Zäpi Pür

BME 3300 Biomedical Engineering Design Report:

Submitted to

Prof. Zoe Reidinger

By:

Group 10

Anna Kjelgaard

Daniela Barbery

Jamie Moore

E. Thatcher Van Atten

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Abstract

As pollution in industrializing regions rises, more people have developed symptoms of allergic rhinitis, other allergy related diseases, and asthma. However, consumers are still not using the air filters currently on the market due to their quality, aesthetics and comfort. The goal of this project was to design a product that would filter pollutants and allergens effectively for daily use while remaining discreet. The team interviewed the client, surveyed members of the WPI community and researched the issues with the air filters currently on the market in order to develop design ideas. The most effective way to incorporate a high quality air filter into someone's daily activities is to integrate it into a piece of clothing because it is inconspicuous. The team chose to integrate an air filter into a scarf because it seals tightly, one size fits all, it is inexpensive, comfortable and fashionable.

Acknowledgements

Team 10 would like to thank Professor Zoe Reidinger for her support, advice and guidance throughout the course of the project. The team would also like to thank Lab Managers Lisa Wall and Elyse Favreau for their help in acquiring materials throughout the duration of the project. Additionally, the team offers their sincere gratitude to Teaching Assistants Alycia Abbott, Johanna Santos, and Kailey Castellano for their guidance and feedback throughout the design process. Lastly, a thanks to all those who participated in our survey. The creation of the final design would not have been possible without the help of each of these individuals.

Executive Summary

Background

Allergies affect millions of people all around the world. As levels of pollution increase, so has the prevalence of allergic rhinitis and other allergic diseases. Allergic rhinitis specifically, is one of the major risk factors for asthma. Approximately 400 million people suffer from allergic rhinitis around the world and approximately 300 million people suffer from asthma (Pawankar, 2012). Considering, these already high statistics, high levels of pollution can worsen asthma symptoms and pollutants are the smallest particles that current air filters can reliably remove from the air. The client initially tasked the team with creating an air filter for people who suffered from severe allergies, however the team decided to design the filter to also remove pollutants, considering the rising pollution levels around the world.

There are three main types of particles that could be potentially harmful to the human body: pollutants, pollen, and airborne food allergens. Pollutants are produced from factories, cars, and machines and have a wide range of sizes. However, the most dangerous particles to the human respiratory system are particles smaller than 2.5 μm. The World Health Organization estimates that 92% of the world's population lives in areas with dangerous amounts of pollution. The ingestion of pollutants is a definitely an issue across the world that needs to be addressed.

Pollen is the most widespread cause of allergies causing allergic rhinitis or “hay fever”. This disease affects up to 30% of the world population and the medical cost of treating allergic rhinitis is approximately $3.4 billion (Pawankar, 2012). Allergic rhinitis can be prevented by inhibiting the ingestion of pollen during the allergy seasons.

Asthmatic reactions to airborne food allergens are much more rare. However, when someone does have this type of allergy, the reactions can be very severe and are more likely to result in fatalities. Food allergies are most prevalent in the shellfish industry where an underestimate of 5-24% of workers in the industry develop occupational rhinitis to shellfish. Occupational asthma is actually very well known in the shellfish industry (Lopata, 2013). There does not seem to be a demand for a filter for airborne food allergens because these reactions are so uncommon.

This design is meant for daily use so the team focused on the three types of air filters that are used for this purpose. Nasal filters, respirators and portable air purifiers are currently the best products for personal air filtration. However, most people who live in areas with hazardous pollution or suffer from severe allergies are still not using them.

The nasal filters are a fairly new filtration device to prevent hay fever and other respiratory allergy symptoms. There are 2 types of filters: the nasal screens that go over the nostril openings and the nose plugs that go inside the nostrils. The nasal screens were developed to filter 99% of the airborne particles to reduce secondhand smoker risks, pet associated allergens, and disease causing pathogens. These filters are uncomfortable and fall out frequently.

Respirators are widely used across the world to prevent the ingestion of hazardous particles. There are various styles and efficiencies of these respirators so they can be useful for many applications. These respirators are not one size fits all and do not seal well on everybody.

The last filter the team researched was the portable version of household purifiers. The new air purifiers have recently become popular and are worn around the neck for removal of dust particles, allergens, and airborne microorganisms. These products have many drawbacks that prevent them from reaching the consumers that need them. The main drawbacks are their quality in filtering particles, their aesthetics and the amount of time it takes to filter the space around the user.

The team also researched the current patents on devices similar to the initial design ideas. The only relevant patent that was encountered in the search was a pending patent filed in 2006 title: “Personal Respiratory Filtration Apparatus” invented by Robert B. Vole, US Patent Number 20110079225A1. This patent highlights the use of a personal respirator that functions as an article of clothing as well as a support system for a breathable, treatable filter.

There are two primary regulatory issues associated with this project. The first regulatory concern is getting the respirator certified by the National Institute for Occupational Safety and Health (NOISH). Another regulatory concern comes from the Occupational Safety & Health Administration. This administration is run by the Department of Labor and is set up to keep employers accountable for the health and safety of their employees.

Need Statement

As pollution in industrializing regions rises, more people have developed symptoms of allergic rhinitis, other allergy related diseases, and asthma. However, consumers are still not using the air filters currently on the market due to their quality, aesthetics and comfort. The team's device must be able to filter particles as small as 0.3 microns, be long-lasting and durable for daily use, fashionable so that people are inclined to wear it in public, and comfortable in different climates.

Design Components

Once the design needs were specified, the team determined functional groups to begin testing the designs for each. The functional groups were the efficiency of the filter, the aesthetics of the device and the temperature in the device.

The filter used for the design was 1900 Filtrete by 3M used for home air conditioning systems. This was the maximum efficiency filter that the team could purchase in a large sheet in order to be able to wrap around the user's head completely. This filter also had pre-made ruffles which are essential for a good fit and seal. Ruffles allow the filter to be flexible while being rigid enough to cover from the user's nose to their chest without being pressed directly onto their face. The metal pieces that were used to secure the filter to the user's nose were obtained from surgical masks. The scarf was 65% polyester and 35% viscose because it is a very soft material, gentle on the skin, and also thin to keep the user as cool as possible. The scarf is plain grey, a neutral color, so that it can be worn with different outfits everyday. The ventilation valves were 3D printed with black ABS plastic and the silicon wafers inside were taken from ventilation valves of other masks. Overall, these materials cost approximately $12 for the final prototype alone.

Testing

Fit Test: The purpose of the fit test was to evaluate the claim that the device forms a tight seal for all users and to prove that the mask is legally allowed to be work occupationally.
Efficiency Test: To determine the effectiveness of our filter in filtering particles from the air effectively.
Temperature Test: The temperature test was performed to test the comfort of the scarf while in use, to provide determine whether exhalation valves decreased the temperature inside of the scarf and to determine the average and maximum temperatures experienced in the scarf while stationary, and while walking.
Air Filter Survey: The air filter survey was meant to determine what air filters are most commonly used, why people chose to wear different air filters and whether they would be more likely to wear a filter if it were in a scarf.

Recommendations

There are several improvements that could be made to the design for increased user benefit. The first recommendation the team suggests is using the 2300 Filtrete material instead of the 1900 Filtrete because it has a higher filter efficiency and the mechanical properties are the same. The design is tailored towards consumers who live in colder climates and are therefore, more likely to wear scarves anyway. The scarf material could be changed to cotton in order to better suit more consumers' needs. Many cultures around the world wear scarves or some kind of head dress even in very hot climates. In India, it is extremely popular to wear scarves covering the face because of the extreme heat (Saxena, 2014). The nose piece could be improved by having a more sturdy metal material for better hold and seal. The team recommends redesigning the ventilation valves in order to make them more low-profile while still having a large surface area allowing air to escape.

Conclusion

After interviewing the client, researching the health complications resulting from impure air, conducting a literature review of current products and surveying members of the WPI community, the team created a functioning prototype of an innovative air filter. The main problems with current air filters on the market are their comfort, their aesthetics and their overall quality. The team developed a scarf that has a removable air filter and two ventilation valves to maintain a low temperature. The filter attaches with velcro so that it can be replaced when it is difficult to breath through and the scarf can be washed. This product is fashionable so that it can have the potential to become a trend and reach large numbers of people across the world who suffer from the effects of impure air.

Authorship

Section	Primary Author(s)	Primary Editor(s)
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1.0 Design Problem Statement

As pollution in industrializing regions rises, more people have developed symptoms of allergic rhinitis, other allergy related diseases, and asthma. However, consumers are still not using the air filters currently on the market due to their quality, aesthetics and comfort. Our client tasked the team with developing a portable, durable air filter that could be used for daily activities. The client required that the device filter allergens for those who suffer from severe seasonal allergies and that it is comfortable and convenient for daily use. The specifications of other stakeholders such as the potential users and other air filter companies were also considered in the design of this product.

2.0 Background Research

Allergies affect millions of people all around the world. As levels of pollution increase so has the prevalence of allergic rhinitis and other allergic diseases. Allergic rhinitis specifically, is one of the major risk factors for asthma. This trend does not seem to be slowing down anytime soon because the environmental factors affecting patients continue to decline. There are three main types of air filters currently on the market: nasal filters, respirators and wearable air purifiers. Each of these products are meant to protect users against the harmful particles in polluted air and the tiny particles that cause allergic reactions. However, they each share several disadvantages that prevent them from truly reducing the symptoms of those who suffer from breathing impure air. The team conducted a literature review on the health issues included in the problem statement and an analysis of the current products in order to optimize the design.

2.1 Different Types of Airborne Particles

The ingestion of pollutants is an issue all over the world. These particles are the smallest that current filters can remove, therefore, the team focused on making a device that could filter these particles even though the client initially tasked the team with creating an air filter for people who suffered from severe allergies. Allergic reactions are caused by many different particles but pollen and food particles are the most common. The team researched each of these types of particles in order to gain a better understanding of how they can be filtered effectively.

