Air Disinfection System

BME-350
BIOMEDICAL ENGINEERING-II

Advisor

Dr. Jahid Ferdous

Assistant Professor

Department of Biomedical Engineering

Sumaiya Ohab | ID- 1718003
Md. Rakib Hossen | ID- 1718011
Shakib Mahmud Ayon | ID- 1718023

Abstract:

Air purification and disinfection systems are intended to effectively clean the air in the environment and reduce or inactivate harmful populations of airborne pathogenic microorganisms, aimed to provide significant assistance in the fight against outbreaks and harmful infections [1]. Bioaerosols can cause many adverse health effects, including allergic, toxic, and infection responses. Exposure to bioaerosols may be especially hazardous in clinics and hospitals. But adding an air disinfection system can reduce the risk of infections and can improve the environment in clinics and hospitals.

Acknowledgement:

We are sincerely grateful to our project instructor Dr. Jahid Ferdous, Assistant Professor, Department of Biomedical Engineering, BUET (Bangladesh University of Engineering and Technology. His continuous guidance, co-operation and support during the whole time has been of significant help to us. Also, his valuable suggestions about design ideas and implementation, different measurements, report preparation have made our job easier. We would like to thank all course teachers of BME – 350, Nusrat Binta Nizam, Lecturer, Department of Biomedical Engineering, BUET, Shoyad Ibn Sabur Khan Nuhash, Lecturer, Department of Biomedical Engineering, BUET and Taufiq Hasan Aneem, Lecturer, Department of Biomedical Engineering, BUET for their great assistance.

Author

Sumaiya Ohab

S201718003

Md. Rakib Hossen

S201718011

Shakib Mahmud Ayon

S201718023

TABLE OF CONTENT:

Contents Page No.

LIST OF TABLES:

LIST OF FIGURES:

1. Introduction:

Air disinfection is the reduction in the number of harmful populations of airborne pathogenic microorganisms to a desired concentration. Bioaerosols are a loosely defined group of airborne particles of biological origin, generally including bacteria, fungi, and viruses, as well as pollen, their fragments, and various antigens. They can impose serious health effects. In addition to SARS-CoV2 and influenzas virus, some bacteria such as Streptococcus pyogenes, Neisseria meningitidis, Corynebacterium diphtheria and Mycobacterium tuberculosis are known to be transmitted predominantly by airborne droplets from infected people, and they may cause nosocomial infections such as surgical site infections, and respiratory and urinary tract infections [1].

Under the influence of controllable and uncontrollable factors, indoor air quality is in a constant state of flux. The individual human microbiome, ventilation, outdoor air, plumbing systems, and foliage all contribute to the airborne particulate burden. For example, tuberculosis is transmitted person-to-person by the airborne route via small particle aerosols measuring 1 to 5 μm [2], sufficiently small that they remain aloft in the air. International literature data report that the increase of infectious risk may be due to heating, ventilation, and air conditioning (HVAC) systems contaminated by airborne pathogens. Contamination could occur at the duct, ventilation grille, and filter levels as a result of dust, oil, water and resin accumulation.

There are a few air disinfection methods such as:

- **Photo Electrochemical Oxidation (PECO)** - PECO uses photons of sufficient energy to initiate a chain of reactions by liberating electrons (negative charge) and forming holes (positive charge). PECO keeps electrons and holes separated which results in extremely fast and complete reactions with no byproducts other than what is supposed to be in the air. Simply put, PECO uses the photons of light as efficiently as possible to completely oxidize the organic pollutants in air.

- **Photocatalytic Oxidation (PCO)** - PCO also uses photons of sufficient energy to initiate a chain of reactions by liberating electrons and forming holes like PECO. However, since negative electrons like to combine with positive holes, very few holes remain available for reaction in a PCO process, which makes the process inefficient.

- **UVGI** - UV germicidal irradiation has been shown to be effective in reducing transmission of airborne infections in hospitals, classrooms, and military housing. Historically, there have been 3 methods of UV air disinfection: duct irradiation, upper-air irradiation, and in-room cleaners.

- **Micro-electrostatic Precipitator (MESP)** - In the MESP system, airborne particles in propelled air flow are electrically charged before passing into honeycomb shaped filter. The filter is formed by layers or rows of tubes which only has 1.8 mm inner spacing, and

each row contains thin electrode sheets with insulation coating that generate intense electrical fields within the tubes. Charged particles - pollutants, bacteria, germs, viruses - are pulled to the walls of the tubes - and firmly stick [3].

Out of all these methods, we have chosen the UVGI method. Here, a circulation method is often used for air disinfection in which air taken in from a specific enclosed space is disinfected by irradiating UV light on it directly and then clean air is supplied outside. Recently, air purifiers with UV light in various sizes have been released to the market for indoor usage in such places as hospital waiting rooms, as well as compact air purifiers for using in small spaces such as inside vehicles.

1.1 Background:

The history of UVGI air disinfection has been one of promise, disappointment, and rebirth. In the late 19th century, investigations of the bactericidal effect of sunlight planted the seed of air disinfection by UV radiation. William F. Wells being the first to nurture this seed, who both discovered the spread of airborne infection by droplet nuclei and demonstrated the ability of UVGI to prevent such spread. Despite early successes in applying UVGI, its use would soon wane due to a variety of reasons that will be discussed in this article. However, with the enduring research of Riley and others, and an increase in tuberculosis (TB) during the 1980s, interest in UVGI was revitalized. With modern concerns regarding multi- and extensive drug-resistant TB, bioterrorism, influenza pandemics, and severe acute respiratory syndrome, interest in UVGI continues to grow. Research is ongoing, and there is much evidence on the efficacy of UVGI and the proper way to use it, though the technology has yet to fully mature.

