Buildings, Energy and Environment Research Group

Department of Architecture and Built Environment

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Experimental Investigation of an Indoor Air Purification System using an Innovative Photocatalytic Mop

Thesis by

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Abstract

This thesis presents a comprehensive investigation of "MopFan," a photocatalytic air purification system, with the overarching goal of improving indoor air quality and its broader impacts on public health, the environment, and the economy. Recognising the critical importance of addressing the pressing issue of air pollution, this study delves into various facets of the MopFan technology and its potential for revolutionising the field of air purification.

To lay the foundation for this research, a thorough review of the existing literature on photocatalytic purifiers is conducted, providing a comprehensive understanding of the current state-of-the-art in air purification technology. By analysing the strengths and limitations of previous studies, this review identifies crucial areas for improvement, particularly in the domains of filter design, catalyst selection, and lighting arrangement. By pinpointing these areas, the study aims to contribute to the ongoing efforts to enhance the efficacy and efficiency of air purification systems.

Building upon this literature review, the research explores novel approaches to fibre configuration and coating for anti-virus protection within the MopFan system. Through experimentation and analysis, the study uncovers the significant effectiveness of copper, tampico, and coco fibres in mitigating viral contaminants, offering a promising solution to combat airborne pathogens. This discovery holds immense potential for shaping future strategies in filter design and material selection, opening new possibilities for the development of advanced air purification technologies.

The thesis then proceeds to focus on the practical implementation of the MopFan technology by designing, prototyping, and rigorously testing prototypes. Each prototype represents a significant advancement in air purification capabilities, showcasing the integration of motor-driven fans, specialised mop technology, and enhanced UV light to maximise the removal of airborne pollutants. Through a comprehensive evaluation of these prototypes, the research demonstrates efficacy in significantly improving air quality and reducing the presence of harmful particles in indoor environments.

This research utilised 3D printing technology to create functional prototypes of the MopFan air purification system, focusing on advancements in air purification capabilities. The prototypes were produced using a specialised 3D printer and ABS filament, with the hub divided into sections for individual printing and easy assembly. Precision was achieved through careful adjustment of printer settings, resulting in accurate prototypes. Although the printing process took 12 to 16 hours per prototype, it enabled efficient construction, comprehensive evaluation, and testing.

In addition to the technical aspects, this thesis also delves into the economic and environmental dimensions of the MopFan technology. An economic assessment showcases the potential for job creation and economic growth associated with the widespread adoption and commercialisation of the technology. By highlighting the economic benefits, this assessment serves as a compelling argument for the financial feasibility and further development. Simultaneously, an environmental assessment emphasises the importance of adopting sustainable practices throughout the lifecycle of the technology. It emphasises the need for responsible manufacturing, energy efficiency, and waste reduction, highlighting the imperative of creating environmentally conscious solutions to address air pollution.

Keywords: Photocatalytic air purification system, indoor air quality, public health, air pollution, photocatalytic purifiers, filter design, catalyst selection

List of publications

1. Tapia Brito, Emmanuel & Riffat, James & Wang, Yixin & Wang, Yuhao & Ghaemmaghami, Amir & Coleman, Christopher & Erdinç, Mehmet & Riffat, Saffa, 2023. Experimental study of the purification performance of a MopFan-based photocatalytic air cleaning system. Building and Environment. 240. 110422. https://doi.org/10.1016/j.buildenv.2023.110422
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3. James Riffat, Cagri Kutlu, Emmanuel Tapia-Brito, Samuel Tekpetey, Francis B. Agyenim, Yuehong Su & Saffa Riffat, 2022, Development and testing of a PCM enhanced domestic refrigerator with use of miniature DC compressor for weak/off grid locations, International Journal of Green Energy, 19:10, 1118-1131 https://doi.org/10.1080/15435075.2021.1984244
4. Tapia-Brito, E., Riffat, J., Wang, Y., Ghaemmaghami, A.M., Coleman, C.M. and Riffat, S., 2022. Experimental Investigation of a MopFan-Based Photocatalytic Air Purification Device. Future Cities and Environment, 8(1), p.5. DOI: http://doi.org/10.5334/fce.149
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Nomenclature

Symbol	Term
∂	Partial derivative symbol
∇	Gradient operator
$\mu g/m^3$	Micrograms per cubic meter
k	Turbulent kinetic energy
Lux	Lighting illuminance
MJ	Megajoules
nm	Nanometre
P_k	Production of turbulent kinetic energy
Pa	Pascal
RH	Relative Humidity
t	Time
u	Velocity vector of the fluid
ε	Turbulent kinetic energy dissipation rate
μ	Dynamic viscosity of the fluid
μ_t	Turbulent viscosity
ρ	Density
σ	Energy consumption
σ_k	Turbulent Prandtl number for TKE
σ_ε	Turbulent Prandtl number for dissipation rate
ω	Demand calibration factor
$C_1\varepsilon$	Turbulence model constant
$C_2\varepsilon$	Turbulence model constant
p	Possibility

Symbol	**Term**
εlat	Latent effectiveness
εsen	Sensible effectiveness
ηe	Energy reduction rate

Subscripts and Superscripts

Symbol	**Term**
a	Air
amb	Ambient
sol	Solution
e	Electricity
in	Inlet
mem	Membrane
out	Outlet
re	Renewable energy
Rr	Real discount rate
R	Interest rate

Abbreviations

Abbreviation	**Term**
ACH	Air Changes per Hour
ACT	Air Cleaning Technology
AOP	Advanced Oxidation Process
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers

Abbreviation	**Term**
BS	British Standard
BSI	British Standards Institution
CAD	Computer-aided Design
CADR	Clean Air Delivery Rate
CFD	Computational Fluid Dynamics
CIBSE	Chartered Institution of Building Services Engineers
CO	Carbon Monoxide
CO_2	Carbon Dioxide
COP	Coefficient of Performance
EER	Energy Efficient Rate
EPC	Energy Performance Certification
ERP	Energy Reduction Package
FM	Formaldehyde Mitigation
GHG	Greenhouse Gas
HCHO	Formaldehyde
HEPA	High-Efficiency Particulate Air
HSE	Health and Safety Executive
HVAC	Heating, Ventilation, and Air Conditioning
HVOC	High Volatile Organic Compound
IAP	Indoor Air Pollution
IAQ	Indoor Air Quality
IAQP	Indoor Air Quality Procedure
IESVE	Integrated Environmental Solution Virtual Environment
KGM	Konjac Glucomannan
NO_2	Nitrogen Dioxide

Abbreviation	**Term**
NVP	Natural Ventilation Procedure
O_3	Ozone
PAPE	Prototype Air Purification Efficiency
Pb	Lead
PCO	Photocatalytic Oxidation
PLA	Polylatic Acid
PM	Particulate Matter
PMM	Particulate Matter Mitigation
PV	Photovoltaic
Rn	Radon
ROS	Reactive Oxygen Species
RPM	Revolutions Per Minute
SA	Sodium Alginate
SO_2	Sulfur Dioxide
SPF	System Performance Factor
TFA	Total Floor Area
TiO_2	Titanium Dioxide
TRNSYS	Transient System Simulation Tool
UON	University of Nottingham
UV	Ultraviolet
VOCM	Volatile Organic Compound Mitigation
VOCs	Volatile Organic Compounds
VRP	Ventilation Rate Procedure
WELs	Workplace Exposure Limits
WO_3	Tungsten Trioxide

Chapter 1 Research Background

Indoor air pollution (IAP) poses a significant health concern as it can contain various pollutants originating from outdoor sources, occupant activities, or building materials. On average, people spend approximately 90% of their time indoors, exposure to indoor air pollution can have immediate and long-term health effects. Extensive studies conducted worldwide have confirmed that air pollution negatively impacts individuals with chronic cardiovascular and respiratory conditions and can even contribute to the development of these diseases in otherwise healthy individuals (Schraufnagel et al., 2019). This problem is further exacerbated by factors such as an aging population, increasing rates of chronic illnesses, and rapid urbanisation. As buildings become more energy-efficient and prioritise carbon reduction, natural ventilation is being reduced, leading to a heightened health risk from indoor pollutants. Hence, there is a pressing need for indoor air purification systems, especially considering the recent COVID-19 pandemic.

Achieving a safe indoor environment solely through natural ventilation or inadequate HVAC systems is challenging (Andersen et al., 2012). While HVAC systems, when functioning as intended, provide thermal comfort and maintain overall good air quality through mechanical ventilation, they can also inadvertently facilitate the transmission of airborne pollutants and viruses. The existing conventional HVAC systems do not effectively remove these pollutants or viruses during the air processing stage. Although research is underway to improve HVAC systems' handling of air pollution and viruses, current systems contribute to the spread of indoor air pollution (Choe et al., 2022).

HEPA filters and electrostatic precipitators, commonly used in HVAC systems, have not demonstrated efficient removal of household pollutants and viruses from the air. Furthermore, employing a high-grade/density filter causes a large pressure drop and can lead to increased energy consumption, frequent maintenance requirements, and potential disposal safety concerns. Additionally, many ionising air purifiers emit negative ions, which can cause particles such as viruses, animal dander, and particulate pollutants to remain suspended in the room, posing a risk of re-exposure. Moreover, ionisers have the potential to generate ozone, which is a respiratory hazard.

1.1 The demand for air purification

In recent years, the negative impact of IAP on human health has gained significant attention. According to a 2018 report by the World Health Organization (World Health Organization, 2018), IAP was responsible for 3.8 million deaths worldwide, with increased risks of developing lung cancer, heart disease, chronic obstructive pulmonary disease, and stroke. With the average British individual spending 90% of their lives indoors (UK Government, 2021), there is a growing need for clean and breathable air to reduce the risks associated with exposure to indoor air pollutants. The importance of clean air has been recognised by the UK government, and measures are being taken to ensure it is a basic human right. The Clean Air Bill has been under discussion in parliament with the aim of reducing ambient PM 2.5 concentrations, the most harmful pollutant to human health (Clean Air Bill, 2021). The Environment Act has also set a target to halt the decline of nature and reduce PM 2.5 concentrations by 2030 (Environment Act, 2021). These initiatives show the UK government's commitment to improving air quality and protecting public health. Air purifiers, specifically photocatalytic air purifiers, have emerged as a promising solution to indoor air pollution (IAP) in recent years.

Air pollution is one of the biggest environmental concerns today. As a result, there has been a growing interest in finding efficient methods to remove pollutants from the air. One promising technology is the use of photocatalytic air filters that employ TiO_2 as a catalyst to break down harmful pollutants (Matz et al., 2019). TiO_2 can be activated by UV light to produce hydroxyl radicals that can oxidise and break down pollutants into harmless substances. Current TiO_2 air filters often have low efficiency due to a small surface area, which limits the number of pollutants that can be broken down. To address this, a new type of air filter using TiO_2-fibres arranged in a mop-like arrangement has been developed, which provides a larger surface area and airflow passage. However, to make the process more efficient, the activity of the photocatalyst itself needs to be improved. Previous research (Koivisto et al., 2018) has revealed long-term durability issues of TiO_2 on polymer fibres. Therefore, a new design has been developed using a different TiO_2 coating that provides the necessary longevity. The ventilation of indoor environments plays a crucial role in maintaining air quality and ensuring a comfortable and healthy living or working space. Traditionally, indoor ventilation has been categorised into two main types: natural ventilation and mechanical ventilation. However, in recent years, there has been a noticeable shift towards a greater reliance on mechanical ventilation and air-conditioning systems, often neglecting the significant benefits that fresh outdoor air can bring (Tham, 2016).

Natural ventilation, as the name suggests, exploits natural air movements, such as wind or temperature differences, to exchange stale indoor air with fresh outdoor air. This method has been practiced for centuries and offers several advantages. It promotes a connection with the external environment, allowing for a constant supply of fresh air, natural cooling, and the removal of indoor pollutants. Natural ventilation also reduces reliance on energy-consuming mechanical systems, contributing to energy efficiency and environmental sustainability.

However, despite these benefits, there has been a growing tendency to prioritise mechanical ventilation and air-conditioning in building design (Tobisch et al., 2021). The convenience and control offered by these systems have led to their widespread adoption. Modern buildings often rely heavily on air-conditioning units, which regulate temperature and humidity levels but may not prioritise the introduction of fresh air. This shift in focus has resulted in a reduction in natural ventilation strategies, leading to a missed opportunity to harness the advantages of outdoor air and its positive impact on indoor environments.

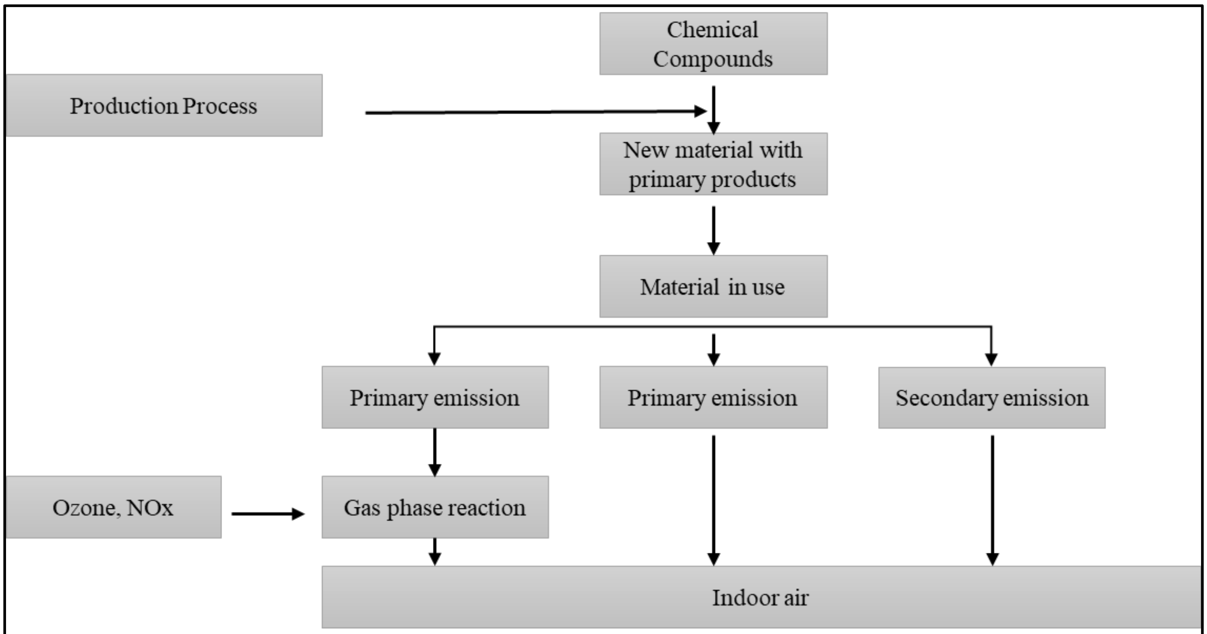


Figure 1.1 Flow chart displaying the production of indoor pollutants

Today, only a limited number of buildings are designed to fully embrace and maximise the benefits of natural ventilation (Saini et al., 2020). Factors such as urbanisation, increased building density, and concerns over energy efficiency have contributed to this trend. To address these pressing health concerns, innovative indoor air purifying technologies, like the MopFan, are essential. By eliminating airborne viruses and pollutants from recirculated air, such solutions ensure the creation of healthier indoor environments, Figure 1.1 demonstrates the production process of these indoor pollutants.

These advanced technologies offer more efficient and energy-saving alternatives to high-grade filters and conventional HVAC systems. The development of low-cost and durable fibre mop units not only contributes to environmental sustainability but also ensures effective air purification. By providing a safe indoor environment, these cutting-edge air purifying systems improve public health, reduce the transmission of diseases, and mitigate the impact of indoor air pollution on vulnerable populations. Table 1.1 lists a breakdown of the health risks of each given pollutant.

Table 1.1 Array of pollutants and associated health concerns (Suzuki et al., 2020)

Pollutant	**Source of Emission**	**Associated Health Concerns**
Carbon Monoxide (CO)	Cigarette fumes, cooking stoves, boilers, kerosene or gas heaters, combustion of fuels	Low birth weight, elevated rate of perinatal deaths
Carbon Dioxide (CO_2)	Burning activities, metabolic processes, motor vehicles in garages	Headaches, drowsiness, difficulty concentrating, decreased attention span
Radon (Rn)	Construction materials, accumulation in soil	Potential for developing lung cancer, respiratory difficulties
Nitrogen Dioxide (NO_2)	Vehicle emissions, fuel combustion, outdoor atmosphere	Aggravation of asthma and wheezing, diminished lung function in children, increased susceptibility to respiratory infections
Sulphur Dioxide (SO_2)	Burning fossil fuels, interaction with the atmosphere	Increased bronchial activity (short-term exposure)

Volatile Organic Compounds (VOCs)	Combustion of gas, wood, kerosene, use of cleaning agents, paints, etc.	Allergic skin responses, visual impairments, memory difficulties, detrimental effects on CNS, kidneys, liver, decreased cholinesterase levels
Fungal Spores	Enclosed spaces, edible items, vegetation, soil	Asthma attacks, allergic responses, irritation of eyes, throat, and nose, respiratory issues including sinus problems
Asbestos	Insulation, fire retardant materials	Mesothelioma, thickening of pleura, pleural plaques, asbestosis
Pollens and Allergens	Ambient atmosphere, vegetation, dust, animals, outdoor environments	Induce allergic symptoms
Particulate Matter (PM2.5 & PM10)	Tobacco smoke, particle resuspension, combustion byproducts	Aggravation of asthma, wheezing, respiratory infections, worsening of COPD, chronic bronchitis, COPD exacerbation
Lead (Pb)	Paints, firearms, lead ammunition, dust, soil, consumer products	Memory impairment, hearing decline, harm to developing nervous system, hypertension, heart and kidney ailments, decreased fertility
Ozone (O_3)	Sunlight-induced chemical reactions	Airways irritation, lung damage, increased risk of pneumonia and bronchitis, exacerbation of asthma

In the era following the Coronavirus pandemic, it is crucial to comprehend the spread of infections within indoor settings. There are two modes of transmission: droplet-borne and airborne (Ham, 2020). These modes rely on air to carry pathogens. The buoyancy of pathogens is influenced by factors such as particle or droplet mass, indoor volume, and air velocity. Understanding these dynamics is essential for developing effective control strategies.

1.2 The growing demand for air purifiers

The demand for air purifiers has witnessed a steady rise, primarily due to various factors and an increasing awareness of the crucial significance of indoor air quality. The following states the key reasons that contribute to the significant demand for air purifiers:

1.2.1 Health concerns

As displayed in Table 1.2 indoor air pollution has emerged as a prominent health challenge as it harbours an array of contaminants such as dust, pet dander, pollen, mould spores, VOCs, and even noxious gases. Prolonged exposure to these pollutants can lead to respiratory problems, allergies, asthma attacks, and various other health issues.

1.2.2 Rising pollution levels

Outdoor air pollution has become a pervasive problem in numerous regions, especially in densely populated urban areas with high vehicular traffic and industrial activities. When outdoor air infiltrates indoor spaces, it carries along pollutants that can significantly compromise indoor air quality.

1.2.3 Allergies and asthma

Allergies and asthma are prevalent respiratory conditions that can be triggered or exacerbated by indoor allergens like dust mites, pollen, pet dander, and mould. Air purifiers equipped with HEPA filters efficiently capture these allergens, providing much-needed relief to individuals suffering from allergies and asthma.

1.2.4 COVID-19 pandemic

The COVID-19 pandemic has further amplified the demand for air purifiers (Dbouk et al., 2021). While air purifiers alone cannot prevent the transmission of the virus, they play a vital role in reducing the concentration of airborne particles, including respiratory droplets that may potentially carry the virus. This has led to a surge in interest for air purifiers as a supplementary measure to enhance indoor air quality and minimise the risk of infection.

1.2.5 Odour and chemical control

Air purifiers equipped with activated carbon filters exhibit impressive capabilities in neutralising unpleasant odours and eliminating VOCs from indoor air. This proves particularly advantageous in households or environments where strong odours or chemical fumes are present, such as lingering cooking smells, tobacco smoke, cleaning product emissions, or paint fumes.

1.2.6 Sensitivity to indoor air quality

Certain individuals exhibit heightened sensitivity to changes in indoor air quality, experiencing symptoms like headaches, fatigue, congestion, or respiratory irritation when exposed to poor air quality.

1.2.7 Peace of mind

Having an air purifier in homes or workplaces instils a sense of assurance and peace of mind, knowing that proactive steps are being taken to improve and maintain optimal indoor air quality. This aspect holds particular significance for individuals who spend substantial amounts of time indoors, such as children, the elderly, or those with compromised immune systems.

Table 1.2 Stimulation of demand for air purification devices (Yoda et al., 2020)

Concerns/Considerations	Description
Health Risks	Air purifiers help address indoor air pollution by filtering contaminants like dust, pet dander, pollen, mould spores, VOCs, and noxious gases.
Outdoor Pollution	Air purifiers mitigate the impact of outdoor pollution by capturing and removing harmful particles, improving overall indoor air quality.
Allergies and Asthma	Air purifiers equipped with HEPA filters provide relief to individuals with allergies and asthma.
COVID-19 Protection	Air purifiers help reduce the concentration of airborne particles, including respiratory droplets that may carry the COVID-19 virus.
Odour and Chemical Control	Air purifiers with activated carbon filters neutralise odours and eliminate VOCs, addressing issues like strong odours, tobacco smoke, cleaning product emissions, or paint fumes.
Sensitivity to Air Quality	Air purifiers create a cleaner and more comfortable environment for individuals who are sensitive to changes in indoor air quality.
Peace of Mind	Having an air purifier provides assurance and peace of mind, especially for individuals who spend significant time indoors, such as children, the elderly, or those with compromised immune systems.

Overall, the increasing demand for air purifiers stems from the imperative need to foster healthier indoor environments, combat respiratory issues, reduce exposure to pollutants, and address specific concerns related to allergies, asthma, odour control, and the COVID-19 pandemic.

1.3 Indoor air quality standards

In the UK, there are numerous standards and guidelines which specify indoor air quality as a priority. These standards and guidelines are founded to regulate and monitor IAQ. These standards and guidelines serve as benchmarks for building design, ventilation systems, and pollutant control. The following states key UK standards and guidelines related to indoor air quality:

1.3.1 Building regulations

The Building Regulations in the UK play a crucial role in ensuring adequate ventilation and maintaining acceptable indoor air quality in buildings. These regulations establish minimum requirements for ventilation systems and the control of indoor air pollutants in both new and existing buildings. The primary objective is to create a healthy and comfortable indoor environment for occupants by addressing factors such as air exchange rates, ventilation rates, and the prevention of condensation and mould growth. By setting these standards, the Building Regulations aim to minimise the potential health risks associated with poor indoor air quality and promote occupant well-being.

1.3.2 Workplace Exposure Limits (WELs)

The Health and Safety Executive (HSE) in the UK sets WELs to protect the health of workers. These limits define the maximum allowable concentrations of hazardous substances in the workplace air. WELs cover a wide range of substances, including gases, vapours, and particulates that can have adverse effects on indoor air quality in occupational settings. By establishing these limits, the HSE ensures that employers take measures to control and reduce exposure to harmful substances, thereby safeguarding the health and well-being of workers.

1.3.3 British Standards

The British Standards Institution (BSI) has developed various standards that focus on indoor air quality. Notably, BS EN 13779:2017 provides guidelines for the design, installation, operation, and maintenance of ventilation systems in non-residential buildings. These standard addresses crucial aspects such as outdoor air intake, filtration efficiency, air distribution, and thermal comfort to ensure that ventilation systems effectively maintain adequate indoor air quality. By adhering to these standards, building owners and designers can implement robust ventilation strategies that enhance occupant comfort.

1.3.4 CIBSE guides

The Chartered Institution of Building Services Engineers (CIBSE) has published guides that offer comprehensive recommendations and best practices for achieving good indoor air quality in buildings. CIBSE Guide A: Environmental Design covers a wide range of topics related to building design, including ventilation strategies, thermal comfort, and air quality objectives. CIBSE Guide B: Heating, Ventilating, Air Conditioning, and Refrigeration focuses specifically on the design and operation of HVAC systems, emphasising the importance of ventilation and air distribution for maintaining high indoor air quality standards.

1.3.5 Public Health England (PHE) guidance

Public Health England offers guidance on indoor air quality in different settings, such as homes, schools, and healthcare facilities. This guidance addresses critical aspects of indoor air quality management, including ventilation rates, moisture control, and the control of specific indoor air pollutants such as radon and VOCs. By following the guidance provided by PHE, building owners, occupants, and facility managers can take appropriate measures to improve indoor air quality, reduce exposure to pollutants, and promote a healthy indoor environment. Table 1.3 displays a concise summary of the indoor air quality standards pertinent to the United Kingdom.

Table 1.3 Summary of UK standards/regulations relating to indoor air quality (McGill et al., 2016)

Standards on Indoor Air Quality in the UK	**Description**
Building Regulations	Establish minimum requirements for ventilation systems and control of indoor air pollutants
	Aim to create a healthy and comfortable indoor environment for occupants
Workplace Exposure Limits (WELs)	Define maximum allowable concentrations of hazardous substances in workplace air
	Cover gases, vapours, and particulates that can affect indoor air quality in occupational settings

British Standards (BS)	Provide guidelines for design, installation, operation, and maintenance of ventilation systems
	Address aspects like air intake, filtration, and air distribution to maintain adequate indoor air quality
CIBSE Guides	Offer recommendations for achieving good indoor air quality in buildings
	Cover topics such as ventilation strategies, thermal comfort, and HVAC system design and operation
Public Health England (PHE) Guidance	Provide guidance on indoor air quality in homes, schools, and healthcare facilities
	Address ventilation rates, moisture control, and control of specific indoor air pollutants

1.4 Carbon emissions

As shown in Figure 1.2, the global carbon cycle involves the movement and exchange of CO_2 and other carbon compounds between the atmosphere, land, oceans, and living organisms. Key processes include photosynthesis, respiration, decomposition, fossil fuel combustion, carbon sequestration, and oceanic exchange. Photosynthesis captures CO_2, while respiration and decomposition release it. Fossil fuel combustion emits large amounts of CO_2, while carbon sequestration removes it.

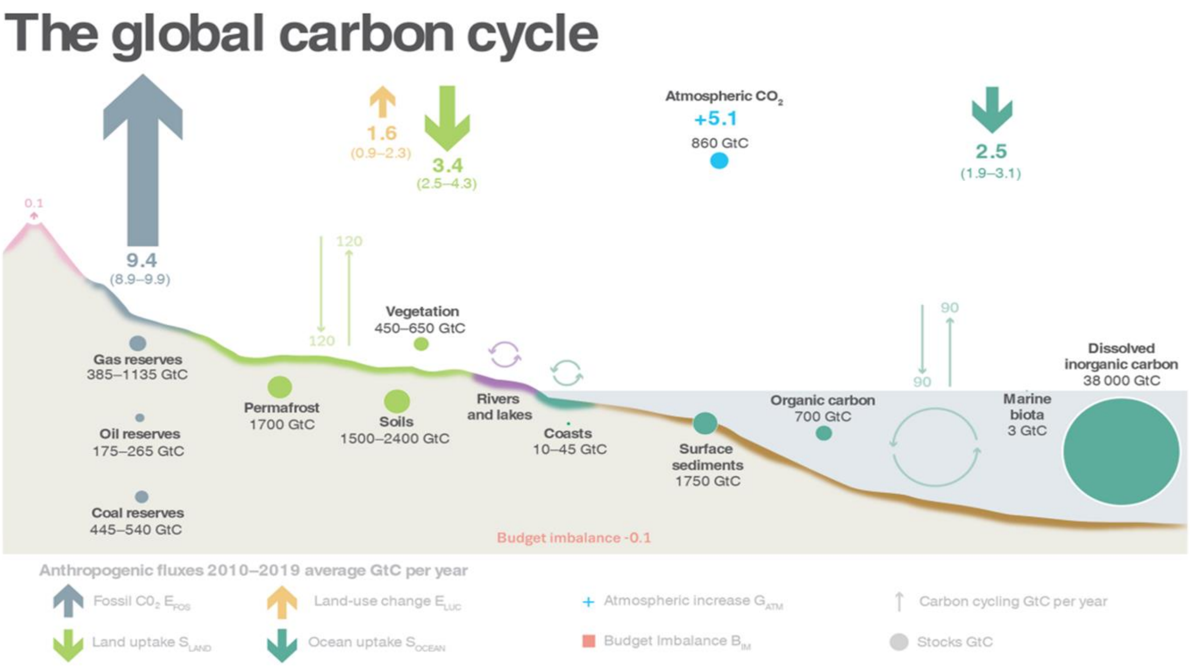


Figure 1.2 Overall perturbation of the global carbon cycle (Friedlingstein et al., 2020)

The global carbon budget, depicted over time, as shown in Figure 1.3, presents a comprehensive view of the various components it encompasses. Fossil CO_2 emissions, along with a minor sink from cement carbonation (shown in grey), as well as emissions from land-use change (ELUC; depicted in brown), are all part of this representation. These emissions are distributed among three primary reservoirs: the atmosphere (GATM; represented in blue), the ocean (SOCEAN; depicted in turquoise), and the land (SLAND; shown in green). Notably, GATM is derived from direct observations, while estimates for SOCEAN and SLAND rely on process model ensembles constrained by available data.

