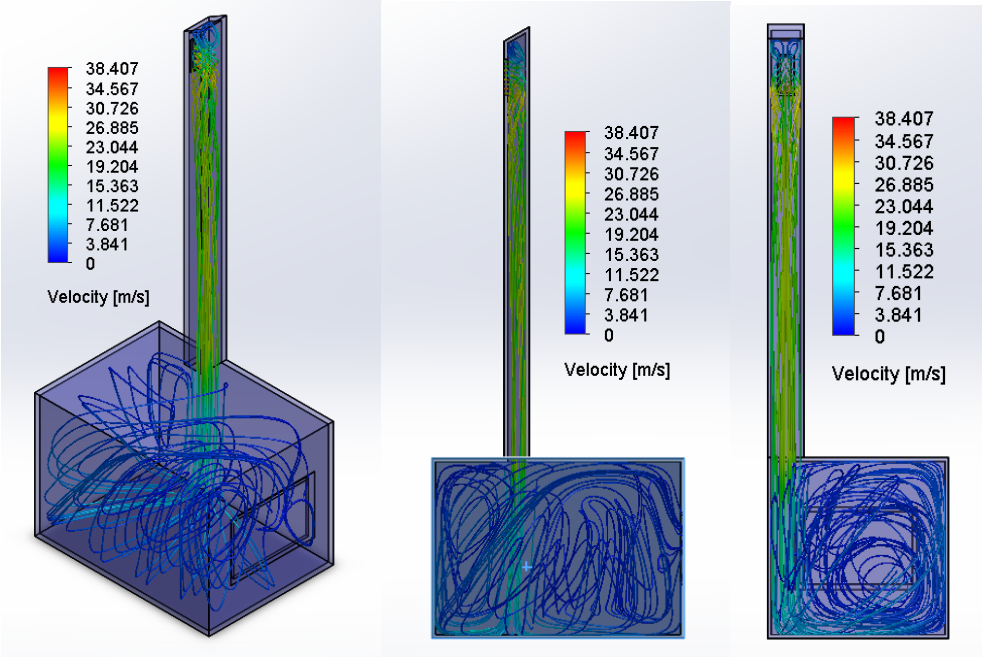

Figure 6. 2m from left wall

When the ventilator is placed 2m away from the left wall (Figure 6), the air pattern becomes somewhat similar to the previous one. However, the air escapes from the room earlier, resulting in a lower air concentration in the room. After the collision with the floor, a significant portion of the air quickly exits the room, while a small amount remains for a short period of time. The remaining air maintains a speed of 11.522 m/s. The rapid airflow prevents the air from lingering, resulting in a decrease in overall room concentration. Additionally, since the ventilator is located on one side of the room, there are no obstacles from any central air layers, allowing the air to freely exit through the window. There is a small section on the left that is attempting to remain in place temporarily.