This is a brief overview of some of the key studies in the history of UVGI air disinfection [4]:

- **1877:** Downes and Blunt' discovered the ability of sunlight to prevent microbial growth. It was later shown that the ability of light to inactivate microorganisms is dependent on the dose (intensity X time) and wavelength of radiation and the sensitivity of the specific type of microorganism.

- **1930:** Gates published the first analytical bactericidal action spectrum with peak effectiveness at 265 nm, very near the 254 nm output of low/-pressure Hg germicidal lamps.

- **1933:** Wells presents the concept of airborne infection via "droplet nuclei"-evaporated droplets containing infectious organisms that can remain suspended in the air for extended durations.

- **1935:** Wells and Fair demonstrated the ability of UVGI to efficiently inactivate airborne microorganisms and proved the concept of infection via the airborne route.

- **1937:** Wells et al. used upper-room UVGI to prevent the epidemic spread of measles in suburban Philadelphia day schools where infection outside the school is unlikely.

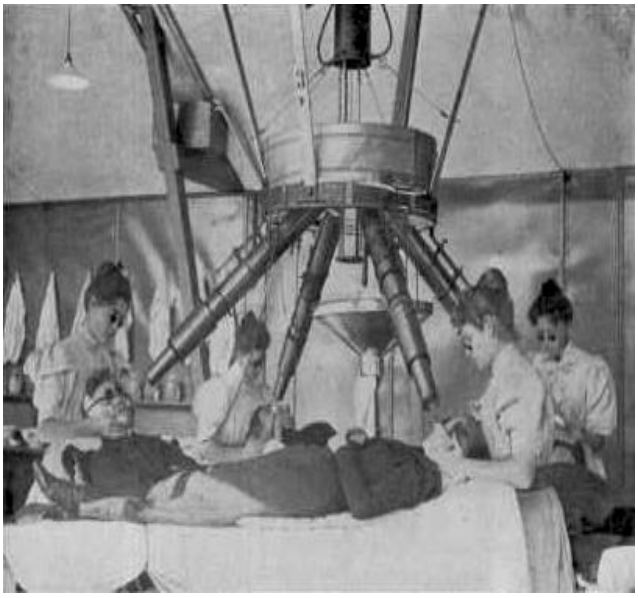

Figure 1: UV lamp used to treat Lupus (tuberculosis of the skin)

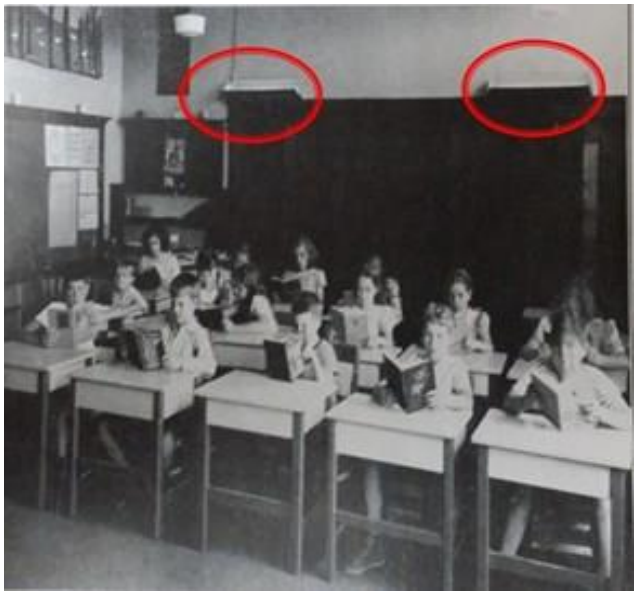

Figure 2: Upper-room UVGI to prevent spread of measles

- **1940s to 1950s:** Several studies were unable to reproduce Wells et al.'s success in using UVGI to prevent the spread of measles in schoolchildren, contributing to the disillusionment with and abandonment of UVGI for air disinfection. These failures have since been attributed to infections occurring outside the irradiated schools.

- **1956-1962:** Riley exposed guinea pigs to air originating from an occupied TB ward and proved that TB is spread via the airborne route. A group of guinea pigs receiving infected air via a UVGI irradiated duct were not infected, while a group receiving air via a non-irradiated duct were infected.

- **1969-1972:** Riley and colleagues conducted model room studies evaluating the use of upper-room UVGI to reduce the concentration of aerosolized test organisms in the lower room. They also showed that air mixing between the upper and lower room is imperative for effective disinfection and confirm that UVGI is less effective at high humidity.

- **1974-1975:** Riley et al. determined virulent tubercle bacilli and BCG to be equally susceptible to UVGI and measure the disappearance rate of aerosolized BCG in a model room with and without upper-room UVGI. Upper-room UVGI was shown to be highly effective in disinfecting the lower room, quantitatively demonstrating the potential of upper-room UVGI to reduce TB infection.