A noteworthy aspect is the possibility of a budget imbalance, wherein the partitioning of emissions may not precisely align with the sum of emissions. To illustrate this, the lower pink line (indicating total emissions) may differ from the combined values of the ocean, land, and atmosphere components. Such a discrepancy requires careful consideration and analysis to understand the underlying factors and implications.The primary source of carbon emissions from buildings is the energy consumed by heating, cooling, and ventilation systems. Air purifiers, on their own, do not directly impact a building's energy consumption or associated

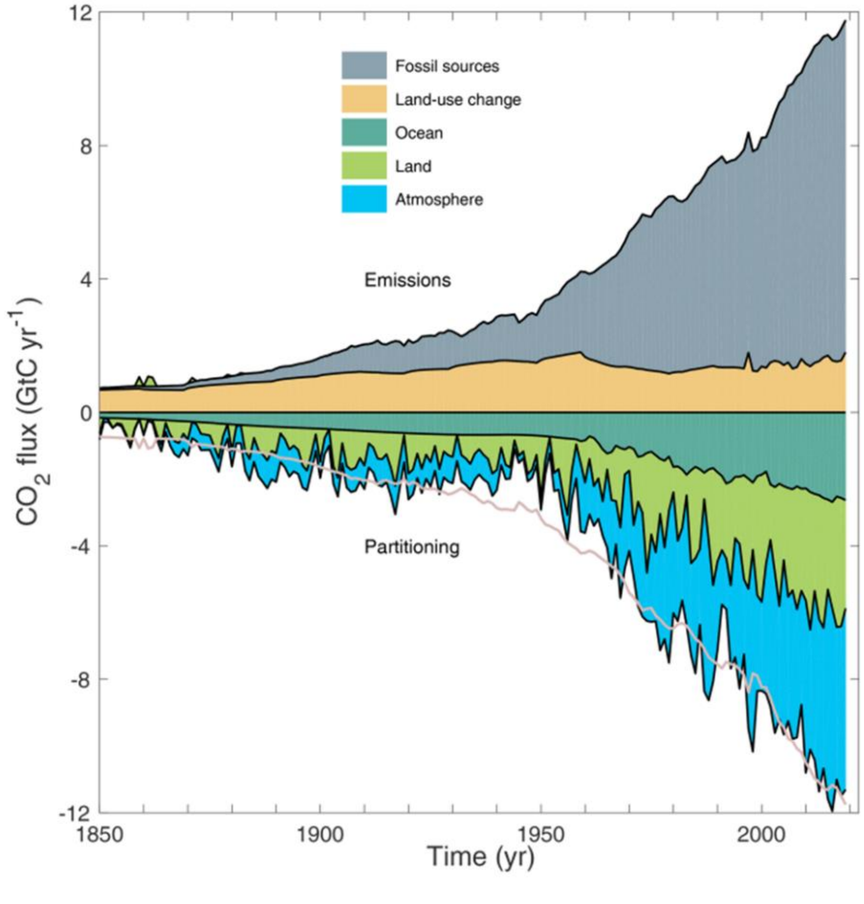


Figure 1.3 Combined components of global carbon emissions (Friedlingstein et al., 2020)

carbon emissions. However, there is an indirect connection between air purifiers and carbon emissions. By improving indoor air quality, air purifiers can enhance the comfort and well-being of occupants. This improvement may potentially reduce the need for excessive ventilation or air conditioning, leading to energy savings and a subsequent decrease in carbon emissions (Marques et al., 2018).

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 62.1, which pertains to Ventilation for Acceptable Indoor Air Quality, establishes guidelines that aim to maintain satisfactory indoor air quality for human occupants while minimising negative health impacts. This standard is formulated using language that can be enforced as part of building codes, simplifying its integration into regulations. To comply with Standard 62.1, there are three available procedures: the Ventilation Rate Procedure (VRP), the Indoor Air Quality Procedure (IAQP), and the Natural Ventilation Procedure (NVP).

The implementation of air purification systems in buildings enables the circulation of indoor air in a safe and clean manner. This, in turn, allows for a significant reduction in the amount of outside air required for ventilation, potentially reaching up to an impressive 85% reduction when employing ASHRAE's IAQP (ASHRAE, 2019).

To effectively decrease carbon emissions from buildings, it is crucial to prioritise energy-efficient building design, proper insulation, optimisation of HVAC systems, utilisation of renewable energy sources, and the implementation of sustainable practices during construction and operation. These measures have a more significant impact on reducing carbon emissions compared to the role of air purifiers alone. When considering carbon emissions and air purifiers, it is crucial to consider the energy consumption and environmental consequences associated with their operation. While air purifiers are effective in enhancing indoor air quality, it is important to acknowledge that certain models may indirectly contribute to carbon emissions. The relationship between air purifiers and carbon emissions can be further explored through various factors. Energy consumption plays a significant role. Air purifiers rely on electricity to power their fans and filtration systems. The amount of energy used by an air purifier can vary depending on its size, filtration technology, and fan speed settings. Models with more powerful fans or advanced filtration mechanisms may consume higher amounts of energy. It is important to note that if the electricity used by the air purifier comes from fossil fuel-based sources, it can indirectly contribute to carbon emissions.

Another aspect to consider is filter replacement. Many air purifiers employ filters to capture and eliminate pollutants from the air. These filters require periodic replacement to maintain optimal performance. The manufacturing and disposal of filters can have environmental implications. Improper disposal or non-recyclable filters can contribute to waste generation and subsequent carbon emissions.

Additionally, the manufacturing process of air purifiers itself has environmental consequences. Various manufacturing activities such as raw material extraction, assembly, packaging, and transportation of air purifiers all contribute to their carbon footprints. Taking into account the environmental impact of the manufacturing process is vital when evaluating the overall carbon emissions associated with air purifiers. To mitigate potential carbon emissions associated with air purifiers, several measures can be taken. First, opting for energy-efficient models is important. These models are designed with energy-saving features such as programmable timers, sleep modes, or sensors that adjust fan speed based on air quality. By choosing energy-efficient air purifiers, the carbon footprint during operation can be minimised.

By implementing these measures - choosing energy-efficient models, promoting filter recycling, and supporting sustainable manufacturing practices - the potential carbon emissions linked to air purifiers can be mitigated. This allows for the improvement of indoor air quality while minimising the environmental consequences. Table 1.4 details a concise summary of the impact of air purification units on carbon emissions.

Table 1.4 Impact on carbon emissions from air purification units (Koohestanian & Shahraki, 2021)

Factors	Impact on Carbon Emissions
Energy consumption	Air purifiers rely on electricity, potentially contributing to carbon emissions if sourced from fossil fuels. Energy consumption varies based on size, filtration technology, and fan settings. Powerful fans and advanced filtration increase energy usage.
Filter replacement	Filters in air purifiers require periodic replacement, and improper disposal or non-recyclable filters can contribute to waste generation and subsequent carbon emissions.
Manufacturing process	Manufacturing air purifiers entails carbon emissions from raw material extraction, assembly, packaging, and transportation. Assessing the carbon

	footprint necessitates considering the environmental impact of the entire manufacturing process.
Measures to mitigate emissions	Opting for energy-efficient models with energy-saving features can minimise the carbon footprint during operation.
	Prioritising air purifiers with recyclable filters or filter replacement programs reduces waste generation and associated carbon emissions.

1.5 Photocatalytic oxidation

Photocatalytic Oxidation (PCO) is a highly effective process that eliminates pathogens, bio-aerosols, volatile organic compounds, and viruses. TiO_2 is the most common and efficient photocatalyst used in this process, as shown in Figure 1.4. PCO functions at room temperature and chemically oxidises volatile organic pollutants, which are primarily converted into CO_2 and water. Hydroxyl radicals, which are produced by the irradiation of TiO_2 with UV photons in the presence of air and trace water vapour, are responsible for removing pollutants in PCO. High-intensity UV LEDs are cost-effective and efficient, while TiO_2 is inexpensive, photostable, inert, insoluble, and non-toxic, making it a common ingredient in toothpaste, sunblock, and paint. This process that employs light energy to initiate oxidation reactions on the surface of a photocatalyst material (Hoffmann et al., 1995). It involves the interaction among a photocatalyst, typically a semiconductor substance, light, and a target substance (pollutant or organic compound), enabling the oxidation of the target substance. During photocatalytic oxidation, the photocatalyst absorbs light photons, usually UV light, which energises the electrons within the photocatalyst material, raising them to higher energy levels. These energised electrons create highly reactive species, such as electron-hole pairs ($e\^- / h\^+$) or superoxide radicals ($O_2\^-$), depending on the specific photocatalyst and reaction conditions. The resulting reactive species from the photocatalyst can then interact with the target substance present on or in contact with the photocatalyst's surface (Mills & Le Hunte, 1997). The oxidising species, such as hydroxyl radicals ($\bullet OH$) or reactive oxygen species (ROS), formed during the photocatalytic process, react with the target substance, causing its oxidation and subsequent breakdown into less harmful or non-toxic byproducts. Photocatalytic oxidation finds applications in diverse fields, including environmental remediation, water purification, air pollution control, and self-cleaning surfaces. It has been effectively employed to eliminate organic pollutants, such as VOCs, pesticides, and dyes, from water and air by utilising the energy of sunlight or artificial light sources to drive the oxidation reactions (Fujishima et al., 2000). By harnessing the power of photocatalytic oxidation, it becomes possible to achieve efficient degradation and removal of a wide range of pollutants, offering a promising approach for sustainable and environmentally friendly treatment of contaminated water and air (S. T. Nguyen et al., 2009).

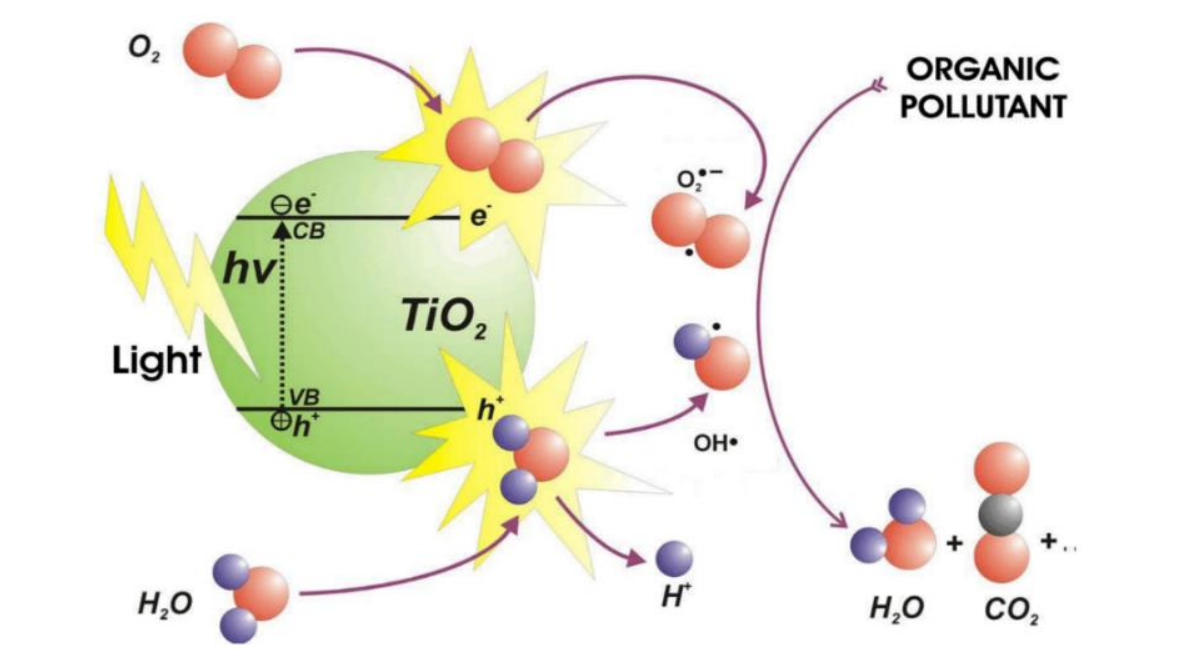


Figure 1.4 Diagram of heterogenous photocatalysis (Ibhadon & Fitzpatrick, 2013)

1.6 Hydroxyl radicals

The primary generation of hydroxyl radicals occurs through a series of intricate reactions involving the breakdown of ozone (O_3) by sunlight and the interaction of excited oxygen atoms ($O(^1D)$) with water vapour (H_2O), as shown in Figure 1.5. These processes mainly take place in the Earth's atmosphere, particularly in the troposphere, which is the lowest layer where weather phenomena occur (Finlayson-Pitts, 1999). There are three key factors in understanding hydroxyl radicals:

1.6.1 Reactivity

Hydroxyl radicals exhibit high reactivity due to the presence of an unpaired electron, enabling them to react readily with various molecules. They react indiscriminately with pollutants, such as VOCs, nitrogen oxides (NO_x), sulphur dioxide (SO_2), and numerous other trace gases present in the atmosphere (Atkinson & Arey, 2003).

1.6.2 Lifespan

Hydroxyl radicals have a brief lifespan and are recognised as one of the shortest-lived species in the atmosphere, typically lasting from milliseconds to seconds. Their short lifespan limits their transport over long distances, confining their reactions to the vicinity of their formation.

1.6.3 Importance

Hydroxyl radicals play a critical role in upholding the self-purifying capacity of the Earth's atmosphere. They serve as key agents in eliminating various pollutants, including greenhouse gases and air pollutants, through oxidation processes. Furthermore, their reactivity influences the atmospheric lifetimes of diverse compounds and impacts the creation of secondary pollutants like ozone and aerosols (Zellner, 2000).

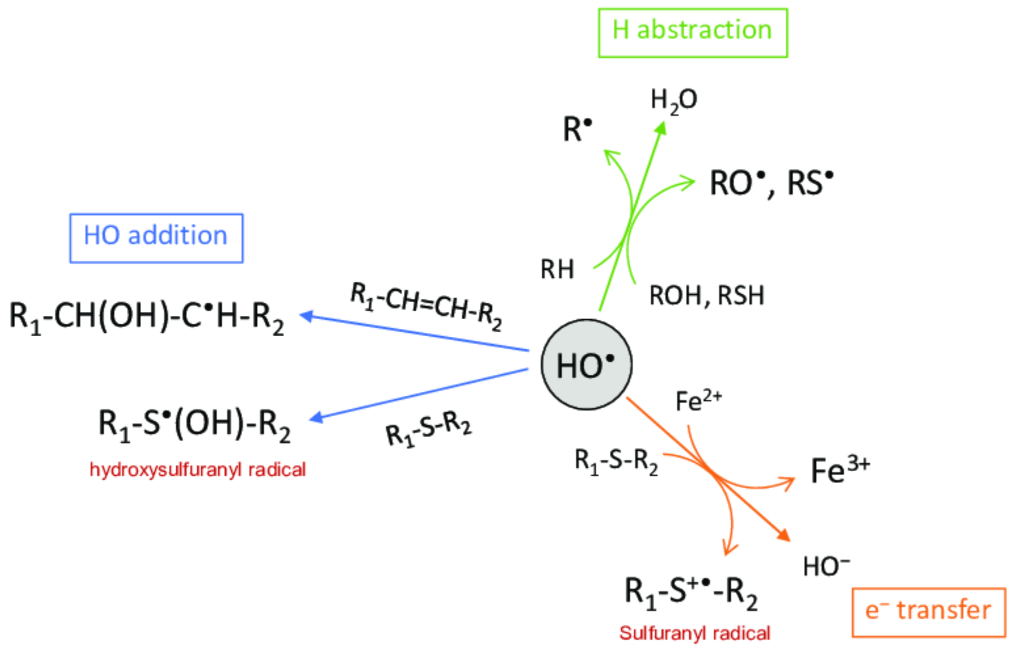


Figure 1.5 Diagram of chemical reactions of hydroxyl radicals (Collin, 2019)

1.7 Titanium dioxide

Titanium dioxide (TiO_2) is naturally occurring and is extensively used across various industries. It serves as a white pigment in paints, coatings, plastics, and cosmetics, owing to its light-scattering and opacity characteristics, as shown in Table 1.5. Moreover, TiO_2 is employed as a photocatalyst in diverse environmental and industrial applications (Rupp et al., 2019). Scientists have investigated the antimicrobial properties of TiO_2, exploring its capacity to impede the growth and functionality of bacteria, fungi, and certain viruses. When exposed to UV light, the photocatalytic nature of TiO_2 triggers the production of ROS, such as hydroxyl radicals. These ROS exhibit potent oxidation capabilities and can induce harm to the structures of microorganisms, including viruses (Meng et al., 2016) . While several studies have demonstrated encouraging outcomes regarding the antiviral effectiveness of TiO_2, it is crucial to acknowledge that its efficacy may vary depending on factors such as the specific virus, experimental conditions, and the photocatalytic properties of the TiO_2 employed (Manosalva et al., 2019). Air filtration systems incorporating TiO_2 have gained significant attention due to the photocatalytic properties exhibited by this compound. These systems leverage the photocatalytic oxidation process to improve the purification of indoor air (Bagheri et al., 2014). In such systems, TiO_2 is commonly applied as a coating on filters or integrated into other filtration materials. When exposed to UV light, TiO_2 acts as a photocatalyst, generating ROS such as hydroxyl radicals and superoxide ions. These ROS possess potent oxidation abilities, enabling them to decompose and neutralise a wide range of airborne pollutants, including VOCs, bacteria, viruses, and odourous compounds (Mahlambi et al., 2015). The photocatalytic oxidation process facilitated by TiO_2 in air filtration systems enhances the overall efficiency of the filtration process by effectively targeting and reducing various contaminants. Table 1.5 presents a detailed summary of the applications of TiO_2

Table 1.5 Applications of titanium dioxide (Fei Yin et al., 2013)

Application	**Description**
Paints and Coatings	TiO_2 finds widespread use in the realm of paints, coatings, and varnishes as a white pigment, offering exceptional opacity and brightness. Its presence enhances durability and colour retention.
Plastics	Within the world of plastics, TiO_2 serves as a captivating pigment, imparting luminosity, opacity, and brightness. It is commonly employed in various products, including PVC pipes, packaging materials, and automotive components.
Paper	The paper industry integrates TiO_2 into paper coatings to elevate brightness, whiteness, and opacity. This infusion augments print quality and lends an aesthetically pleasing appearance to the paper.
Cosmetics	In the realm of cosmetics, TiO_2 plays a crucial role, gracing makeup, skincare products, and sunscreens. It acts as a safeguarding UV filter,

	reflecting and scattering harmful rays while providing a lustrous base for cosmetic applications.
Food and Beverage	Known as E171, TiO_2 serves as a food additive, enhancing the whiteness and opacity of various consumables. It adorns confectionery, icing, chewing gum, and dairy products, imbuing them with an enticing visual appeal.
Pharmaceuticals	Within pharmaceutical formulations, TiO_2 fulfils diverse functions. It can assume the role of a colouring agent in tablets, capsules, and ointments. Additionally, it acts as an opacifier, ensuring consistent distribution in select medications.
Sunscreens	The inclusion of TiO_2 as a key constituent in sunscreens and sunblock arises from its capacity to reflect and scatter UV rays. This pivotal role offers protection against both UVA and UVB rays, minimising the risk of sunburn and skin cancer.
Ceramics	Within the ceramics industry, TiO_2 imparts vitality to glazes and ceramic coatings, augmenting their opacity, brightness, and chromatic uniformity. These attributes culminate in vibrant and captivating ceramic finishes.
Photocatalysis	Thanks to its photocatalytic properties, TiO_2 accelerates specific chemical reactions when exposed to light. This quality renders it invaluable in environmental applications, such as air and water purification, where it aids in the breakdown of pollutants.
Solar Cells	TiO_2 assumes a crucial role as a primary component in dye-sensitised solar cells (DSSCs), functioning as a semiconductor. Its inclusion facilitates the conversion of sunlight into electricity, contributing to the advancement of solar energy technology.

1.8 Use of fibres to increase surface area

One approach to enhance the surface area of a purification system involves utilising fibres instead of a flat plate configuration. This alternative design offers several benefits by increasing the contact area between the air stream and the purification medium. Incorporating fibres into the system leads to a substantial augmentation in the available surface area for interactions with airborne pollutants. The three-dimensional arrangement of fibres forms a network of interconnected channels, facilitating extensive exposure of the purification medium to the passing air. This enlarged surface area allows for enhanced processes such as adsorption, absorption, and catalytic reactions, resulting in improved efficiency in removing pollutants (Šišková et al., 2021). The fibrous structure promotes turbulence and mixing within the air stream, facilitating better distribution of pollutants across the purification medium. As the air flows through the intricate network of fibres, it encounters an increased number of contact points, thereby creating more opportunities for pollutants to be captured and treated effectively (X. Yang et al., 2022). Furthermore, the utilisation of fibres offers versatility in material selection. Various types of fibres, such as activated carbon, zeolites, or specialised catalytic fibres, can be employed depending on the specific pollutants targeted for removal. This flexibility allows for the customisation of purification systems to address a wide range of contaminants, ensuring effective and targeted pollutant removal (Zhu et al., 2020). The fibrous configuration also provides potential advantages in terms of maintenance. The porous nature of fibres facilitates easier flushing or desorption of accumulated pollutants, enabling the regeneration and reuse of the purification medium. This characteristic contributes to the long-term sustainability and cost-effectiveness of the system (Parasuraman et al., 2022).

1.9 Ultraviolet light for pollutant removal

UV light has demonstrated its efficacy as an effective technique for eliminating pollutants in various applications, including air purification. UV light, especially in the germicidal range at a wavelength of 254 nm, as depicted in Figure 1.6, possesses potent oxidative properties that can eradicate organic compounds, neutralise odours, and eradicate airborne pathogens (Xiao Jiangrong et al., 2016). When pollutants in the air are exposed to UV light of the appropriate wavelength, it disrupts the molecular structure of organic compounds, leading to their decomposition. This process, referred to as photolysis, breaks down VOCs and other pollutants into smaller, less harmful molecules, thereby enhancing the quality of indoor air (Y. Huang et al., 2016). In addition to photocatalysis, UV light can also induce a photocatalytic reaction when combined with a suitable catalyst, such as TiO_2. This combination amplifies the elimination of pollutants by generating ROS like hydroxyl radicals, which possess robust oxidising properties. These ROS can effectively degrade and neutralise a wide array of pollutants, including VOCs, bacteria, viruses, and mould spores (Destaillats et al., 2012). UV-based air purification systems typically employ UV lamps or LEDs that emit UV light within the germicidal range. These lamps are strategically positioned within the system to maximise the exposure of the air to UV light. As the air passes through the purification system, the UV light irradiates the pollutants, facilitating their decomposition or oxidation. It is crucial to note that UV-based air purification systems must be designed with safety measures to prevent direct human exposure to UV light. Prolonged exposure to UV radiation can be harmful to the skin and eyes. Therefore, these systems are usually enclosed to ensure that the UV light remains contained within the purification chamber (X. Zhang et al., 2022). UV light-based air purification has gained widespread use in diverse settings, including hospitals, laboratories, commercial buildings, and residential spaces. It provides an efficient and chemical-free approach to eliminating pollutants, thereby enhancing indoor air quality and promoting a healthier environment.

UV light, particularly in the germicidal range, represents a highly effective method for removing pollutants in air purification. It achieves this through the processes of photolysis and photocatalysis. UV-based air purification systems offer a chemical-free and efficient approach to enhancing indoor air quality by neutralising odours, eliminating pathogens, and reducing the concentration of various pollutants (Han et al., 2022).

In the healthcare sector, the utilisation of UV light for disinfection and sterilisation purposes has been widely adopted by several hospitals for many years. These facilities employ robust, industrial-grade devices capable of eliminating various microorganisms, including the highly contagious COVID-19 virus. The application of UV light extends to hospital rooms, furniture,

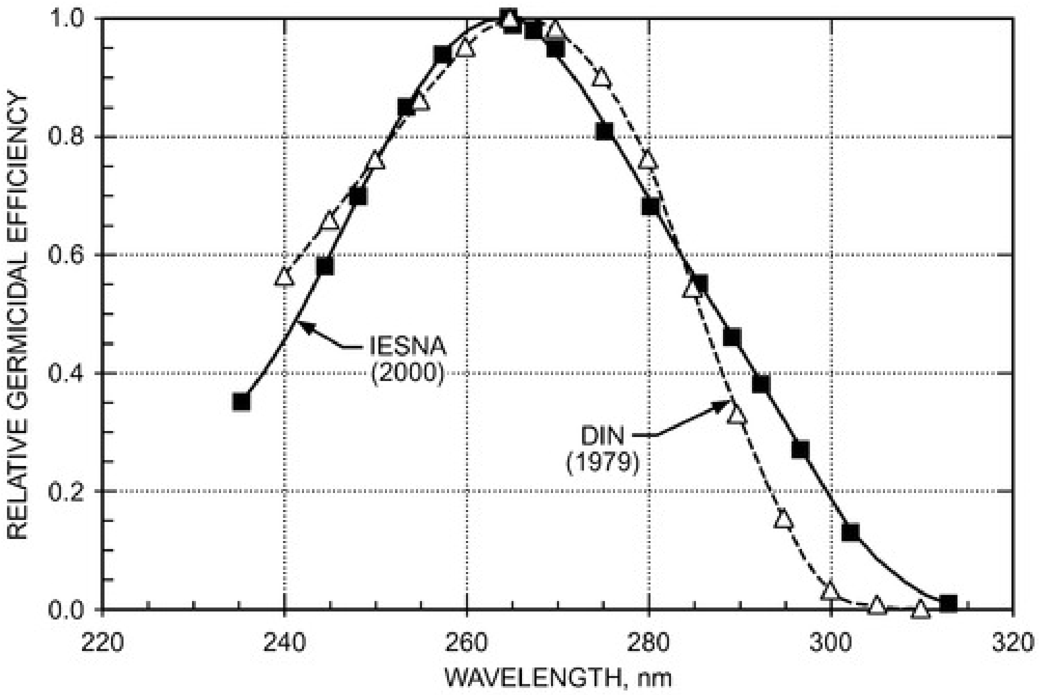


Figure 1.6 Graph of the UV-C germicidal wavelengths (ASHRAE, 2019)

objects, clothing, and tools, ensuring thorough sanitisation. UV radiation encompasses a range of electromagnetic wavelengths between 100 and 405 nm. Within this spectrum, it is crucial to consider three distinct subintervals: UVA, UVB, and UVC.

Based on the standards defined by CIE1984 and CIE1987, UVA light occupies a wavelength range from 315 to 400 nm. CIE1984, also referred to as the CIE 1931 XYZ colour space, is a colorimetric standard that measures human colour perception. It is widely used in colour-related applications like colour matching and reproduction, serving as a fundamental framework for colour measurement and calculations. CIE1987, or CIECAM, is a standard designed to anticipate colour perception in different viewing scenarios. By taking into account factors such as illuminants, background colours, and viewing environments, it offers a comprehensive model for comprehending colour appearance and human perception of colour. UVB light falls within the 280 to 315 nm wavelength range, while UVC light encompasses wavelengths between 100 and 280 nm, as shown in Figure 1.7.

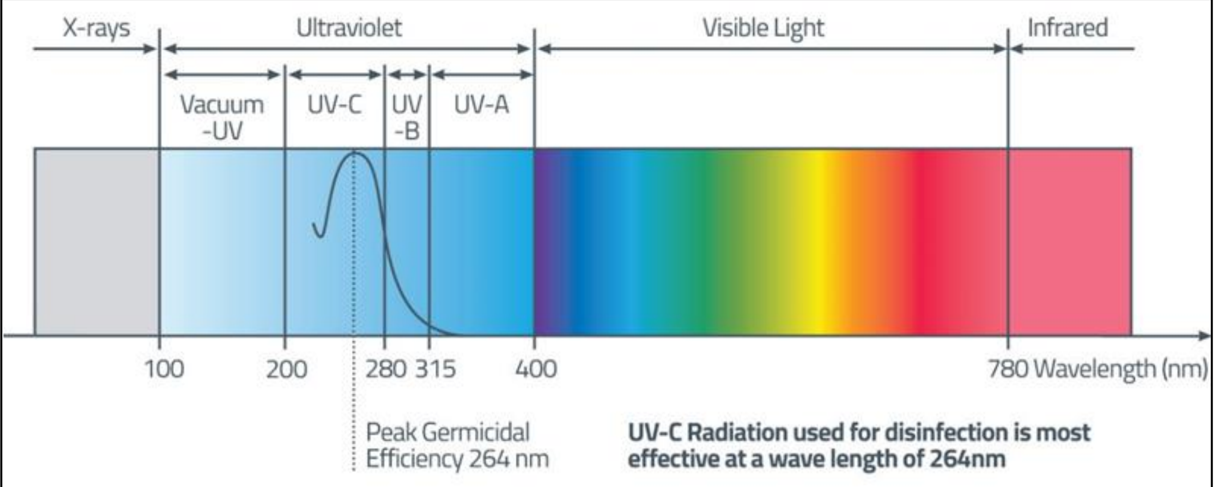


Figure 1.7 Diagram of the UV light spectrum with consideration of the UV-C disinfection range (T. T. Nguyen et al., 2022)

These different UV subintervals possess varying properties and applications. UVA, with its longer wavelengths, is commonly associated with tanning beds and can penetrate the deeper layers of the skin, potentially causing long-term damage. UVB, with intermediate wavelengths, is known to play a crucial role in vitamin D synthesis but can also lead to sunburn and contribute to skin cancer development. UVC, with its shorter wavelengths, has significant germicidal properties, effectively destroying a broad range of microorganisms by damaging their DNA or RNA structures.

While UVA and UVB radiation can be found in natural sunlight and have various biological effects, UVC light is mostly filtered by the Earth's atmosphere and is not present in significant quantities. However, artificial UVC sources are widely used for disinfection purposes due to their potent germicidal capabilities. Understanding the distinct wavelengths and properties of UVA, UVB, and UVC light is crucial when designing and implementing UV-based disinfection systems in healthcare settings. Proper consideration and implementation of specific UV wavelengths ensure effective microbial eradication while minimising potential risks associated with prolonged exposure to UVA and UVB radiation. Table 1.6 displays a summary of the characteristics of each UV wavelength.