- CASE F

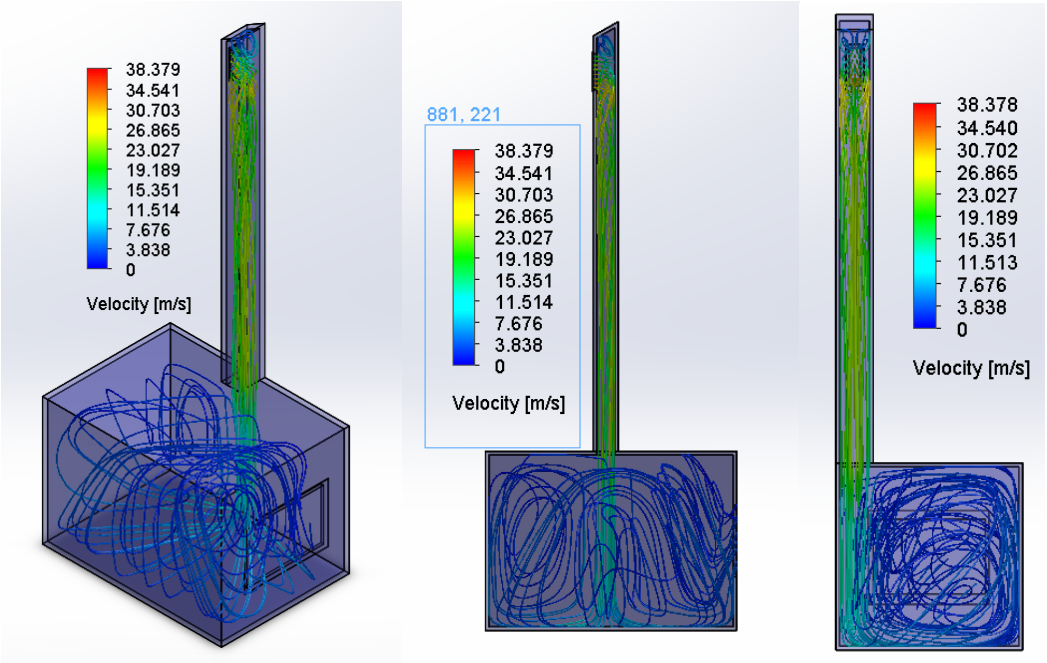

Figure 7. 3m from left wall

In this scenario, when the ventilator is shifted 1m forward from its previous position, there is a slight increase in air concentration on the left side of the ventilator. However, this only occurs in areas where there is a hindrance of air layers descending rapidly. However, all the layers quickly begin to shift towards the window. As a result, the airflow was unable to reach the corners of the room, as shown in the diagram above Figure 7. The extent of air expansion was quite restricted. The high speed of air, measuring 38.378 m/s, significantly contributed to the earlier escape of air from the room through the window. In general, the air concentration in the room was quite low. However, it is important to focus on the impact of the high-speed air as it descends and interacts with the floor. However, this small concentration is inadequate to cover an entire room.

5.2. Data Analysis

Table 1. Summary of Results

Effect of Chimney position on the wind speed (inlet from Window)									
FIXED PARAMATERS:									
Temperature:		Inlet (From Window) Pressure:	Outlet (From Chimney) Pressure:		Room Size	Window Size	Chimney Size	Vent Size	Vent Position
293.20 K		101325 Pa	100325 Pa		7m x 5m x 5m	3m*3m	0.7m*1m	0.3m*1m	0.5 m from TOP
OBSERVED PARAMETERS:									
Chimney Position --->	Extreme LEFT on LEFT WALL	1m from LEFT WALL	2m from LEFT WALL	3m from LEFT WALL	Extreme RIGHT on LEFT WALL	Middle of the ROOM	Extreme LEFT on RIGHT WALL	Center on RIGHT WALL	Extreme RIGHT on RIGHT WALL
Max Wind Speed (m/sec)	36.06	34.507	35.288	34.696	38.071	34.343	34.602	33.637	33.977
Effect of Chimney position on the wind speed (inlet from Ventilator)									
FIXED PARAMATERS:									
Temperature:		Inlet (From Window) Pressure:	Outlet (From Chimney) Pressure:		Room Size	Window Size	Chimney Size	Vent Size	Vent Position
293.20 K		101325 Pa	100325 Pa		7m x 5m x 5m	3m*3m	0.7m*1m	0.3m*1m	0.5 m from TOP
OBSERVED PARAMETERS:									
Chimney Position --->	Extreme LEFT on LEFT WALL	1m from LEFT WALL	2m from LEFT WALL	3m from LEFT WALL	Extreme RIGHT on LEFT WALL	Middle of the ROOM	Extreme LEFT on RIGHT WALL	Center on RIGHT WALL	Extreme RIGHT on RIGHT WALL
Max Wind Speed (m/sec)	38.815	36.982	38.407	38.378	38.699	38.01	38.202	38.272	38.151

6. Conclusion

Table 1 summarize the findings. We can note that when the air inlet is from the ventilator, and the exit is from the window, with a pressure difference of 1KPa between the two ends, we get a maximum speed of 38.82 m/sec. The ventilator is positioned at the extreme left side of the left wall of the room, opposite to the window.