2.1.1 Pollutants

The World Health Organization estimates that 92% of the world's population lives in areas with dangerous amounts of pollution. In 2012, there were over three million deaths related to or caused by breathing polluted air. Many cities, such as New Delhi, frequently reaches levels 13-14 times the safe limit.

Pollution particles from factories, cars, and machines have a wide range of sizes. However, by far the most dangerous particles to the human respiratory system are particles smaller than 2.5μm, commonly referred to as PM2.5. These particles are small enough to be ingested into the body and lungs, and are dangerous enough to cause both immediate and long term health effects.

Nearly all doctors recommend that city dwelling patients avoid spending time outside when pollution levels are high. This information is generally widely available from local weather forecasts and online sensors. Doctors also strongly suggest air purifying systems in homes, office buildings, and to use personal respirators when outdoors. (CDC 2015)

The EPA also has created an index of air quality in one of their subsets named Air Now. The service displays the air quality index in colors depending on the severity, green being 0-50 in the air quality units, and 300-500 being burgundy. Air now and the EPA issue advisories in the United States when air quality reaches dangerous levels in certain areas of the country. These advisories are to be taken seriously, as hazardous air quality is noticeably harder to breathe, and can contribute to short term health problems just from a few minutes of exposure. Other countries also have very similar systems to warn the public of unsafe air quality so as to advise people to stay inside and to wear proper respirators if outdoor activity cannot be avoided.(EPA n.d.)

2.1.2 Pollen

Pollen is the tiny round particles that are released from trees and many other plants during the spring, summer and fall. These microscopic particles are meant to fertilize other plants by floating around in air currents until they reach their destination. Pollen from trees, grass and weeds is the most common type that causes allergic reactions. The chemical makeup of pollen determines how likely it is to induce allergic rhinitis symptoms. For instance, the particle size of trees, grasses and weeds are small, light and dry so they are very easily transported by wind for long distances. Ragweed pollen has been collected 400 miles out at sea and 2 miles in the air. It can also produce a million grains of pollen per day during season. Pine pollen is less allergenic because its chemical composition makes it heavy so it settles to the ground quickly without travelling in the air very long (Pawankar, 2012).

Pollen is the most widespread cause of allergies. Many particles never reach another plant and instead end up becoming ingested by humans and triggering an allergic reaction. This type of seasonal allergic rhinitis is also known as “hay fever”. The symptoms of allergic rhinitis include: stuffy or runny nose, itchy and watering eyes, and sneezing. This is a result of the inflammation of the nasal mucosa when the pollen particles are inhaled through the sinuses. This condition affects up to 30% of the world population and the medical cost of treating allergic rhinitis is approximately $3.4 billion. Furthermore, these statistics are likely to be low because the symptoms can often be attributed to the common cold. 40% of the people who suffer from allergic rhinitis also have asthma, which is well known for the limitations it puts on someone’s performance in daily activities (Pawankar, 2012).

Allergic reactions to food, chemicals or animals are more preventable through simply avoiding close contact. In the case of pollen allergies, it is difficult to avoid even by staying indoors due to the fact that it is airborne and frequently carried by wind currents. This is why allergic rhinitis is the most common allergic disease. Epidemiologic studies show that it is increasing worldwide, especially in industrialized countries. Increased pollen levels are also observed in polluted urban areas (Pawankar, 2012). A pollen count is a measure of the concentration of pollen in the air in a certain area expressed in grains of pollen per square meter of air collected over 24 hours. The highest pollen counts are early in the morning on warm, dry, windy days and the lowest are on cold, wet days (Stöppler, 2016).

2.1.3 Food Particles

Asthmatic reactions to airborne food allergens are incredibly rare. However, when someone does have this type of allergy, the reactions can be very severe and are more likely to result in fatalities. It is widely believed that asthmatic reactions to airborne food particles are much more common than they actually are. Even many physicians mistakenly conclude that asthma, in some patients, is caused by airborne food allergens but avoiding the food in question did not improve the asthma symptoms. Food allergies can however worsen asthma symptoms when airborne food particles are ingested (Beausoleil, 2007). Although it is rare for food allergies to cause asthma directly, they do affect each other.

The reason why it is uncommon for food particles to cause asthmatic reactions is because the protein or the molecule that causes the reaction is large and generally does not become airborne in the quantity required to trigger a reaction. For example, if one person opens a bag of peanuts in an enclosed room with someone with a peanut allergy, the person with the allergy will most likely not react. However, if 20 people simultaneously opened bags of peanuts in an enclosed room with a person with a peanut allergy, there could be enough peanut protein in the air to induce a reaction (Pong, 2013).

The most common food allergies that result in reactions to airborne or aerosolized particles are shellfish and seafood allergies (Beausoleil, 2007). These are most prevalent in the shellfish industry where an underestimate of 5-24% of workers in the industry develop occupational rhinitis to shellfish (Lopata, 2013). This can result in respiratory symptoms, dermatitis, or both. Occupational asthma is actually very well known in the shellfish industry (Lopata,2013). This suggests that there is some degree of correlation between the two.

2.1.4 Hospitalizations and Demand

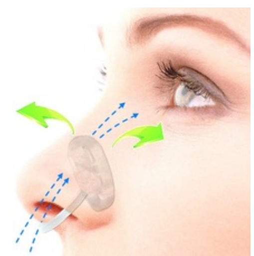
For this project it is essential to analyze the demand and why this demand is not being met with the products on the market currently. One of the ways to analyze this is to target a specific user. To find this specific target we searched through different respiratory and airborne hospitalization rates and demand in the United States. In 2014, the U.S. Department of Health and Human Services (DHHS), CDDP, and National Center for Health Statistics came up with hospitalization data of hay fever and respiratory allergies cases. For children, the frequencies for hay fever were 6,124 and for respiratory allergies were 7,352. These frequencies are predominantly between the ages of 5 and 17 years old. These frequencies were higher in the southern US (5,699 cases) than in any other region with more cases in respiratory allergies than hay fever. The second region with the highest frequencies was the west side of the country (3,155) with more cases in hay fever than respiratory allergies. For adults, the frequencies of hay fever were 19,089 and for asthma were 17,713. Most of the adult hay fever cases and respiratory disease hospitalizations are between the ages of 18 and 64 years old, 15,301 cases of hay fever and 14,634 cases of asthma. In the past 12 months 25.2 million people in the US have been diagnosed with hay fever, 7.4 million people with respiratory allergies, and ~25 million with asthma (CDC, 2014). These numbers are alarming, specifically all the hospitalizations of moderate/severe cases that do not seek preventative medicine.

2.2 Current Air Filters

There are many different air filters on the market for construction, painting, military and other jobs that place workers in environments with harmful air particles. This design is meant for daily use so the team focused on the three types of air filters that are used for this purpose. Nasal filters, respirator and portable air filters are currently the best products for personal air filters. However, most people who live in areas with hazardous pollution or suffer from severe allergies are still not using them.

2.2.1 Nasal Filters

Nasal filters are a fairly new filtration device to prevent hay fever and other respiratory allergy symptoms. There are two types of filters: the nasal screens that go over the nostril openings and the nose plugs that go inside the nostrils. The nasal screens were developed to filter 99% of the airborne particles to reduce secondhand smoker risks, pet associated allergens, and disease causing pathogens. The nasal screens (Patent No. 8,550,079 and 9,132,300) are placed externally on the nostrils to filter all the air that goes through the nose (First Defense). These nasal screens come in 3 different sizes (small, medium and large) and a package of 7 pairs costs around $10 to $14 online (Amazon). They were first sold in 2010 and about 1.7 million units have been sold. This filters are not recommended for children under 12 years old without adult supervision due to their size. The nasal filters are plugs that go internally in the nostrils and bridge over the outside of the nose, as seen in Figure X. This nasal filter comes in packages with different nose sizes, shapes, and functions with an average cost of $17 online (3 nose plugs per box and a replacement filter for each). The filtration media for this plugs is a 3M filter. There is the single layer replacement made of woven mesh (0.04mm) to filter pollen, pet hair and dander. Another replacement is the electrostatic filter with a thinner fiber layer to filter pollen, dust, mold and germs. The third replacement uses an activated carbon layer and electrostatic filter to filter vehicule exhaustion and second-hand smoke. The cons of these two products are: they can be uncomfortable to wear, the screens/filters are disposable (can get really expensive), they only filter the nose (pollen, dust, etc can go through the mouth), and it is difficult to fit varying nose sizes and shapes (WoodyKnows).



2.2.2 Respirators

Respirator filters are widely used across the world to prevent the ingestion of hazardous particles. They are used by citizens, surgeons, various trade workers, etc. respirators can be made out of a multitude of materials, like wool, plastic, glass, cellulose, and combinations of two or more of these (3M, n.d.). There are various styles and efficiencies of these filters so they can be useful for many applications.

The history of filters can be traced all the way back to the 16th century. During that time, a finely woven cloth dipped in water was used to protect sailors from toxic powder weapons. The first patented filter was designed in 1848 by Lewis P. Haslett. The 'Haslett's Lung Protector,' as he called it, filtered dust using one-way clapper valves and moistened wool. Haslett's filter was the beginning of a long string of patents for various different types and styles of air purifiers (3M, n.d.).

The modern filter can now be purchased at varying filter efficiency ratings. Efficiency ratings are enforced by the United States National Institute for Occupational Safety and Health (NIOSH). These ratings are represented in the table below:

Oil resistance	Rating	Description
Not oil resistant	N95	Filters at least 95% of airborne particles
	N99	Filters at least 99% of airborne particles
	N100	Filters at least 99.97% of airborne particles
Oil Resistant	R95	Filters at least 95% of airborne particles
	R99*	Filters at least 99% of airborne particles
	R100*	Filters at least 99.97% of airborne particles
Oil Proof	P95	Filters at least 95% of airborne particles
	P99	Filters at least 99% of airborne particles
	P100	Filters at least 99.97% of airborne particles
*No NIOSH approvals are held by this type of disposable particulate respirator.		