- **1985-1992:** After decades of decline, there was an unexpected rise in TB in the United States, leading to a renewed interest in UVGI for air disinfection.

- **2009:** Escombe et al. significantly reduced TB transmission to guinea pigs housed atop an occupied HIV-TB ward using upper-room UVGl, providing the first controlled clinical evaluation of upper-room UVGI to prevent TB transmission. Nardell et al. are currently completing a similar study.

1.2 Literature Review:

In terms of theoretical research, the topic of air disinfection via UV lights is very appealing. In different times, scholars have put fourth their views and findings on this topic.

W. J. KOWALSKI, PE, and WILLIAM P. BAHNFLETH, PhD, PE in the year 2000 [5], addressed the factors that determine the design parameters of ultraviolet germicidal irradiation (UVGI). In this article, the methods that can be used to size systems more effectively are discussed. The information led the industry back to the path of continuous improvement.

In 2018 [6], JOSEPH FIRRANTELLO, WILLIAM BAHNFLETH, and PAUL KREMER reported field measurements of changes in pressure drop and heat-transfer characteristics of fouled coils treated with ultraviolet germicidal irradiation designed for surface disinfection. Pressure drop data were controlled for airflow and latent load, and overall heat-transfer coefficient data were controlled for heat exchanger entering conditions.

1.3 Motivation:

Our main motivation while taking up this project was the Covid-19 pandemic.

- During the pandemic, an increasing amount of evidence has suggested that the virus can be transmitted through the air inside buildings. The ventilation system used to create the indoor environment would facilitate the transmission of the airborne infectious diseases. However, the existing ventilation systems in most buildings cannot supply sufficient clean outdoor air for diluting the virus concentration. To reduce the airborne infection risk and minimize energy consumption, especially in existing buildings with well-mixed ventilation systems, this investigation used an ultraviolet-C (UV-C) air disinfection device (Rheem's third generation products, RM3) with 99.9% disinfection efficiency to clean air carrying the COVID-19 virus (severe acute respiratory syndrome coronavirus 2, SARS-CoV-2) which could help promote environmental sustainability and create healthy cities [7].

- The outbreak of SARS-CoV-2 has made us all think critically about hospital indoor air quality and the approaches to remove, dilute and disinfect pathogenic organisms from the hospital environment. The air quality highly depends on the disinfection system and the health condition of the patients as well as doctors, nurses, technicians and every single person present in the hospital depends on the efficacy of the disinfection system.

The air quality can be ensured, and the risk of infections can be reduced by installing an air disinfection system which will ensure the health condition. That is why we have chosen this project so that we can design an air disinfection system and ensure the health conditions.

1.4 Problem Statement:

As we have gone through the existing models of air disinfection system, it came to our notice that there are a few features that are not user friendly. But with the increasing risk of Covid-19 spread and other infections, the disinfection devices should be more user friendly and cost effective.

- There is no product available that can be directly connected to ac. But as we know most of the hospital rooms and operation theatres are air conditioned, so it will be more user friendly if the disinfection device is directly attached to the AC and it can be operated with the AC easily.

- There are some available air disinfection systems that are installed inside AC but they are not easily operable, and they cannot be easily assembled. These models have very complex mechanisms that are hard to design and implement.

- The normal room disinfection devices that are available in the market need to use extra fans for ensuring air inflow to the device. More components in the model make it more complicated and heavyweight.

- The existing disinfection devices are very costly and not easily affordable for common people.

1.5 Objectives/Specific Aims:

Our main goal while designing the disinfection system was to solve the problems we mentioned before in the problem statement section. The suitable solutions we could think of are:

- Improving the existing design
- Disinfection duct attached to air conditioner
- Avoid using fans for inflow
- Easily operable
- Cost minimization

2. Design:

As our device must be attached to the AC for the circulated air to be purified, the measurement of our device is dependent on the dimensions of the inlet of the ac. As our device is practically implantable, so the design of it should be more realistic.

2.1 Initial/Preliminary Designs:

The project goal was air conditioner-based air disinfection system. A compact air duct with was designed to fit with the air inlet of the AC, so that incoming air will pass through the duct. There is a UVC light placed inside the duct. UV light is a band of electromagnetic radiation classified into four wavelength ranges: vacuum UV (100 to 200 nm), UV-C (200 to 280 nm), UV-B (280 to 315 nm), and UV-A (315 to 400 nm). Wavelengths from 100 nm to 280 nm are germicidal. At 253.7 nm (commonly referred to as “UV-C”), the UV wavelength changes the structure of DNA and RNA, the genetic code of all life forms, inhibiting the ability of cells to reproduce. While bacteria and viruses absorb UV-C energy at different rates, no microorganism tested to date has proven resistant when subjected to an appropriate dose. So, while passing through the duct air will be disinfected. First a sketch model of the duct was done (Figure 01).