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Biographies

Abu Huraira Atta Ullah is a final year industrial engineering student at the University of Engineering and Technology (UET), Lahore, Pakistan. He has strong skills in design and development, and project management. His Final Year Project (as an Industrial Collaboration) has a title "Design and Development of an Adjustable Pattern for Roller Shell Casting (Using SOLIDWORKS, Ansys, 3D Printing, MAGMASOFT)".
He has also completed the following semester projects:

- 2D Drawing of Complex Automobile Parts using AutoCad2020 in a semester project
- Comparison of experimental and theoretical calculations of weld strength using Charpy Impact Test
- Select the best material of crumple zone (bonnet) for the sake of safety of driver, passenger and car
- To evaluate the optimal kinematics of Watt's linkage based on Four Bar Mechanism
- Experimental Evaluation of Impression Machining of Aluminum Plates Using G&M Codes
- Performed Ergonomic analysis of Pakistan Railways Workshops by using tools of REBA, RULA and OWAS
- Design a robotic car with a robotic arm or end effector for hurdle detection and removal from the path using Arduino.

His field experience includes the Internship with Qadri Group of Companies Pvt. Ltd., Lahore, from 10th July 2023–21st August 2023 as a Leader for Manufacturing (LFM). He is the Department's Ambassador and has also served as the Chief Organizer for Departmental Sports Gala 2023.

Zoheir Hamid is an undergraduate computer science & engineering student at Mississippi State University, Starkville, Mississippi, USA.

Muhammad Ashhub Ali is an undergraduate software engineering student at the National University of Science and Technology (NUST), Islamabad, Pakistan. He has strong skills in Cloud Computing, Web Engineering, and Embedded Systems.

Dr. Anjum Ali completed his Ph.D. degree in August 1988 from the University of Alabama, Huntsville, Alabama, U.S.A. He has been teaching Electrical and Computer Engineering subjects since March 1978. His first teaching appointment, as a lecturer of Electrical Engineering, was at the University of Engineering and Technology (UET), Lahore, Pakistan, after winning gold medals in each of the last three years of his undergraduate engineering education. His teaching experience includes twelve years at Mercer University, Macon, Georgia, USA, and about nine years at three different universities in Saudi Arabia. As a tenured ECE faculty member at Mercer University (1988-1999), he developed and taught a number of computer engineering courses, starting from the first undergraduate course in the area to various advanced MS level electives. He has also worked, as an associate professor, at the Lahore University of Management Sciences (LUMS), Lahore, Pakistan, from 1996 to 1998 (on leave from Mercer University). During his stay at LUMS, he developed the computer engineering portion of the CS curriculum and helped the university transition from the quarter system to the semester system. He served as the chairman of the Electronics Engineering and Instrumentation Department at the Hail Community College (now University of Hail), Hail, Saudi Arabia, from February 2000 to June 2002. During his stay there, he developed a four-year degree program in Electrical Engineering for the University of Hail. Dr. Anjum Ali moved to Pakistan in July 2002, and joined Al-Khawarizmi Institute of

Computer Science (KICS) at the University of Engineering and Technology, Lahore, as a professor in December 2002. During his stay at KICS, he initiated many research and development projects and won research grants. He also developed teaching materials related to courses in computer architecture for the Virtual University of Pakistan. He has been a professor of Electrical Engineering at the National University of Computer and Emerging Sciences, (FAST-NU), Lahore, from May 2005 to May 2018. He was the Head of Electrical Engineering from March 2007 to September 2013, and during this time he developed multiple long-range policies and procedures for the university, which are still in place. He was also the Acting Director, Lahore Campus, at different occasions during his stay at FAST-NU, Lahore. Dr. Anjum Ali served as the convener of the National HEC Computer Engineering curriculum development committee. The HEC committee (NCRC) developed and finalized the 2009 HEC Computer Engineering Curriculum for all Pakistani universities. Dr. Anjum Ali has taught many EE, CE and CS courses and supervised numerous graduate as well as undergraduate students during his 40 years of teaching career. He has over 30 conference and journal publications. He is also the founding editor of the FAST-NU Research Journal. His areas of current research interest include embedded control systems and computer architecture.