Table X: List of efficiency ratings enforced by NIOSH. (3M, n.d.)

High-efficiency particulate arrestance (HEPA) filters are the most efficient of modern day filter technology. A HEPA filter can remove up to 99.97% of all airborne particles with diameter of 0.3 μm or larger. These high efficiency values are reached by decreasing resistance to airflow through the filter.

2.2.3 Portable Air Purifiers

Several companies have created portable versions of household purifiers to filter allergens, bacteria, and pollutants. These purifiers are marketed by various companies as functioning both indoors and outdoors to remove particles such as allergens and pollutants. The purifiers are ionic emitters that produce unipolar air ions that do not contain other particles. These devices offer many aspects that are attractive to consumers. For one, the purifiers are much less invasive than other filters on the market and are simply worn around the neck. They also claim to be silent and can run up to 40 hours on a single charge. The price point of these filters ranges from about $50-over $100 and come in a variety of shapes and colors. (NCBI)

Compared to traditional air purifiers, the portable versions are much less effective. According to a study by Indoor Air, the portable air purifiers took 15 minutes to filter approximately 50% of particles around the face area of the user while in a relatively small room. It took 1.5 hours for the portable air filters to get to almost 100% filtration. This is compared to the non-portable air purifiers, which filtered 90% of particles in 6 minutes, and nearly 100% in 12 minutes. (NCBI u.d.)

2.2.4 Drawbacks of Current Designs

There are several major drawbacks that discourage potential users from purchasing the wearable air filters currently on the market. The disposable surgical respirators are by far the most popular filter worn in public, mainly in Asian countries, and the trend is beginning to spread to Europe and the United States. However, there is a large misconception about these masks and their use. Most users wear them to avoid breathing in bacteria in the air that will make them sick. In reality, the masks were designed to protect patients undergoing surgery from any germs they may contract from the surgeon's mouth, not the other way around (Yang, 2017). They are designed to be loose-fitting and comfortable, the lack of a tight seal makes them almost completely ineffective for filtering air that the user breathes in. This drawback is apparent in many of the common half-face respirators. The areas around the nostrils and on the sides of the chin wrinkle when the user smiles or laughs compromising the seal of even some of the more advanced masks with rubber edges. Air that is inhaled by a user travels in the path of least resistance so when the seal on a mask is broken, the air being inhaled is traveling directly through that opening and in turn, not being filtered at all. Users with facial hair will not benefit from most half-face respirators because the hair creates a small gap in the seal (UC Santa Cruz, 2016). Even when a mask if fully sealed, the disadvantage then is that it becomes more difficult to breathe as it takes more effort to inhale air through the filter media. This is one of the biggest challenges to overcome in developing an effective wearable filter. The other drawbacks of current devices relate to the comfort they provide.

Comfort is an extremely important factor for any device that a user is expected to wear or operate during daily activities. The surgical masks and half-face respirators currently used by the public become hot very quickly due to the warm air being exhaled by the user combined with their body heat being trapped under the mask. Also, on the cheeks and the top of the nose where the mask is sealed tightly, it causes discomfort and often leaves the user with red pressure marks on the skin. Many of these masks are held tight with elastics that wrap around the user's ears which causes the same problem of being too tight. It is good for a mask to be held down tightly but the force of the material being pressed down on the user's skin should be distributed evenly to avoid uncomfortable points like this.

The primary disadvantage of the nasal filters is that they require the user to only inhale through their nose if they are going to effectively filter particles. There was no reliable information gathered from research online so the team purchased two types of nasal filters and tested them in lab. The nasal filters use an adhesive to remain sealed which works well if the user is stationary. If the user begins breathing heavily or moving around, the filters will likely fall out. The other disadvantage of these is that they are either disposable and can only be used once or in the more durable version, the filter must be replaced after each use. Aside from these technical drawbacks, the nasal filters are not completely hidden and cause discomfort. The nasal filters can be seen on the user which is one of the likely reasons this device is not popular as a wearable air filter. Most people are not willing to wear a device that sticks out of their nose in public. Secondly, any device in the nostrils will cause some irritation or discomfort to the user especially if the user is experiencing any sinus problems.

The major disadvantage of a wearable air purifier is that it loses most of its functionality when the user is outside. It is mainly used on long flights because the air is trapped in a small cabin with lots of people. The second disadvantage related to its efficacy is the limited battery life. This device runs on lithium batteries that must be recharged every 40 hours (Orr, 2017). As far as the aesthetic appeal of the device, it must be worn on top of clothing in order to work. It is moderately low-profile but some potential consumers may not want to wear a device this size as a necklace in public because it is not stylish and it could get in their way during daily activities. Past users have complained about the 'smell' of the ozone being unpleasant (Orr, 2017).

2.2.5 Patents

Along with researching the current solutions to the need already on the market, the team conducted research to determine what designs have been patented. This is to ensure that the final design does not infringe on previous work, and to demonstrate the proof of concept. Several searches using Google Patents as well as other patent search engines were used to generate a list of relevant patents. The keywords; scarf, filter, respirator, air filter, and mask were used to search the databases. After filtering out the hundreds of irrelevant patents not pertaining to respirators, there were several existing patents that are similar in concept of the final design created by the group. The only relevant patent that was encountered in the search was a pending patent filed in 2006 titled; "Personal Respiratory Filtration Apparatus" invented by Robert B. Vole, US Patent Number 20110079225A1. This patent highlights the use of a personal respirator that functions as an article of clothing as well as a support system for a breathable, treatable filter. The patent discusses putting a filter in a scarf, as well as a t-shirt. The patent claims that the filter is integrated into the fabric of the articles and secured behind the head by loop fasteners. It also claims that the mask may be treated with chemicals such as Menthol vapor or aromatherapy treatments. And finally, it claims that the material will be surrounded by a gauze material through which the treatment may be absorbed.

This patent does not claim many of the applications that the final design incorporated. For one, this patent does not discuss the filtration of allergens or pollutants, and instead focuses on bacteria and the treatment of disease. Secondly, the patent claims for the filter to be inserted into clothing or scarves, and does not claim to be a fully functioning unit as a scarf. Noting these significant differences with this patent, the team believes that the final design does not infringe on this patent (Vole, R. B 2011).

The only other relevant patent found was filed in 2015, by Tzu-Chin YU titled; "Wearable Device for Delivering Air", WO 2016086273 A1. This patent claims that a personal respiratory apparatus that provides air to a user to provide a fully immersive entertainment experience. It claims to use a flow generator with a filter configured to remove particles in the air. It also claims that the filter uses an ionizer purifier as well as several sets of filters. Finally, it claims several different methods for integrating the purifier into articles of clothing of the users, including a scarf.

Although this idea is similar, it is understood by the design team that the final design does not infringe on this patent. First, this patent uses electronic ionizing purifiers to deliver the air to the user. This is different from a respirator mask because the air is being actively provided to the user, and is using different methods of filtration than the design team's prototype. Secondly, the patent lists several claims for different wearable integrations of the device, including a necklace and bracelet. It should also be noted that this patent was originally filed in French, and therefore the exact wording of the claims is unknown by the group. (Yu, T. 2014)

Other relevant patents were considered, but they were all filed in other countries, in different languages. Regardless of language, it is believed that the final design of the product does not infringe on any patents and provides a unique and novel approach to solve this issue. Therefore, it is suggested that the final design could be accepted by the US Patent Office.

2.2.6 Regulatory Considerations

There are two primary regulatory issues associated with this project. The first regulatory concern is getting our respirator certified by the National Institute for Occupational Safety and Health (NOISH). This agency is part of the CDC and issues guidelines for workplace safety. NOISH also certifies respirators to ensure that employees are using the correct materials while on the job. NOISH also publishes several manuals and guidelines on the safe and effective use of respirators through the CDC's website. In these publications, NOISH only recommends respirators that have been certified to filter at least 95% of 0.3μm particles, and strongly urges employees to only trust masks with a NOISH certification. NOISH certifications can be found prominently featured on the respirator itself. This certification is referred to as 'N95'. There is a series of certifications given by NOISH certifying filtering; 95%, 99% and 99.97% (100%). NOISH also differentiates whether respirators are oil resistant with the letters 'N' for non oil resistant, 'P' for extremely oil resistant and 'R' for completely oil resistant. (NOISH 2016)

This certification is imperative for our product, because NOISH directly advertises in the United States that all non-certified filters are less safe. Receiving a NOISH certification would support our claims on the product's efficiency and become a marketing tool for sales in the US. Although there are hundreds of masks sold in the US without NOISH certification, it is more assuring to customers for our mask to be held to the standard of a government agency.

Another regulatory concern comes from the Occupational Safety & Health Administration. This administration is run by the Department of Labor and is set up to keep employers accountable for the health and safety of their employees. It is required by federal and state law to adhere to OSHA guidelines on respirators. It is a federal law that employers administer a fit test of employees who are required to use a respirator for part of their job. These fit tests must be conducted every year, and the employee must wear the exact same make and model of respirator as they wore for the fit test. Employers are also supposed to retest employees after major weight changes, major dental work, significant scarring, or facial surgery. There are two types of fit tests that conform to OSHA's guidelines. The qualitative and quantitative fit test. The quantitative fit test uses a machine to measure the amount of leakage from the facepiece. The respirators have a probe attached to them that is connected to a machine that monitors the controlled negative pressure, as well as the ambient aerosol. The exact numbers of what safe levels of these variables are allowed were not disclosed by OSHA. The qualitative fit test relies on the user's sense of smell and taste. A vial of strong smelling solution such as saccharin, bitrex, or isoamyl acetate is nebulized close to the wearer's face. If the wearer can smell or taste the solution the particles have entered the mask, meaning that the fit test has failed. If not, the fit test passes and the wearer is legally allowed to wear the respirator for their occupation. (*OSHA n.d.)*

3.0 Design Process

This project sought to design an air filter for people whose health suffers due to unclean air, whether it be smog, pollen or other allergens. The team devised three main objectives: to determine the issues with current air filters, to specify the potential user's needs and to design a functioning air filter prototype. The first two objectives occurred simultaneously in order to provide the information that drove the design of the final prototype.