Table 1.6 UV LED wavelength characteristics (Yin et al., 2020)

UV LED Strip	**Wavelength (nm)**	**Intensity (W/m^2)**	**Application/Characteristics**
UVA	315-400	14	Suitable for longer exposure times; effective disinfection
			Can penetrate deeper layers of the skin; potential long-term damage
UVC	200-280	10	Highly effective germicidal activity; shorter exposure times
			Destroys a broad range of microorganisms; potential risks to human health
UVB	280-315	8	Plays a crucial role in vitamin D synthesis; can cause sunburn
			Contributes to the development of skin cancer

1.10 The proposed "MopFan" system

Presenting a novel concept for indoor air quality and air filtration, this research introduces innovative systems that incorporate a mop mounted on a specially designed shaft within a reflective casing. As the air moves through the MopFan systems, it encounters a substantial TiO_2-fibre surface area, strategically exposed to high-intensity UV LEDs positioned within the reflective fan casing.

To optimise the effectiveness of the setup, the internal surface of the fan casing is coated with UV reflective vinyl, directing the UV light to focus on the TiO_2-fibre area. The outcome are fan systems that not only facilitates efficient airflow but also achieves an extensive UV illumination of the TiO_2, generating significant quantities of hydroxyl radicals. These radicals play a crucial role in effectively eliminating pollutants present in the air. The proposed systems exhibit great promise in providing improved indoor air quality and effective air purification.

The MopFan system is a significant improvement over current indoor air cleaner/sterilisation systems, which use filters or mesh UV systems. The unique feature of the MopFan system is the use of TiO_2-coated fibres in a mop arrangement, providing an extensive UV- TiO_2 interaction surface area and airflow passage. This design enables the system to remove harmful indoor pollutants, including volatile organic compounds, bio-aerosols, and pathogens, through PCO technology. The novel MopFan system's advantages, such as being low-cost, efficient, and nearly silent, make it an ideal indoor air cleaner/sterilisation system. The system's PCO process has been proven to be effective in destroying and removing harmful indoor pollutants, making it a desirable solution for indoor air quality improvement.

As presented in Figure 1.8, one concept of a MopFan system is composed of a cylindrical mop with flexible fibres, resembling a chimney sweep brush, which are specially coated with TiO_2. Unlike traditional filter or mesh-based UV systems, the TiO_2-covered fibres in the mop configuration provide a significantly larger surface area for UV- TiO_2 interaction and enhanced airflow passage. This innovative system combines the cylindrical brush with a fan that propels air through the fibres. As air passes through the fibres, it undergoes a thorough treatment process.

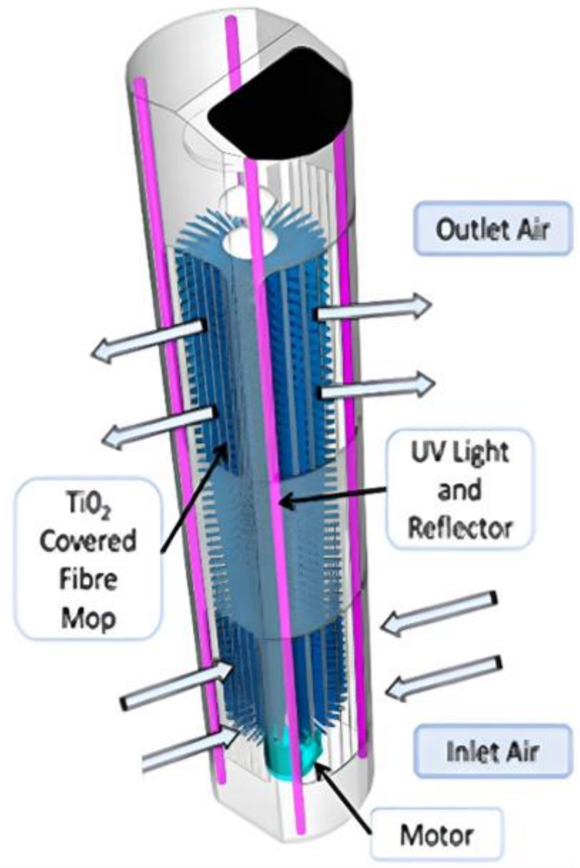


Figure 1.8 Diagram of MopFan design concept

The fibres TiO_2 coating initiates a photocatalytic reaction when exposed to UV light, which helps break down harmful pollutants and contaminants present in the air. The MopFan system offers several advantages over conventional UV-based air treatment systems. Its unique mop arrangement ensures a greater contact area between the air and the TiO_2-coated fibres, facilitating efficient pollutant degradation. The fan component ensures a continuous flow of air, allowing for consistent and effective purification throughout the designated space.

This concept incorporates a range of innovative features, ensuring optimal air purification efficiency and performance. When activated, the motor initiates the movement of the blades, generating an upward airflow that directs external air towards the mop's fibres. The synchronised motion of the mop and the fan ensures effective air circulation within the device. Within the purifier's body, a TiO_2 coating on the mop's fibres undergoes a photocatalytic reaction when exposed to UV light. This reaction occurs precisely as the contaminated air passes through the purifier, facilitating the degradation of airborne pollutants. The MopFan system efficiently directs the purified air towards the top air exit of the device case, facilitated by the force generated by the MopFan. During this process, the air traverses the extensive surface area of the TiO_2-coated fibres. To maximise the effectiveness of the UV light, high-intensity UV LEDs are strategically positioned within the fan housing, illuminating the fibres. The interior surface of the housing is coated with a light-reflective substance, optimising UV ray concentration and ensuring a consistent and robust UV irradiation. Through its superior airflow dynamics and intensive UV irradiation, the MopFan system demonstrates substantial potential for improving indoor air quality.

The MopFan concept can be adapted for a variety of fixed and mobile applications. For example, the system can be scaled up or down depending on the size of the space that needs to be decontaminated. One possible application is to integrate MopFan with existing HVAC systems. By doing so, the TiO_2/UV surface can be placed in the flow path of the air as it circulates through the building. This means that the air can be decontaminated as it passes through the system, improving the overall air quality in the building. The MopFan would be rotated by the airflow of the HVAC system, ensuring that they are constantly exposed to the air. Another possible application is for use in transportation settings, such as trains or airplanes. The floor unit with axial, helix mops could be mounted horizontally in overhead racks or between back-to-back seats. This would allow for efficient decontamination of the air inside the train or airplane, reducing the risk of viral transmission. The MopFan concept represents a promising new approach to air decontamination. By combining the power of TiO_2/UV technology with the high surface area of mop fibres, the system can efficiently remove viruses, bacteria, and other harmful pollutants from the air. As the world recovers from the COVID-19 pandemic and other viral threats, innovative solutions like the MopFan concept will play an increasingly important role in protecting public health and safety.

As presented in the following chapter, studies have been conducted on the effects of loading the photocatalyst surface with different metals. For example, in one study, silver nitrate and sodium carbonate were added to a TiO_2 slurry and dried baked, which greatly increased the efficiency of the PCO process. In another study, it was found that adding platinum, palladium, or gold to the TiO_2 increases oxidation rates by a factor of 3 to 5. Antimicrobial metals, such as silver, platinum, and copper, have also been shown to be effective in reducing the spread of pathogens. Copper fibres are economical and TiO_2 coated fibres can be fabricated into a fan mop, where the TiO_2 may also be doped with copper. To find the most effective yet economical system to counter SARS-CoV-2 and future viruses, the optimum geometry for air flow, mop-fibre arrangement and type, antimicrobial metal integration, and UV light/intensity and fibre optics has been explored (Hajkova et al., 2007). In this development, Nano-sized TiO_2 photocatalysts of controlled morphology and superior photocatalytic activity were investigated. Titanium isopropoxide was used as the precursor in a modified sol-gel process to produce amorphous TiO_2 with low particle agglomeration. The amorphous TiO_2 was transformed into crystalline particles using controlled hydrothermal or thermal processes.

Establishing the virus pollution removal capability of the MopFan concept is key. Modelling indicates the concept will produce significantly greater quantities of powerful hydroxyl radicals compared to current systems. The feasibility study modelling will indicate the optimum UV LED arrangement, mop fibre density, and pattern. In addition to its virus removal capabilities, it can help remove common pollutants such as VOCs, HCHO, chloride, benzoin, isobutane, particulates, dust, and allergens. This can be especially important for those who suffer from respiratory issues, allergies, or asthma. Furthermore, MopFan could be applied in a variety of settings, including hospitals, schools, offices, and homes.

In conclusion, the TiO_2-mop fan concept shows great promise in the fight against SARS-CoV-2 and future viruses. Its ability to remove pollutants and improve indoor air quality also makes it an asset in a variety of settings. With continued research and development, MopFan could become a key tool in the fight against infectious diseases and in promoting a healthy indoor environment. A breakdown of the key features of the MopFan concept are stated in Table 1.7.

Table 1.7 Key features of the MopFan concept

Key Points
The study proposes a new air filtration system using a mop mounted on a shaft within a fan casing, rotated by a high-efficiency motor.
The MopFan system utilises TiO_2-fibre surface area and high-intensity UV LEDs to generate hydroxyl radicals that remove pollutants.
Nano-sized TiO_2 photocatalysts with controlled morphology and superior photocatalytic activity were investigated.
Loading the photocatalyst surface with metals like silver, platinum, and copper enhances the oxidation rates and antimicrobial properties.

The MopFan system aims to counter SARS-CoV-2 and other viruses while improving indoor air quality.
The system can be adapted for various applications, such as care homes, hospitals, schools, offices, and transportation settings.
Integration with existing HVAC systems or use in tabletop or mobile units is possible to decontaminate air in different spaces.
The MopFan concept offers scalability, versatility, and low maintenance requirements.
It has the potential to efficiently remove viruses, bacteria, and pollutants, contributing to public health and safety.

1.11 Benefits of the MopFan system

The MopFan system is intended to provide air purification for indoor environments and reduce energy consumption by eliminating airborne viruses from recirculated air using innovative air-processing technology. This system aims to benefit various sectors including public spaces, healthcare facilities, transportation, HVAC industry, and builders. The implementation of MopFan offers a range of impacts and benefits:

1.11.1 Environmental benefits

MopFan supports the UK's commitment to a green recovery in accordance with the Clean Air Act and clean growth goals. Traditional HVAC systems that eliminate air recirculation to combat viruses consume approximately 20% more energy. With the building and transportation sectors accounting for over 60% of carbon emissions, this increase in energy usage is a significant concern (González Lezcano, 2022). MopFan overcomes the limitations of high-grade filters by providing a more effective and energy-efficient solution. By potentially reducing space heating loads by 20%, MopFan contributes to energy savings. Additionally, the low-cost, durable, replaceable, and fully recyclable fibre unit used in MopFan promotes environmental sustainability.

1.11.2 Economic impacts

The MopFan system would play a vital role in economic recovery by facilitating a return to normalcy and safeguarding against future pandemics. Even a 1% increase in productivity adds £20 billion to the UK economy, emphasising the long-term economic benefits of MopFan. This significantly influences the supply chain and customer base for industry partners, resulting in at least a two-fold increase in unit production annually.

1.11.3 Social advantages

MopFan's ability to remove common indoor air pollutants and airborne viruses makes it a versatile solution that can be easily integrated into both existing and new HVAC systems. By providing safe environments in buildings and public transport, MopFan promotes public health, job security, social inclusion, and equality. This technology also helps minimise the impact of pandemics on minority and vulnerable populations. By strengthening the UK's economic and social resilience, MopFan saves lives and improves mental well-being.

1.11.4 Government priorities

MopFan aligns perfectly with government initiatives focused on clean air, clean growth, and pandemic resilience. It effectively addresses urgent environmental and public health concerns while promoting economic recovery. By supporting the implementation of MopFan, the government demonstrates its commitment to creating a sustainable and safe indoor environment for the public.

1.12 Aim and objectives of the research

Research Aim: To assess the effectiveness of an innovative photocatalytic mop-based system in improving indoor air quality by removing or deactivating indoor pollutants and contaminants.

The following states objectives this study sets out to address:

1.12.1 To design, optimise and fabricate novel prototypes of the MopFan photocatalytic air purification system

Prototypes of the MopFan system will be constructed and then tested both in a laboratory and residential buildings. The MopFan prototypes will employ PCO, where a surface coated with TiO_2 reacts under UV light, generating hydroxyl radicals that break down organic compounds and airborne contaminants. The MopFan system sterilises incoming air through UV irradiation over a large mop surface.

1.12.2 To investigate the purification performance of the MopFan photocatalytic air purification system in eliminating a wide range of pollutants

This research will undertake a comprehensive experimental investigation to examine the efficacy of an air cleaning system utilising MopFan technology. The primary objective is to assess the purification performance of the MopFan-based system, specifically targeting the enhancement of indoor air quality. Rigorous experiments and measurements will be conducted to evaluate the system's proficiency in effectively eliminating a wide range of airborne pollutants, including VOCs, particulate matter, bacteria, and other contaminants. By comparing pollutant concentrations before and after the operation of the MopFan-based system, the extent of pollutant reduction is analysed and quantified, providing insights into its efficiency and contributing to the overall improvement of air quality.

1.12.3 To evaluate the impact of the MopFan photocatalytic air purification system on indoor air quality

A comprehensively evaluation the holistic impact of the MopFan-based system on the quality of indoor air will be performed. This encompasses a multifaceted assessment that not only focuses on the reduction of air pollutant levels. To achieve this objective, the study will carefully monitor and analyse changes in air pollutant levels before and after the implementation of the MopFan-based system.

1.13 Novelty of the research work

The MopFan is an innovative air purification device for the following reasons:

1.13.1 Increased surface area by integrating mop and fan

The MopFan represents a significant advancement in the field of air purification by introducing the integration of mop and fan functionalities into a single device. This approach fundamentally transforms the way air purification is achieved, offering a host of unique benefits, and setting the MopFan apart from conventional air purifiers that solely focus on air filtration. By combining the functions of a mop and a fan, the MopFan provides a comprehensive solution for enhancing air quality. While traditional air purifiers primarily target the removal of airborne contaminants through filtration, the MopFan goes beyond this limitation by incorporating a mop component. This innovative integration allows the MopFan to address both airborne pollutants and dust, particles, and debris, providing a holistic approach to indoor air purification. As the fan circulates the air, it creates an efficient airflow that promotes the distribution of purified air throughout the space.

1.13.2 Photocatalytic air purification

The MopFan utilises state-of-the-art photocatalytic technology to achieve superior air purification. Through the integration of advanced photocatalysts, such as TiO_2, and the utilisation of UV light, the MopFan harnesses the power of ROS to efficiently degrade and eliminate an extensive array of airborne pollutants. By incorporating photocatalysts like TiO_2, the MopFan can initiate a photocatalytic process that triggers a series of powerful chemical reactions. Unlike conventional air purifiers that rely solely on filtration methods, the MopFan harnesses the natural power of photocatalysts to enhance the efficiency and effectiveness of pollutant removal. The generation of ROS through the photocatalytic process ensures a more comprehensive and thorough purification, surpassing the limitations of conventional purifiers and providing a significant boost in performance.

1.13.3 The use of natural fibres in the filter design

Utilising natural fibres in the design of a filter for a photocatalytic air purifier offers numerous advantages, combining sustainability, effective filtration, and enhanced user experience. Natural fibres, derived from renewable plant sources such as coco and tampico, provide a sustainable and environmentally friendly option for filter materials. These fibres have inherent filtration properties that efficiently capture airborne particles and pollutants, including dust, allergens, pollen, and even some bacteria. The dense and porous structure formed by natural fibres creates an effective barrier, ensuring improved indoor air quality and a cleaner living environment.

In addition to their filtration capabilities, natural fibres offer other notable benefits. Their low resistance to airflow facilitates optimal air circulation, maintaining the air purifier's performance without excessive pressure drops. This characteristic enhances energy efficiency and ensures an uninterrupted flow of purified air. Furthermore, natural fibres provide added comfort and allergen control, thanks to their breathable properties. They allow for better air circulation, reducing the likelihood of moisture buildup or the growth of mould and mildew within the filter. This feature enhances user comfort and contributes to a healthier living space.

1.13.4 The use of copper fibres in the filter design

Incorporating copper fibres into the filter design brings numerous benefits, including antimicrobial properties, improved filtration, and enhanced durability. Copper fibres possess inherent antimicrobial qualities, effectively reducing the presence of airborne microorganisms. They have been proven to inhibit the growth of bacteria, viruses, and fungi, providing an additional layer of protection against harmful pathogens. By integrating copper fibres, MopFan can effectively neutralise microorganisms, fostering a healthier indoor environment. Furthermore, copper fibres exhibit filtration capabilities. Their fine and densely packed structure efficiently captures airborne particles and pollutants such as dust, allergens, and fine particulate matter. This heightened filtration performance significantly contributes to better indoor air quality by effectively trapping and removing these contaminants from the air. The integration of copper fibres in the filter design ensures that the air purifier delivers cleaner air, minimising the potential health risks associated with airborne pollutants. Additionally, copper fibres offer enhanced durability. Copper is renowned for its corrosion resistance and long-lasting nature, guaranteeing the longevity and effectiveness of the filter. The robustness of copper fibres enables prolonged and consistent filtration performance, reducing the need for frequent filter replacements and maintenance. This durability factor contributes to the overall cost-effectiveness and sustainability of the MopFan system.

1.13.5 The capacity to integrate bio-aerogel filters

The potential integration of bio-aerogel filters into the MopFan system holds significant promise, offering notable benefits such as enhanced filtration efficiency, improved air quality, and sustainable air purification. Bio-aerogels, derived from natural and renewable sources, present an environmentally friendly option for filter materials. These filters exhibit filtration capabilities, efficiently capturing and removing airborne particles, allergens, and pollutants from indoor environments. The porous structure of bio-aerogels provides a large surface area, allowing for effective trapping and retention of contaminants, resulting in improved air quality and a healthier living space. Moreover, the integration of bio-aerogel filters into the MopFan system can lead to increased particle removal efficiency. The unique composition of bio-aerogels, often incorporating natural polymers and additives, enhances their filtration performance, enabling them to target specific pollutants effectively. Another advantage of bio-aerogel filters is their sustainability. Made from renewable materials, bio-aerogels offer a more environmentally conscious solution compared to traditional filter materials. Their production requires fewer resources and generates fewer carbon emissions, contributing to reduced environmental impact. Additionally, bio-aerogels can be recycled or safely disposed of, promoting a circular economy and minimising waste. By integrating bio-aerogel filters into the MopFan system, users can benefit from improved filtration efficiency, cleaner air, and a more sustainable air purification solution.

1.13.6 Compact and portable design

The MopFan sets itself apart with its compact and portable design, offering convenience and adaptability. Its lightweight structure enables effortless transportation and seamless integration into a variety of indoor spaces, including homes, offices, and commercial settings. This portability distinguishes the MopFan from larger and more cumbersome air purification systems, granting users the flexibility to target specific areas with precision and ease. The MopFan's compact form factor ensures that it can be easily moved and positioned wherever air purification is desired. Whether it's a small living room, a compact office cubicle, or a confined commercial space, the MopFan fits into any environment without occupying excessive floor space. Its streamlined and unobtrusive design allows for optimal placement, ensuring maximum airflow and coverage.

1.14 Use of 3D printing

3D printing, also referred to as additive manufacturing, uses digital design files to construct three-dimensional objects. This process builds objects layer by layer, utilising diverse materials like plastic, metal, ceramics, or even living cells.

The incorporation of 3D printing technology in the MopFan concept brings possibilities to a wide range of applications. By leveraging 3D printing, precise control over the geometry and internal structure of the MopFan components is achievable. This level of control allows for the creation of more efficient and compact MopFan units. Additionally, 3D printing enables rapid iterations in design and testing, accelerating the development of optimised designs. This approach ensures swift production, design flexibility, reduced material waste, and cost-effectiveness.

The flexibility offered by 3D printing technology allows the MopFan system to be adapted for both fixed and mobile applications, with scalability ranging from small to very large units. It seamlessly integrates with existing HVAC systems, effectively decontaminating the air as it flows through the building. This adaptability makes the MopFan system suitable for use in various settings, including residential homes, office spaces, healthcare facilities, and public transportation.

1.15 Patent protected design

The MopFan system distinguishes itself in the rapidly expanding air purification market through its unique combination of effective PCO technology, innovative design, and the incorporation of 3D printing. This blend results in superior virus mitigation capability, adaptability, and seamless integration with existing infrastructure, positioning the MopFan system as a true game-changer in the field of air purification.

Moreover, the MopFan system is the first of its kind, and additional patent filings can be pursued to further protect its intellectual property. In addition to the existing patents held by the University of Nottingham (WO20040162960 and 96935172.5), these additional patent filings ensure that the innovative features and functionalities of the MopFan system remain safeguarded.

1.1.6 Thesis structure

Chapter 1: This chapter provides a comprehensive overview of the research background. It highlights the importance of improving indoor air quality as a solution to these challenges. The chapter defines the scope of the thesis, outlining its research novelty and aims.

Chapter 2: The literature review in this thesis examines various purification technologies, focusing on photocatalytic methods. It explores their effectiveness, limitations, and applications in improving indoor air quality. The review covers different purification approaches, catalyst choices, reactor designs, and mechanisms of action. It also investigates the use of filter substrates and evaluates the "MopFan" system's research. The review identifies research gaps and informs subsequent experimental investigations, contributing to a better understanding of photocatalytic technologies' potential in indoor air quality enhancement.

Chapter 3: This chapter elucidates the theoretical foundations guiding the research, outlines the methodology employed, and provides an in-depth exposition of the system's design and functioning. It emphasises the interplay between theory, methodology, and system components, highlighting the rationale for selecting performance indicators that align with research objectives. This comprehensive overview serves as the intellectual backbone, ensuring readers gain a holistic understanding of the study's underpinnings and approach.

Chapter 4: This chapter focuses on investigating the substrate and fibre coating processes for both individual fibre testing and fibre coating for prototypes. This chapter aims to provide an in-depth understanding of the techniques and methodologies involved in substrate preparation and fibre coating, which are crucial steps in the development of prototypes.

Chapter 5: This chapter encompasses the design and prototyping of systems within the Small Business Research Initiative (SBRI) project. It outlines the project's objectives, iterative design process, incorporation of innovative technologies, and practical implementation of prototypes.

Chapter 6: This chapter focuses on gathering and analysing testing data from the prototypes developed in Chapter 5. This includes both quantitative and qualitative measurements to assess the prototypes' performance, with the aim of identifying areas for improvement.

Chapter 7: This chapter introduces a new project funded by the Engineering and Physical Sciences Research Council (EPSRC). It builds upon the knowledge and findings from Chapter 6. The insights gained from the analysis in Chapter 6 inform the objectives and scope of the research in Chapter 7.

Chapter 8: Similar to Chapter 6, Chapter 8, this chapter centres on the testing and analysis phase, this time for prototypes developed in the EPSRC project (Chapter 7). The improvements or modifications suggested in Chapter 6, based on the testing data from the SBRI project (Chapter 5), have been implemented in the design of the prototypes in Chapter 7. This demonstrates a clear progression where lessons learned are applied to enhance subsequent projects.

Chapter 9: This chapter presents a detailed economic and environmental assessment of the MopFan system. It evaluates the system's cost-effectiveness, energy consumption, and carbon emissions. The findings provide insights into its economic viability and environmental impact, guiding recommendations for improvement.

Chapter 10: This chapter provides an overview of the research conducted, presents the conclusions drawn from the research, and discusses potential avenues for future research. It summarises the objectives, methodology, and key findings of the research, highlighting its significance. The chapter also identifies areas for further investigation and suggests potential directions for future research.

Chapter 2 Literature Review

As COVID-19 demonstrated that pandemics pose a significant threat, it is essential to develop air purification devices that can efficiently remove airborne pollutants and reduce the risk of infection. Photocatalytic air purifiers show promise in reducing indoor pollutants and viral transmission, offering critical insights into design and efficacy. This review examines catalyst arrangement, substrate, chemical composition, airflow, UV light, and its impact on performance. It also investigates catalyst distribution, substrate material, catalyst composition, and airflow patterns for optimisation. UV light frequency and intensity are explored for their influence on pollutant degradation. These findings inform the development of efficient and cost-effective PCO air purifiers targeting indoor pollutants, including PM2.5, VOCs, and viruses, enhancing indoor air quality and safety during pandemics.

2.1 Review methodology

This comprehensive review intends to delve into the intricacies of photocatalytic air purifiers, with a specific focus on their design and pollutant removal methods. The primary objective of this investigation is to assess the current advancements in PCO air purifiers by critically examining pertinent literature pertaining to catalyst arrangement, substrate selection, chemical composition, airflow type, UV light frequency, and light intensity. By conducting an analysis of these aspects, it becomes feasible to develop highly efficient prototypes of PCO air purifiers capable of significantly reducing indoor airborne pollutants, including particulate matter of size 2.5 micrometres or less (PM2.5), VOCs, and even viruses.

2.1.1 Objective

The main objective of the literature review is to explore the field of photocatalytic air purifiers, focusing specifically on their design and pollutant removal methods. The goal is to evaluate the current advancements in PCO air purifiers by critically analysing relevant literature.

2.1.2 Scope

The review aims to cover various aspects related to the design and functioning of PCO air purifiers. This includes catalyst arrangement, substrate selection, chemical composition, airflow type, UV light frequency, and light intensity. By considering these factors, the review intends to gain a comprehensive understanding of the key elements that contribute to the effectiveness of PCO air purifiers.

2.1.3 Data collection

The literature review involves gathering relevant scholarly articles, research papers, conference proceedings, and other credible sources of information. These sources will provide the necessary data and insights on the different aspects of photocatalytic air purifiers, allowing for a thorough analysis.

2.1.4 Analysis

The collected literature is critically examined and analysed in detail. The review aims to identify trends, patterns, and significant findings related to the design and pollutant removal methods of PCO air purifiers. By analysing the literature, the review intends to gain a comprehensive understanding of the advancements made in the field.

2.1.5 Synthesis

The findings from the analysis are synthesised to draw conclusions and identify gaps in knowledge. The review aims to provide a comprehensive overview of the current state of PCO air purifiers, highlighting their strengths, weaknesses, and areas for further improvement. The synthesis may also involve discussing the potential of developing highly efficient prototypes of PCO air purifiers that can effectively reduce indoor airborne pollutants, including PM2.5, VOCs, and viruses.

2.2 The evolution of MopFan

The first published research paper on the MopFan concept was in 1995 (Riffat et al., 1995). In this research paper, a unique mop fan with a flexible fibre impeller is introduced, specifically designed for application in livestock buildings. The fan incorporates a continuously irrigated mop that use water to eliminate particulate and gaseous pollutants from the air, eliminating the need for filter systems. The fan's straightforward design allows for cost-effective construction, as shown in Figure 2.1. To assess its efficacy in removing particles, the mop fan was tested using wood dust particles spanning sizes from 0.5 to 100 μm. The experiments involved varying fan speeds and water injection rates. The findings revealed that higher rates of water injection and fan speeds, as well as larger particle sizes, resulted in more efficient particle removal. For instance, at a fan speed of 700 rev/min and a water flow rate of 2.5 ml/s, particle removal rates ranged from 92% to 99%, contingent on the particle size. However, the paper acknowledges the need to address the challenge of dust build-up within the fan casing. In conclusion, the mop fan exhibits promise for livestock building ventilation and proficient elimination of airborne particles. Nevertheless, further enhancements are required to tackle the issue of dust accumulation within the fan casing.

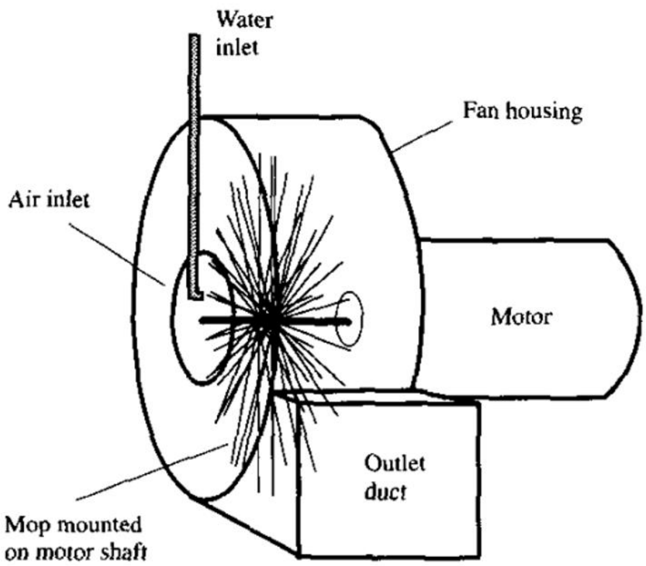


Figure 2.1 Diagram of an early concept of MopFan (Riffat et al., 1995)

The next article came in 2000 (Riffat et al., 2000). The research paper primarily focuses on the development and design of an innovative evaporative air cooler, as shown in Figure 2.2. The authors delve into the technical aspects of the cooler, including its design features and operational principles. The main objective of the cooler is to enhance indoor thermal comfort while simultaneously reducing energy consumption. It achieves this by leveraging the process of evaporative cooling, where water evaporation is employed to cool the air. The paper thoroughly discusses the specifics of the cooler's design, highlighting its unique features. To evaluate the performance of the evaporative air cooler, the researchers conducted several experiments. These experiments encompassed assessing the cooler's cooling capacity, energy efficiency, and other relevant parameters. The outcomes of these experiments are presented and analysed within the paper. In summary, this research paper introduces a novel evaporative air cooler and provides comprehensive insights into its design, performance, and potential applications. The primary aim of this cooler is to enhance indoor thermal comfort while minimising energy consumption.

