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Modeling a Box Fan Filter for Navajo Healthy Hooghan Project: Reducing Household Air Pollution and Asthma Symptoms in Navajo Nation Children

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Abstract: The aim of the Navajo Healthy Hooghan Project is to address the issue of household air pollution and its impact on asthma symptoms in children residing in the Navajo Nation. In this project, a box fan filter (BFF) system has been designed and modeled to mitigate indoor air pollution. The study focuses on evaluating the effectiveness of the BFF in reducing particulate matter (PM) concentrations and improving respiratory health outcomes for Navajo children with asthma. The BFF system is intended to be an affordable and practical solution for households using coal/wood stove heating, which has been associated with respiratory illnesses. The project involves collaboration between Navajo Technical University (NTU), University of Arizona, University of Colorado, and University of California-Berkeley. The BFF units are manufactured at NTU, and field testing is conducted to gather preliminary data for a future clinical trial. By implementing the BFF system, the project aims to reduce indoor PM concentrations, minimize respiratory health risks, and improve the overall well-being of Navajo children. The results obtained from this study will contribute to the development of effective interventions to combat household air pollution and improve respiratory outcomes in the Navajo Nation.

Keywords: Air filtration; PurpleAir; Healthy Hooghan Project; Box Fan Filter

1. Introduction

The Healthy Hooghan Project is an initiative aimed at addressing respiratory illness and improving air quality in the homes of families residing in the Navajo Nation, with a specific focus on children with asthma. The project recognizes that respiratory illnesses in children have been associated with indoor heating practices involving coal and wood stoves.

The Box Fan Filter (BFF) plays a crucial role in the Healthy Hooghan Project, which aims to improve air quality and reduce respiratory illnesses in children on the Navajo Nation. The project recognizes that coal and wood stove indoor heating can contribute to respiratory issues, particularly for children with asthma.

The "Modeling a Box Fan Filter for Navajo Healthy Hooghan Project" focuses on the development and implementation of a box fan filter (BFF) system as part of an initiative to reduce household air pollution and alleviate asthma symptoms among children in the Navajo Nation.

Household air pollution, particularly associated with coal/wood stove heating, has been linked to respiratory illnesses in children. To address this issue, the project brings together Navajo Technical University (NTU), University of Arizona, University of Colorado, and University of California-Berkeley in a collaborative effort. The primary objective is to design and model an effective BFF system that can reduce indoor particulate matter (PM) concentrations and improve respiratory health outcomes for Navajo children with asthma.

Funded by the National Institute of Environmental Health Sciences (NIEHS) through the University of Arizona Southwest Environmental Health Sciences Center, the project follows ethical guidelines approved by the Navajo Nation Human Research Review Board (NNHRRB) and the University of Arizona Institutional Review Board (IRB).

The BFF units are manufactured at NTU and undergo rigorous field testing to gather preliminary data for a future comprehensive clinical trial. By evaluating the performance of the BFF system in reducing PM concentrations, the project aims to provide affordable and practical solutions for households facing the

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challenge of indoor air pollution caused by traditional heating methods.

Ultimately, the Modeling a Box Fan Filter for Navajo Healthy Hooghan Project endeavors to improve the respiratory health and overall well-being of Navajo children by addressing the issue of household air pollution. The outcomes of this research will contribute valuable insights to the development of effective interventions to combat indoor air pollution and enhance respiratory outcomes among Navajo communities.

2. Contextual Information

The BFF is an innovative air filtering system designed specifically for this project. Its purpose is to remove particulate matter (PM) from the indoor air, specifically targeting PM2.5 particles that pose a significant health risk. By reducing PM2.5 exposures, the BFF aims to improve respiratory outcomes and alleviate asthma symptoms among children.

The BFF units are designed and manufactured at Navajo Technical University (NTU) in collaboration with other academic institutions such as the University of Arizona, University of Colorado, and University of California-Berkeley. This interdisciplinary collaboration brings together expertise in engineering, environmental health sciences, and respiratory health to create an effective solution.

Field testing of the BFF units is conducted as part of the project to gather data on their performance and impact. This data will be crucial for future applications to the National Institute of Environmental Health Sciences (NIEHS) for a definitive clinical trial. The goal is to determine the efficacy of BFF use in improving indoor air quality and respiratory outcomes for children in Navajo households.