3.1 Interviews with the Client

When the team met with the client, Professor Zoe Reidinger, there was a better understanding of where to start the design process. The client also made the team think about the other stakeholders and final design objectives with the following questions:

1. *What is the main intent of the air filter and who is going to be the user of it (for surgeons or people with seasonal allergies)?*
   This is up to the team after doing research on the current users and current preventative designs. Research to find the current clinical need with hospitalizations and demand on the different reason of why someone would need to have an air filter device. After this research the team had an idea of what the unmet need and why is this not met yet.

2. *How invasive should the filter be?*
   This really doesn't matter if there's enough research that would show that the design this team is developing is better than current solutions for the targeted user. For the testing phase of this project it will become very complicated specifically if it's a device that needs to be transplanted.

3. *Are there any mechanical limitations for the current designs or any future designs?*

The mechanical limitations could come from the nosepiece and how it bends and forms around the nose. Another limitation could be the seal around the face and making sure the material is flexible enough to form around the face and sturdy enough to maintain its shape.

4. *If there is a patent pending on a design similar to our design, are we allowed to use it?*
   That acceptable if the design this group develops iis similar to another design that has a patent pending. Just making sure that the developed design is not the same or has multiple similar characteristics.

5. *Are we allowed to work with filters already developed by other companies as long as the design is different than current applications?*
   Yes, it is allowed to use an existing filter for this design project and use it in the device as long as the device is completely designed by this team.

6. *What could be potential ethical issues for this project?*
   The potential ethical issues with the regulatory concerns with the filter itself. Another potential ethical issue is the material used for this device can irritate people's skins or can cause symptoms or consequences that the scarf is trying to stop in the first place. The last ethical issue we thought of is the price of the product since it's intended to preserve the respiratory health of the clients, but it is still a commercial product.

3.2 Survey

Purpose: (1) To evaluate the importance of aesthetics as a design goal. (2) To determine the population's interest in using a respirator.

Methods: The survey was created using Qualtrics to ask the following questions; Do you suffer from allergies?, Do you live or have you been to a place with severe pollution?, Have you ever worn an air filter?, How likely would you be to wear an air filter if it prevented the effects of severe allergies?, How likely would you be to wear an air filter if you were in a place with hazardous pollution?, How much more likely would you be to wear a scarf that filters air just as effectively?.
The survey was sent out to hundreds of people from around the WPI community and responders were encouraged to give their honest answers. The data from the survey was then analyzed in order to determine trends in people's preference for air filters.

3.3 Design Constraints

There were some constraints while designing, prototyping and finalizing this device. The two biggest constraints in this project were time and budget. This team had only 7 weeks to go through the complete design process to create an air filtration device. This time constraint caused a lot of material changes due to not enough time to order the desired materials, such as the 2200 3M filter (99.99% filtration efficiency). The time constraint not only caused issues with the materials, but also with the design process. The ventilation system for the scarf was selected not because it is fairly efficient, but mostly because it was preexistent and simple to implement to the design. The design could have had improved valves or other ventilation device that would've worked more efficiently to meet the team's objectives.

As mentioned above the budget was also a big constraint for the completion of this project. This team received only $155 for the prototyping, testing and the final design development. The final materials and tests were within the team's budget, but the the design was kept very standard instead of a more complex design. This is because the budget was not enough to cover extra materials to test multiple scarf fabrics. This was thought to have various options that could target the different seasons (winter, summer, etc).

Another constraint was to find an appropriate silicone piece for the 3D printed exhalation valves. The silicone piece that goes in between the two parts of the exhalation valves needed to be extremely thin to fit in between and move only when air flows outwards. The materials selected were a sheet of crafting foam that was compressed, but that wasn't thin enough to work efficiently. The next material that was tested was the thinnest sheet of silicone found, but it was still too thick for it to fit in between the valves and work properly. The only solution was to reuse the silicone pieces of an N95 respirator valves and resize them to fit the design's valves, which was not the preferred design approach.

3.4 Preliminary Design Ideas

The design process started by brainstorming ideas for a device that can serve the client better than existing solutions while also conforming to the need of the client. There were many ideas that came up in the first few brainstorming meetings, however the following criteria were repeated and deemed the most important considerations.

3.4.1 Improved Nasal Filter

The first idea the team was very invested in was a nasal filter design because this was something the team perceived as very discreet. They are like "contacts for the nose" because these nasal filters can be inconspicuous yet effective. Some important characteristics that were researched while considering this design were the filter's sealing effectiveness, the replacement filter cost and the replacement method. The nasal filters have a great sealing system in each nostril. The replacement method of this filter is simple and easy to perform and the replacement filters are inexpensive. The nasal filter stopped being the best design for our targeted need/client when we addressed the issue of not having a filtration system for the mouth. The importance of having a filtration system for the mouth is as important as having one for the nose, both are part of the respiratory system that can inhale all these airborne particles. The next ideas were to achieve a more complete filtration system for both the mouth and the nose, but still considering the current need for discretion.

3.4.2 Improved Respirator

The next idea was to improve the existing respirators because it would cover the nose and mouth. Based on background research and personal experience it was thought that the respirator should be aesthetically pleasing, seal better, and be one size fits all. Many masks claim that they are one size fits all but since they are so stiff and unmalleable to facial features, they do not seal well on everyone and therefore are not truly “one size fits all”. If the mask was one size fits all, that would assist in creating a better seal since the size of the mask is a common reason for the broken seal. This can be done by designing the mask to be flexible so it could fit to different facial features.

There are many advantages and disadvantages to designing a respirator. Some of the advantages are that they are inexpensive and they have been extensively tested so we would have an extensive amount of data to consider. They could be purchased and produced for very little money which allows for funds to be targeted on even better materials. Some of the disadvantages are that it would be difficult to make an aesthetically pleasing respirator. Respirators look ridiculous no matter how you wear them because people associate them with specific construction jobs but not a daily accessory. It would also be difficult to make them comfortable because the material that is used currently is hot and itchy. It would need to be made out of a different material and that material would then need to be extensively tested. Once we started discussing the specifications and how we could address the disadvantages of the mask, we then came up with the scarf design.

3.4.3 Scarf Filter

The scarf filter was the final design idea discussed by the team. This design would involve a filter being installed into a breathable scarf material. This filter should remove particles size 0.3 μm and larger from the air. The design is more aesthetically pleasing than the respirator and it would just look like an everyday accessory. This design can seal well and be one size fits all, considering the user can tie the scarf tightly around their head and fit it securely to their face.

However, there are some disadvantages to this design. A major challenge would be designing the scarf to be comfortable year round, for every season. Many people do not wear scarves in the summer and some do not wear scarves at all so some users would need to become accustomed to wearing scarves. Another disadvantage to the scarf design would be the cooling system that would need to be installed. Currently, the main function of a scarf is to keep the user warm so making the scarf a comfortable temperature consistently would be very difficult.

3.5 Design Considerations

After the evaluation of what was already on the market and the discussion of potential new design ideas, a list of important design considerations was created. The list was then narrowed down to the most important considerations and placed in a concept map, seen in Figure X.

- Aesthetically pleasing: The most prominent issue respirators on the market today encounter is that people do not want to wear them because they are unappealing. They need to be designed so they are as unnoticeable as possible. This can be accomplished by choosing neutral colors and common materials.
- Comfortable: The scarf should be comfortable to wear in all allergy seasons and at any time of year in a place with severe pollution. The installation of exhalation valves will allow hot air to escape without letting unfiltered air in. This is designed to keep the user cool. Material will be used that is compatible with sensitive skin to avoid rashes and irritation on the face.
- Easy to use: The final product must be easy to use and intuitive for the user. If the design requires extra parts or replacements, they should be easily replaceable.
- Reusable: The product should be as convenient as possible so the design should be reuseable. The filter should not be disposable, it is less cost effective and wasteful. The design should last for a decent amount of time before the filter needs to be changed or cleaned.
- Well Sealed: In order to successfully filter out all of the particles in the air the design must be well sealed. This can be addressed in the part of the design that attaches the product to the user's face. It should be easy to adjust and fit most people. We will also

add a metal piece designed to form to your nose to provide a seal across your face and to hold the scarf on the face.

- <u>Efficiently Filter Particles</u>: The filter should filter a particle size of 0.3 μm and larger. This will filter most harmful allergens and pollutants. The filter's compatibility with the scarf material also needs to be considered.

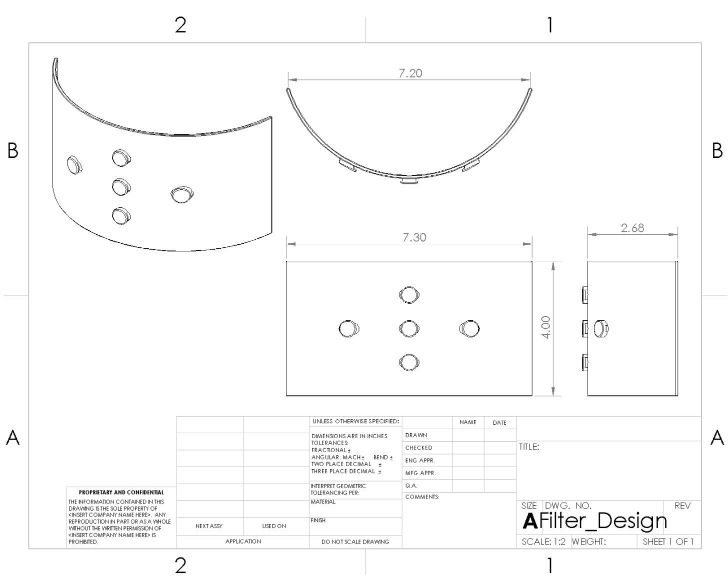
Each design idea was then evaluated based on the design considerations discussed above. The outcome of the evaluation can be seen in Table X. They were evaluated on a 1 to 5 scale, 1 being very poor and 5 being great.