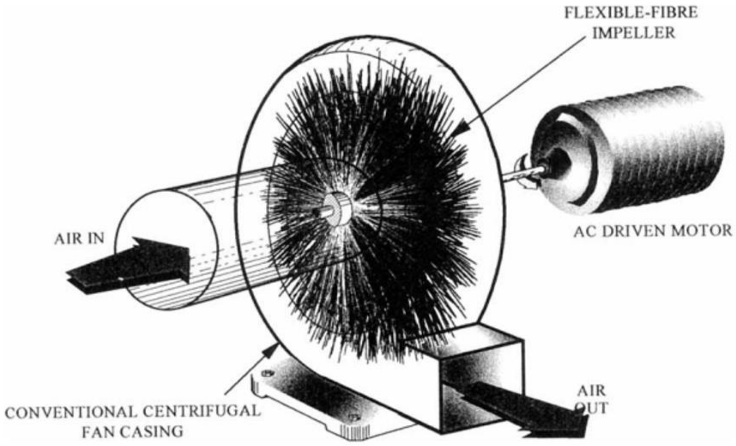


Figure 2.2 Diagram of a centrifugal MopFan design (Riffat et al., 2000)

Then in 2001 (Riffat & Shehata, 2001), the next article discusses a new type of fan, which uses a brush disk instead of bladed impellers. The fan serves as both an air moving device and a filter. The performance of the fan was tested and found to be similar to that of centrifugal fans. The article also discusses the optimisation of mop fan performance through the construction of mops with different fibre numbers and diameters.

In 2004 (Riffat et al., 2004), an investigation on a liquid desiccant system for air-conditioning buildings was thoroughly explored. The focal point of the study was a versatile flexible fibre mop fan, which served a multitude of functions simultaneously. These functions encompassed contaminant removal, dust elimination, humidification or dehumidification, and effective air circulation. Operating like a chimney sweep brush, the mop fan was ingeniously positioned on a shaft within a centrifugal fan casing. Its flexible fibre needle impeller significantly amplified heat and mass transfer in the evaporator and absorber units, displaying comparable performance traits to conventional centrifugal fans. The experimental phase entailed a comprehensive evaluation of the mop fan's capacity to both humidify and cool air. The noteworthy findings revealed that the cooling achieved by the mop impeller adhered to an adiabatic process. The mop's efficiency in saturating airflow paralleled that of commercially available air purifiers. Furthermore, a subsequent set of tests assessed the mop fan's adeptness in dehumidifying air. Results showcased its potential in utilising liquid absorbent sprays, such as lithium bromide and potassium formate (HCOOK), to successfully extract moisture from the passing air streams. To ascertain practical application, a dedicated system was meticulously devised, integrating the cooling and absorbing prowess of the mop fan. The constructed system served as the testbed for further investigations and experimental analyses.

After this in 2006 (Birnie et al., 2006), the subsequent study explored the application of PCO as an ACT to address the rising concern of IAQ driven by stricter building regulations emphasising air tightness. The focus of the article centres around immobilising TiO_2 on organic polymers as a cost-effective and energy-efficient approach to enhancing IAQ. The authors propose a straightforward spray coating method utilising a resin that cures at room temperature and present the outcomes of their experimental tests. Emphasising the significance of finding a technique that is both uncomplicated and economical, the article underscores the need for a coating method capable of covering complex geometries while preserving the photoactivity of the catalyst.

Then in 2007 (Riffat & Zhao, 2007), the MopFan air cleaning system introduced a flexible fibre mop that is treated with photocatalytic TiO_2, as shown in Figure 2.3. This treated mop efficiently removes pollutants from indoor air while simultaneously cleaning itself. The researchers conducted tests on 11 different types of mop impellers to establish a fluid dynamic model. The model provides insights into the characteristic parameters of the system, including air flow rate, pressure, and efficiency, which are influenced by factors such as rotation speed, number of mop fibres, and diameter. The maximum static efficiency of the mop fan was determined to be approximately 9%, whereas a standard forward-curved centrifugal fan exhibited a higher efficiency range of 45% to 60%.

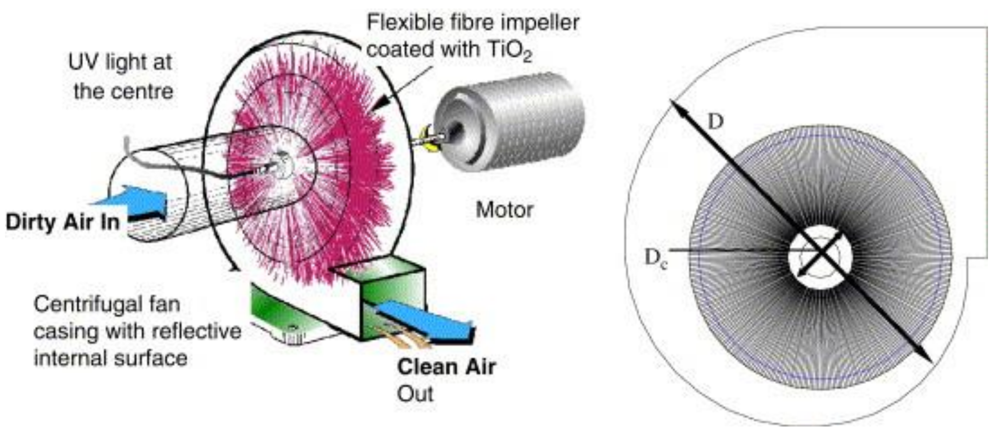


Figure 2.3 Diagram of an improved centrifugal MopFan design (Riffat & Zhao, 2007)

Following this in 2008 (Ma et al., 2008), a fully functional prototype of the MopFan, utilising cutting-edge photocatalytic side-emitting optical fibres, underwent development, construction, and thorough examination. The performance of this innovative system was meticulously compared to that of a previously tested mop fan utilising traditional polymer fibres. Notably, the results highlighted the photocatalytic MopFan's superiority, primarily attributed to its optimised arrangement of UV lamps and a more uniform transmission of UV light. This led to enhanced efficiency in air purification. Furthermore, the study revealed an intriguing finding regarding the concentration of room pollutants at the end of the cleaning process. It was found that the concentration is directly influenced by the rate of pollutant generation when utilising the photocatalytic mop fan air cleaning system.

In 2010 (Qiu & Riffat, 2010), The MopFan concept underwent significant enhancements compared to previous experiments, particularly those involving a mop fan impelling desiccant system and a spraying desiccant system. In the previous test systems, the desiccant chamber generated numerous small mists, which posed potential risks to human health and had the capacity to corrode indoor furniture. In contrast, the improved MopFan concept addressed these issues. The liquid droplets utilised in the new design descended at a slower rate, allowing for extended contact time between the liquid and humid air. This longer interaction time significantly improved the system's effectiveness in dehumidifying the air. Furthermore, the modified MopFan concept minimised the risks associated with small mists, ensuring a safer and more efficient air dehumidification process.

Then in 2012 (Zhang et al., 2012), an extensive study focused on the challenges associated with biomass gasification and the critical need for effective product gas cleaning technologies. The product gas resulting from biomass gasification comprises various minor species and contaminants, such as particles, tar, alkali metals, chlorine, nitrogen compounds, and sulphur compounds. The presence of these contaminants necessitates their removal to meet the specific requirements of different end-users or applications. The article provides a comprehensive review of recent advancements in product gas cleaning technologies. These advancements include primary treatments involving the optimisation of biomass feedstock and gasifier design, as well as secondary treatments encompassing downstream cleaning systems based on physical or catalytic strategies. In this context, the authors propose an innovative cleaning technology concept that combines a mop fan and an electro filter. This novel approach has demonstrated considerable potential in effectively removing fine particles, tars, and chemical contaminants from the product gas. The integration of these two technologies could offer an efficient and comprehensive solution to address the challenges associated with biomass gasification and ensure a cleaner and more valuable product gas for various applications.

In 2013 (Riffat & Ma, 2013), an innovative air cleaning system, referred to as the photocatalytic mop fan, was developed specifically for indoor settings, as shown in Figure 2.4. This system incorporates a flexible fibre mop that is coated with TiO_2 and activated by UV radiation. The TiO_2 coating undergoes a chemical oxidation process, effectively breaking down volatile organic pollutants present in the air. The photocatalytic mop fan system boasts low energy consumption while providing efficient removal of particulate pollutants, odours, viruses, bacteria, and volatile organic pollutants. The design of the mop fan system is optimised for various aspects, including pollutant degradation efficiency, energy consumption, appearance, and cost reduction. Leveraging previous research on MopFan performance, the system was designed and constructed. Experimental testing has confirmed its effectiveness in destroying microparticulate pollutants emitted from diesel fumes.

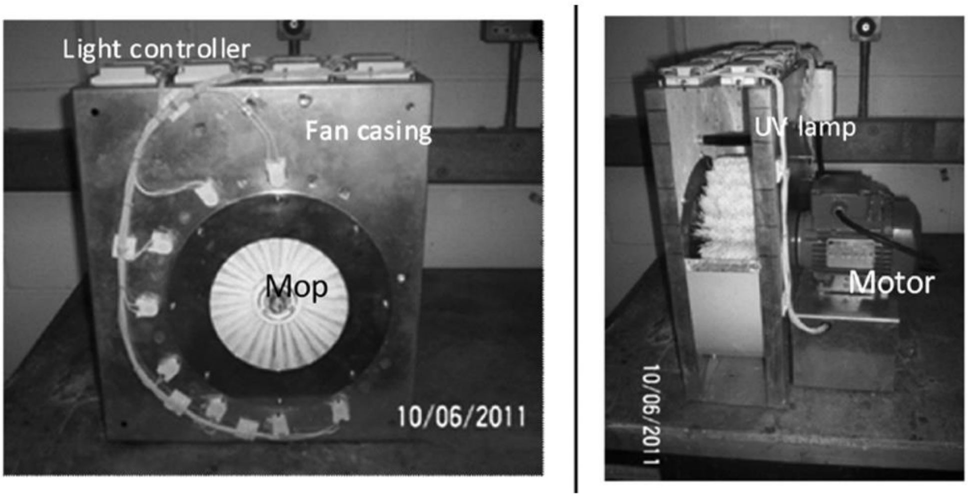


Figure 2.4 Images of an early-stage prototype (Riffat & Ma, 2013)

After a 6-year break in research, research continued in 2019 (Wongwatcharapaiboon et al., 2019). The expansion of economic development, construction industries, and road traffic in Southeast Asia has led to a significant air pollution problem. While air filters have been employed to mitigate air quality issues, their high cost poses a challenge. This research aims to develop an affordable solution for PM2.5 air filtration by integrating a lamp and investigating its filtration performance, as shown in Figure 2.5. The design incorporates a fabric filter and a floor lamp driven by a fan unit, and the addition of a photocatalytic process enhances the air purification performance. The study conducts tests in a bedroom under three different conditions, and none of the examined conditions exceed the National Ambient Air Quality Standards (NAAQs) threshold of 35 μg/m^3. The filtration lamp achieves a MERV15 and MERV16 rating, with regime B lamp featuring a fan speed of 3 m/s and regime C lamp with a fan speed of 2 m/s.

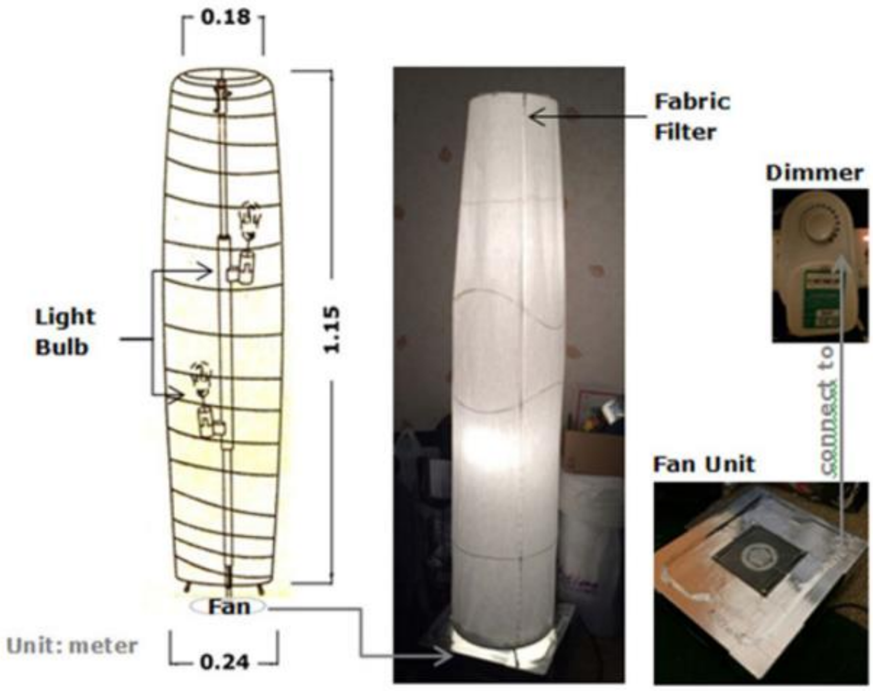


Figure 2.5 Images of an alternative design fan (Wongwatcharapaiboon et al., 2019)

2.3 Analysis of the evolution of MopFan

The evolution of MopFan technology, as evidenced by the research papers provided, demonstrates a progressive exploration of innovative solutions for air cleaning, thermal comfort, and energy efficiency. These findings reveal several trends, patterns, and key insights:

2.3.1 Diversification of applications

Initially introduced for use in livestock buildings, the concept of MopFan expanded to encompass a wider range of applications. From livestock ventilation to indoor air quality improvement, thermal comfort enhancement, and even biomass gasification and PM2.5 filtration, MopFan technology demonstrates versatility and adaptability.

2.3.2 Integration of evaporative cooling

One prominent trend observed in the research papers is the integration of evaporative cooling techniques into the MopFan design. By utilising water evaporation for air cooling, the MopFan systems aim to enhance indoor thermal comfort while minimising energy consumption. This approach aligns with the growing emphasis on energy-efficient solutions and sustainable technologies.

2.3.3 Focus on particle removal and air cleaning

The early MopFan designs were primarily focused on eliminating particulate and gaseous pollutants from the air, thus serving as air cleaning devices. The introduction of PCO technology further enhanced the pollutant removal capabilities of MopFan systems, enabling the efficient degradation of volatile organic pollutants, odours, viruses, bacteria, and fine particles.

2.3.4 Optimisation and performance evaluation

The research papers consistently employed performance evaluation and optimisation strategies to enhance the effectiveness and efficiency of MopFan systems. Parameters such as fan speed, water injection rates, fibre numbers, and diameters were systematically tested and analysed to determine their impact on particle removal rates, cooling capacity, energy consumption, and overall system performance.

2.3.5 Challenges and further enhancements

While the research papers showcased the potential of MopFan technology, they also acknowledged several challenges that need to be addressed. Dust accumulation within the fan casing, limited interaction between liquid and humid air, and the development of cost-effective and efficient coating methods were identified as areas for further research and improvement.

2.3.6 Cost-effectiveness and energy efficiency

A recurring theme throughout the research papers is the emphasis on cost-effectiveness and energy efficiency. MopFan systems were designed to provide efficient air cleaning and thermal comfort enhancement while minimising energy consumption and operating costs. This focus aligns with the need for sustainable and economically viable solutions in various applications.

2.3.7 Technological advancements and design innovations

The evolution of MopFan technology involved continuous technological advancements and design innovations. From the introduction of brush disks and flexible fibre mops to the integration of photocatalytic coatings, researchers consistently sought to optimise the performance, reliability, and practicality of MopFan systems.

In summary, the evolution of MopFan technology demonstrates a progressive exploration of innovative solutions for air cleaning, thermal comfort enhancement, and energy efficiency. The research papers highlight the potential and versatility of MopFan systems while identifying areas for further research and improvement. The investigation of photocatalytic technology and optimisation strategies signify the commitment to developing effective, cost-efficient, and sustainable solutions for a wide range of applications.

2.4 Photocatalytic air purifiers

The COVID-19 outbreak has underscored the significance of preserving good IAQ. The primary transmission mode for the virus is through respiratory droplets in the air, highlighting the need to create air purification systems that can efficiently eliminate contaminants. Numerous IAQ devices exist that use different technologies to reduce airborne pollutants, including PM2.5, VOCs, and viruses. However, photocatalytic air purifiers are attracting more interest due to their potential in removing airborne pollutants (Aldekheel et al., 2022) . Photocatalytic air purifier's use photocatalysts, such as TiO_2, that react with UV light to create active oxygen species, including hydroxyl radicals and superoxide anions, which neutralise

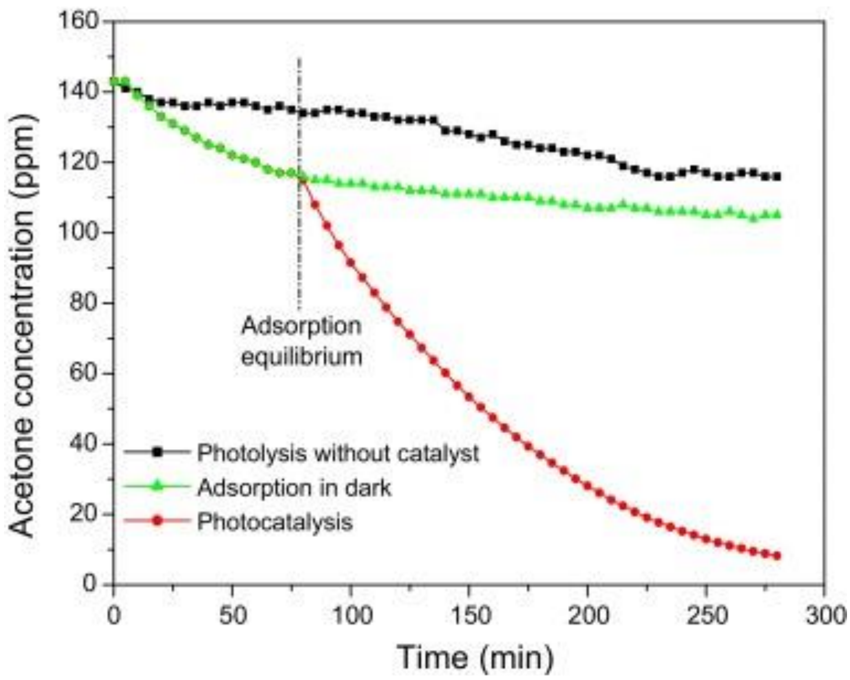


Figure 2.6 Graph displaying acetone concentration tests using photocatalysis (Pétigny et al., 2021)

airborne pollutants, as shown in Figure 2.6. Several studies have demonstrated that photocatalytic air purifiers can effectively reduce contaminants, including VOCs, PM, and even viruses (Pétigny et al., 2021).

One study (Mo et al., 2009) evaluated the effectiveness of a photocatalytic air purifier against SARS-CoV-2, the virus responsible for COVID-19 pandemic. The results demonstrated that the device was able to significantly reduce viral load in the air, indicating its potential as a tool for limiting the spread of COVID-19. In conclusion, the COVID-19 pandemic has highlighted the importance of maintaining clean indoor air quality.

2.4.1 Impact of UV light on photocatalysis

The next article (Hall et al., 2000) provides a comprehensive overview of the design aspects involved in creating air purifiers specifically designed for aircraft passenger cabins, employing the innovative PCO technology. The selection of an appropriate catalyst material is crucial for the success of the PCO technology. TiO_2 is a commonly used catalyst due to its high catalytic efficiency, stability, and durability. The choice of catalyst directly impacts the purifier's ability to degrade various organic compounds and pathogens present in the cabin air. To activate the photocatalyst, a reliable UV light source must be selected. It is important to choose a light source that emits UV-A or UV-C light, which effectively triggers the photocatalytic process. UV-A light is generally preferred over UV-C light in aircraft cabins due to its lower energy and reduced potential for harmful effects on passengers and crew. Additionally, the lifespan of the UV light source and its ease of replacement should be considered during the design process. In order to maximise the efficiency of the PCO air purifiers, the inclusion of pre-filters is recommended. These pre-filters remove larger particles such as dust, pollen, and hair before the air enters the PCO unit. By doing so, the lifespan of the PCO catalyst is extended, and its effectiveness in degrading pollutants is maintained. To monitor the quality of the cabin air in real-time, integrating air quality sensors is essential. These sensors enable continuous monitoring of pollutant levels, allowing the air purifier to adjust its purification process accordingly. Intelligent controls can be incorporated into the system to automate the adjustment of purification settings based on the detected air quality conditions. The ease of maintenance and safety features should be considered during the design phase.

2.4.2 Simulating photocatalytic purifier performance

Another article (Queffeulou et al., 2010) focuses on the application of a CFD approach to predict the performance of photocatalytic air purifier apparatus. Specifically, it explores the utilisation of experimentally determined kinetic parameters to enhance the accuracy of simulating the PCO process within these devices, as shown in Figure 2.7. By integrating these parameters into the CFD model, researchers can effectively forecast the efficiency and effectiveness of the air purifier in degrading pollutants and improving air quality. The incorporation of experimentally determined kinetic parameters into the CFD model plays a crucial role in accurately representing the complex chemical reactions involved in the PCO process.

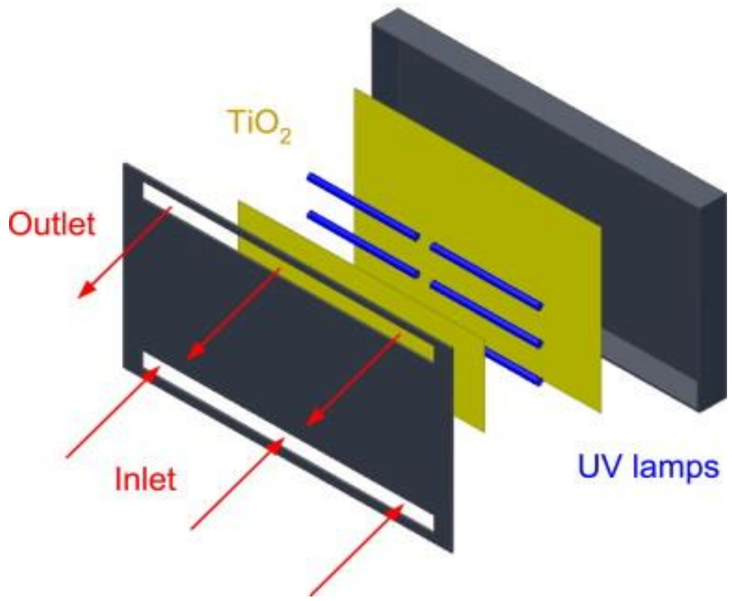


Figure 2.7 Reactor design with TiO_2 (Queffeulou et al., 2010)

These kinetic parameters provide insights into the reaction rates and pathways, enabling a more precise simulation of the photocatalytic activity within the air purifier apparatus. By using data obtained through experiments, the CFD approach offers a comprehensive and realistic representation of the PCO process, which in turn facilitates a more reliable prediction of the device's performance. The ability to predict the performance of photocatalytic air purifier apparatus through the CFD approach offers numerous advantages. Firstly, it provides a cost-effective and time-efficient method for evaluating and optimising the design and operation of these devices. By simulating various scenarios and configurations, researchers can identify the most effective parameters and conditions that lead to optimal performance. This allows for the development of air purifiers that are tailored to specific environments and pollutant types, ensuring maximum efficiency in pollutant degradation. Furthermore, the CFD approach can aid in the analysis of the airflow patterns and distribution within the air purifier apparatus. By considering factors such as air velocity, turbulence, and residence time, researchers can gain insights into the spatial distribution of pollutants and their contact with the photocatalyst surface.

2.4.3 Exposure to TiO_2 particles

In the next study (Koivisto et al., 2018), ceramic honeycomb cells were coated with a nano-sized TiO_2 suspension, and the researchers examined particle emissions, exposure levels, and dose rates during the coating process, as shown in Figure 2.8. They used three different methods to evaluate the health risks associated with TiO_2. The results showed that dip coating resulted in minimal release of particles, but the use of an air blade drying process increased particle concentrations in the room. The TiO_2 particles were found in various phases and sizes. The inhalation dose rate for particles smaller than 10 μm, including 3.7% TiO_2, was determined to be less than 5.6 μg/min. During an 8-hour exposure, the total deposited dose was estimated to be less than 2700 μg, with the majority deposited in the upper airways. The fraction of TiO_2 deposited in the relevant regions was 13 μg. The calculated TiO_2 dose remained well below the recommended risk levels for inflammation (300 μg/day) and tumours (44 μg/day). PCO is a form of air purification technology that uses a semiconductor, such as TiO_2, to eliminate pollutants.

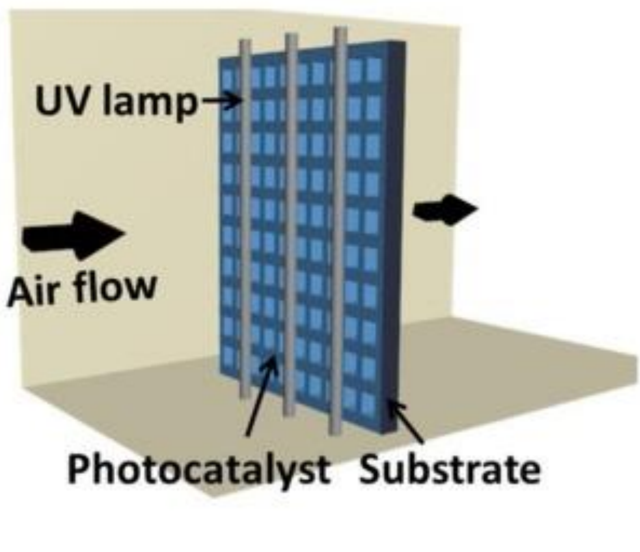


Figure 2.8 Honeycomb reactor design (Ren et al., 2017)

The semiconductor and the pollutants are illuminated by UV light, which has a wavelength of 180nm-400nm. This interaction produces hydroxyl radicals and oxide ions that attract and oxidise pollutants, breaking them down into non-hazardous components, including water vapour and CO_2 (Ni et al., 2022). PCO air purifiers have several advantages over other air purification technologies. The decomposition of pollutants begins during the PCO reaction, unlike HEPA filters, where hazardous pollutants may still be present on the filter surface. PCO air purifiers are effective in removing a wide range of pollutants, including VOCs, odours, and even viruses (Assadi et al., 2023). PCO air purifiers do not produce harmful byproducts, making them safe for use in occupied spaces.

2.4.4 Catalyst arrangement and airflow type

The design of PCO air purifiers can vary significantly depending on the type of catalyst arrangement used. For example, fixed-bed reactors are commonly used for large-scale applications, while photocatalytic fibres or films are used for smaller-scale applications. Additionally, the substrate used for the catalyst can also impact the performance of the air purifier. Common substrates include glass, ceramics, and metals (Ren et al., 2017). The chemical composition of the catalyst is also crucial in determining the effectiveness of the PCO air purifier. TiO_2 is the most commonly used semiconductor, but other materials such as zinc oxide, tungsten oxide, and iron oxide have also been used.

Airflow type is another important factor in the design of PCO air purifiers. The airflow can be either laminar or turbulent, and the choice of airflow type will depend on the specific application. For example, turbulent airflow is better suited for larger-scale applications, while laminar airflow is more appropriate for smaller-scale applications. The UV light frequency and intensity used in PCO air purifiers are also important parameters. UV-C light, which has a wavelength of 254nm, is commonly used, but UV-A and UV-B light can also be effective. The intensity of the UV light will depend on the specific application and the type of catalyst used (Assadi et al., 2023). In conclusion, the design and method of pollutant removal of photocatalytic air purifiers are critical factors in their effectiveness. By examining the current state of the art in PCO air purifiers, it is possible to develop effective prototypes capable of reducing indoor airborne pollutants such as PM2.5, VOCs, and viruses.

2.4.5 Viral inactivation and reactors

Recent studies have shown that PCO air purifiers can inactivate viruses, including SARS-CoV-2, by breaking down their protein structure through the photocatalytic reaction. However, there is still limited research on the effectiveness of PCO air purifiers in real-world settings with varying airflow and ventilation conditions (S. Kim et al., 2022). Furthermore, the effectiveness of PCO air purifiers in reducing viral transmission may be impacted by factors such as the size and concentration of the viral particles, as well as the airflow rate and direction within the room. Therefore, further research is required to understand the potential of PCO air purifiers in reducing viral transmission in real-world settings. In conclusion, while PCO air purifiers have shown promising results in reducing airborne pollutants, additional research is required to determine their effectiveness in reducing viral transmission. Unlike traditional air purifiers that use HEPA filters, photocatalytic air purifiers do not require frequent filter replacements (Peck et al., 2016). Instead, they degrade pollutants into harmless components like CO_2 and H_2O, thereby offering a sustainable and effective solution to IAP. Several studies have demonstrated the effectiveness of photocatalytic air purifiers in removing indoor air pollutants such as nitrogen oxides, VOCs, and bacteria (Mo et al., 2009). In summary, photocatalytic air purifiers offer a sustainable and effective solution to indoor air pollution. Due to the recent COVID-19 pandemic, the demand for effective air purification devices has increased.