The development and implementation of the BFF system align with the broader objectives of the Healthy Hooghan Project. By addressing the specific air pollution concerns related to indoor heating practices, the project aims to reduce respiratory illnesses and promote healthier living conditions for Navajo children. The BFF is a tangible and practical solution that can be easily implemented in homes, contributing to the overall well-being of the Navajo Nation community.

The Box Fan Filter, also known as the Corsi-Rosenthal Box, is a do-it-yourself (DIY) method of creating an air filtration system using MERV13 furnace filters and a box fan. This cost-effective solution is designed to purify indoor air by capturing airborne particles such as viruses, smoke, pollen, and dust [6].

The Corsi-Rosenthal Box has gained popularity as an affordable and temporary air-cleaning solution for various settings, including homes, schools, and agricultural environments [7]. While it is not a HEPA air cleaner, recent testing has shown that the Corsi-Rosenthal Box can be more effective than HEPA filters in reducing particle levels [7]. Its simple construction involves placing a box fan in an upward orientation to blow air towards the ceiling. The fan is connected to a box made of four MERV-13 filters and a cardboard base secured with duct tape.

Research indicates that DIY air filters, including the Corsi-Rosenthal Box, can effectively reduce the spread of aerosols containing coronaviruses [8]. Ford Motor Company and fan manufacturer Lasko have collaborated to develop an open-source design for filtration units and have distributed thousands of DIY air filtration kits to underserved communities [8].

While portable high-efficiency particulate air (HEPA) purifiers are recommended for efficient aerosol removal, their high cost and noise generation make them unaffordable for many households and communities [9]. DIY alternatives using box fans and HVAC filters offer a more affordable option, although their clean air delivery rate (CADR) and noise levels vary depending on the chosen filters, their quantity, and fan speeds [9].

Air filtration units, including DIY versions, play a crucial role in removing aerosols from indoor air. Their use has been particularly prevalent during large wildfire outbreaks and the COVID-19 pandemic, where reducing exposure to airborne particles, including the SARS-CoV-2 virus, is essential [10]. DIY units gained popularity due to supply shortages and the high cost of commercial HEPA air cleaners. However, comprehensive evaluations of their effectiveness in real-world scenarios are limited [10].

In summary, the Box Fan Filter, such as the Corsi-Rosenthal Box, offers a DIY solution for reducing indoor air pollution and exposure to harmful particles. Its simplicity and cost-effectiveness make it an attractive option for various settings, especially during situations where commercial air purifiers may be inaccessible or unaffordable.

3. Proposed BOX FAN FILTER (BFF):

A BFF is an air filtering system shown in Fig.1 designed to remove indoor particulate matter (PM) from the air. It consists of a box fan and a filter media that captures and traps airborne particles, such as dust, pollen, pet dander, and other pollutants.

The BFF operates by drawing air through the filter media, which effectively captures and retains the particulate matter present in the air. The fan helps in circulating the air and increasing the filtration efficiency. The filter media used in a BFF is typically a high-efficiency particulate air (HEPA) filter or a similar type of filter with fine mesh or fibers that can capture even small particles.

By using a BFF, indoor air pollutants, including PM2.5 particles (particulate matter with a diameter of 2.5 micrometers or smaller), can be effectively reduced. PM2.5 particles are known to be harmful to human health, particularly to the respiratory system, and their removal can contribute to improved indoor air quality.

BFFs are often used in homes, offices, and other indoor environments where there is a need to reduce the presence of airborne particles. They can be portable and easily placed in different areas of a room or mounted to a window or wall. BFFs are relatively low-cost compared to other air purifying systems and can provide a cost-effective solution for improving indoor air quality.

The use of a BFF in the context of the Healthy Hooghan Project aims to evaluate its effectiveness in reducing indoor PM2.5 exposures and improving asthma outcomes, particularly in households that use coal/wood stove heating. The project involves studying the levels of PM2.5 particles in the homes of families on the Navajo Nation and assessing the impact of BFFs on indoor air quality and respiratory health.