Evaluation Matrix	Nasal Filters	Respirators	Scarf
Aesthetically Pleasing	5	1	5
Comfortable	1	3	5
Easy to Use	5	5	5
Reusable	1	4	5
Well Sealed	1	3	4
Efficiently Filter Particles 0.3 μm and larger	Not specified	5	5
Total Score	13	21	29

Table X: An evaluation matrix visually comparing each of the design ideas

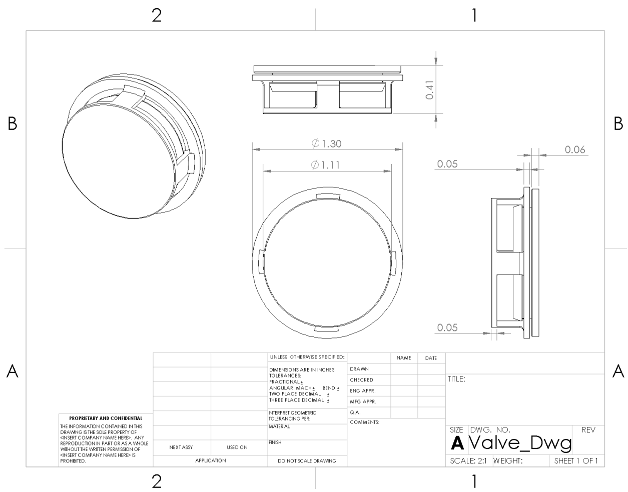
This evaluation matrix portrays that the best design choice would be the scarf filter. It received a 29/30 and scored 5 in almost all of the categories. It received a 4 in the well sealed category due to the fact that the seal of the scarf would rely on the user tying the scarf correctly.

After the design was chosen, the specifications were discussed. The filter used for the insert will have a NOISH certified 1900 3M filter that filters about 93% of airborne particles of 0.3 microns or larger such as allergens, pollen, and pollutants (3M, n.d.). A model of the first filter-insert design can be seen in the CAD model in Figure X. The filter lasts around 3 months when used in a home air conditioning system in which the air pressure and number of particles is much greater than an adult breathing, so the user will not need to replace the filter often. This reduces the cost



of the product for the user in the long run.

The scarf will be made out of a soft, breathable polyester material that will not cause any allergic reactions or irritations on the skin, even if used for long periods of time. This will allow the product to be comfortable and allow the user to breathe and talk without any difficulty. This is possible because of the installation of exhalation valves to the design. The CAD drawing of the exhalation valves can be seen in Figure X.



Instructions would need to be provided to ensure that the user is attempting to wear the scarf in a way that a tight seal is formed. Air travels along the path of the least resistance so, if there is a good seal the air would only travel through the filter. The design needs to include a nosepiece in order to hold the material onto the user's face and assist in creating the tight seal.

The device will be portable so the user can take it anywhere. The scarf will be easy to put on and remove at any time. The scarf can be washed, since the filter is removable. When the filter is removed, the user can throw the scarf in the laundry with the rest of their clothes. This scarf will be also aesthetically pleasing to increase the likelihood of people using it.

3.6 Testing

The tests conducted aimed to evaluate the design considerations of the prototype. The tests were created in a way that factors in the limited window available to test the prototype, as well as the limited resources and materials. The tests were all completed inside of lab 007 in Goddard Hall and under the standards of general lab safety. When necessary, respirators, goggles, and other materials were worn to ensure the safety of the group members.

3.6.1 Fit Test

Purpose: **(1)** To evaluate the claim that the device forms a tight seal for all users. **(2)** To prove that the mask is legally allowed to be work occupationally.

Methods: This test followed the procedure guidelines put in place by OSHA's qualitative fit test. Bottles of saccharin solution were nebulized close to the users face while the user was wearing the respirator securely. The user waited for 30 seconds after the spray sense taste or smell of the solution. The test was repeated with the three other members of the group to establish a ‘universal fit’. A control was conducted where all users experienced the nebulized saccharin solution without wearing the mask.

3.6.2 Efficiency Test

Purpose: To determine the effectiveness of our filter in filtering particles from the air effectively.
Methods: Approximately 1 gram of Aluminum particles of 5.0μm were blown by a fan into the filter at distances of 1 ft, 2 ft and 3 ft. The number of particles that reached the opposite side of the filter were counted and recorded. A control of a piece of paper with 1 gram of aluminum particles on it was used as the baseline for the tests and was also under the same procedure.

3.6.3 Temperature Test

Purpose: **(1)**The temperature test was performed to test the comfort of the scarf while in use. **(2)** To determine whether exhalation valves decreased the temperature inside of the scarf. **(3)** To determine the average and maximum temperatures experienced in the scarf while stationary, and while walking.
Methods: The test subject was instructed to put on the mask and place an instant digital thermometer probe securely stationed in the face area inside the scarf. The temperature of the room was recorded to form a baseline reading for the temperature. The subject wore the scarf while sitting for 11 minutes and the temperature was recorded every 30 seconds. The trials were conducted with no air vents, with one, and with two air vents to determine their effectiveness. Another test subject also administered a similar test, but while walking inside of the Goddard Hall building.

4.0 Findings and Analysis

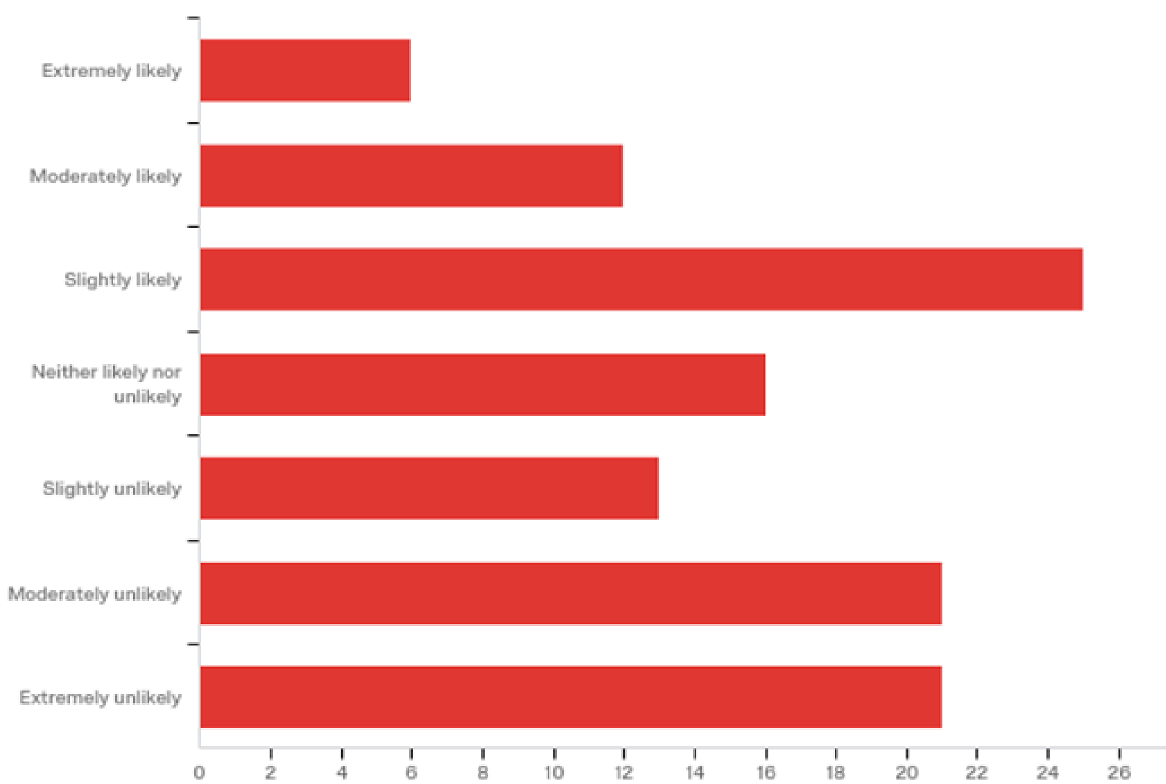
The data discussed in the following section evaluates the results from the three experiments. The data was then interpreted and analyzed to fully relate back to the design objectives that the experiments were designed to test.