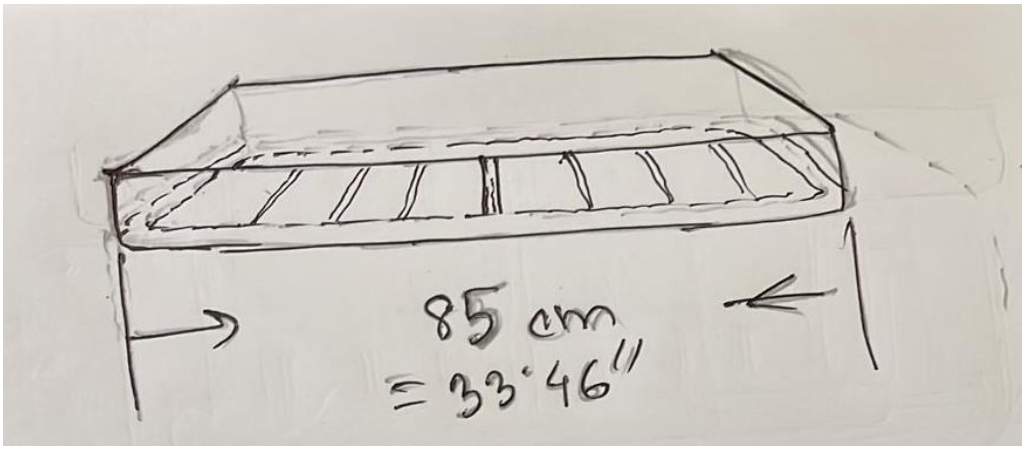

Figure 3:Duct sketch (Front view)

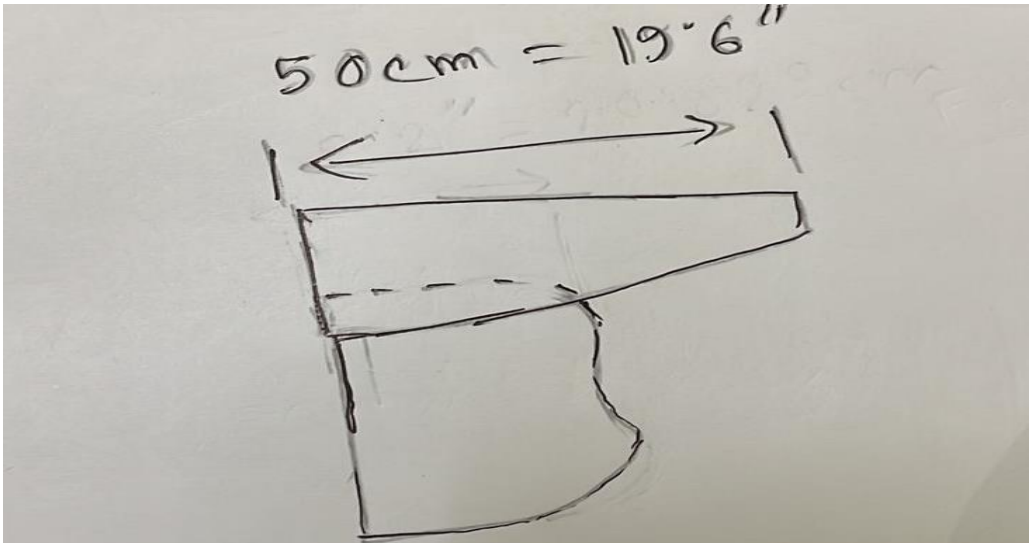

Figure 4: Duct sketch (side view)

According to the sketch, a SolidWorks model was built up. While designing the model, the entire product was divided into two parts: duct and chamber. The chamber part is for the light placement, and it will provide easy access to light maintenance and power source management.