The next study (Enesca, 2021) analyses photocatalytic reactors. The constraints associated with conventional methods in the elimination of organic pollutants, encompassing adsorption, coagulation, filtration, microorganism, and enzyme approaches, have prompted the exploration of alternative remedies. Photocatalytic technology, recognised as an advanced oxidation process (AOP), emerges as a promising avenue to tackle these limitations. The diverse designs and configurations exhibited by photoreactors are highlighted in this review. These variations are contingent upon factors like working regime (static or dynamic), photocatalyst morphology (powders or bulk), and volume. Specific guidelines are presented, focusing on the interplay between photoreactor characteristics, including working regime, volume, and flow rate, along with irradiation scenarios comprising light spectra, irradiation period, and intensity. Additionally, the parameters of the photocatalytic process, such as photocatalyst materials and dosage, pollutant type and concentration, pollutant removal efficiency, and constant rate, are also discussed.

The comprehensive efficacy of photocatalysis is thoroughly examined in this review, with a focus on two primary photoreactor geometries: cylindrical and rectangular. By undertaking a methodical evaluation of primary data reported in scientific literature, the review encompasses diverse perspectives on enhancing the performance of photocatalytic reactors, such as the semiconductor shown in Figure 2.9.

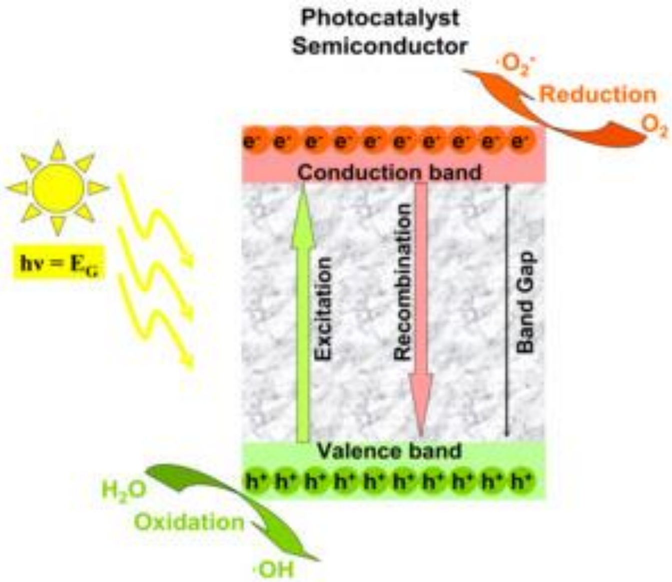


Figure 2.9 Photocatalyst Semiconductor (Enesca, 2021)

Another study (Mo et al., 2009) explores the purification of indoor VOCs using PCO. While highly active photocatalysts have been developed, their instability limits practical applications like indoor air cleaners. Figure 2.10 depicts the experiments and models of PCO reactions.

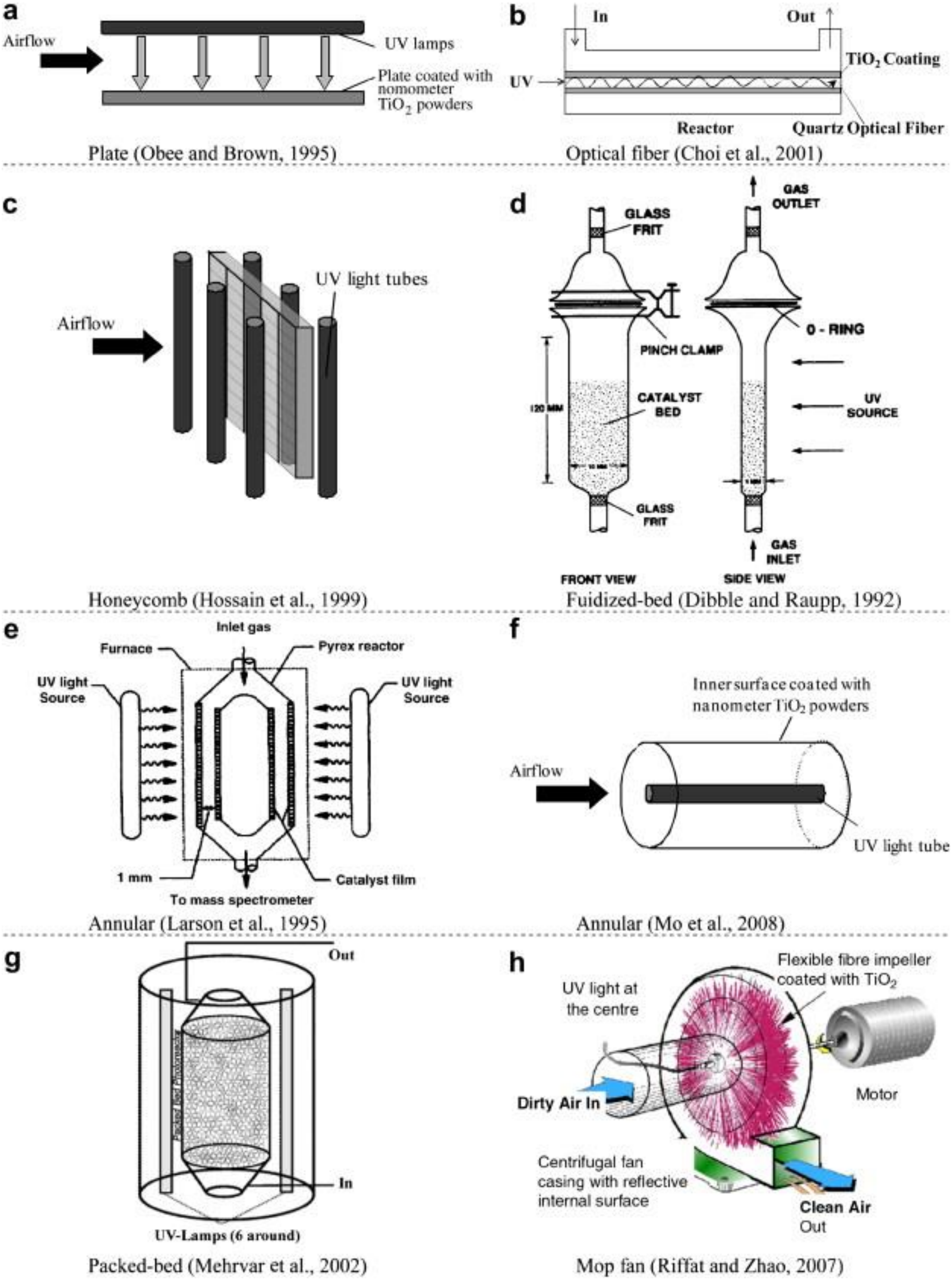


Figure 2.10 Kinetic experiments and models for PCO reactions (Mo et al., 2009)

Understanding reaction mechanisms for VOCs in PCO remains incomplete, especially for specific compounds. It is vital to control harmful intermediates, including carcinogens. Oxygen and hydroxyl radicals significantly influence pathways and intermediate formation, necessitating adjustments in water vapour and oxygen concentrations. Limited investigation exists regarding the impact of multi-compound VOCs and PCO in real indoor environments.

Designing efficient PCO reactors poses challenges due to the lack of coordination between the reaction structure and UV sources. A potential solution lies in utilising UV-transparent materials and a honeycomb structure to enhance efficiency (Mo et al., 2009).

2.4.6 Photocatalytic studies

Photocatalytic air purifiers are becoming increasingly popular due to their potential application in different settings such as residential and commercial buildings, cars, and even aerospace (Zhong & Haghighat, 2015). Unlike traditional air purifiers that use HEPA filters to capture pollutants, photocatalytic air purifiers utilise photocatalytic oxidation to deactivate viruses, particles, and other harmful pollutants without leaving them on the filter surface. One of the significant advantages of photocatalytic air purifiers is their energy efficiency and sustainability as they operate at room temperature (Dumont & Hequet, 2017). As research into PCO technology continues, there is a growing opportunity to design effective air purifier prototypes that can significantly reduce indoor airborne pollutants and improve indoor air quality (Poormohammadi et al., 2021). Table 2.1 displays a summary of the photocatalytic studies reviewed.

Table 2.1 Photocatalytic processes for the inactivation and removal of airborne viruses

Catalyst Type	Virus Type	Light Source	Detection Method	Efficiency	Effect Mechanism
2 mm and 5 mm pleated and spiral-type Pd- TiO_2 catalysts (J. Kim & Jang, 2018)	Vaccinia virus, influenza virus H3N3	Vacuum UV (VUV) wavelength ≥200 nm	-	More than 90%	UV light plays a significant role in degrading chemical bonds by producing potent oxidants

					like reactive oxygen species (ROS), hydroxyl radicals, and ozone.
Cu/TiO_2 non-woven fabric (NWF) (Moon et al., 2020)	HuNoV genogroup II genotype 4 (HuNoV GII.4)	Ultraviolet A light-emitting diode (UVA-LED)	373 nm	MBS-RT-qPCR	Photocatalysts generate ROSs and H+ ions, while metal-containing photocatalysts release metal ions that can cause morphological damage to viruses.
HVAC ducts (Qiao et al., 2021)	Coronaviruses in aerosols	UV-C flow reactors	RT-PCR and fluorescein for doped into the nebulised aerosol	-	-
Light irradiation (VL) (Hitchman, 2020)	Bovine coronavirus (BCoV)	UV light	TCID50 assay	Completely effective	Combination of physical damage caused by metal ions and chemical oxidation by ROSs, which are generated

					over the photocatalysts, contributes to the inactivation of viruses.
Nanosized TiO_2 18 mm diameter (Khaiboullina et al., 2020)	SARS-CoV-2	100 µL, median tissue culture infectious dose (TCID50	UV radiation	254nm, 99V, 30W, 0.355A	The production of free electrons during photocatalysis leads to the generation of ROSs such as O_2- and OH- radicals. These ROSs, including anti-microbial H_2O_2
Packed bed non-thermal plasma reactor (Linga Reddy et al., 2013)	MS2 virus	Catalytic packed bed non-thermal plasma reactor	qPCR	95%	Free radicals and other generated ROSs participate in the virus inactivation
Porous ceramic coated with photocatalytic nano-TiO_2 (Daikoku et al., 2015)	Influenza virus A/PR/8/34 (H1N1)	Ultraviolet light wavelength than 400 nm	Real-time PCR	81.49–99.72%	-

TiO_2 photocatalytic reactor (S.-H. Kim et al., 2017)	Human norovirus (HuNoV)	UV irradiation	254 nm (UV-B)	PMA-qRT-PCR	TiO_2 thin films (Hajkova et al. 2007)
TiO_2-coated glass plates (Ishiguro et al., 2011)	Bacteriophages	Low-intensity, long-wavelength UV irradiation	qPCR	-	TiO_2 thin films exhibit photocatalytic activity, leading to the degradation of viral RNA due to the production of reactive oxygen species.
TiO_2 (Nakano et al., 2012)	Influenza virus H1N1	Under ultraviolet	-	100%	TiO_2 photocatalysis, through the generation of ●OH and O_2, contributes to the destruction of viral proteins, particularly those involved in binding.
Ultraviolet light C (UVC) 254 nm with about 10%	Influenza A viruses H1N1 and H3N2	Low-pressure Hg vapour	RT-PCR	99.9%	Disrupting the genetic materials of airborne

power of Vacuum ultraviolet (VUV) light at 185 nm (Szeto et al., 2020)					pathogens and render them inviable
UV-PCO scrubber (Zhao et al., 2014)	Infectious bursal disease virus (IBDV)	UV lamp	EID50	>99.7%	UV inactivation process involving uracil dimerisation in viral RNA.

2.5 Analysis of photocatalytic air purifiers

The following section aims to identify trends, patterns, and findings found in the review of photocatalytic air purifiers, HEPA purifiers, and PCO technology.

2.5.1 Significance of indoor air quality

The COVID-19 pandemic has accentuated the critical importance of maintaining good indoor air quality. With the primary mode of transmission of the virus being through respiratory droplets in the air, there is a heightened need for effective air purification systems that can efficiently eliminate contaminants. Poor indoor air quality can lead to various health issues, including respiratory problems, allergies, and reduced productivity. As a result, the focus on improving IAQ has increased significantly.

2.5.2 Photocatalytic air purifiers

Photocatalytic air purifiers have gained attention due to their potential in removing airborne pollutants. These purifiers utilise photocatalysts, such as TiO_2, which react with UV light to generate active oxygen species, including hydroxyl radicals and superoxide anions. These reactive species effectively neutralise and break down airborne contaminants, such as VOCs, PM, and even viruses. The photocatalytic process offers a promising solution for improving indoor air quality and reducing the spread of harmful pollutants.

2.5.3 Effectiveness against SARS-CoV-2

The articles highlight studies that have specifically evaluated the effectiveness of photocatalytic air purifiers and HEPA purifiers in reducing the transmission of SARS-CoV-2, the virus responsible for COVID-19. The findings indicate that both types of purifiers can significantly reduce the viral load in the air, thereby limiting the potential for transmission. This supports the use of these air purification technologies as important tools in combating the spread of the virus, particularly in enclosed spaces where social distancing and adequate ventilation may be challenging.

2.5.4 Design considerations for aircraft cabin air purifiers

One of the articles focuses on the design aspects involved in creating air purifiers specifically for aircraft passenger cabins, utilising PCO technology. Due to the limited space available in aircraft cabins, the design of these purifiers needs to be compact and lightweight. Additionally, the choice of catalyst material, such as TiO_2, is crucial for efficient pollutant degradation. The selection of a suitable UV light source, preferably UV-A due to its lower energy and reduced potential for harm, is also important. The integration of pre-filters, air quality sensors, intelligent controls, and safety features ensures optimal performance and maintenance of the purifiers.

2.5.5 Computational Fluid Dynamics (CFD) approach

The use of a CFD approach with experimentally determined kinetic parameters allows for accurate prediction of the performance of photocatalytic air purifier apparatus. This approach incorporates data obtained through experiments into the CFD model, enabling a realistic representation of the PCO process and the device's efficiency in degrading pollutants. The CFD approach provides insights into airflow patterns, pollutant distribution, and spatial contact with the photocatalyst surface. It offers a cost-effective and time-efficient method for evaluating and optimising the design and operation of air purifiers, leading to enhanced performance and pollutant removal efficiency.

2.5.6 Combination of purification technologies

While photocatalytic air purifiers and HEPA purifiers have demonstrated effectiveness in reducing airborne pollutants, it is worth noting that a comprehensive approach combining multiple purification technologies may be beneficial. The integration of PCO technology, HEPA filtration, and activated carbon can provide a synergistic effect, targeting a broader range of pollutants and enhancing overall air quality. By combining different technologies, it is possible to achieve optimal purification and ensure the removal of various contaminants, including gases, particles, and volatile compounds.

Overall, the trends, patterns, and findings from the provided information highlight the growing recognition of the importance of indoor air quality, the potential of photocatalytic air purifiers in reducing airborne pollutants and viruses, the design considerations for air purifiers in different environments (such as aircraft cabins), the use of CFD for performance prediction, and the benefits of combining multiple purification technologies. These insights contribute to the advancement and development of air purification systems that can effectively enhance indoor air quality, promote healthier environments, and reduce the risk of airborne transmission of diseases like COVID-19.

2.6 Photocatalytic oxidation

Photocatalytic oxidation (PCO) is a process that applies semiconductor materials such as TiO_2 to react with pollutants. TiO_2 is a widely used photocatalyst due to its affordability, safety, and effectiveness in breaking down different pollutants without requiring additional chemical additives. In PCO, the catalyst is exposed to UV light with wavelengths ranging from 180nm-400nm, which generates hydroxyl radicals and oxide ions that attract and oxidise pollutants, as shown in Figure 2.11. These pollutants are then decomposed into harmless components like water vapour and CO_2. Compared to HEPA filters, PCO has an added benefit since pollutants are transformed into non-hazardous substances, whereas HEPA filters may still contain hazardous pollutants on their surface (Kolarik & Wargocki, 2010). Air purifiers employing PCO technology are thus becoming increasingly prevalent as they can efficiently neutralise airborne pollutants.

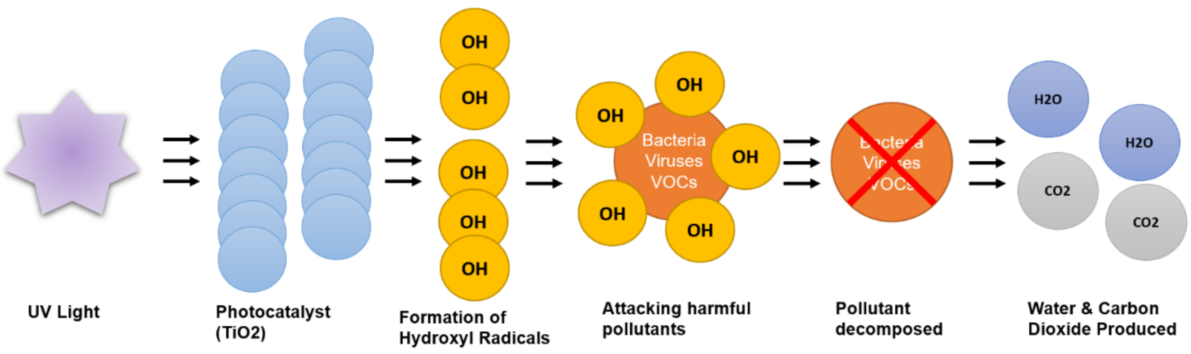


Figure 2.11 Diagram displaying photocatalytic oxidation

2.6.1 Removal of pollutants with PCO

The effectiveness of PCO technology in removing airborne pollutants has been demonstrated in several studies. For example, a study by Liu et al. (2020) showed that a PCO air purifier was highly effective in removing HCHO, toluene, and benzene, with removal rates of 91.2%, 92.1%, and 90.8%, respectively. Another study (J. Kim & Jang, 2018) found that a PCO air purifier significantly reduced indoor concentrations of VOCs such as HCHO, acetaldehyde, and toluene. Additionally, PCO technology has also been shown to be effective in removing biological pollutants such as bacteria and viruses.

Another study (Lu et al., 2022) reported that a PCO air purifier effectively removed airborne bacteria and viruses in a hospital ward, with removal rates of 96.8% and 87.5%, respectively. PCO technology is a promising approach to purify indoor air by effectively breaking down various pollutants into harmless components. With its demonstrated effectiveness in removing both chemical and biological pollutants, air purifiers with PCO technology are gaining popularity as a solution for improving indoor air quality (Sun et al., 2008).

2.6.2 Vacuum ultraviolet oxidation

A recent study (Xu et al., 2018) in China evaluated a vacuum ultraviolet oxidation (VUV-PCO) purifier, is depicted in Figure 2.12. The purifier is equipped with a nanoporous TiO_2 film, a radial fan, and Mn-Fe catalyst. To assess its effectiveness in an enclosed room, the study evaluated its ability to eliminate VOCs and O_3. The results of the evaluation were highly promising, as the purifier demonstrated notable efficacy in reducing various VOCs, including HCHO, nonanal, pentanal, benzene, toluene, octanal, ofm-xylene, and ortho-xylene. The reduction rate achieved was as high as 78.71%, showcasing the purifier's performance. An additional noteworthy feature of the purifier is the incorporation of a heated ozone removal unit, which further contributed to the elimination of VOCs. This innovative technology holds great potential for enhancing air quality and minimising harmful substances in various environments. The study emphasises the significance of VUV-PCO air purifiers and highlights the need for further investigations in diverse environmental settings.

2.6.3 Comparison of commercial photocatalytic purifiers

A comprehensive study conducted in France (Wongaree et al., 2016) aimed to compare the efficiency of various commercially available photocatalytic air purifiers, shedding light on the critical role played by the design and assembly of PCO air purifiers in determining their overall effectiveness. Surprisingly, certain purifiers showcased significantly higher efficiency levels than others, despite operating at reduced flow rates. The key differentiator was identified in their ability to distribute the photocatalytic substance optimally towards the irradiation source, along with a well-optimised configuration of lamp, photocatalyst, and fan components.

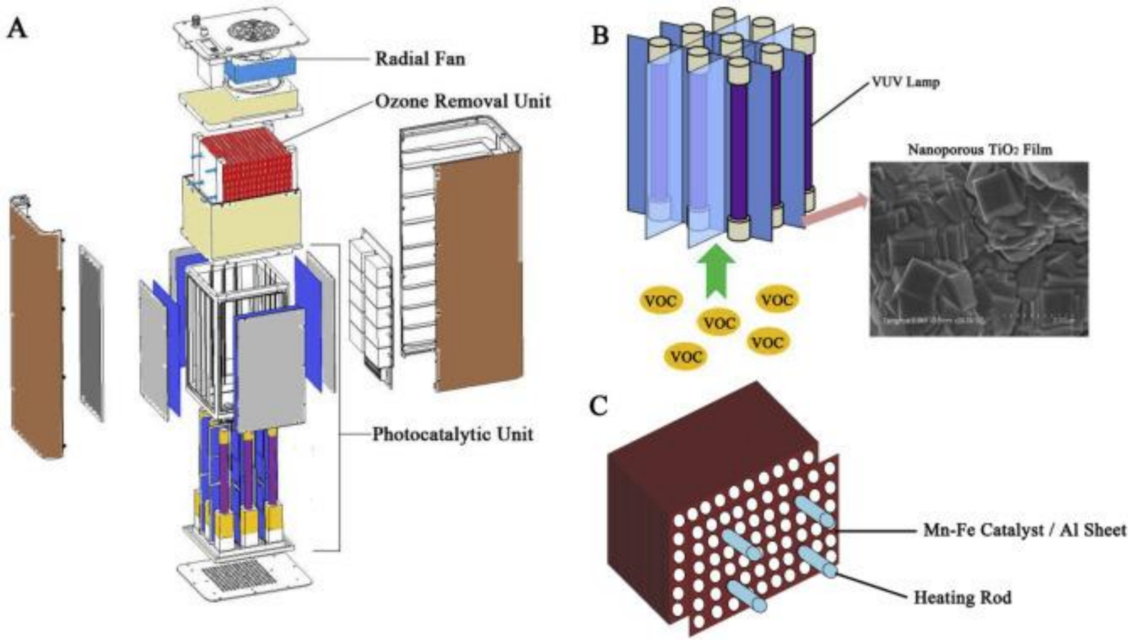


Figure 2.12 Diagram of a photocatalytic unit (Xu et al., 2018)

Building upon these intriguing findings, the study explored innovative arrangements of the PCO catalyst, with a particular focus on the utilisation of TiO_2-coated fibres as an alternative to conventional coated metal plates. The results from one such investigation revealed that TiO_2 nanofibres offered a substantial increase in surface area, resulting in enhanced adsorption capability and visible light absorption. This breakthrough approach significantly improved air purification efficiency while simultaneously reducing energy requirements. The study highlighted the pivotal role of substrate selection in the performance and energy efficiency of PCO air filters. Substrates with high surface areas, like aluminium honeycomb mesh, demonstrated superior purification efficiency but came with the trade-off of higher energy consumption due to pressure drop. On the other hand, substrates such as carbon cloth and nickel foam proved to be more energy-efficient but had a relatively lower surface area. Additionally, the energy cost associated with the lamps used remained a primary factor influencing the overall energy consumption of PCO air purifiers.

Another important aspect to consider in the use of PCO air purifiers is their maintenance and replacement of parts. A study conducted (G. Zhang et al., 2016) analysed the performance and durability of a commercial PCO air purifier. The study found that the performance of the purifier decreased significantly after six months of continuous operation due to the accumulation of dust and contaminants on the photocatalytic filter. The study concluded that periodic cleaning and replacement of the photocatalytic filter is necessary for optimal performance and longevity of the purifier.

In addition to maintenance, it is also important to consider the environmental impact of PCO air purifiers (Bragoszewska et al., 2019). A study conducted evaluated the environmental impacts of a commercial PCO air purifier throughout its life cycle. The study found that the production phase of the purifier had the largest environmental impact, followed by the disposal phase. The study also found that the use phase of the purifier had relatively low environmental impact. The study suggests that the design and production of PCO air purifiers should take into consideration the reduction of environmental impact throughout the life cycle of the product.

The next study (Lin et al., 2020) provides extensive research that has been conducted to explore treatment technologies for produced water, aiming to comply with environmental regulations and enable reuse. Due to varying contaminants, multiple technologies are necessary. While photocatalysis holds potential, its understanding and treatment effectiveness strategies are lacking. Photocatalytic activity is influenced by factors such as aqueous chemistry, ionic substances, and high organic content.

2.6.3 Improving IAQ with PCO air purifiers

PCO air purifiers offer a promising solution to reducing airborne pollutants in indoor environments (Li et al., 2021). However, the efficacy of the purifiers is highly dependent on the design and assembly of the purifier, as well as the catalyst used. Furthermore, maintenance and replacement of parts are important factors to consider for optimal performance and longevity of the purifier. Finally, the environmental impact of PCO air purifiers should also be considered in the design and production of the product. Further research is necessary to fully understand the potential benefits and limitations of PCO air purifiers in various indoor settings.

A study conducted by (Kang et al., 2020) investigated the effectiveness of a photocatalytic air purifier on indoor air quality and the human body. The experiment was conducted in a residential apartment in Korea with 25 participants. The purifier used in the study was equipped with a filter coated with TiO_2 and a UV lamp. The results showed that the concentration of airborne particles, such as PM2.5 and PM10, were significantly reduced after the purifier was turned on. The study also measured the level of VOCs and found that the concentration of VOCs was reduced by 50-90% after the purifier was turned on, such as that shown in Figure 2.13. Furthermore, the study conducted measurements on the human body, such as heart rate variability and lung function, before and after the purifier was turned on. The results showed that the use of the air purifier improved lung function and heart rate variability, indicating a positive impact on human health. This study suggests that air purifiers can not only improve indoor air quality but also have a positive impact on human health.

In a study (Day et al., 2018), the effectiveness of a hybrid air purifier that combines a HEPA filter with a photocatalytic filter was tested. The experiment was conducted in a typical office in China, and the results showed that the hybrid air purifier significantly reduced the concentration of airborne particles, such as PM2.5 and PM10, as well as the concentration of VOCs. The study also measured the removal efficiency of the photocatalytic filter against bacteria and found that the filter was effective in reducing bacterial counts. Moreover, the study evaluated the energy consumption of the hybrid air purifier and found that it consumed less energy compared to traditional air conditioning systems. The study suggests that the hybrid air purifier is a promising solution for improving indoor air quality and reducing energy consumption.

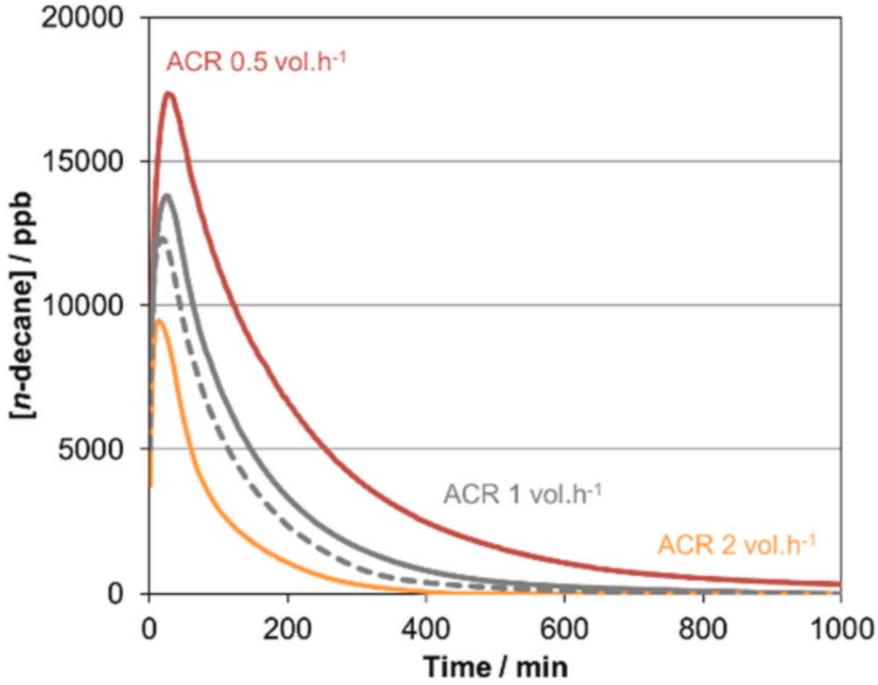


Figure 2.13 Graph displaying pollutant decay time (Pétigny et al., 2021)

In conclusion, photocatalytic air purifiers have been shown to effectively reduce indoor air pollutants, such as PM2.5, PM10, VOCs, and bacteria. The studies also suggest that air purifiers can have a positive impact on human health by improving lung function and heart rate variability. However, it is important to note that the efficiency of air purifiers may vary depending on the type of filter used, the size of the room, and other factors such as outdoor air pollution levels. Therefore, it is recommended to carefully select the appropriate air purifier for the specific indoor setting and to regularly maintain and replace the filters to ensure optimal performance. Table 2.2 displays a breakdown of the studies containing research on PCO.

Table 2.2 Photocatalytic oxidation studies

Source	**Study Design**	**Filtration Type**	**Measurement**	**Results**
(Afshari et al., 2020)	Experimental chamber	Activated carbon fibre with TiO_2	Impact of TiO_2 properties and support material	Improved durability. Synergy between TiO_2 and carbon led to regeneration of adsorbent.