4.1 Survey Data

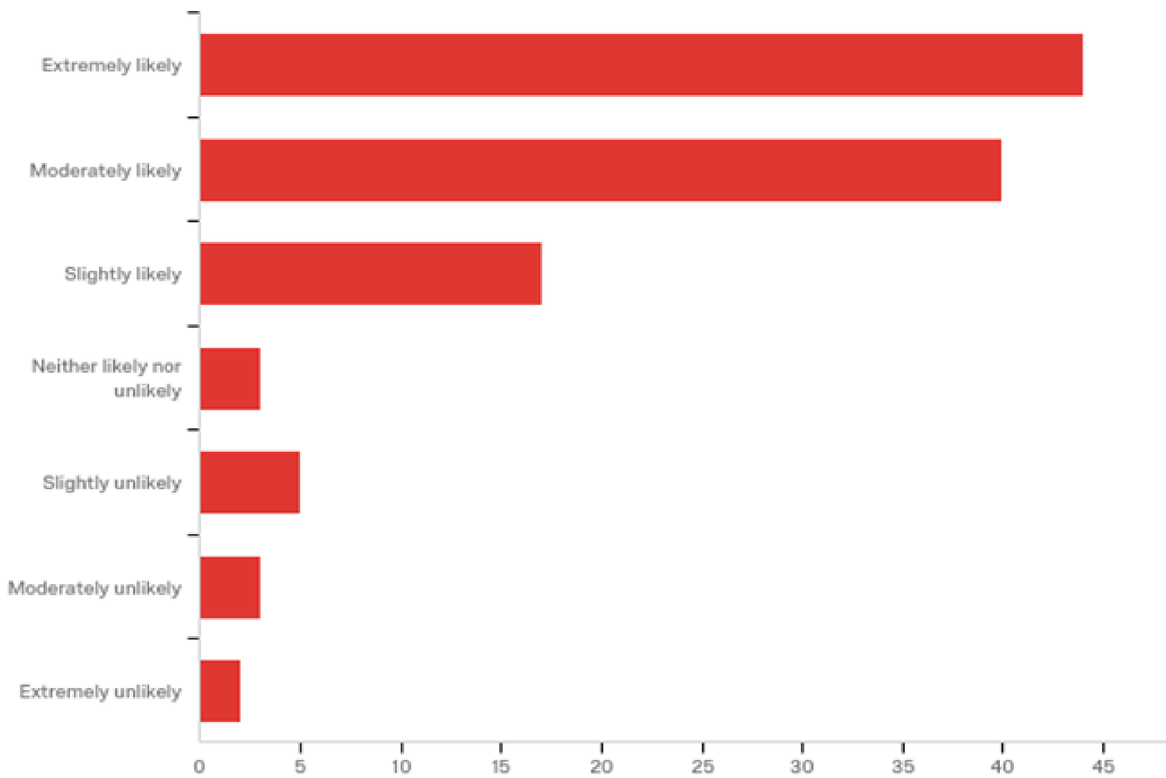
The goal of the Air Filter Survey was to determine the reasons why people use air filters now, why they would potentially use an air filter and how much more likely they would be to use a scarf that functions as an air filter. The team found that people are more concerned with the effects of pollution on their health than they are with severe allergies. This data was used to focus the design process even more; the device would be designed to filter pollutants. Smog particles, smoke and other pollutants are much smaller than allergen particles such as pollen. Therefore, a pollutant filter would catch both groups. However, if the team were to market this device, it would be advertised primarily as a pollutant filter due to the survey responses.

Some of the questions in the survey did not produce data that showed people would be more willing to wear a scarf that works as a filter than current products. These questions were placed at the beginning of the survey to get the respondent to start thinking about air filters, allergens and pollutants. One of the questions was “have you ever worn an air filter?” followed by a question asking which of the three main types they had used. This would be used to see which air filter currently available is most commonly used by the public. Since the data from these questions was not significant with respect to the three main reasons for making the survey, the team did not feel it was necessary to draw conclusions from responses to these questions (see attached document). The questions that the team focused on were “how likely would you be to wear an air filter if it prevented the effects of severe allergies?”, “how likely would you be to wear an air filter if you were in a place with hazardous pollution?” and “how much more likely would you be to wear a scarf that filters air just as effectively?” (FIGURE NUMBERS). The reason why the team chose these questions to analyze is because of how they affect the design process. If respondents had reported that they are more likely to wear an air filter for allergens, the design would incorporate a less effective filter than it would for pollutants due to the particle size.

How likely would you be to wear an air filter if it prevented the effects of severe allergies?

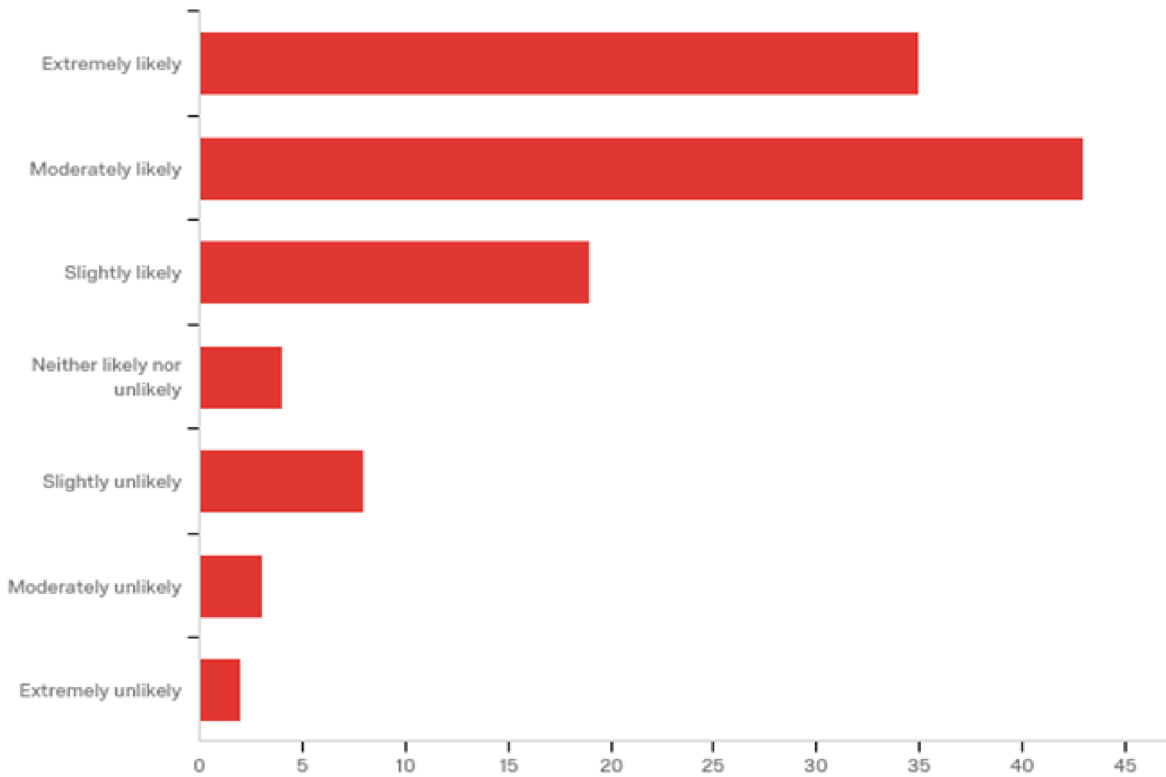


How likely would you be to wear an air filter if you were in a place with hazardous pollution?



The first two questions allowed us to gauge public opinion on what type of particles they are more concerned with filtering. The contrast between these two bar graphs shows a clear preference of filtering pollutants rather than allergens. 62% of respondents reported that they would either be neutral or unlikely to wear a filter to prevent the effects of severe allergens whereas 88% of respondents reported that they would be at least slightly likely to wear a filter in an area with hazardous pollution.

How much more likely would you be to wear a scarf that filters air just as effectively?



The third question, “how much more likely would you be to wear a scarf that filters air just as effectively?”, allows us to determine how much aesthetics matter for an air filter. Through initial research, the team found many air filter products currently exist but they are not being used. The design ideas were based on the perception that current products are not used because people do not like their appearance. 85% of respondents said that they would be at least slightly more likely to wear a scarf that filters air just as effectively as other respirator air filters. This question helped to confirm this suspicion and specify the final design, moving forward with a scarf that acts as an air filter.

4.2 Fit Test Data

The data of the fit test is qualitative. The procedure the group followed for this test corresponded to OSHA's guidelines for a qualitative fit test. A quantitative fit test that is certified by OSHA costs several hundred dollars for the kit, as well as specialized computational software.

Test Participant	Fit Test Status
Control (no mask)	Fail, Fail, Fail, Fail
Subject 1	Pass
Subject 2	Pass
Subject 3	Pass
Subject 4	Pass

The test was administered to each test subject first without the mask as a control. This was to ensure that each participant could indeed smell and taste the nebulized test solution before they were subjected to the experimental trial while wearing the scarf. Each participant could smell and taste the solution, and therefore failed the fit test.

The experimental trials were conducted after each subject had securely put on the prototype device. The four different test subjects were selected to demonstrate that the device can be used on different faces and still maintain a tight seal. This hypothesis has been supported by the data of the fit test experiments. All four test subjects could not smell or taste the nebulized solution, meaning that the particles could not enter the mask without getting filtered out. This test is certified by OSHA, and therefore all four test subjects would be able to wear this prototype while on the job for the next year.

4.3 Efficiency Test Data

The efficiency data for this experiment is inherently qualitative. To add a qualitative measure to these data, the design team decided to determine the efficiency by counting the number of particles that either went fully through the filter or became visible through the back side of the filer. This is a reasonable method of evaluation, as the particles are large enough to determine individually. Furthermore, the size of the particles is substantially greater than the certified filter size from the manufacturer of the filter. Therefore it is logical to conclude that if particles of 5μm get through the filter so that they are visible on the other side of the filter, they should count as passing through the whole filter.

The figure X above is a magnified image of the section of the front of the filter where the majority of the particles landed. The image depicts the majority of the particles being trapped in the first few layers of the filter, as will become evident when viewing the backside of the filter.

The figure X above is of the same area of the filter as shown in the previous image. The filter did not allow any particles to pass through the filter, nor did any particles become visible from the other side of the filter. The image is not of a high enough resolution to fully prove this statement, however a detailed evaluation of the filter was provided by the members of the design team.

In summary, the filter was able to filter 100% of 5µm aluminum particles. This supports the claim that the filter is efficient at filtering allergens and pollutants. Although the particles were much larger than the 0.3µm limit of the filter, these data still provide evidence that the specific filter that was used in the prototype of the scarf was effective.