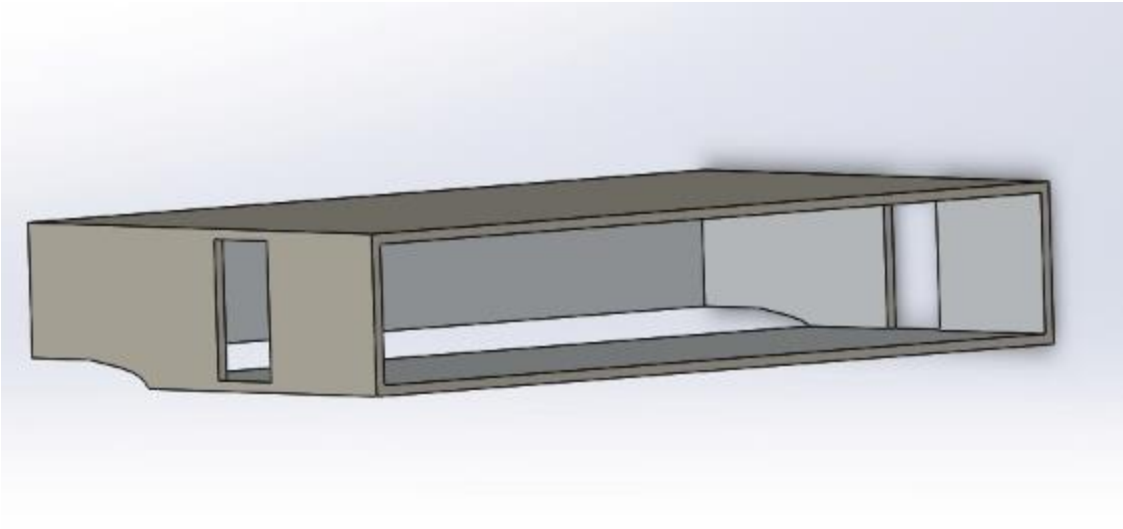

Figure 5: SolidWorks model of the duct

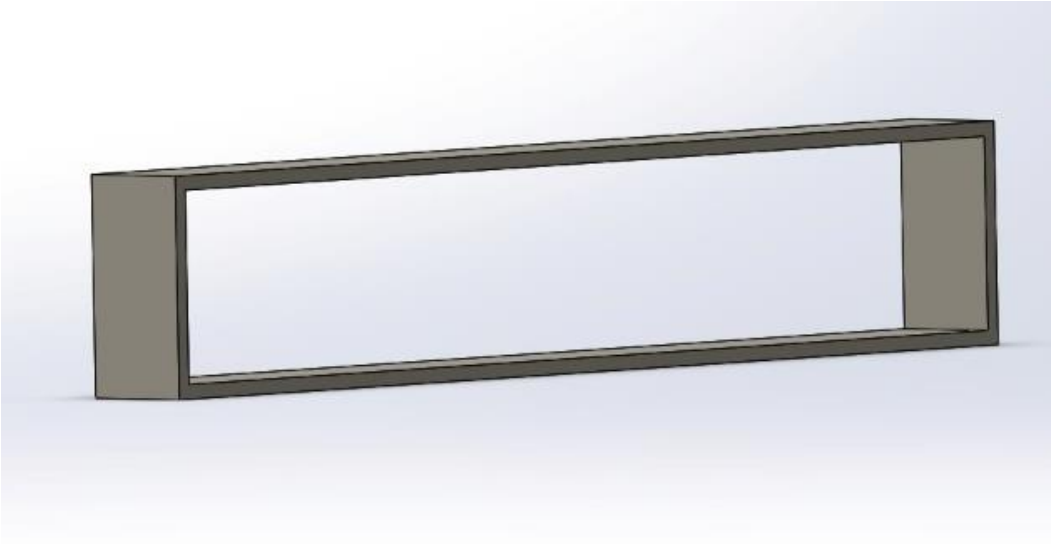

Figure 6: SolidWorks model of duct

2.2 Evaluation of preliminary Design:

After the primary design, three things were considered. They are:

(i) Dimensions: The duct dimension is 33.46×19.6×6 inches. It has a gap of 33.46×6 inches for chamber placement which is 6 inches inside from the inlet of the duct. There is a curved outlet which is designed according to the inlet of AC and its surrounding shape for proper placement. The chamber dimension is equal to the gap. It will be inserted into the duct through drawer mechanism. The whole structure has uniform thickness of 1 cm.

(ii) Material: As the whole system will be attached to the AC, so light weight material is perfect such as plywood, plastic, plastic board etc. Inside surfaces of the duct will be covered by reflective material like aluminum foil paper to avoid light absorption.

(iii) UVC light: This is the most important part of this system. To maintain proper intensity and dose for satisfactory killing rate, the wavelength of the UVC light should be 253.7nm and it should have a proper wattage. In our initial design, 2 or more lights were considered in the plan.

2.3 Final Design:

There are some updates in final design due to availability of materials, testing facilities and time shortage. Also, there are some dimensional changes in the final product. Material for developing the system was light plastic wood. It is 8 mm in thickness. The duct width is reduced to around 33.2 inches.

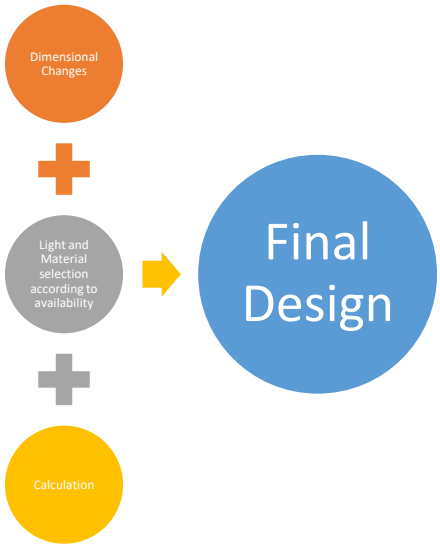

Figure 7: Flow diagram of final design

Considering the dimensions and air stream velocity, a 16W 13 inches UVC light with one sided 4 pins connector was selected which can be powered through an adapter. Instead of more light with low wattage it was easy to place, and it reduces complexity in design. The final product is shown below-