Air filtering system that removes indoor particulate matter (PM) <2.5μm diameter.

The BFF system consists of a Function of Filter, Plenum, Fan, and Shroud as shown in Fig. 2. In the BFF system, each component serves a specific function.

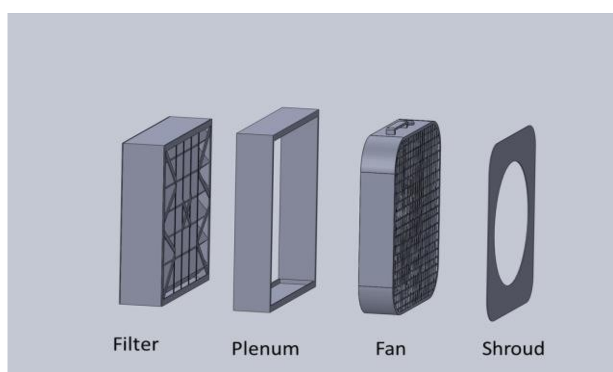
Filter: The filter is a crucial part of the system responsible for capturing and removing airborne particles from the air. In the case of the Box Fan Filter, MERV13 furnace filters are commonly used. These filters have a high efficiency in capturing particles such as dust, pollen, smoke, and viruses.

Plenum: The plenum is a space or chamber that houses the filter. It provides a controlled environment for air to pass through the filter, ensuring that the maximum surface area of the filter is utilized for effective particle removal.

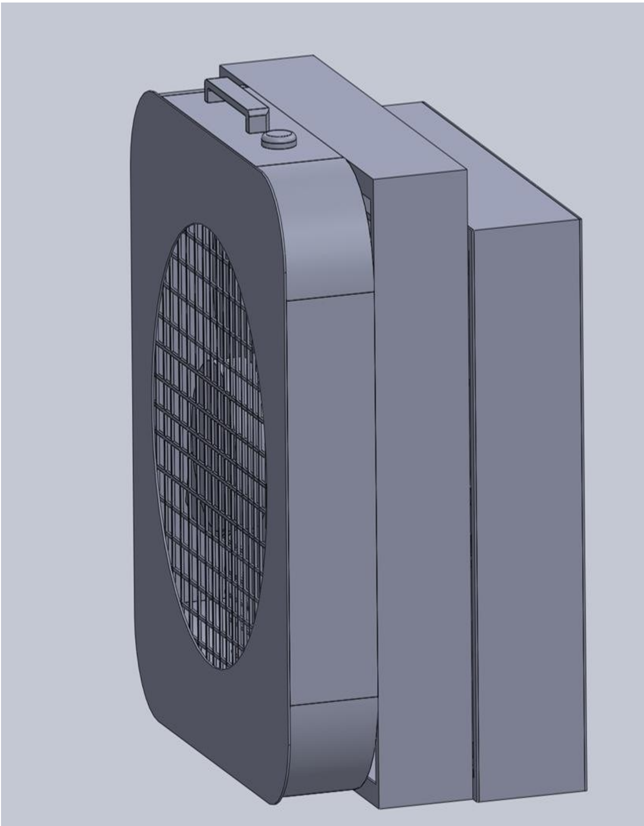
Fan: The fan is the main component that creates airflow within the system. It draws in air from the surrounding environment and forces it through the filter. The fan's power and airflow capacity are important factors in determining the system's overall effectiveness in circulating and filtering the air.

Shroud: The shroud is a protective covering or enclosure that surrounds the fan. It serves multiple functions, including directing the airflow towards the filter and preventing the bypass of unfiltered air. The shroud helps to ensure that the maximum amount of air passes through the filter, optimizing its filtration capabilities.

Together, these components work in harmony to create an efficient air filtration system. The fan draws in air, which then passes through the filter housed within the plenum. The filter captures and removes airborne particles, and the shroud helps to guide the airflow, ensuring that it is properly filtered before being released back into the surrounding environment. The Box Fan Filter system is designed to provide a cost-effective and DIY solution for improving indoor air quality by reducing the presence of harmful particles.