4.4 Temperature Test Data

The data from the temperature test is represented in Figures X and X below:

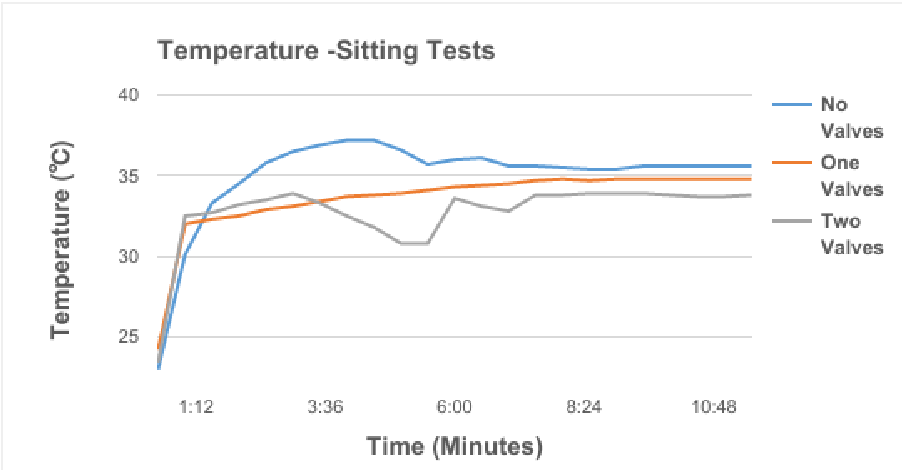


Figure X: This graph represents the temperature over time for each type of scarf for the sitting trials.

The sitting test data was very stable over time due to the fact that there were few variables to consider. The user simply sat stationary in a chair for 11 minutes. Figure X reveals the scarf with two valves is cooler when the user is sitting.

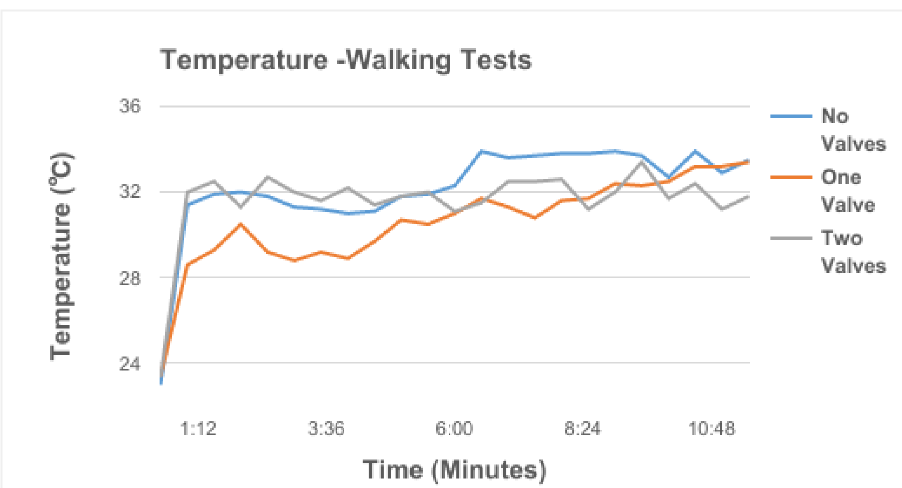


Figure X: This graph represents the temperature over time for each type of scarf during the walking trials.

The walking test data was much less stable than the sitting data. This is due to the amount of variables in these trials. These variables include the user walking up and down stairs and corridors having varying air qualities, pressures, and temperatures. These variables could potentially affect the temperature results of the walking data. The walking trials revealed that the scarf with two valves is cooler and much more consistent when the user is walking.

The temperature test revealed that the hypothesis was correct and that for both the sitting and walking trials, the scarf with two valves was cooler. However, it was only cooler by a few degrees, meaning that although adding more valves could decrease the temperature even more, it is believed that a completely redesigned electronic cooling system would be needed make the scarf comfortable enough to wear for all seasons.

5.0 Final Design

The final design fulfilled all of the design considerations discussed earlier. The scarf filters particles 0.3 μm and larger, is comfortable, and aesthetically pleasing. These considerations are supported by the test results from the efficiency test, temperature test, and survey results respectively. The scarf is also discreet. It looks like an everyday accessory. The filter is easily replaceable due to the velcro design and the scarf is washable, making maintenance easy.

5.1 Specifications

The final design included the thin scarf material, two 1.3 in. valves, velcro to make replacing the filter easier, and the 1900 3M filtrete. The filter used for the final design only filters 93% of particles 0.3 μm and larger and the filter lasts at least three months of very heavy use. This was not the filter that was intended to be used in the final design. Ideally, a more efficient filter that removes 97% of particles from the air would have been used from the beginning, but would have taken weeks to ship. Because of this, the group settled for the 93% for the prototypes (3M, n.d.).

The final prototype is used by wrapping the scarf securely around the user's head and neck, making sure the nosepiece is secured comfortably on the nose. The scarf is adjusted to ensure a perfect seal and is safe to be used throughout the day.

5.1.1 Materials

There were three features that changed throughout each prototype. The first was the material used for the scarf. In a lab section the original scarf was a surgical mask. Next, the black scarf from Savers was used as seen in the middle of Figure X . It was originally thought that this material felt comfortable and would conceal the filter well. However, this material quickly got very warm and was extremely uncomfortable and itchy. The next scarf material therefore needed to be the thinnest material available (right of Figure X). This material was much more breathable and significantly more comfortable. It was therefore used for the final design. The next feature that changed was the size of the exhalation valves. First the valves with a 1.5 in. diameter were used(left of Figure X). These valves were too large and looked a too noticeable, comprising the discretion. Next a vent with a diameter of 0.85 in was used (right of Figure X). The 0.85 in was chosen because half of the larger valve (0.75 in.) was too small to print on the 3D printer used. These valves were very hard to work with and were inefficient because there was not much space for the air to be released through the valve. Finally 1.3 in. was tried, because it would be large enough to allow air through while also looking discreet. Lastly, the method of attachment of the vent to the scarf needed to be changed. Originally it was attempted to sew a pouch into the scarf, but the filter was hard to put on and off. It was then decided to use velcro. Now the filter is easy to pull on and off, making it much easier to replace.

5.1.2 Financial Considerations

Although a majority of our budget was spent throughout the design process, it cost approximately $12 to make the final product. If bought in bulk, the price to manufacture each scarf would decrease to $4.46 per scarf.

Material	1 m of filter	1 m of scarf	1 valve	1 nosepiece	Silicon for 1 valve
Price ($)	3.00	1.40	0.03	0.02	0.01

Table X: This table portrays the price of each material if bought in bulk (Guangzhou u.d.) (Ebei u.d.)

Considering these prices, the scarf could be sold for $15 and obtain a 336% profit. See Appendix E for a detailed bill of materials and cost analysis.

5.1.3 Ethical Issues

The goal of this project was to design a new way for people to filter harmful allergens and pollutants. There are inherent ethical issues with the product because it is dealing with the safety of others, and the repercussions will likely not be realized for many years. The main ethical concern with the product is the effectiveness of the filter. A major concern would be if the product is marketed to filter pollutants and allergens and then does not filter to the standard advertised. To address this concern, it was decided to use a filter already on the market that is lab tested to filter 93% of particles 0.3 μm and larger.

Another ethical issue is the material of the filter itself. Many filters that the group looked at were made out of fiberglass and other materials that are either irritant to the skin, or can degrade into harmful particles. Allergies or particle inhalation from the mask itself is a major problem as the product has potential to cause the problems it was designed to prevent. However, this issue was brought up briefly and was quickly resolved soon into our design process when it was decided to place a layer in between the user's face and the filter. This layer will not allow parts of the filter to go directly into the user's mouth or nose, and it will also stop direct contact from the filter. It was also decided to not use a fiberglass filter or any filter that would potentially become irritating to the user.

The final ethical issue that the group discussed was the price of the product. It is an ethical issue to sell this product for a massive product, because it is designed to improve the health of its users. However, as a product for sale, there is somewhat of a fiduciary responsibility to make the product as successful as possible. Furthermore, this product was surprisingly expensive to manufacture for single model. However, this was mostly a problem with limited resources and buying one filter that could be used for 10 products. The price has been tentatively set to $15 a scarf. This is an extremely competitive price for a non disposable filter, especially when compared to other products designed for aesthetics. It can also be argued that this filter does not need to be the least expensive on the market as there are masks with similar function for under $1.

5.1.4 Design Improvements

If there were more time and resources to design this prototype, there are many improvements that could be made to the current design.

One improvement would be to design a more supportive nosepiece. The nosepiece used in this prototype was too weak to hold up the filter and the scarf for an extended period of time. It worked well enough to test, but if a user were to wear it for an extended period of time the nosepiece would not seal for the duration of the use period.

The cooling system needs to be completely redesigned. As explained by our temperature test, adding valves does make the scarf cooler, but only by a degree or two. In order to get the temperature inside the scarf down to a comfortable temperature for all seasons, an unreasonable amount of valves would need to be installed into the scarf. Because of this, an electronic system would need to be designed and installed because it does not seem feasible to rely on fluid dynamics to cool the user down.

If the valves were to still be used, they would need to be designed to snap on and off easily. The valves were very hard to pull apart and sometimes broken in the process.

The filter inside the scarf needs to be upgraded to a more efficient model. When building the prototype, we did not have access to the more efficient filter we originally wanted to purchase because it would have taken too long to ship.

Another improvement would be to increase the selection of scarf designs and colors to appeal to more users. This will increase the fashionability of the product and therefore increase the chances of the product becoming a trend.

Lastly, it would be ideal to design a material that filters particles 0.3 μm and larger and is also a scarf. This would eliminate the need for the production of a replaceable filter and would make the whole product one piece. This new scarf would need to be washable and have an intricate cooling system to prevent overheating.