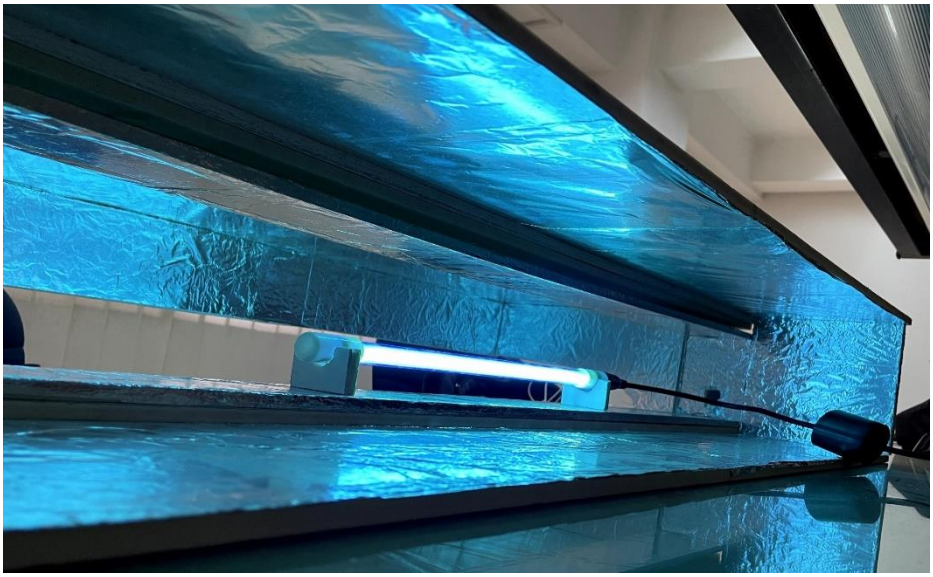

Figure 8: Final product

The chamber height reduced as extra partitions are added to make the chamber slide into duct. The adapter cable is inserted through a hole in one side of the chamber.

3. Final Design Evaluation:

After completing the final design, it was implemented into a real product. Then various readings were taken using different devices and necessary calculations were done.

3.1 Methods:

For evaluation of intensity, dose of the UVC light and air velocity are measured. Air velocity is measured by anemometer for various mode of air conditioner. Intensity and dose readings are taken by placing sensor of radiometer in 25 different points of the duct surface. For location, the width line of the duct inlet is assumed X axis line and length line as Y axis line. Both intensity and dose values are taken after 1 minute of placing the sensor.

The next step is calculating some parameters such as exposure time and effective dose in one cycle. Then removal rate of 12 common micro-organisms is calculated [8].

3.2 Results:

a) Measuring dose and intensity:

The intensity and dose were measured by a radiometer for different position in the surface of the duct. X and Y indicates the co-ordinates values (inches). The dose is linear with the intensity.

Dose [mJ/cm^2] = Intensity [mW/cm^2] × Time[s]

Table 1: Dose and intensity data obtained from radiometer

X	Y	Intensity	Dose
0	7.5	0.147	7.427
0	3.5	0.166	9.719
0	0	0.272	16.535
10.2	7.5	0.879	55.756
10.2	3.5	1.352	81.252
10.2	0	1.003	59.43
21.5	7.5	2.492	143.178
21.5	3.5	1.254	76.755
21.5	0	0.994	59.511
33.2	7.5	0.121	7.258
33.2	3.5	0.156	9.337
33.2	0	0.27	16.22
33.2	14	0.148	7.513
33.2	19.5	0.155	8.986
16.6	14	1.122	62.046
16.6	19.5	0.581	34.629
0	14	0.165	8.647
0	19.5	0.192	11.467
10.2	14	0.77	45.6
10.2	19.5	0.475	28.535
21.5	14	0.805	47.02
21.5	19.5	0.449	26.575

Here, the dose values are for 1-minute readings.

b) Generating Heatmap:

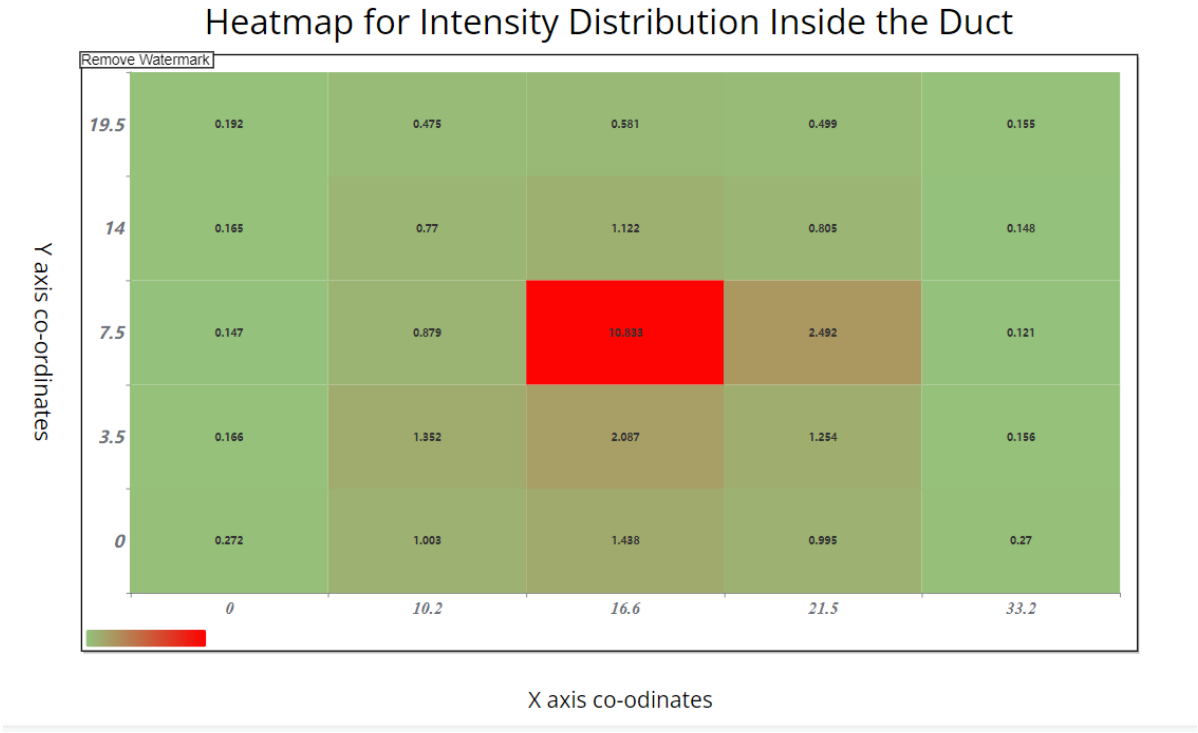

Figure 9: Heatmap of UVC intensity

c) Readings from anemometer:

From the anemometer, the air velocity through the inlet of the air conditioner always varies form 1.3 m/s to 1.6 m/s in auto mode. So, mean velocity is v = 1.45m/s

d) Calculating exposure time and dose:

The heat map shows the intensity distribution over the duct surface. From the map, we can see that the intensity is larger in middle site (x = 10.2 to 21.5 inches) because of the position of the UVC light. The mean intensity, Im = 1.133 mW/cm^2

Duct length = 19.6 inches = 50 cm = 0.5m

Inlet area of the duct A = width × height = 0.84 m × 0.1364 m = 0.114 m^2

Assuming the air velocity in the duct inlet is equal to the air velocity is AC inlet, air flowrate, Q = Av = 0.1653 m^3/s.

As the light will cover the entire area of the duct, so effective volume is equal to the duct volume.

Exposure time Et = Volume/Q = A*length/Q = 0.345s

So, Dose, D = Im × Et = 0.391 mJ/cm^2 = 3.91 J/m^2

e) Calculating removal rate of 10 common microorganisms:

Removal rate = [1-e^-(kD)] × 100

Where k is the constant associated with the target organism and D is required dose.

Table 2: Removal or reduction rate (%) of some pathogen

Species	D	K	Removal Rate (%)
Bacillus subtilis	3.91	0.032	11.76
Clostridium tetani		0.019	7.16
Legionella Pneumophilla		0.256	63.25
Pseudonomas aeruginosa		0.042	15.14
Streptococcus feacalis		0.052	18.4
Hepatitis A virus		0.032	11.76
Hepatitis Poliovirus		0.04	14.48
Saccharomyces cervisiae		0.038	13.81
Influenza		0.064	21.53
Rotavirus		0.028	10.37
Dysentery bacilli		0.105	33.67
Klebsiella terrifani		0.089	29.39

Average removal rate is 20.89%.

In this system, a 2.5 ton AC was considered. It could cover 1500 square feet of surface. So, assuming a room with 1500 square feet surface area and 10 feet height (Ideal case), total air volume is = volume of the room = 1500×10 = 15000 cubic feet = 424.7527 cubic meter.

Time required for air passing through the duct for 1 cycle = Total volume/flowrate = 424.7527/0.1653 = 2569.58 seconds.

So, in that time 20.89% of air is disinfected. For full disinfection, required time = (2569.58/20.889) × 100 = 12300 seconds = 3.42 hours.

3.3 Discussion:

From the intensity of various locations of the duct, a heatmap is generated to show intensity distribution all over the area. The light is 16 W and 13 inches in size. It is placed in the middle of the chamber. The position of chamber is 6 inches far from duct inlet and 3 inches in width. So, the middle portion of the duct (X = 10.2 to 21.5) has larger intensity. The accuracy of heatmap depends on the number of readings. So, if more readings were taken then it would be more accurate.

The calculated exposure time indicates the time needed to travel the duct for certain amount of air.

According to an article in HVAC air disinfection system air stream velocity should be less than 2.54 m/s and minimum exposure time is 0.24 s. Both the conditions are satisfied by the values in our system. The amount of germicidal energy absorbed by a pathogen over exposure time determines the fraction of the pathogen reduced. It depends on dose and a constant K. Table 1 shows the calculated removal rate of common pathogens available in air. These rates indicate the number of pathogens reduced in one cycle hence passing through the system once.

Average removal rate 20.89% is a very satisfactory value. It means 20.89% of pathogens present in a certain volume of air passing through the duct will be eliminated or inactivated. Generally, operation theaters, CT scan rooms or personal rooms are larger than 1500 square feet, so the total time of 100% disinfection should be greater than 3.42 hours. All these results are theoretically calculated, practically testing is not possible due to limitation of facilities.

4. Conclusion:

Air purification is a very important system to stay protected against airborne microbes. This technology has already evolved and is a common tool in household air purification. These products are known as “Air Purifiers”.

An air purifier is one way to help make allergy season more pleasant. Air purifiers can help filter out pollen, mold, pet dander and other common irritants from your environment. Existing air purification products are of different sizes and has different capacities to purify air. But these products are not much of help for health care places like- hospitals, diagnostic centers etc. In these places, we must make sophisticated purification system which can disinfect aerosol particles, microbes etc. So, we brought a new product which uses a very well-known UV purification system in a small and compact shell.

4.1 Novelty of our Design:

In our product, we have come up with -

- **Duct system:** We are more acquainted with the duct system for commercial ACs. But nowadays most places have non-commercial split ACs. In hospitals also we rarely see properly designed duct system. Our product is a duct system for all non-commercial ACs. In commonly used ducts, we see the duct connected to the outlet. In our product, the duct connects to the inlet. The main purpose of the duct is not to distribute air in the room rather use the pressure created by the inlet to suck in air. The sucked in air will be purified while it passes through the disinfection chamber.
- **Detachable Chamber:** The duct has a detachable disinfection chamber inside. This chamber houses a 16W UV-C light which disinfects airborne microbes by destroying their DNAs. The detachability of the chamber makes it easier to access the lights. In this way, consumers can easily change the in need.
- **Fanless System:** Our product uses the suction pressure of the inlet to suck in the air inside the duct. As the duct is closed off from three sides the suction pressure is properly utilized.