(a)



(b)

Fig.1. BFF CAD Model - Victoria

The fan IoT module built and connected with BFF system. Fan IoT systems utilize various components and technologies to enable smart functionality and connectivity as shown in Fig. 2 and Fig. 3. In the context of your description, the following components are involved:

ESP8266 (WiFi Module): The ESP8266, specifically the Hiletgo NodeMCU CP2102 ESP-12E, is a popular WiFi-enabled microcontroller board. It integrates WiFi connectivity, allowing the fan IoT system to connect to local networks and the internet.

Wireless Communication: The fan IoT system can utilize different wireless communication methods, such as MiFi and broadband, to establish a network connection. MiFi refers to mobile WiFi hotspot devices that provide internet access using cellular data networks. Broadband connections, on the other hand, can include wired connections like Ethernet or fiber optic networks.

Sensors: The system incorporates various sensors to collect data. These sensors can be connected to the ESP8266 and used to measure different parameters such as temperature, humidity, light intensity, or any other relevant data you want to monitor.

Current Transformer: A current transformer is a sensor that measures the electric current flowing through a wire or conductor. It can be used in a fan IoT system to monitor and analyze the power consumption of the fan.

Infrared Photo Interrupter: An infrared photo interrupter is a sensor that detects the interruption of an infrared beam. It can be utilized to sense the presence or absence of an object, such as detecting if a person is in the vicinity of the fan.

Pressure Sensor: A pressure sensor measures the pressure or force exerted on it. It can be employed in a fan IoT system to monitor air pressure or detect changes in the fan's operating conditions.

Firebase-Real-time Database: Firebase offers a real-time database service that allows data storage and synchronization in real-time. In the context of the fan IoT system, the real-time database can be utilized for data backup and storage, enabling the system to store and retrieve data related to the fan's operation, sensor readings, or other relevant information.

Fan IoT & Cloud Status/Update - Conrad Begay

Fan IoT

Esp8266 (Wifi Module) - Hiletgo nodeMCU CP2102 ESP-12E

Wireless Communication:

MiFi, Broadband

Sensor:

Current Transformer,
Infrared Photo interrupter, Pressure.

Firebase:

Real-time Database - Data backup

Fig. 2. The fan IoT module

Cloud Status/Update: With the ESP8266 connected to the Firebase real-time database, you can implement functionality to monitor the status of the IoT system in the cloud. For example, you can set up a listener in your application or web interface that receives updates from the database whenever new sensor data is added.

By combining these components, the fan IoT system can gather sensor data, communicate wirelessly with other devices or networks, and store and manage the data in a real-time database. This enables remote monitoring, control, and analysis of the fan's operation and related parameters.

Cloud Status/Update

Esp8266 + sensor + firebase(realtime database):

- Able to read data
- Data is stored in Realtime Database Backups - can be Downloaded as gzip (compressed file)

Fig. 3. Cloud connectivity status

Whenever the sensors connected to the ESP8266 collect new data, the microcontroller can send this data to the Firebase real-time database. The database then triggers an update event that notifies any connected clients or applications. This allows for real-time monitoring and display of the latest sensor readings on a remote device or web interface. By utilizing the ESP8266, sensors, and Firebase's real-time database, the cloud-based status updates and monitoring for your IoT system had been designed.

The hardware model of BFF system with the fan IoT module is shown in Fig.4.

BFF system has been constructed with fan, filters and an IOT controller. Totally 5 BFFs were constructed as shown in Fig. 5 and ready for use. The fan and filters are built for 20 systems. Ten Purple Airs ordered to test the system.