(Assadi et al., 2023)	Review	PCO	Bacterial inactivation	Increase in inactivation
(Chanklom et al., 2021)	Experimental chamber with simulated indoor air	TiO_2 loaded on PLA	Benzene degradation	Highest PCO efficiency was 5% with PLA/ TiO_2 film.
(Costarramone et al., 2015)	Laboratory airtight chamber	Commercial photocatalytic devices	Mineralisation of a mixture of five VOCs	Concentration of low weight VOCs reduced slower than heavier VOCs.
(Darvish et al., 2020)	Evaluation of photocatalytic activity CO_2 and NO_2 gases under visible light	Air purifier reactor with MWCNT/ TiO_2 thin film by dip-coating	Concentration reduction of CO_2 and NO_2 gases	High visible light PCO activity for CO_2 and NO_2 degradation.
(Destaillats et al., 2012)	Field study	PCO	TVOC	Increase in removal rate
(Dumont & Hequet, 2017)	Modelling laboratory-scale recirculation closed-loop reactor	PCO	Clean Air Delivery Rate (CADR) of PCO	Removal efficiency lower than 5%.
(Enesca, 2021)	Review	PCO	VOC	Increase in removal rates
(G. Zhang et al., 2016)	Lab experiment	PCO	TVOC	Higher removal rate
(J. Kim & Jang, 2018)	Photo-reactor comprised of a hollow cylinder made of stainless steel	VUV, TiO_2/VUV	MS2 inactivation and ozone degradation	< 90% MS2 inactivated in 0.009 s.
(Jaison et al., 2023)	Review	UV PCO	TVOC	Increase in removal rates
(Koivisto et al., 2018a)	Ventilated chamber located at an industrial research laboratory	Dip coating of ceramic honeycombs	Worker's exposure levels, PM	Increased concentrations of <200 and <400 nm particles.
(Kolarik & Wargocki, 2010)	Rooms polluted by typical sources of	TiO_2 honeycomb catalyst plates, TUV lamps	CADR, perceived air quality	Improved perceived air quality with

	indoor pollution			3x CADR increase.
(Kolarik & Wargocki, 2010)	Performed in an office polluted by a mixture of typical building materials	7 honeycomb titanium type catalyst sections and 4 UV bulbs	HCHO, VOCs, Butanone, Acetone, Acetic acid	HCHO increased, acetaldehyde decreased.
(LI et al., 2005)	Lab experiment	TiO_2 catalysts	Ln3+ TiO_2 catalysts	Enhanced PCO degradation
(Lu et al., 2022)	Lab experiment	PCO	Virus inactivation	Increase in removal rate of SARS-CoV-2
(M. Kim et al., 2020)	Experimental chamber (1.0 m^3) and real smoking room (61.9 m^3)	O3 decomposition MnOx-coated filter	TVOC concentration	TVOC concentration reduced by 80% in 30-minute exposure.
(Ma et al., 2008)	Experimental study	PCO	TVOC	Higher removal rate
(Mohan & Shiva, 2019)	Experimental chamber	Layer-by-layer self-assembly of TiO_2 NPs/AC on non-woven fabric using chitosan	Toluene removal	CSAT-PET 1.5 times higher toluene removal efficiency than pure TiO_2-PET.
(Nakao, 2012)	Lab experiment	TiO_2 coated ceramic air filters	Bacterial removal	Increase in removal rate
(Ni et al., 2022)	Lab experiment	PCO	HCHO	Increase in removal
(Ochiai et al., 2013)	Experimental chamber	Excimer-lamp with TiO_2	Acetaldehyde gas, phenol, waterborne pathogens	Successful Decompose acetaldehyde gas and phenol.
(Poormohammadi et al., 2021)	Review	PCO	Viruses	Increase in removal rates
(Queffeulou et al., 2010)	Modelling	PCO	Bacterial inactivation	Predicted increase in removal
(Riffat & Ma, 2013)	Experimental study	PCO	TVOC	Increase in removal rate
(Riffat & Zhao, 2007)	Experimental Study	PCO	TVOC	Increased removal rate

(S. Kim et al., 2022)	Experimental chamber	Photocatalytic air purifier using TiO_2/H-ZSM-5	VOCs, HCHO, airborne viruses	VOC removed, prevented HCHO emission, inactivated SARS-CoV-2.
(Shiraishi & Ishimatsu, 2009)	Experimental chamber	Continuous adsorption/desorption unit with zeolite particles-loaded honeycomb rotor	Toluene at concentrations of 3.4, 7.8, and 10.6 mg m−3	10-minute treatment reduced toluene concentration to almost zero.
(Sun et al., 2008)	Simulated aircraft cabin room	UV/TiO_2 technology	HCHO, acetaldehyde, acetone, methyl ethyl ketone, methanol, ethanol, isoprene, toluene	VOCs such as toluene, ethanol, and isoprene partially reduced.
(Taranto et al., 2009)	Lab experiment, material comparison	Close-loop photocatalytic reactor, UV lamps, TiO_2 honeycomb and cellulose fibres	Methanol removal	Aluminium honeycomb has higher methanol removal efficiency than fibrous tissue.
(Tichá et al., 2016)	Lifecycle Assessment	Air purifiers and photocatalytic coatings based on nano TiO_2	Removal of undesirable microorganisms and airborne pollutants from the indoor environment	PCO coating reduced microorganisms and airborne pollutants.
(Wongaree et al., 2016)	Experimental Chamber	Electrospun carbon nanotube/titanium dioxide (CNT/TiO_2) nanofibres as visible light active photocatalysts	Gaseous benzene	Higher MB degradation (58%) than CNT/TiO_2 nanofibres.

(Wongwatcharapaiboon et al., 2019)	Experimental Study	PCO	TVOC	Increase in removal rate
(J. Wu et al., 2022)	Modelling	UV PCO	TVOC	Increase to removal rate
(X. Huang et al., 2009)	Feasibility of UV LED/TiO_2	UV diodes and TiO_2 coated HEPA filter	Aerosol containing Staphylococcus aureus	TiO_2 coated HEPA filter removed Staphylococcus aureus in a 52-hour period.
(Xiao Jiangrong et al., 2016)	Self-made multi-functional environmental test chamber	Mechanical filtering purifier, photocatalytic purifier, negative ion purifier, and multifunctional air purifier	TVOC	Increase in temperature and humidity led to an increased TVOC removal rate.
(Xu et al., 2018)	Elimination of VOCs and O_3 by-product, evaluated in a sealed actual room	VUV-PCO air purifier with nanoporous TiO_2 film	VOCs & O3	Purifier effectively removed VOCs and O_3.
(Zhong & Haghighat, 2018)	Modelling	Correlation between by-products and operational conditions was statistically analysed	Concentration, RH, airflow, and irradiance	Nonlinear and linear predictive regression techniques were used to develop predictive models.

2.7 Analysis of photocatalytic oxidation studies

The following section aims to explore trends, patterns, and findings found in the review of the effectiveness of PCO technology in removing airborne pollutants.

2.7.1 Removal of chemical pollutants

PCO air purifiers have demonstrated high effectiveness in removing various chemical pollutants, such as HCHO, toluene, benzene, and VOCs. Studies have shown significant reduction rates for these pollutants, contributing to improved indoor air quality.

2.7.2 Removal of biological pollutants

PCO technology has also been effective in removing biological pollutants, including bacteria and viruses. Air purifiers equipped with PCO technology have shown high removal rates for airborne bacteria and viruses in different environments, such as hospital wards.

2.7.3 Comparison of PCO air purifiers

Studies have compared the efficiency of different commercially available PCO air purifiers and found that design and assembly play a crucial role in their effectiveness. Factors such as the distribution of the photocatalytic substance, the arrangement of the catalyst, and the optimisation of the lamp, photocatalyst, and fan contribute to the purifiers' efficiency.

2.7.4 Selection of substrate

The selection of substrate materials for PCO air filters impacts their performance and energy efficiency. High surface area substrates offer superior purification efficiency but may require higher energy consumption due to pressure drop. Other substrates may be more energy-efficient but have lower surface area.

2.7.5 Maintenance and replacement

Proper maintenance and periodic cleaning or replacement of the photocatalytic filter are necessary for optimal performance and longevity of PCO air purifiers. Accumulation of dust and contaminants on the filter surface can significantly reduce the purifier's effectiveness over time.

2.7.6 Environmental impact

The environmental impact of PCO air purifiers throughout their life cycle has been evaluated. The production phase was found to have the largest environmental impact, followed by the disposal phase. The use phase of the purifiers had relatively low environmental impact. Consideration of environmental factors in the design and production of PCO air purifiers can help reduce their overall environmental footprint.

2.7.7 Hybrid air purifiers

Hybrid air purifiers that combine PCO technology with other purification methods, such as HEPA filters, have shown promising results in reducing airborne particles, VOCs, and bacterial counts. These hybrid systems offer a comprehensive approach to indoor air purification and can contribute to improved air quality while consuming less energy compared to traditional air conditioning systems.

Overall, the findings suggest that PCO air purifiers are effective in removing a wide range of airborne pollutants, including both chemical and biological contaminants. However, factors such as design, substrate selection, maintenance, and environmental considerations should be taken into account to ensure optimal performance and minimise the environmental impact of PCO air purification systems.

2.8 Filter substrate & geometry

In 2018, Kim and Jang conducted a study to investigate the influence of filter frame shape on the effectiveness of air purifiers (J. Kim & Jang, 2018). They tested three different shapes of photocatalytic frames: a 2mm pleated frame, a 5mm pleated frame, and a spiral frame. The study found that the 2mm pleated frame was the most effective in degrading ozone and MS2 viruses, while humidity levels did not significantly affect the results. When illuminated by VUV lamps, the catalyst inactivated up to 90% of live MS2 viruses, and exposure to ozone at 35ppb for 0.0009s also showed high efficacy in inactivating viruses. The inactivation speed was much faster than other UV-based purifiers, indicating the potential of this system as an alternative to UV air purifiers. Figure 2.14 displays the reactor model used in this study.

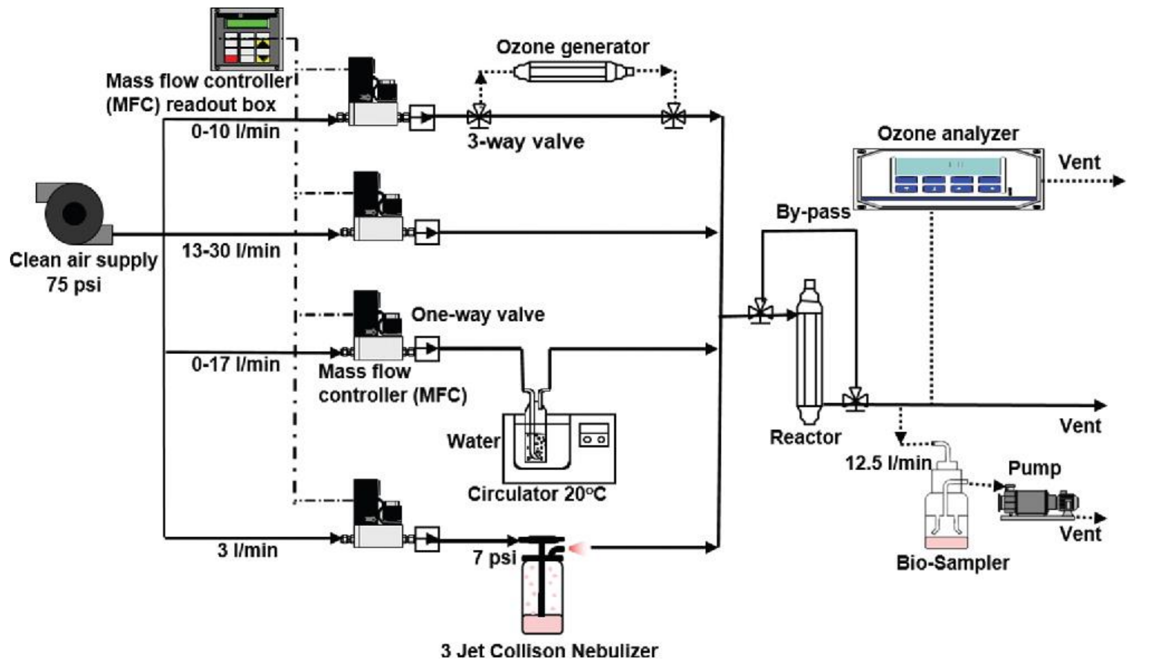


Figure 2.14 Diagram of a reactor model (J. Kim & Jang, 2018)

In 2009, a study (Shiraishi & Ishimatsu, 2009) was conducted using a miniaturised honeycomb zeolite rotor in a $1m^3$ room to measure toluene concentrations. The rotor reduced toluene concentrations from 3-11mg to nearly zero in just 10 minutes. The experiment was repeated over 100 times in six months, with no decrease in the filter's ability to absorb toluene observed despite heavy usage. Figure 2.15 displays the facilitated reactor model for this study.

This suggests that micro-sized TiO_2 filter geometries have the potential to effectively remove toluene from indoor areas. However, the study also found that a regeneration procedure is necessary to remove toluene from the zeolite rotor, making it unclear whether this type of filter could be a viable alternative to UV purifiers.

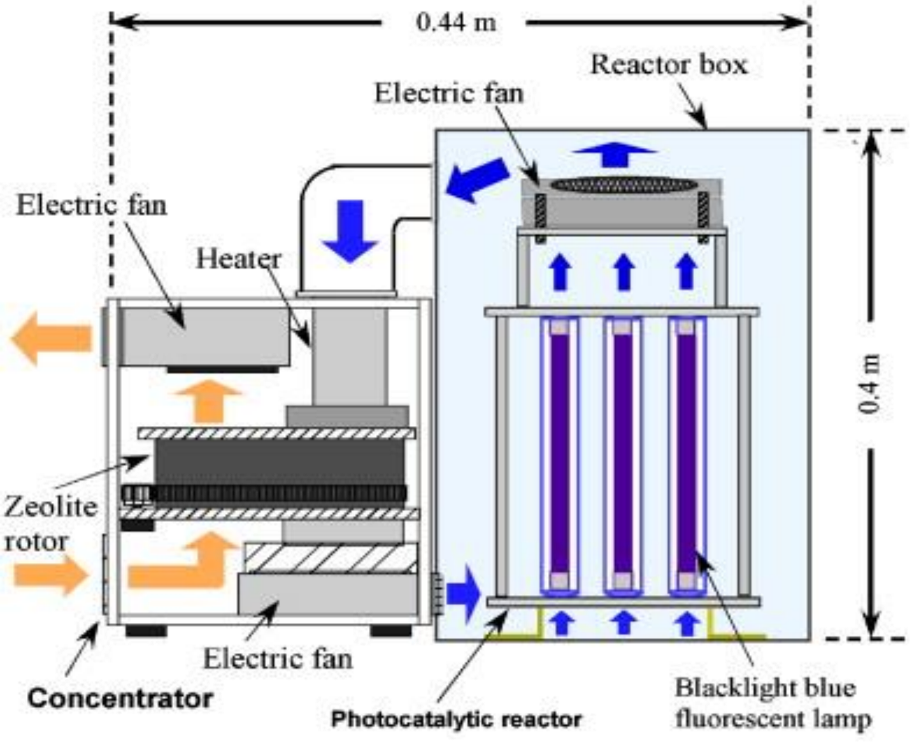


Figure 2.15 Photocatalytic reactor diagram (Shiraishi & Ishimatsu, 2009)

In a conducted study (Taranto et al., 2009), researchers explored the effectiveness of a honeycomb filter geometry in the removal of methanol and toluene. The results revealed that methanol exhibited a higher removal rate, mainly due to its lower oxidation reactivity, while the removal of toluene required higher energy input. This study highlights the promising potential of using honeycomb filters for air purification, particularly for methanol removal, but it also acknowledges the necessity for further research to assess their efficacy against other pollutants. One important consideration raised in the study is the impact of different filter geometries on pressure drops. The choice of geometry can influence the efficiency of pollutant removal. Additionally, using materials with larger surface areas in the filters can reduce pressure drops but may lead to increased energy requirements, presenting potential economic disadvantages. Hence, a cautious approach is required in selecting both the filter geometry and the materials to ensure optimal air purification efficiency.

A study (Mohan & Shiva, 2019) to assess the effectiveness of a chitosan/activated carbon/TiO_2 (CSAT) filter in removing VOCs from indoor environments. The researchers prepared the filter using a fabric filter with a novel preparation method and tested its ability to remove toluene under both dark and UV illuminated conditions. Results indicated that the CSAT-PET filter removed toluene with high efficiency, up to 91%, whereas the pure TiO_2 filter only removed up to 62%, as shown in Figure 2.16. Furthermore, the CSAT-PET filter remained stable over five cycles, indicating that it is a low-cost and reusable option for various applications without any signs of degradation. This study suggests that CSAT-PET filters could be a potential solution for air pollution control in indoor environments.

A study (Darvish et al., 2020) was conducted to investigate the efficacy of MWNCT/TiO_2 film filters in the photocatalytic treatment of NO_2 and CO_2. The filters were prepared using a dip coating method and were exposed to UV illumination in a specially designed reactor. The results showed the degradation of CO_2 and NO_2, consistent with the pseudo-first-order rate law, demonstrating the effectiveness of TiO_2 in combination with other elements to efficiently remove gases. This study used a different chemical composition and geometry from the previous study, highlighting the versatility of filter designs in achieving efficient gas removal. The findings suggest that MWNCT/TiO_2 film filters could be a potential solution for air pollution control in different environments.

A study (Tapia-Brito et al., 2022) was conducted to compare the efficacy of different TiO_2-coated substrates in reducing VOC concentrations in a real-world setting. Brass, plastic, and organic fibres were tested, and the results showed that the organic fibres performed the best, removing 0.8 mg/m^3 of VOC concentration within a 90-minute period. The authors hypothesised that the increased porosity of the organic fibres allowed for greater absorption of the TiO_2 coating compared to other substrate materials, resulting in improved coating durability and a more effective VOC reduction rate during the testing period. This study provides further evidence for the potential of TiO_2-coated organic fibres as an effective and efficient solution for VOC reduction in various indoor environments.

The efficacy of photocatalytic purifiers (X. Zhang et al., 2022) is determined by various factors, including the catalyst used, filter design, lighting arrangement, and the type of pollutants targeted for removal. The type of catalyst and filter design can affect the surface area available for reactions and the contact time between pollutants and the catalyst. Moreover, the lighting arrangement can affect the catalyst's ability to initiate the reaction, while the targeted pollutants can determine the reaction's selectivity and the required irradiation energy. Despite these variables, photocatalytic purifiers have been shown to be an effective and safe solution for removing various indoor pollutants.

Recent studies have concentrated on enhancing the efficiency of photocatalytic purifiers by improving their design, particularly their filter design and coating. One strategy has been to increase the catalyst's surface area and coating composition to optimise pollutant removal. However, some studies have observed a decrease in airflow when increasing the filter's surface area, which can decrease the purifier's effectiveness. To address this issue, researchers have investigated different filter materials and coatings, such as chitosan/activated carbon/TiO_2, to optimise the purifier's effectiveness while maintaining adequate airflow (Mohan & Shiva, 2019). Furthermore, researchers have also explored different coating methods, such as dip coating, to improve the purifier's photocatalytic activity without reducing airflow (Darvish et al., 2020). The combination of various design modifications can significantly improve the efficiency of photocatalytic purifiers and reduce the level of pollutants in indoor air.

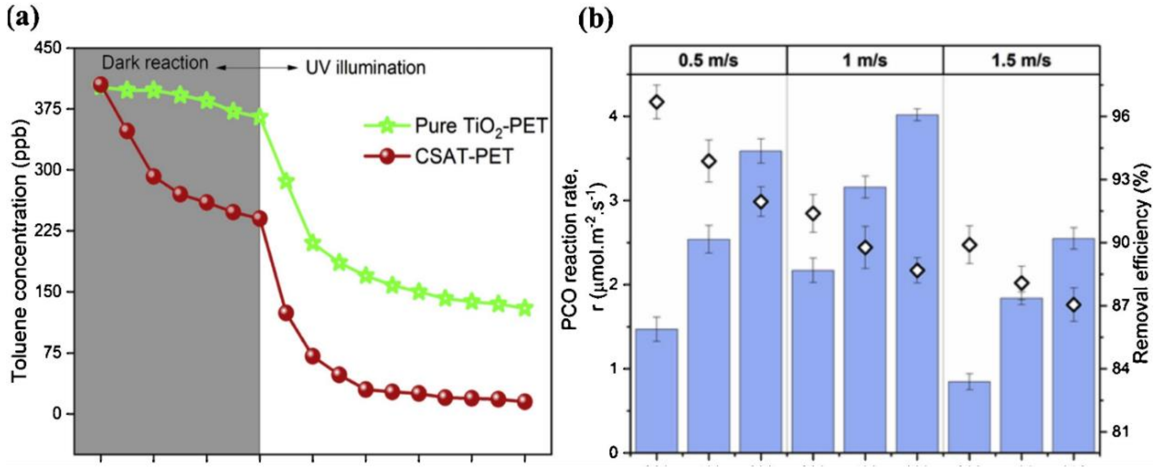


Figure 2.16 Increased reduction of toluene in CSAT-PET vs Pure TiO_2 (Mohan & Shiva, 2019)

Innovative designs such as honeycomb filters have been explored by researchers to address the issue of decreased airflow while increasing the filter's surface area. Honeycomb filters have been shown to provide one of the largest surface areas possible without compromising mechanical strength, making them a promising solution for enhancing the efficiency of photocatalytic purifiers. Studies have demonstrated impressive results in removing pollutants such as toluene and methanol using honeycomb filters (X. Huang et al., 2009).

Furthermore, some researchers have investigated the use of TiO_2 blended with other chemicals to improve the removal of specific pollutants. For instance, a study showed that blending TiO_2 with WO_3 significantly improved the removal of HCHO from indoor air (Enesca, 2021)). The lighting arrangement is another critical component of the photocatalytic reaction that can significantly impact the purifier's efficiency. Optimal UV wavelength and LED diodes are sometimes overlooked, but they can have a dramatic impact on the photocatalytic reaction's efficiency. By arranging lights and adjusting their intensity, researchers can increase the efficiency of photocatalytic purifiers (M. Yang et al., 2023). Additionally, adding reflective surfaces can intensify light intensity, further enhancing the purifier's efficiency in removing pollutants. Overall, advancements in filter design, catalyst selection, lighting arrangement, and reflective surfaces offer promising solutions to optimise the efficiency of photocatalytic purifiers, resulting in improved air quality indoors.

In this next study (Bortolassi et al., 2019) reviewed, researchers evaluated TiO_2/PAN, ZnO/PAN, and Ag/PAN nanofibres electrospun with identical conditions and weight ratios. Nanoparticle addition affected PAN solution viscosity and conductivity, influencing nanofibre formation. TiO_2/PAN/DMF and ZnO/PAN/DMF solutions had comparable viscosity and conductivity, while Ag/PAN/DMF showed significantly higher values. Scanning electron microscopy confirmed nanofibre formation and even dispersion of Ag, while TiO_2 and ZnO formed fibre clusters. Filter characterisation revealed low pressure drop (68.13 to 183.47 Pa). TiO_2_F had the highest filtration efficiency (approx. 100%) but the largest pressure drop. Ag_F exhibited over 98% filtration efficiency, low pressure drop (68.13 Pa), high QF (0.06 Pa−1), and effective antibacterial activity against E. coli. ZnO_F showed filtration efficiency over 97%. The study emphasises the maintenance of high filtration efficiency with nanoparticle-loaded PAN, particularly Ag/PAN nanofibres, making them suitable for air filtration applications like masks, cleanrooms, and indoor air purification due to their potent bactericidal properties.

Photocatalytic purifiers have become increasingly popular as an effective way to remove pollutants from indoor air (Sun et al., 2008). The technology relies on a catalyst, typically TiO_2, to initiate a photocatalytic reaction that breaks down pollutants into harmless by-products, such as CO_2 and water H_2O (Jaison et al., 2023). The effectiveness of photocatalytic purifiers depends on several factors, including the catalyst used, filter design, lighting arrangement, and the type of pollutants targeted for removal (J. Wu et al., 2022). Many studies have focused on improving the design of photocatalytic purifiers to enhance their effectiveness in removing pollutants. One area of focus has been on filter design and coating. By increasing the catalyst surface area and coating composition, it is expected that the purifiers will become more efficient and effective in removing pollutants (Mohan & Shiva, 2019). However, some studies have reported reduced airflow when the filter surface area is increased, which can decrease the efficacy of photocatalytic purifiers since less polluted air comes into contact with the catalyst (Nakao, 2012). To address this issue, researchers have turned to honeycomb filters, which offer one of the largest surface areas possible without compromising mechanical strength (Darvish et al., 2020).

Honeycomb filters have shown impressive results in removing pollutants such as toluene and methanol. While TiO_2 is the most commonly used catalyst, some studies have opted for TiO_2 blended with other chemicals to improve the removal of specific pollutants (Xu et al., 2018). Lighting arrangement is another critical component of the photocatalytic reaction that can significantly increase the purifier's efficiency. LED diodes and using the optimal UV wavelength are sometimes overlooked, but they can have a dramatic impact on the photocatalytic reaction's efficiency. By arranging lights and adjusting their intensity, researchers can increase the efficiency of photocatalytic purifiers. Additionally, reflective surfaces can be added to further intensify the light intensity (J. Wu et al., 2022). While photocatalytic purifiers have been shown to be highly effective in removing VOCs such as toluene, research is needed to address other pollutants like PM2.5 (LI et al., 2005). However, a significant finding is that photocatalytic purifiers consistently neutralise viruses, making them a promising technology for combating this specific pollutant (G. Zhang et al., 2016). The technology's ability to neutralise viruses is particularly relevant in the context of the COVID-19 pandemic, where there is a heightened demand for indoor air purification technologies. Despite their effectiveness, photocatalytic purifiers do generate CO_2 and H_2O by-products. The environmental impact of commercial demand for these purifiers is yet to be fully understood, and further research is required to assess the technology's sustainability (Jaison et al., 2023). Table 2.3 lists the identified substrate geometries investigated in this review.

Table 2.3 Identified substrate geometries

Source	Substrate Geometry	Measurement	Results
(Darvish et al., 2020)	MWNCT/TiO_2 film	NO_2 and CO_2	100% degradation
(J. Kim & Jang, 2018)	2mm, 5mm pleated frame, and spiral frame	Ozone and MS2	2mm pleated frame showed highest activity
(Mohan & Shiva, 2019)	Chitosan/activated carbon/TiO_2 filter	Toluene	CSAT-PET: 91% removal, Pure TiO_2: 62% removal
(Parasuraman et al., 2022)	Curved filter	VOC	Higher degradation with curved filter
(Shiraishi & Ishimatsu, 2009)	Miniaturised honeycomb zeolite rotor	Toluene	Toluene concentration reduced to nearly zero
(Tapia-Brito et al., 2022)	Plastic, brass, organic	VOC	Organic substrate showed highest efficacy
(Taranto et al., 2009)	Honeycomb filter	Methanol and toluene	Higher methanol removal rate

2.9 Analysis of filter substrates and geometries

From the provided information on filter substrate and geometry in the context of photocatalytic purifiers, the following trends and findings can be observed:

2.9.1 Influence of filter frame shape

A study (J. Kim & Jang, 2018) conducted investigated the influence of filter frame shape on the effectiveness of air purifiers. They tested different shapes of photocatalytic frames and found that the 2mm pleated frame was the most effective in degrading ozone and MS2 viruses. This suggests that the filter frame shape can have an impact on the purifier's performance.

2.9.2 Honeycomb filter geometry

Studies have explored the use of honeycomb filter geometry in photocatalytic purifiers. A study (Shiraishi & Ishimatsu, 2009) demonstrated the effectiveness of a miniaturised honeycomb zeolite rotor in reducing toluene concentrations. The results showed that the honeycomb filter effectively reduced toluene levels in a short period. Honeycomb filters offer a large surface area without compromising mechanical strength, making them a promising solution for improving the efficiency of photocatalytic purifiers.

2.9.3 Filter material selection

The choice of filter material can affect the efficiency of air purification. Researchers have investigated different filter materials such as chitosan/activated carbon/TiO_2 (CSAT) filters and TiO_2-coated organic fibres. A study (Mohan & Shiva, 2019) found that CSAT filters exhibited high efficiency in removing toluene compared to pure TiO_2 filters. Additionally, another study (Tapia-Brito et al., 2022) observed that organic fibres coated with TiO_2 showed improved VOC reduction rates. The selection of filter materials should consider factors such as porosity, absorption capability, and coating durability for optimal air purification efficiency.

2.9.4 Filter coating and catalyst composition

Researchers have explored blending TiO_2 with other chemicals to enhance the removal of specific pollutants. A study (Enesca, 2021) demonstrated that blending TiO_2 with WO_3 improved the removal of HCHO. The composition and coating of the filter can significantly impact the efficiency of photocatalytic purifiers in removing specific pollutants.

2.9.5 Lighting arrangement and reflective surfaces

The lighting arrangement plays a crucial role in the efficiency of photocatalytic purifiers. Optimal UV wavelength and LED diodes can enhance the photocatalytic reaction's efficiency. Adjusting light intensity and incorporating reflective surfaces can intensify the light and improve the purifier's effectiveness in removing pollutants.

2.9.6 Consideration of pressure drops and energy requirements

Different filter geometries may result in pressure drops, and using materials with a larger surface area can decrease pressure but may increase energy requirements. A study (Taranto et al., 2009) emphasised the need to carefully consider filter geometry and material selection to balance air purification efficiency and energy consumption.

Overall, the design of filter substrate and geometry in photocatalytic purifiers can significantly influence their effectiveness in removing pollutants. Factors such as filter frame shape, honeycomb filter geometry, material selection, coating composition, lighting arrangement, and consideration of pressure drops and energy requirements all play a role in optimising the efficiency of photocatalytic purifiers for air purification.