6.0 Summary and Conclusion

After interviewing the client, researching the health complications, conducting a literature review of current products and surveying members of the WPI community, the team created a functioning prototype of an innovative air filter. The main problems with current air filters on the market are their comfort, their aesthetics and their overall quality. The team developed six design requirements in order of precedence: filter 0.3 micron particles, aesthetically pleasing, discreet, comfortable and removable filters. The final prototype was created using a 1900 Filtrete filter for a home air conditioning unit, a polyester scarf from H&M, Velcro, two thin metal pieces from a surgical mask and two 3D-printed ventilation valves with silicon wafers inside them. After conducting tests of our prototype and ventilation valves, the data showed that the design considerations had been met. There are still improvements that could be made to the design, such as a better ventilation system and scarf material. These improvements will further reduce heat so that the scarf can be worn comfortably year round. The team recommends that future designs find a way to completely integrate the filter material into a comfortable scarf material so fewer layers allow heat to escape easily and the entire unit is washable. Overall, Zäpi Pür is an air filter that effectively blocks pollutants and allergens while maintaining the discretion of a stylish scarf.

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Appendix A: User Guide

Purpose: The purpose of this standard operating procedure is to describe the steps for the normal operation and maintenance of the portable respirator Zäpi Pür to effectively filter pollutants and allergens from being ingested by the user.

Scope: This procedure applies to all users of the portable respirator Zäpi Pür, and to any similar devices.

Responsibility: All group members in BME 3300 Group 10 attending Worcester Polytechnic Institute and all users who may use the device.

Materials:

1 Assembled portable respirator (Zäpi Pür)

1 replaceable 3M 1900 filtrete filter.

Procedure:

1. Take the replaceable 3M filter and connect the velcro corners of the filter to the corresponding velcro spots on the scarf. If done correctly, the top part of the ventilators will line up with the bottom part already attached to the filter.
2. Fold the scarf in half so that the half with the filter attached moves down to meet the other half, making sure to align the bottom corners of the scarf.
3. Take the scarf with both corners, making sure the flat end of the vents are oriented towards the user and in the top half of the scarf.
4. Take both corners of each side into each hand and drape the ends of the scarf around the shoulders.
5. Cross the ends of the scarf so that the end originally on the right shoulder is now wrapped around the neck and resting on the left shoulder.
6. Feel around the top edge of the scarf directly above the air vents to locate the nosepiece of the scarf.
7. Lift the scarf material up to the face so that the nosepiece is resting comfortably on the nose.
8. Adjust the nosepiece by pinching the two metal wires until they follow the contours of the nose.
9. Pull both ends of the scarf located on the shoulders so that the material is now snug to the face.
10. Adjust the excess scarf material so that it is not blocking the vents on the exterior material of the scarf.
11. As a precaution, run two fingers around the perimeter of the scarf to ensure a tight seal completely around the face.
12. If there is not a tight seal, take the two ends of the scarf and simultaneously lift them from the back of the neck and pull.
13. Repeat steps 11 and 12 until the scarf material is fully sealed around the face

Replacement:
If the Zäpi Pür respirator becomes noticeably more difficult to breathe from, or is visually substantially dirty, replace the filter by simply unfolding the scarf and repeating the procedure described above. The filter is designed to last the user at least three months of heavy use.

Appendix B: Assembly Guide

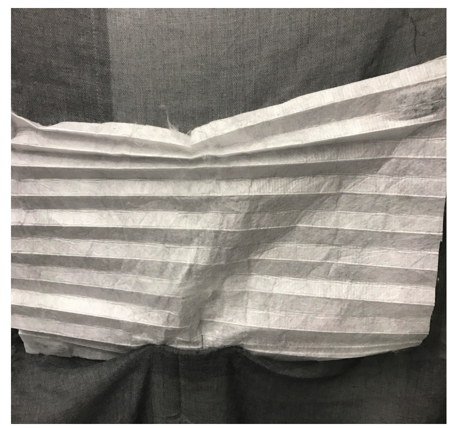
Purpose: The purpose of this assembly guide is to provide the steps needed to accurately recreate a fully functioning Zäpi Pür respirator device.

Materials:

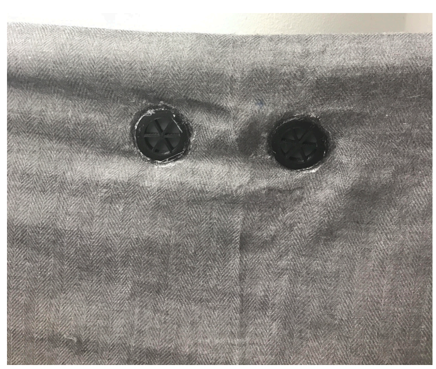
1 24x24 inch 3M 1900 Filtrete filter
1 Grey polyester blend H&M scarf
2 3D printed valves
2 silicon valve pieces from an N95 respirator
4 pieces of 1x1 inch velcro (both sides)
2 metal wire adjustable nose pieces from disposable surgical masks
Hot glue and scissors

Procedure:

1. Take the box of 3M Filtrete and carefully remove the filter from the box.
2. Carefully take off the wire mesh on the filter, making sure not to remove any part of the filter where glue is attached.
3. Fully stretch the filter material so that the filter does not bunch up, and lays flat.
4. Cut a piece of filter that is 15.5 inches long and 19 inches wide.
5. Take the non fuzzy sides of the four 1x1 inch velcro pieces and use the glue on the back of the velcro to stick to the four corners of the filter.
6. Lay the scarf on the table so that it is completely flat and mark the middle of the scarf.
7. Lay the filter on top of the scarf so that it is oriented where the wide side is horizontal.
8. Mark the four edges of the filter and place the remaining velcro patches in the corners so the two velcro sides will align.
9. Disassemble two disposable surgical masks to obtain the two pieces of metal wire. Take the metal wires and hot glue them to the top of the filter where the midpoint of the wires is aligned with the midpoint of the filter.



10. Take two N95 respirators with vents and remove the vent by popping the top off. Remove the silicon from the middle of the vent.
11. 3D print the vents, similar to the vents on the N95 respirator, but at 1.3 inches in diameter instead of 1.5 inches. Use Solidworks to design the exact specifications.
12. Cut the silicon around the circumference of the 3D printed vents.
13. Fold the scarf so that it is in half widthwise and align the bottom corners of the scarf. Flip the scarf so that the side with the nose piece is facing upward.
14. Cut two small holes in the scarf, the filter, and the second layer of the scarf 2 ¾ inches from the top of the halved scarf and directly below the ends of the metal nose pieces.



15. Gently insert the bottom part of the 3D printed vents through the hole so that the top part of the upper area of the bottom piece is protruding from the other side of the scarf.

16. Use hot glue to secure the rim of the bottom piece of the vent to the scarf and filter.
17. When the glue has dried, place the silicon on top of the bottom piece and snap the top piece of the filter to the bottom piece.
18. Remove any excess filter from around the vents.

Appendix C: Manufacturing Specifications

Model	Zäpi Pür
Material	67% Polyester, 39% Viscose
Filter	1900 3M Filtrete 93% Efficiency
Exhalation Valves	Black ABS Plastic Filament
Valve Inserts	Silicon
Velcro	Velcro
Hot Glue	Hot glue rods and Heat
Nosepiece	Aluminum

Appendix D: Dimensions

Scarf	54.5in x 54.5in
Filter	15.5 in x 19 in
Velcro	1in x 1in
Vents	1.3 in diameter

Appendix E: Bill of Materials and Cost

Starting Budget	**$155**
3M Maximum Allergen Filtrete	$21.22
Black Savers Scarf	$6.98
A.C. Moore Foam Sheet	$0.50

Nasal Filters from Amazon	$37
Silicon Gasket Sheet	$15.67
3D Printing Plastic	$23
Allegro Industries Saccharin Sensitivity Solution (Pack of 6)	$10.43
H&M Scarf (2)	$9.99 (x2)
Total Spent	**$134.28**
Remaining Funds	**$20.72**

The final cost of producing the final prototype was approximately $12. However, this is taking the price of the filter and dividing it into the area actually used for the prototype. The budget at first looked like a lot, however every week another item needed to be purchased. The group first decided to buy nasal filters from Amazon, as there was very little credible information available on their effectiveness. Next the group purchased the materials for the second prototype. This included the original scarf from a local Savers, a foam sheet from A.C. Moore served for the preliminary silicon wafer, and the 3M filtrete was used for the second prototype as well as the final. Later the foam sheet proved too bulky to be used as the vent wafer. A silicon gasket sheet was purchased to be an improvement from the foam sheet, however it too immediately proved to be ineffective as the wafer. Next 3D printing plastic was needed to manufacture the final versions of the vents. For the next two prototypes a more comfortable, breathable scarf was purchased from H&M. Finally, the Saccharin solution was purchased to conduct the fit test.

Appendix F: Full Survey

The following is the full list of questions and possible responses from the survey:

Which of these best describes you?

I suffer from severe seasonal allergies I suffer from mild seasonal allergies

I suffer from airborne food allergies

I do not suffer from seasonal allergies or airborne food allergies

Do you live or have you been to a place with severe pollution?

Yes, No, I don't know

Have you ever worn an air filter?

Yes ,No, Unsure

If yes, this person was asked to identify which filter he/she used given images of; a surgical mask, a portable air purifier, or a allergen mask.

How likely would you be to wear an air filter if it prevented the effects of severe allergies?

Extremely likely, moderately likely, slightly likely, neither likely nor unlikely, slightly unlikely, moderately unlikely, extremely unlikely

How likely would you be to wear an air filter if you were in a place with hazardous pollution?

Extremely likely, moderately likely, slightly likely, neither likely nor unlikely, slightly unlikely, moderately unlikely, extremely unlikely

How much more likely would you be to wear a scarf that filters air just as effectively?

Extremely likely, moderately likely, slightly likely, neither likely nor unlikely, slightly unlikely, moderately unlikely, extremely unlikely