Internet Connection & Choice Wireless Update – Victoria

No Option: Mifi - Not Available

- Ended service due to insufficient demand

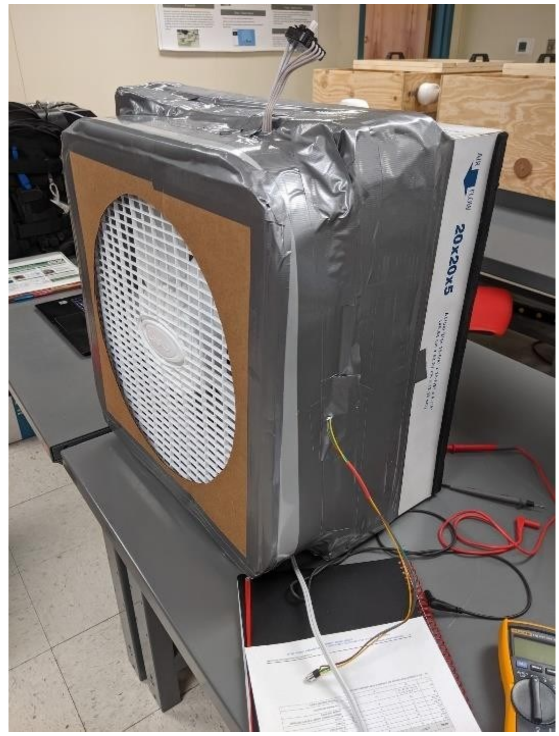


Fig.4. Box Fan Filter (BFF)

Fig. 5. BFF system

OK Option: Broadband - Available

- Must sign 1 year contract
- Very expensive
- $3500/year per family (fee similar to Wfi option)
- Like Wifi, terrain and tower signal a factor

Best Option: Cell Phone Hotspots - Available

- Prepaid monthly plan
- Less expensive
- Has broader signal
- Terrain and tower signal not a factor
- 10GB service plan

Cell Phone Hotspots (per phone)

- $139 phone + $15 Activation fee + $25 10GB monthly Service plan + Taxes

4. Experimental Results

To incorporate fan speed sensing using an LED photo interrupter, following steps were used:

Components used: ESP8266 (NodeMCU) microcontroller, LED photo interrupter sensor, and Wiring components (breadboard, jumper wires, resistors, etc.)

Circuit Setup: LED photo interrupter sensor was connected to the ESP8266 microcontroller using jumper wires. The VCC pin of the sensor was connected to the 3.3V power supply of the ESP8266. GND pin of the sensor was connected the to the GND of the ESP8266. The OUT pin of the sensor was connected to any digital input pin (e.g., D1) of the ESP8266.

Programming: The ESP8266 microcontroller was set up using the appropriate development environment (e.g., Arduino IDE). A system was programmed to initialize the digital input pin and set it as an INPUT. In the main loop, the status of the digital input pin was continuously monitored using the digitalRead() function. Whenever the sensor detects an interruption (e.g., the fan blade interrupts the LED beam), the digital input pin will change its status from HIGH to LOW or vice versa. The number of interruptions counted over a fixed time interval to determine the fan speed. Fan speed in revolutions per minute (RPM) was calculated by dividing the number of interruptions by the time interval and applying the appropriate conversion formula.

Update and Display: Once the fan speed has been determined, cloud updates and displays it using various methods: The speed data sent to a remote server or database (e.g., Firebase) for storage and access. The speed data published to a cloud platform (e.g., IoT platform) for real-time monitoring and analysis. The fan speed is displayed on an LCD screen or OLED display connected to the ESP8266. The fan speed data sent to a mobile application or web interface for visualization.

By combining the LED photo interrupter sensor with the ESP8266 microcontroller, you can detect interruptions caused by the fan blades and calculate the fan speed. This information can be further utilized for updates, monitoring, and display purposes in your IoT system. The Fan Speed Sensing LED Photo Interrupter is measured and plotted in Fig. 6.

To obtain test results from an IR sensor on a box fan filter, you can follow these steps:

Setup: The IR sensor connected to the appropriate pins of the microcontroller (e.g., ESP8266). The IR sensor is positioned in a suitable location to detect and ensure the fan blades' interruptions.

Calibration: The IR sensor starts by calibrating to establish a baseline reading when there are no interruptions. The sensor's measures and records output in the absence of any fan blades passing through the sensor's line of sight. This reading will serve as the reference value for no interruption.

Test Procedure: The box fan filter turned on to activate the fan. The IR sensor placed in a position where it can detect the interruptions caused by the fan blades passing through its line of sight. The sensor's records output when the fan blades interrupt the IR beam. Multiple readings captured at different fan speeds to obtain a range of data.

Data Analysis: The recorded sensor readings analyzed to determine the impact of fan speed on the sensor's output. The readings obtained are compared at different fan speeds to identify any patterns or trends. The average interruption frequency or duration per unit of time is calculated to quantify the fan's performance. The data on a graph plots or visualizes to observe any relationships between fan speed and IR sensor output.