2.10 Particle removal with bio-aerogel Filter

A study (Wang et al., 2021) conducted on the utilisation of bio-aerogel offers an effective approach for the removal of particulate pollutants. While the MopFan system is primarily designed to eliminate VOCs and similar substances, it is not as efficient in capturing particles. However, by combining the filtering capabilities of bio-aerogel with the MopFan system, a comprehensive solution can be achieved. This integration allows for the simultaneous removal of both gaseous and particulate pollutants, providing a complete and robust filtration solution. By incorporating bio-aerogel filters into the MopFan system, the combined setup ensures efficient and thorough purification, effectively addressing a wider range of pollutants in various indoor environments. The use of these filters in tandem with the MopFan system present a complete solution to air purification of both gaseous pollutants and particulate matter.

Bio-aerogel exhibits a highly porous 3D structure that greatly contributes to their filtration performance. The incorporation of wheat straw into the biomass-based aerogels imparts unique multi-cavity characteristics, enhancing surface area and influencing pore formation. Through a comparative analysis against various commercial filters, these biomass-based aerogels have showcased their potential as highly effective filtration materials for removing PM 2.5 and PM 10 particles in diverse applications.

In controlled transparent chamber tests, the PM 2.5 and PM 10 removal efficiencies of biomass-based aerogel K90 reached an impressive 99.50% and 99.40%, respectively, while HEPA filters demonstrated comparable effectiveness with removal efficiencies of 98.80% for PM 2.5 and 98.20% for PM 10. Notably, biomass-based aerogels have a more compact structure and smaller volume compared to HEPA filters, which rely on additional pleated features to optimise their efficiency. In stark contrast to surgical masks, silica aerogels, and regular cloth filters, the thin discs of biomass-based aerogel K90 exhibited superior performance in removing PM particles.

To validate the filtration results from the transparent chamber, the same experiments within a realistic room setting were conducted. K70 and HEPA filters showcased improved filtration performance compared to the transparent chamber tests. Although a slight reduction in filtration efficiency was observed for biomass-based aerogel K90 in the real room, the PM 2.5 removal efficiency still exceeded 97%. With its environmentally friendly nature and notable efficiency, this biomass-based aerogel holds significant promise as an advanced air pollutant filter, providing filtration capabilities.

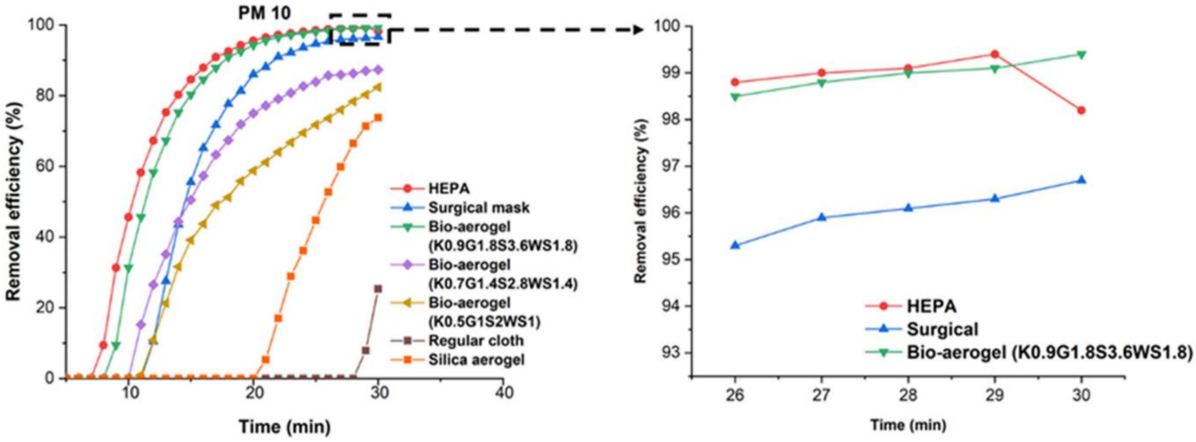


Figure 2.17 The PM 10 removal efficiency of (a) different filters from 0 min to 30 min, (b) HEPA, surgical mask and biomass-based aerogel (Wang et al., 2021)

2.10 Summary of literature review

The synthesis of the literature review on previous MopFan research, PCO studies, photocatalytic purifiers and substrate geometries, highlights the advancements, gaps, and potential for developing efficient prototypes in the field of air-cleaning technologies. Both MopFan and PCO air purifiers have shown promise in improving indoor air quality, but there are still areas for further research and optimisation.

The evolution of the MopFan has advanced air-cleaning technology, focusing on indoor air quality, particle removal, pollutant elimination, and thermal comfort enhancement. Features like evaporative cooling, brush disk impellers, liquid desiccant systems, and photocatalytic coatings have expanded MopFan capabilities.

However, challenges remain. Preventing dust build-up within the fan casing requires further research. Optimising parameters like fan speed, water injection rates, and fibre characteristics can enhance particle removal efficiency. Cost-effective coating methods and materials need exploration to make MopFan and air purifiers more accessible.

PCO air purifiers, using photocatalytic oxidation, effectively remove various indoor pollutants like VOCs, PM, odours, viruses, bacteria, and volatile organic compounds by generating active oxygen species. They offer benefits like efficient pollutant removal, low energy use, and adaptability for different settings, even enhancing other air-cleaning systems. However, they may struggle with larger particles and require additional filtration like pre-filters. Safety concerns regarding UV exposure need addressing, and catalyst durability, like TiO_2, needs improvement for long-term effectiveness.

Efficient prototypes of MopFan and PCO air purifiers can be developed by addressing the identified gaps and optimising key design aspects. Integration of multiple air cleaning mechanisms, such as combining PCO technology with filtration systems, can enhance overall performance and pollutant removal capabilities. Optimising catalyst performance, including durability, stability, and photocatalytic activity, is essential for long-term effectiveness. Efficient prototypes should also incorporate safety measures to minimise UV exposure and ensure the well-being of occupants. Additionally, cost-effective materials and manufacturing processes should be explored to make PCO air purifiers more affordable and accessible.

Future prototypes of MopFan should focus on preventing dust build-up, optimising parameters for maximum performance, and exploring cost-effective manufacturing methods. These advancements will enhance the overall efficiency and affordability of MopFan, making them accessible to a wider range of users.

By addressing these considerations, efficient prototypes can be developed, offering reliable and effective solutions for improving indoor air quality. The integration of multiple air cleaning mechanisms, such as combining PCO technology with filtration systems, will ensure comprehensive pollutant removal. Design optimisation for particle capture, implementation of safety measures, and improvements in catalyst performance and longevity will contribute to the overall efficiency and durability of the prototypes. Furthermore, considering cost-effectiveness in terms of materials and manufacturing processes will make the prototypes more accessible to a wider user base.

In conclusion, the synthesis of the literature review emphasises the potential of MopFan and PCO air purifiers in enhancing indoor air quality. By addressing the identified gaps and optimising key design aspects, efficient prototypes can be developed, providing clean and healthy air environments in various settings. Continued research and development in these areas are crucial to meet the growing demand for effective air-cleaning technologies and create a positive impact on human health and well-being.

Chapter 3 Methodology and Theoretical Framework

This chapter serves as a foundational exploration of the 'MopFan' system. It clarifies the theoretical principles guiding its development, outlines the research methodology employed, and provides an overview of the system's design and functionality. This scientific exposition underscores the essential interplay between theory, methodology, and system components, with a focus on the rationale behind the selection of performance indicators aligned with research objectives. This introductory overview aims to establish a clear framework for understanding the underpinnings and approach of the study. The research process between chapters are detailed in Table 3.1.

Table 3.1 Research process

Chapter	Title	Focus and Progression
1	Introduction	- Establishes research background. - Highlights the importance of indoor air quality improvement. - Defines thesis scope, novelty, and aims.
2	Literature Review	- Examines purification technologies. - Focuses on photocatalytic methods and their effectiveness. - Identifies research gaps to inform subsequent experiments.
3	Theoretical Framework and Methodology	- Elucidates theoretical foundations and research methodology. - Details system design and functioning. - Links theory, methodology, and system components.
4	Substrate and Fibre Coating	- Investigates substrate and fibre coating techniques. - Provides insight into crucial steps in prototype development.
5	Design and Prototyping (SBRI Project)	- Discusses objectives, iterative design process, and innovation. - Outlines practical implementation of prototypes.
6	Testing and Analysis (SBRI Project)	- Gathers and analyses testing data from SBRI project prototypes.

		- Aims to identify areas for improvement based on results.
7	Introduction to New Project (EPSRC)	- Introduces the EPSRC project, building upon knowledge from Chapter 6. - Sets objectives and scope informed by Chapter 6 insights.
8	Testing and Analysis (EPSRC Project)	- Focuses on testing and analysis of EPSRC project prototypes. - Demonstrates application of lessons from Chapter 6 to enhance prototypes.
9	Economic and Environmental Assessment	- Presents economic and environmental assessment of the MopFan system. - Evaluates cost-effectiveness, energy consumption, and environmental impact.
10	Conclusion and Future Directions	- Summarises research, conclusions, and findings. - Discusses potential future research directions and areas for further investigation.

3.1 Theoretical frameworks underpinning photocatalytic purification

This section explores the theoretical foundations essential to comprehending the core principles and mechanisms behind the development and operation of the photocatalytic purifier under investigation.

3.1.1 Photocatalytic oxidation

Photocatalytic oxidation serves as the fundamental theoretical framework upon which this research is built. This process hinges on the principle of utilising a photocatalyst, often TiO_2, to expedite the oxidation of various organic and inorganic contaminants upon exposure to UV light. The mechanisms and chemical reactions inherent to photocatalytic oxidation are pivotal elements of this study, elucidating how the process effectively leads to the degradation of pollutants present in air or water.

Photocatalytic Oxidation: Forms the foundation for the study's aim to assess the MopFan system's effectiveness in improving indoor air quality (Research Aim) and informs the investigation of the system's purification performance (Objective 1.12.2).

3.1.2 UV light

UV light plays a pivotal role in the photocatalytic purifier's operation. This framework is integral to understanding how the system functions, as it provides the necessary energy to activate the photocatalyst. Delving into the principles of UV light, encompassing its specific wavelengths, intensity, and interactions with the photocatalyst, offers insights into the foundational element responsible for initiating the oxidation process. Detailed discussions on the role of UV light and its optimal conditions are essential for a holistic comprehension of the purifier's functionality.

UV Light: Essential for both the aim of enhancing indoor air quality through the MopFan system (Research Aim) and the system's design and optimisation (Objective 1.12.1). It's also relevant to evaluating the system's impact on indoor air quality (Objective 1.12.3).

3.1.3 Catalyst-coated fibres

The practical implementation of photocatalytic purification systems hinges on the theoretical framework of catalyst-coated fibres. This aspect of the research pertains to the engineering and design of the purifier. The catalyst-coated fibres represent a critical component, as they enable efficient contact between pollutants and the photocatalyst, facilitating the degradation process. An in-depth examination of the methodologies employed for coating these fibres and their inherent advantages, such as durability and pollutant capture efficiency, enhances the practical understanding of the system's design.

Catalyst-Coated fibres: Crucial for designing and optimising the MopFan system (Objective 1.12.1) and indirectly influences the system's impact on indoor air quality (Objective 1.12.3) by ensuring effective pollutant removal.

3.1.4 Increased surface area

The concept of increasing surface area forms the theoretical basis for optimising the photocatalytic purifier's efficiency. Enhancing the surface area available for interactions between the catalyst and pollutants is fundamental to maximising pollutant removal capacity. Within this framework, research investigates various materials, structures, and configurations aimed at achieving increased surface area. This theoretical approach directly informs the design of the purifier and its ability to effectively address environmental pollution challenges.

Incorporating and interweaving these theoretical frameworks throughout the research methodology, materials selection, and performance evaluation criteria ensures a comprehensive understanding of the photocatalytic purifier's efficacy in mitigating environmental pollution issues. These foundational frameworks collectively contribute to the successful development and application of the purification system under scrutiny.

Increased Surface Area: Integral to designing an efficient purification system (Objective 1.12.1) and directly aligns with the research aim to enhance indoor air quality through the MopFan system. It also contributes to the system's effectiveness in improving indoor air quality (Objective 1.12.3).

3.2 Research methodology

The research methodology section serves as the blueprint for the entire study, outlining the systematic approach and techniques employed to address research objectives. It defines how data will be collected, analysed, and interpreted to ensure the validity and reliability of the research findings. This section provides a clear framework for the research process, enabling readers to understand the methods used to investigate the research questions and hypotheses. An outlined methodology is provided in Table 3.2.

3.2.1 Research approach

The research employs a mixed methods approach, combining qualitative and quantitative methods. Qualitative methods are used in the literature review and theoretical foundation chapters to assess existing research and theories. Quantitative methods are evident in chapters involving data collection and analysis to assess prototype performance, economic and environmental assessments, and testing data analysis.

3.2.2 Data collection methods and techniques

The data collection methods and techniques vary throughout the thesis. In the literature review (Chapter 2), qualitative data is collected from existing literature sources, such as academic papers and research articles. In the theoretical foundations and methodology chapter (Chapter 3), qualitative data is collected, and the research methodology is documented. In the substrate and fibre coating processes chapter (Chapter 4), a combination of qualitative and quantitative methods is used, involving experimental techniques for substrate and fibre coating processes. The design and prototyping chapter (Chapter 5) involves qualitative and quantitative data collection methods for documenting the design and prototyping process. In the testing and analysis chapters (Chapters 6 and 8), quantitative data is collected through experiments and measurements to assess prototype performance. The economic and environmental assessment chapter (Chapter 9) uses quantitative data collection and analysis methods to evaluate economic and environmental factors.

3.2.3 Data analysis methods and procedures

The data analysis methods and procedures are as follows. In the literature review (Chapter 2), qualitative content analysis is used to assess and synthesise existing research. In the theoretical foundations and methodology chapter (Chapter 3), qualitative analysis of theoretical frameworks is performed, and the research methodology is documented. In the substrate and fibre coating processes chapter (Chapter 4), a combination of qualitative analysis of experimental results and quantitative analysis for some parameters is conducted. The design and prototyping chapter (Chapter 5) involves qualitative and quantitative data analysis where applicable for documenting the design and prototyping process. In the testing and analysis chapters (Chapters 6 and 8), quantitative data analysis is performed, which includes statistical methods, graphical representation, and comparison to assess prototype performance and identify areas for improvement. In the economic and environmental assessment chapter (Chapter 9), quantitative analysis includes economic and environmental metrics, such as cost-benefit analysis and environmental impact assessment techniques.

Table 3.2 Outline of research methodology implemented

Step	**Methodology**
1.	Approach
	Employ a mixed methods approach.
	Use qualitative methods in literature review and theoretical foundation chapters.
	Apply quantitative methods in data collection and analysis chapters.
2.	Data Collection
	- Qualitative data collection from existing literature in Chapter 2.

	- Qualitative data from theoretical sources in Chapter 3.
	- Combination of qualitative and quantitative methods in Chapter 4.
	- Qualitative and quantitative data collection in Chapter 5.
	- Quantitative data collection through experiments in Chapters 6 and 8.
	- Quantitative data for economic and environmental assessment in Chapter 9.
3.	Data Analysis
	- Qualitative content analysis in Chapter 2.
	- Qualitative analysis of theoretical frameworks in Chapter 3.
	- Combination of qualitative and quantitative analysis in Chapter 4.
	- Qualitative and quantitative data analysis in Chapter 5.
	- Quantitative analysis including statistics in Chapters 6 and 8.
	- Quantitative analysis of economic and environmental metrics in Chapter 9.

3.3 System overview

The development and progression from the SBRI prototypes to the improved EPSRC prototypes represent the research timeline conducted in this thesis.

3.3.1 SBRI prototypes (Pre-prototypes)

In the initial phase of the research, the SBRI prototype MopFan air purification systems were created. These prototypes served as a foundation for the subsequent development of more advanced systems. Three distinct SBRI prototypes were designed:

1. Prototype A (Centrifugal fan): This prototype incorporated an existing centrifugal fan design into the air purification system, focusing on optimising impeller dynamics, retrofitting processes, component selection, and comprehensive testing.
2. Prototype B (Commercial tower fan): Derived from a commercial tower fan, Prototype B underwent thorough design optimisation, with a particular emphasis on brush speed, hub redesign, component integration, material selection, and offering various blade options.

3. Prototype C (Custom-built tower fan): Prototype C was a custom-built tower fan developed from scratch, featuring enhancements for larger-scale performance, including a highly reflective UV-enhanced aluminium casing, CAD-based design, component collaboration, enhanced illumination, and ease of maintenance.

These SBRI prototypes, each with its unique design features and innovations, laid the groundwork for more advanced air purification systems.

3.3.2 EPSRC prototypes

Building upon the knowledge and insights gained from the SBRI prototypes, the research led to the creation of the EPSRC MopFan prototypes, which represent a significant leap forward in indoor air quality and purification technology. These prototypes offer a comprehensive solution to air purification and disinfection.

1. Design and Key Components: Both Prototype "1" and Prototype "2" feature motor-driven fans and tubular structures that guide contaminated air through the purification process. The specialised mop, a key component, plays a central role in air purification.
2. UV Light Sources: The prototypes incorporate UVA and UVC radiation for disinfection purposes, allowing flexibility in tailoring the disinfection process based on specific needs and safety considerations.
3. Functionalities: The primary functionality of the EPSRC MopFan prototypes is to purify and disinfect contaminated air by drawing it into the system, exposing it to UV light, and efficiently removing pollutants.
4. Design Considerations and Principles: Considerations include UV wavelength selection to balance germicidal efficacy and safety, mechanical synchronisation for optimal purification efficiency, and the use of CFD simulations to understand airflow characteristics.

The progression from the SBRI prototypes to the EPSRC prototypes demonstrates an evolution in design sophistication, component integration, and a deeper understanding of air purification principles. The SBRI prototypes laid the foundation, addressing various design challenges and material choices. In contrast, the EPSRC prototypes represent a refined and advanced solution, incorporating mechanical and UV-based technologies to enhance indoor air quality and disinfection. This progression showcases the iterative nature of research and development, where initial prototypes serve as stepping stones towards more effective solutions.

3.4 Prototype design and evaluation overview

Designing a MopFan system involves consideration of various aspects, including the airflow system, photocatalytic oxidation technology, materials and safety considerations. The process begins by determining the specific requirements of the MopFan, such as airflow rate, purification efficiency, noise level, size, and power consumption. Next, an efficient airflow system is developed, taking into account factors like fan size, blade design, and motor specifications. The integration of PCO technology using TiO_2 coated surfaces is essential for effective air purification, requiring careful consideration of the optimal configuration and placement of TiO_2-coated fibres or surfaces. Selection of suitable UV lights emitting the necessary frequencies and intensity is crucial. Material selection is important for durability, lightweight construction, and compatibility with the PCO process, ensuring a safe and effective design. Attention is also given to creating an appealing design that seamlessly blends into different indoor environments.

Prototyping and testing are carried out to evaluate functionality, airflow performance, purification efficiency, and noise levels, leading to iterative refinements of the design. Table 3.3 states the specific requirements/specifications that guide the development and evaluation of MopFan prototypes.

Table 3.3 Prototype functions and evaluation strategies.

Prototype functions and evaluation strategies	**Description**
Utilise PCO technology	The method involves irradiating TiO_2 surfaces with UV lights to generate hydroxyl radicals, which disintegrate organic compounds and contaminants in the air streams through reactions with oxygen.
Design MopFan as a purification system	The MopFan system is designed as a purifier with TiO_2-coated fibres that move the air while efficiently removing pollutants.
Optimise UV frequencies and intensity	To optimise the UV frequencies and intensity to ensure effective photocatalytic oxidation and sterilisation of air contaminants.

Enhance photocatalytic oxidation by doping TiO_2 with metals	Enhance the photocatalytic oxidation process by doping the TiO_2 coating with metals, thereby improving the system's effectiveness in removing pollutants from the air.
Design, optimise, and fabricate MopFan prototypes	Designing, optimising, and fabricating prototypes of the MopFan system, including 3D-printed components.
Evaluate effectiveness in removing pollutants and allergens	Evaluate the effectiveness of the MopFan system in removing various pollutants and allergens from indoor air, ensuring its efficiency in purifying indoor environments.
Enable efficient and silent pollutant and allergen removal	The MopFan system aims to provide efficient and nearly silent removal of pollutants and allergens from indoor environments, making it suitable for various applications.
System Requirements	Efficient, low noise, and effective at removing VOCs.
TiO_2 Coating Requirement	Durable coating on fibres and strips with no risk of creating airborne particles.
Evaluation Partner	University of Nottingham Medicine and Health Sciences Department (Assessing MopFan's ability to deactivate the SARS-CoV-2 virus).

3.5 Comparing static and rotational MopFan systems

In this research, two distinct mop arrangements are being examined: the Rotational MopFan system and the Static MopFan system. These arrangements differ in their design and operation, each offering unique approaches to air purification.

The Rotational MopFan system utilises a motor-driven mop arrangement. Within a casing, the mop fibres are driven by the motor and rotate, functioning similar to fan blades. The rotation of the mop fibres creates a swirling and dynamic airflow within the system, effectively capturing and removing airborne particles and pollutants. This rotational movement enhances the system's ability to circulate and purify the air, promoting improved indoor air quality. On the other hand, the Static MopFan system features a static mop housed within a casing. In this arrangement, an axial fan is employed to pump the air over the stationary mop fibres. The fan generates a directed and consistent airflow that passes over the static mop fibres, facilitating efficient filtration and purification of the air. The static mop fibres effectively trap and retain contaminants, further enhancing the system's ability to deliver clean and purified air.

By investigating these two different mop arrangements, this study aims to compare their performance, efficiency, and overall effectiveness in air purification. Understanding the distinct characteristics and functionalities of each arrangement will contribute to advancements in air purification technologies.

3.6 Performance indicators and rationale

In this section, an evaluation of the MopFan prototypes is outlined, employing precise performance indicators to assess their air purification capabilities, precision in prototyping, consistency in performance, and their potential to mitigate contaminants in indoor environments. These indicators provide a detailed foundation for evaluating the performance of the prototypes.

3.6.1 Prototype Air Purification Efficiency (PAPE)

1. Measurement: PAPE is determined by conducting controlled air quality tests with each MopFan prototype in a controlled environment.
2. Metric: The indicator quantifies the reduction in concentration of specific airborne pollutants (e.g., particulate matter, volatile organic compounds) before and after the operation of each prototype.
3. Unit: Reduction in pollutant concentration is expressed as a percentage, reflecting the degree of purification achieved.
4. Testing Procedure: Air samples are collected before and after prototype operation, and pollutant levels are measured using specialised instruments like particle counters and gas analysers.

3.6.2 Volatile Organic Compound Mitigation (VOCM)

1. Measurement: VOCM is evaluated by introducing a known concentration of VOCs into the air during controlled experiments.
2. Metric: The indicator quantifies the reduction in VOC concentration in the air samples, measured in micrograms per cubic meter ($\mu g/m^3$), before and after the operation of each MopFan prototype.
3. Unit: Reduction in VOC concentration is expressed as a percentage reduction, indicating the efficacy of VOC removal.

4. Testing Procedure: VOCs are introduced into the air, and air samples are collected before and after prototype operation. The concentration of VOCs is determined through pollutant monitor.

3.6.3 Formaldehyde Mitigation (FM)

1. Measurement: FM assesses the ability of each MopFan prototype to reduce HCHO concentration in controlled experiments.
2. Metric: The indicator quantifies the reduction in HCHO concentration in the air samples, measured in μg/m³, before and after the operation of each prototype.
3. Unit: Reduction in HCHO concentration is expressed as a percentage reduction, reflecting the prototype's effectiveness in formaldehyde removal.
4. Testing Procedure: HCHO is introduced into the air, and air samples are collected before and after prototype operation. The concentration of formaldehyde is determined through a pollutant monitor.

3.6.4. Particulate Matter Mitigation (PMM)

1. Measurement: PMM assesses the ability of each MopFan prototype to reduce particulate matter concentration (e.g., PM2.5 and PM10) in controlled experiments.
2. Metric: The indicator quantifies the reduction in particulate matter concentration in the air samples, measured in μg/m³, before and after the operation of each prototype.
3. Unit: Reduction in particulate matter concentration is expressed as a percentage reduction, indicating the prototype's effectiveness in mitigating airborne particles.
4. Testing Procedure: Particulate matter is introduced into the air, and air samples are collected before and after prototype operation. The concentration of particulate matter is determined through particle counters and size-specific analysis to measure PM2.5 and PM10 levels.

3.7 Integration of theory, methodology and system

The chosen theoretical frameworks play a significant role in influencing the research methodology and the selection of system components for the MopFan. The following sections detail how these theories inform various aspects of the research

3.7 Theoretical Frameworks in Relation to Research Methodology and System Components

Theoretical frameworks serve as the foundational basis upon which the research methodology and the selection of critical system components for the MopFan indoor air purification system are built. These frameworks guide the researchers' choices of materials, methodologies, and components, all aimed at achieving the primary objective of enhancing indoor air quality.

1. Photocatalytic Oxidation: The theoretical framework of photocatalytic oxidation stands as a cornerstone for the research, influencing both the methodology and the selection of crucial system components. It informs the researchers' choice of pollutants for testing and guides the use of a photocatalyst, such as TiO_2, as well as the measurement of pollutant degradation rates. Furthermore, it dictates the integration of the photocatalyst into the system to enable effective pollutant degradation. This theoretical framework is fundamental to the entire research endeavour and the core of the MopFan system's design.

2. UV Light: A comprehensive understanding of UV light principles informs not only the research methodology but also the design of essential system components. Specific aspects of UV light, such as wavelength, intensity, and interaction requirements, guide the researchers in selecting UV light sources and configuring UV exposure chambers within the MopFan system. UV light sources become integral components of the system, as they are crucial for activating the photocatalyst and driving pollutant degradation.

3. Catalyst-Coated Fibres: The theoretical framework concerning catalyst-coated fibres plays a pivotal role in shaping both the research methodology and the selection of system components. This theory influences the choice of materials for the fibres used in the system. To ensure effective pollutant degradation, these fibres must be coated with the selected photocatalyst, making them a key component of the purification mechanism. Theoretical understanding informs the researchers' decisions regarding materials and coating techniques, ensuring optimal performance.

4. Increased Surface Area: The concept of increasing surface area remains a guiding principle that directly influences the research methodology and the design of system components. It prompts the researchers to explore materials and design elements that maximize the contact area between the catalyst and pollutants. This theoretical framework directly informs the engineering aspects of the purification system, guiding the choice of components and materials used in its construction.

In the context of system components, these theoretical frameworks continue to shape the researchers' decisions regarding their selection and integration into the MopFan indoor air purification system. They ensure that the research methodology and system design align seamlessly with the overarching goal of enhancing indoor air quality through innovative and effective means.

3.7.2 Interconnectivity between theory, methodology, and system design

The interconnectivity between theory, methodology, and system design is evident throughout the research process:

1. The theoretical frameworks (e.g., photocatalytic oxidation, UV light) inform the research methodology, guiding how experiments are designed, pollutants are chosen, and data is collected.
2. The research methodology, in turn, shapes the selection of product/system components. It specifies the parameters and conditions under which components like photocatalysts, UV light sources, and catalyst-coated fibres are tested and integrated into the MopFan system.
3. The system design is influenced by both the theoretical understanding and the research methodology. It takes into account the principles of photocatalytic purification and UV exposure, incorporates catalyst-coated fibres, and maximises surface area to optimise pollutant removal.
4. Performance indicators, such as PAPE, VOCM, FM, and PMM, are established based on the theoretical foundations and are integral to the evaluation of the MopFan system's effectiveness. These indicators are directly connected to the theoretical concepts and are used to assess the real-world performance of the system, closing the loop between theory, methodology, and system design.

In summary, the chosen theoretical frameworks not only guide the research methodology but also inform the selection and integration of system components. The interplay between theory, methodology, and design is essential for the successful development and evaluation of MopFan prototypes for indoor air purification.

3.8 Summary of methodology and theoretical framework

This chapter serves as a critical cornerstone in understanding the research approach and the foundational principles guiding the investigation of the 'MopFan' system. This chapter is not just a summary of research methodology but provides a key framework for the study. Here's a conclusion drawn from this chapter:

In conclusion, Chapter 3 has laid a robust foundation for the research journey into the 'MopFan' system. It has illuminated the theoretical underpinnings that drive the operation of photocatalytic purification and has highlighted the interconnectedness of theory, methodology, and system design. The chosen theoretical frameworks, such as photocatalytic oxidation, UV light, catalyst-coated fibres, and increased surface area, have directed the research methodology, shaping experiments and data collection methods.

The research approach, encompassing a mixed methods strategy, is methodically delineated, ensuring the validity and reliability of the study's findings. The systematic blueprint for data collection and analysis, detailed in this chapter, will enable readers to follow the logical progression of the research process.

Moreover, the chapter provides a comprehensive overview of the 'MopFan' system's evolution, from SBRI prototypes to advanced EPSRC prototypes. This progression demonstrates the iterative nature of research and development, where initial designs serve as stepping stones toward more effective solutions.

The introduction of performance indicators, such as PAPE, VOCM, FM, and PMM, underscores the commitment to rigorous evaluation and empirical testing of the 'MopFan' system's capabilities. These indicators offer a precise foundation for assessing air purification efficiency and pollutant removal in indoor environments.

Ultimately, this chapter establishes the groundwork for subsequent chapters, where the 'MopFan' system's efficacy in improving indoor air quality will be rigorously assessed. It underscores the importance of theory, methodology, and systematic evaluation in advancing indoor air purification technologies and underscores the holistic and scientific approach underpinning this research endeavour.