4.2 Pros and Cons of our Design:

It is quite hard to make any design 100% perfect. Though we have tried our best to install all the possible advantages in our design but there are some disadvantages also.

- **Pros:**

  - ✓ **Portability:** The product is placed on the AC inlet. But the device can be easily detached from the AC as well. It is not a one-time set-up device. The consumer can attach and detach the device in times of need.
  - ✓ **Chamber Detachability:** The duct consists of a removable chamber which houses a UV-C light. The light used in the product is powered via an adapter. So, the chamber can be detached from the duct by disconnecting the light from its' adapter. The chamber slides inside the duct smoothly.
  - ✓ **Easily Assembled:** The duct is simply placed on top of the inlet of the AC. It is not connected by any special connectors. So, any consumer can easily set-up the device without much difficulty.
  - ✓ **Cost efficiency:** In our air disinfection, we haven't used any costly components. So, the overall price of the product remains very well inside budget for all types of consumers.

- ✓ **Lightweight:** The material used in the prototype is plastic wood. This is a very light yet sturdy material. As the device is placed on the AC, a serious concern is if the AC can take the load or not. But as of now the weight of the device is light enough to lift it up with on hand only. So, the device can be easily set-up on the AC without any difficulties.

- **Cons:**

  - **Respective Size:** As we have already made sure that our device needs to cover the whole inlet of AC. So, initial designs were made sure of it. We completed the project with the same idea. So, the overall size is seemingly huge. But this can be easily rectified.
  - **Exposure of Light:** Direct exposure of skin and eyes to UVC radiation from some UVC lamps may cause painful eye injury and burn-like skin reactions. Never look directly at a UVC lamp source, even briefly. UVC exposure is also harmful for certain materials as it degrades plastics, polymers, and dye textile. UVC lamps also contain mercury which is toxic in small amounts. Our product right now has an open face that bleeds UV light outside.
  - **Non-generic product:** We have taken measurements from a 2.5-ton AC. As ACs are of various sizes, each model has different sizes of air-inlet. As we had limited resource to work with, we could only manage a single AC for measurements. So, our product is specified to that AC only.

4.3 Limitations:

We completed the product within our given timeline. But for certain limitations we can't claim this prototype to exactly what we had imagined it to be.

- We didn't have any machines to collect air sample which can testify our products effectiveness. So, as of now our product is still fully theory based.
- For the intensity measurements we couldn't arrange for a room without any lights. So, the measurements can't be stated as accurate. As we know, every light resource has UV lights in its' spectrum. So, in our case, as we couldn't eliminate other UV lights, our intensity measurements can't be claimed to be accurate.
- We couldn't set-up the device on any AC, as the ACs available to us didn't have proper ceiling clearance.
- We couldn't study the fact if we could reduce the length of the device without disturbing the airflow into the inlet. Because of which our product is relatively big in size.

4.4 Future Recommendations:

Because of many reasons we couldn't refine our product within the given time. Rather we presented our idea through the prototype. But, in future we wish to improve the imperfections of the product and refine it as much as we can.

- We wish to properly solidify our claim that the device can disinfect a large portion of a certain volume of air. So, we plan to collect air sample of before and after passing through our duct. Then measure the particle presence in the air in both cases.
- We wish to study if there will be any variations in the airflow for the duct. So, we can reduce the size of the duct and make it more compact.
- UV light bleeds out when illuminated, so we wish to add filter in the front face of our device.
- We plan to connect the duct with the ceiling with a clamp system in future and also add necessary materials at curve part of the duct so that it can be easily attached to any model of AC.

5. References

[1] T. Karitonas, "TestLab," 22 January 2021. [Online]. Available: https://testlabsuk.com/blog/air-disinfection-systems-whats-behind-their-efficacy-claims/.

[2] *. N. K. R. A. M. a. J. D. S. Ehsan S. Mousavi, "COVID-19 Outbreak and Hospital Air Quality: A Systematic Review," *Environmental Science and Technology,* p. 14, 2021.

[3] AirQuality, "AirQuality," [Online].

[4] N. G. Reed, "The History of Ultraviolet Germicidal Irradiation for Air Disinfection," *NCBI,* 2010.

[5] P. a. W. P. B. P. P. W.J. KOWALSKI, "UVGI Design Basics for Air and Surface Disinfection," *Researchgate,* 2000.

[6] W. B. &. P. K. Joseph Firrantello, "Field measurement and modeling of UVC cooling coil irradiation for heating, ventilating, and air conditioning energy use reduction (RP-1738)—Part 1: Field measurements," *Researchgate,* 2018.

[7] X. Z. A. M. Q. C. Shubham Srivastava, "Effective ventilation and air disinfection system for reducing coronavirus disease 2019 (COVID-19) infection risk in office buildings," *National Library of Medicine,* 2021.

[8] Signify, "UV-C disinfection for air, sufaces and water".*Signify.*