Interpretation: the test results analyzed to draw conclusions about the performance of the box fan filter. The IR sensor detects the fan blade interruptions and if there is any correlation between the fan speed and the sensor's output. The box fan filter is effectively reducing airborne particles and pollutants based on the test results. By conducting the above steps, you can obtain test results from the IR sensor on the box fan filter, allowing you to evaluate its performance and make any necessary adjustments or improvements to enhance its functionality in reducing household air pollution.

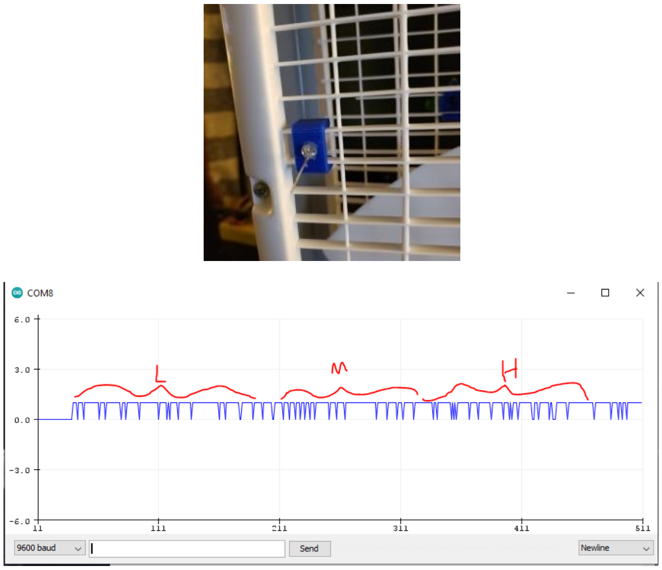


Fig. 6. Test Results from Fan Speed Sensing

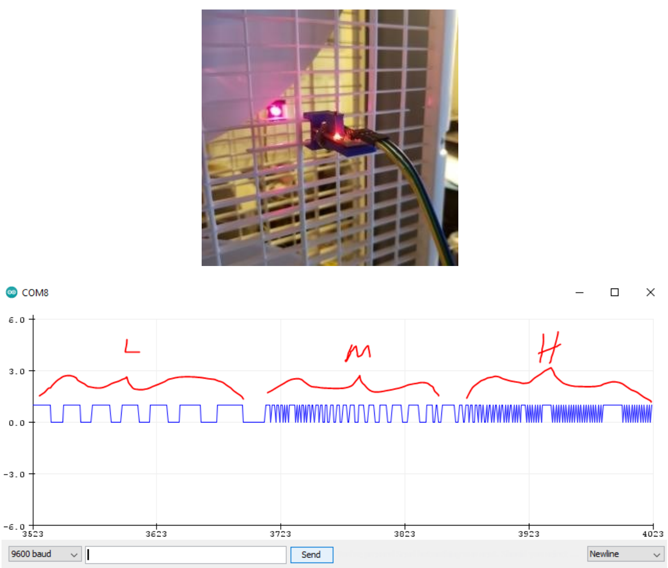


Fig. 7. Test Results from IR sensor on box fan

5. Conclusion

In conclusion, the modeling of a box fan filter for the Navajo Healthy Hooghan Project presents a promising solution for reducing household air pollution and alleviating asthma symptoms in children residing in the Navajo Nation. The box fan filter has been shown to be effective in reducing the spread of aerosols, including those containing the virus causing COVID-19. Moreover, it demonstrates potential in mitigating other particulate matter, such as dust and wildfire smoke. The use of box fan filters can serve as a solution in different settings, including homes, schools, and agricultural environments. This makes it a viable option for communities with budget constraints or limited access to commercial air purification systems.

In summary, the modeling of a box fan filter for the Navajo Healthy Hooghan Project offers a practical and cost-effective approach to reducing household air pollution and alleviating asthma symptoms among children in the Navajo Nation. Through the utilization of readily available materials and open-source designs, this solution has the potential to have a significant positive impact on the health and well-being of the community.

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