Chapter 4 Preparation and Coating of Fibre Substrate for Photocatalytic Oxidation

This chapter explores an essential component of MopFan, the filter substrate. This chapter focuses on the crucial role of substrate coating in achieving effective air purification. Additionally, the chapter highlights the significance of fibre coating, particularly the use of TiO_2 coating, in enhancing the photocatalytic oxidation process for efficient removal of pollutants and allergens from the air.

4.1 Fibre selection

From the research on fibres and plates selection, material coating durability tests, and anti-virus performance tests, significant findings have emerged. Specifically, the observations have shown that the TiO_2 coating solution, composed of TiO_2, sodium alginate, and water, effectively coats fibres. Furthermore, the coated copper fibres have demonstrated efficiency in removing VOCs and particulate pollutants. This highlights the potential effectiveness of the TiO_2 coating solution in enhancing the fibre's capabilities to negate environmental pollutants.

A brush manufacturing company was approached to provide samples of various bristle materials capable of meeting the desired physical characteristics for a circular brush. The materials supplied by the company included crimpled brass, natural synthetic, organic coco, organic tampico, crimpled steel, hand-sanded plastic, and pre-sanded plastic. To ensure a fair and valid comparison, a uniform bristle diameter of 0.4 mm was selected for all materials. A selection process was conducted to evaluate and choose the most suitable bristle materials from the options provided.

To prepare the fibres for further testing, their surfaces needed to be smoothed. The fibres underwent sanding using a sandblaster to create a suitable texture for coating. A solution consisting of water and 2% TiO_2 powder was prepared for the bristle coating process. In order to enhance the adherence of the coating, 3% sodium alginate (SA) powder was incorporated into the solution. The solution was thoroughly stirred and de-bubbled, after which the fibres were coated with it. Microscopic examinations were conducted to verify the effectiveness of SA in promoting improved adhesion between the coating and the bristle fibres. Additionally, biological tests were carried out to evaluate the antiviral properties of the coated fibres. Table

4.1 displays the fibre/sheet types tested, as these were to be used in the construction of prototypes.

Table 4.1 Fibre/sheet types utilised in the prototypes

Material	**Type**	**Dimensions (mm)**
Copper	Fibre	0.1mm dia.
	Fibre	0.3mm dia.
	Fibre	0.4mm dia.
	Fibre	0.5mm dia.
Brass	Fibre	0.4mm dia.
	Fibre	0.5mm dia.
	Fibre	1.1mm dia.
Steel	Fibre	0.4mm dia.
Plastic	Fibre	0.4mm dia.
Coco	Fibre	0.4mm dia.
Aluminium	Sheet	0.4mm thk.
Copper	Sheet	0.4mm thk.

4.2 Pre-treatment of individual fibres

Prior to the production of prototypes, individual fibres were coated and examined for their characteristics. Surface preparation is an important step in coating application to ensure good adhesion between the coating and the substrate. Sanding papers were used in this study to roughen the smooth surface of the fibres to improve the adhesion of the coating. The friction direction was shown in Figure 4.1 which indicates the direction in which the sanding should be performed.

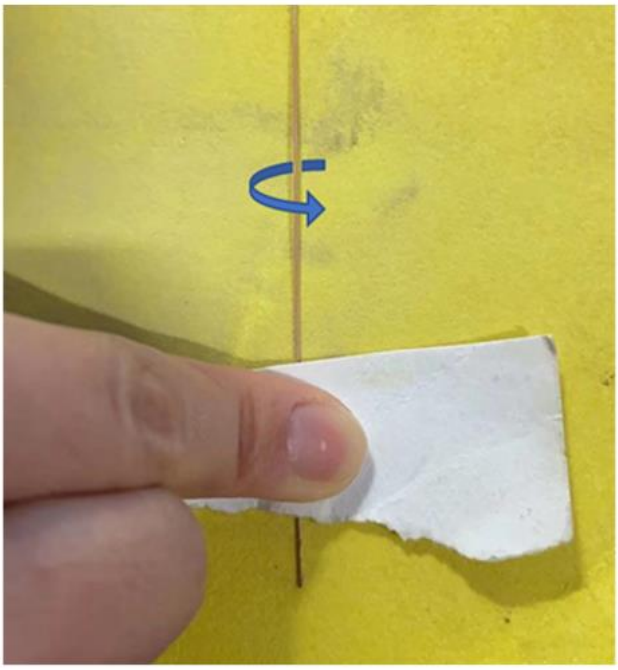


Figure 4.1 Image of the horizontal sanding of a fibre for individual analysis

The following states the reasons for sanding individual fibres horizontally as opposed to in a sandblasting chamber:

4.2.1 Consistent finish

Horizontal sanding ensures a uniform and consistent surface appearance, especially with composite materials like fibre. It promotes an even distribution of the sanding process for a more balanced outcome.

4.2.2 Damage prevention

Horizontal sanding minimises the risk of excessive fibre damage or deep grooves. It allows for controlled sanding, preventing uneven wear or excessive material removal in specific areas.

4.2.3 Preserving structural integrity

By cutting across the fibres instead of directly into them, horizontal sanding reduces the chances of fraying or splintering. This preserves the fibres' structural integrity during the sanding process.

4.2.4 Enhanced visual inspection

Sanding horizontally provides better visibility for identifying imperfections like scratches, marks, or unevenness. It facilitates effective surface inspection, enabling prompt identification and resolution of flaws.

4.2.5 Efficient material removal

Horizontal sanding efficiently removes material and creates a smoother surface. It aids in levelling out high spots or irregularities, resulting in a more even and refined finish.

4.3 Preparation of coating solution

TiO_2 powder and sodium alginate are the primary constituents of the coating solution, working together to provide a uniform, durable and evenly distributed coating. The procedure to prepare this coating solution involves several steps, ensuring the proper incorporation of these components and the formation of a homogeneous and effective mixture. Table 4.2 presents a summary of the coating solution preparation.

Table 4.2 Preparation of coating solution

Step	Description	Ingredients/Actions
1	Mixing water and TiO_2 powder	- Clean container is prepared.
		- 200 mL of water is measured and poured into the container.
		- The appropriate amount of TiO_2 powder is added to the water to achieve a 5% concentration.
		- A planetary mixer is employed to thoroughly blend the water and TiO_2 powder, ensuring the particles are well dispersed and the mixture is uniform.
2	Adding sodium alginate powder	- The solution obtained from Step 1 is transferred to a clean container.
		- The desired concentration of sodium alginate (3%) is carefully measured.
		- The sodium alginate powder is gradually introduced into the solution while stirring continuously. This process facilitates the

		dissolution and dispersion of the sodium alginate particles, resulting in a homogeneous mixture.
3	Allowing the solution to settle for debubbling	- The solution obtained from Step 2 is transferred to a suitable container.
		- The container is placed in an indoor environment at a consistent temperature.
		- The solution is allowed to settle for approximately 8 hours to facilitate the debubbling process. This settling time enables the solution to stabilise and allows any air bubbles present to rise and dissipate.
4	Coating the fibres with the solution	- The debubbled solution obtained from Step 3 is used.
		- The fibres intended for coating are immersed or otherwise treated with the solution.
		- The coating process can involve techniques such as spraying, dipping, or brushing, depending on the specific requirements of the fibres and desired coating thickness.

To achieve a homogeneous mixture, a planetary mixer, as shown in Figure 4.2, was employed in the process. A planetary mixer is a versatile and efficient mixing device commonly employed in various industries. In this particular context, it was used to blend the water and TiO_2 powder, ensuring that the particles are well dispersed, and the mixture achieves uniformity. The planetary mixer consists of a mixing bowl or container and a mixing mechanism.

To begin the blending process, the appropriate amount of TiO_2 powder is carefully measured and added to the water in the mixing bowl. The planetary mixer is then activated, causing the mixing paddle to rotate on its own axis and revolve around the bowl simultaneously. This motion creates a shearing force that disperses the TiO_2 particles throughout the water. As the mixing paddle rotates, it continually lifts and folds the mixture, ensuring that the TiO_2 powder is evenly distributed and incorporated into the water. The combination of rotation and revolution creates a dynamic and consistent blending action that helps break up any agglomerates or clumps, promoting uniform dispersion of the TiO_2 particles.

Figure 4.2 Images of a magnetic stirrer and planetary mixer

4.4 Coating process of individual fibres for analysis

Coating the fibres involves a series of steps to ensure effective and uniform coverage of the desired coating solution. Table 4.3 lists the steps involved in coating the fibres.

Table 4.3 Individual fibre coating process

Step	Description	Ingredients/Actions
1	Dip cotton swab or brush into the coating solution	- Coating solution
		- Cotton swab or brush
2	Apply coating solution onto the fibre	- fibre to be coated
		- Coating solution
3	Allow the coating to dry for a few minutes	- Drying time
4	Repeat Steps 1 to 3 for multiple coats	- Coating solution
		- fibre to be coated
5	Use a hairdryer to dry the fibre completely after the final coat	- Hairdryer

When it comes to the application of coatings, the number of coating layers employed can be flexible and determined based on the desired thickness of the coating. This flexibility allows for customisation, enabling the achievement of specific objectives and performance requirements. To ensure a smooth and flawless coating, it is vital to adhere to a fundamental principle: each layer must be allowed to dry thoroughly before applying the subsequent layer. This practice is crucial to prevent issues such as clumping or unevenness, which can negatively impact the final appearance and functionality of the coating. By allowing each layer to dry completely, the coating material can properly settle and adhere to the underlying surface. This not only promotes better adhesion but also minimises the risk of the layers merging or forming undesirable irregularities. Moreover, ensuring adequate drying time between layers enhances the overall durability and longevity of the coating. It enables proper curing and chemical reactions within the coating, contributing to its ability to withstand environmental factors, abrasion, and other forms of wear and tear.

4.5 Fibre sanding for prototypes

The process of sanding the fibres on the brush involves a series of steps that ensure proper preparation before coating. These steps include utilising a 220L sand blast chamber, as shown in Figure 4.3, using fine glass grit measuring 0.2-0.5mm, and applying the grit at 80 psi.

Figure 4.3 Image of a 220L sand blasting chamber

Once the sanding process is complete, the sanded fibres will be coated with a solution containing TiO_2. Table 4.4 lists a step-by-step summary of fibre sanding for the prototypes constructed.

Table 4.4 Fibre sanding method for use in prototypes

Description	**Ingredients/Actions**
Sanding Preparation	- The brush containing the fibres is placed inside a 220L sand blast chamber. - Safety measures such as gloves, goggles, and a dust collection system are used to protect the operator and maintain a clean working environment.
Selection of Glass Grit	- Fine glass grit with a particle size range of 0.2-0.5mm is chosen for the sanding process. - This specific particle size ensures effective sanding without causing excessive damage to the fibres.
Sand Blasting Procedure	- The selected glass grit is loaded into the sand blast chamber. - The sand blast chamber is pressurised to 80 psi, creating a controlled and forceful stream of grit particles. - The operator directs the stream of grit towards the brush, focusing on the fibres to be sanded. - The sanding process involves moving the sand blast nozzle in a back-and-forth motion over the fibres, ensuring even coverage and removing any surface imperfections. - The force of the grit particles hitting the fibres gently removes any unwanted material, roughness, or inconsistencies, creating a smoother and more even surface.

4.6 Microstructure and morphology of the coated materials

In this particular investigation, the utilisation of the KERN OBL 135C825 digital compound microscope, as shown in Figure 4.4, examined the internal arrangement of the coated fibres. To achieve this, a methodical approach that involved the careful preparation of samples containing the coated fibres. These prepared samples were then mounted onto microscope slides, facilitating their convenient observation under the microscope. By operating the digital compound microscope, detailed images of the samples were captured at varying levels of magnification. This enabled a comprehensive analysis of the intricate structure and morphology of the coated fibres, yielding insights. The choice to employ the digital compound microscope was particularly significant in this study, as it offered an avenue to obtain a thorough comprehension of the microstructural attributes exhibited by the coated fibres. The ability to scrutinise the samples at high magnification levels proved to be immensely advantageous. It allowed them to identify and examine any imperfections, defects, or irregularities present in the coating applied to the fibres. Furthermore, the distribution patterns and thickness of the coating layer could be effectively investigated, offering crucial details regarding its uniformity and performance characteristics. These findings were of utmost importance in assessing the efficacy of the coating process. Moreover, the comprehensive understanding gained through this study holds considerable practical significance. The information acquired from the high-resolution observations and analyses is instrumental in evaluating the overall effectiveness of the coating process.

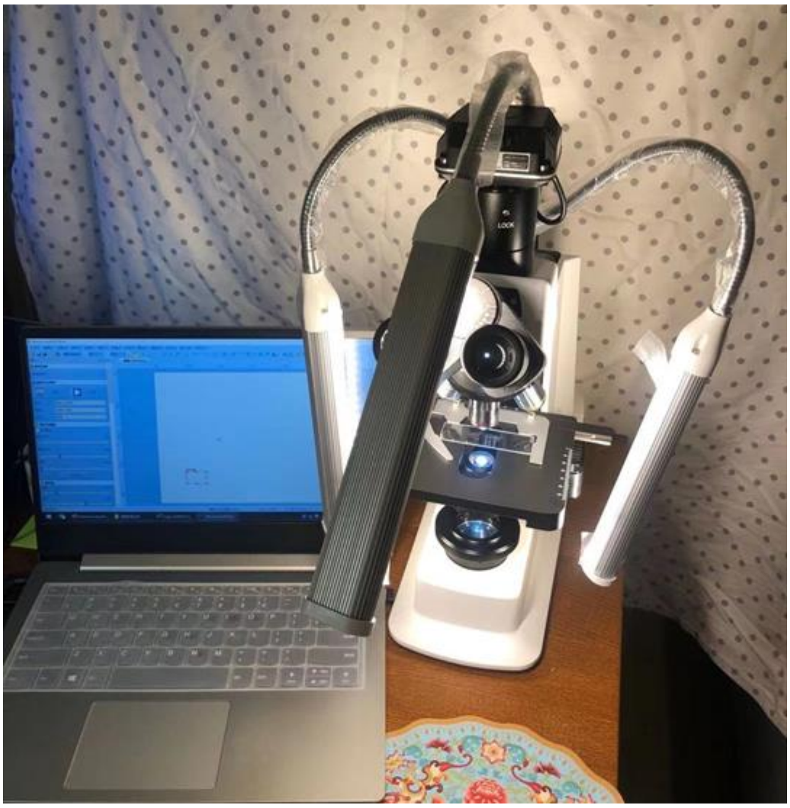


Figure 4.4 Image of a KERN OBL 135C825 digital compound microscope

4.6.1 Coating inspection results

The experimental results indicated that the coating solution employed in the study was effective in coating the various types of fibres that were chosen for investigation. The images presented in Figure 4.5 demonstrated that the thin fibres were coated thoroughly, and the coating exhibited strong adhesion to the surface of these fibres. This observation was further validated by conducting a wiping test on the coated samples using a black cloth, which revealed that the coating remained intact and did not easily come off. However, when it came to the thick plastic fibre with a diameter of 1.1 mm, the coating did not adhere well, and it exhibited poor stability during the drying process. Consequently, the coating layer on the thick plastic fibre easily fell off after it had dried. This issue was visually evident from the appearance of a small crack on the surface of the thick plastic fibre, as illustrated in Figure 4.5(e). The presence of this crack provided additional support to the observation that the coating did not firmly adhere to the surface of the thick plastic fibre.

In the case of the plastic fibres, Figure 4.5(d) and 4.5(e) exhibited the presence of cracks and gaps on the surface of the coated fibres. These imperfections can be attributed to the inherent low surface energy of plastic fibres. The low surface energy creates a challenge for the coating to establish strong adhesion and uniform coverage on the surface of the plastic fibres. Consequently, the coating may form cracks or gaps, compromising its integrity and leading to uneven coverage. Furthermore, the cracks and gaps observed on the surface of the coated plastic fibres may also be a result of the shrinkage of the coating material during the drying process. As the coating solution dries, it undergoes a reduction in volume, which can cause the formation of cracks and gaps in the coating layer. This phenomenon is more pronounced on materials with higher shrinkage tendencies, such as the plastic fibres in this study. These findings suggest that the thickness of the fibre plays a significant role in the effectiveness of the coating solution. Thinner fibres are easier to coat, and the coating adheres well, while thicker fibres required more attention and possibly a different coating solution to ensure effective coating. These findings could have implications for the use of coated fibres in various applications, such as in the development of textiles or composites. Further research may be necessary to explore the use of different coating solutions and methods for different thicknesses of fibre.

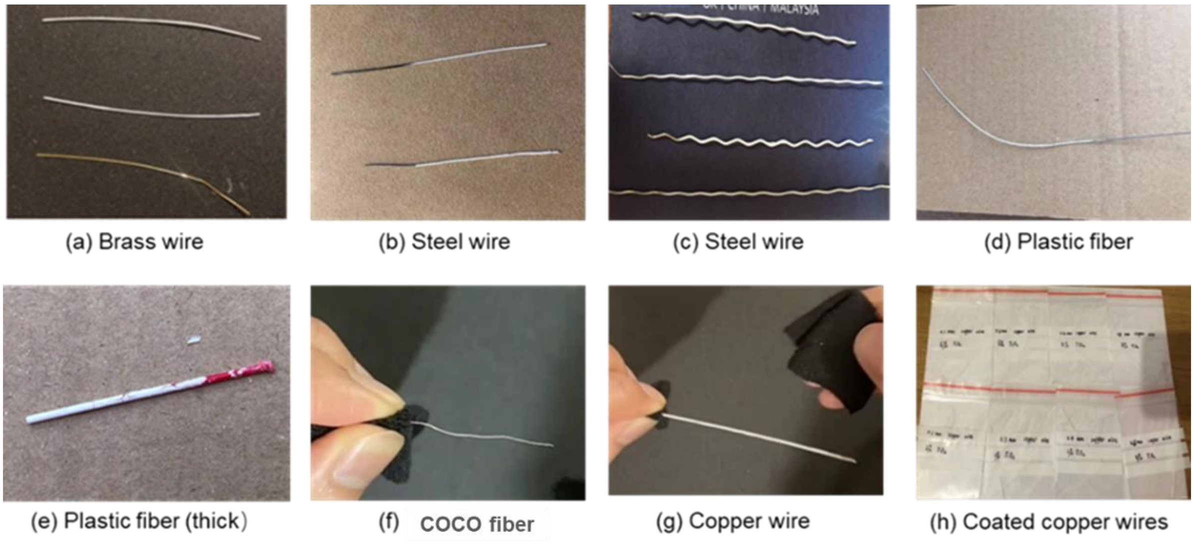


Figure 4.5 Images of coated fibre types

In the case of the aluminium sheet, the coating layer demonstrates even distribution and strong adhesion to the surface. However, in Figure 4.6(a), the coating on the aluminium sheet is applied uniformly across its entire surface, ensuring consistent coverage without any noticeable gaps or areas of inadequate coating.

In contrast, when considering the copper sheet coating, the situation differs. Figure 4.6(b) illustrating this coating on the copper sheet is not uniform and exhibits partial coverage. This suggests that the application of the coating on the copper sheet was not as successful in achieving complete and consistent coverage as it was with the aluminium sheet.

To achieve a more even coating on the copper sheet, secondary layers were likely required. The need for additional coating layers could be attributed to factors such as uneven surface preparation or sanding of the copper sheet prior to coating application. If the copper sheet's surface was not sanded evenly or had irregularities, it could have affected the adhesion and distribution of the coating, leading to incomplete coverage in certain areas.

Comparatively, the aluminium sheet may have had a more uniform and even surface texture due to a more thorough and consistent sanding process. As a result, the coating applied to the aluminium sheet adhered well and spread evenly across its surface, without the need for additional layers.

(a) Coated aluminum sheet (b) Coated copper sheet

Figure 4.6 Image of coated sheet types

In addition, Figure 4.7 showcases three additional brush components that were intended for use in subsequent prototypes. These components underwent a vigorous sanding process prior to the coating application in order to enhance their porosity. The purpose of this extensive sanding was to create a textured surface that would facilitate better adhesion of the coating material.

The first component depicted in Figure 4.7(a) is the coated copper brush. After the vigorous sanding, the coating solution was applied to the copper brush, resulting in an even and uniform coating across its surface. The coating adhered firmly to the copper brush, demonstrating good adhesion without any signs of flaking or detachment. This observation indicates that the sanding process effectively prepared the copper brush for optimal coating performance.

The second component shown in Figure 4.7(b) is the coated plastic brush. Similar to the copper brush, the plastic brush underwent thorough sanding to increase its porosity. Using a sandblaster instead of individual sanding resulted in the coating application on the plastic brush yielding a smooth and evenly coated surface, exhibiting consistent coverage without any signs of flaking or irregularities. This outcome suggests that the sanding process effectively enhanced the surface texture of the plastic brush, enabling the coating to adhere uniformly. Lastly, Figure 4.7(c) displays the coated plastic brush strips. These strips were also subjected to vigorous sanding to enhance their porosity and promote better coating adhesion. As with the previous components, the coating on the plastic brush strips was applied evenly, resulting in a uniform coating without any flaking or detachment. The sanding process effectively prepared the plastic brush strips, allowing for successful coating application and adherence.

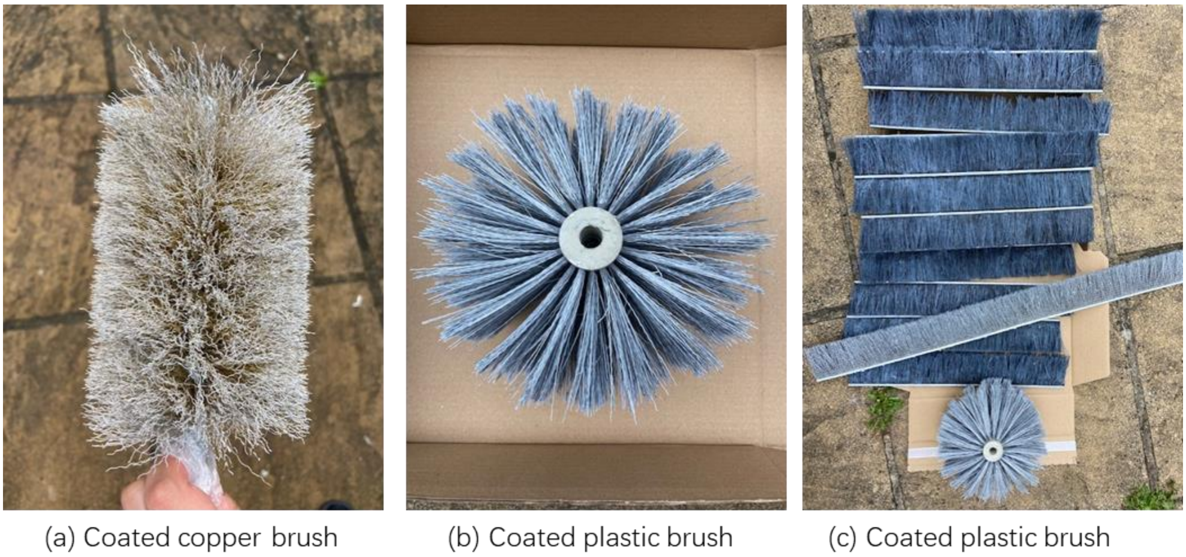


Figure 4.7 Images of coated brush types

The coating layer on the copper wires exhibits uniformity and strong adhesion to the wire's surface, as depicted in Figure 4.8(a) and 4.8(b). In these figures, the coating appears as a continuous and consistent layer that encapsulates the copper wire. This uniformity suggests that the coating solution was applied evenly, ensuring complete coverage without any visible gaps or inconsistencies. Upon closer examination, it is evident that the coated copper wire possesses a rougher surface texture in comparison to the uncoated wire.

This roughness can be attributed to the inclusion of TiO_2 nanoparticles within the coating solution. When the coating solution is applied to the copper wire, the TiO_2 nanoparticles become incorporated into the coating layer. As a result, they contribute to the formation of surface irregularities or roughness, which can be observed both visually and under microscopic analysis. The presence of TiO_2 nanoparticles in the coating solution plays a significant role in creating the rough surface texture of the coated copper wire. These nanoparticles have distinct physical properties that affect the overall characteristics of the coating. They can contribute to the formation of nanoscale features on the surface, leading to the roughness observed. The rough surface texture of the coated copper wire can have various implications. It may enhance certain properties, such as increased surface area, which can be beneficial in applications where enhanced adhesion or improved conductivity is desired. Additionally, the roughness can also influence the wire's interactions with its surroundings, such as altering its optical properties or providing a textured surface for further functionalisation.

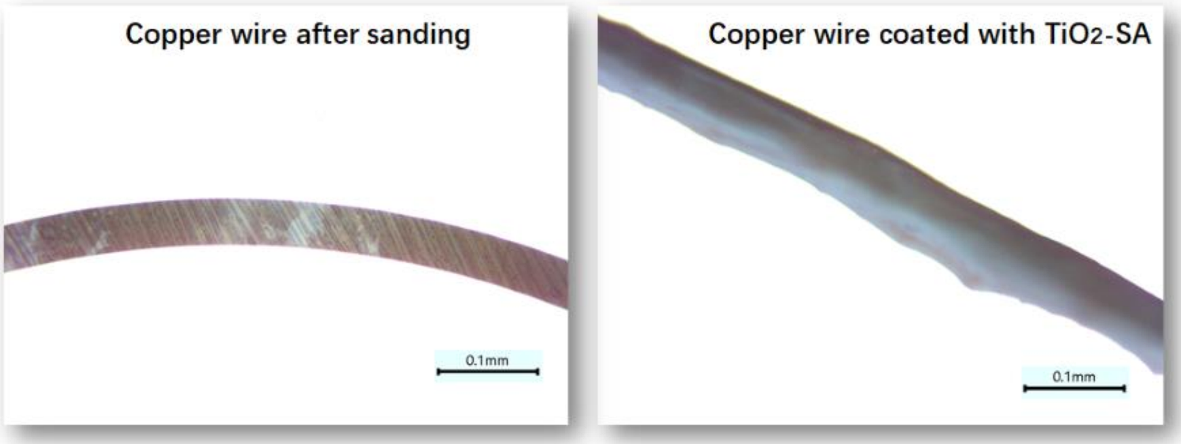


Figure 4.8 Microscopic images of copper wire before and after coating

The analysis of the microstructure provides insights into the effectiveness of the coating process in applying a layer of TiO_2 nanoparticles onto the surface of the fibres and sheet. It should be noted that the adhesion of the coating may vary depending on the specific material being used. The results obtained from the coating tests on thin fibres, brushes, and sheets have sparked further interest among researchers, prompting them to explore the applicability of the coating process to other materials. For this study, aluminium/copper sheets, copper brushes, and plastic brushes were carefully selected as representative examples.

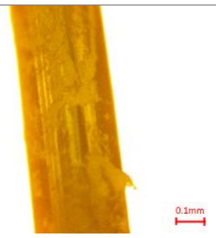
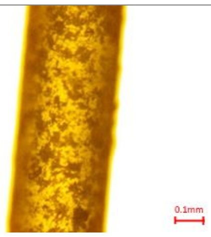
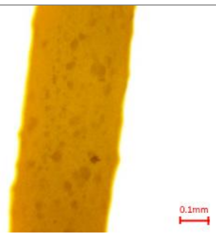
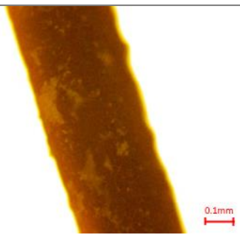
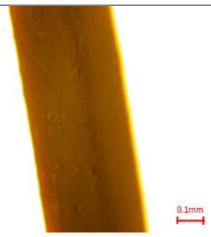
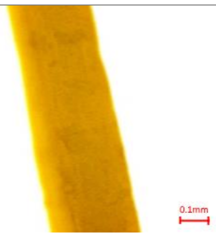
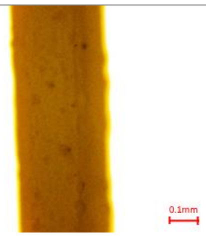
The outcomes of these observations demonstrate the success of the coating process on these materials, with the coatings exhibiting excellent adhesion to their respective surfaces. This positive outcome holds great promise, as it suggests that the coating process can be extended to a broader range of materials, thereby opening up new avenues for diverse applications.

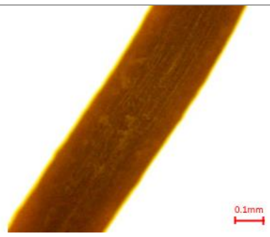
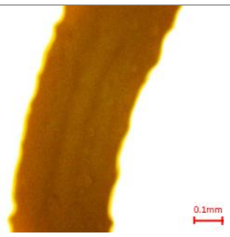
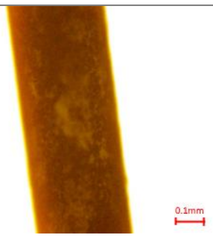
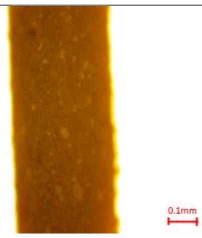
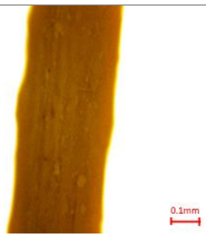
Moreover, this research contributes to the advancement of innovative coating methods that enhance the durability and functionality of various materials. By enabling the coating of different surfaces and materials, this process facilitates the creation of robust and long-lasting products capable of withstanding harsh environments and rigorous usage.

4.6.2 Microstructure of coating

Table 4.5 presents the observed results, highlighting the impact of SA on the appearance and coverage of the fibres with the TiO_2 solution. Fibres coated with SA exhibited a more uniform appearance, with fewer gaps left uncovered by the TiO_2 coating solution. Notably, in cases such as crimpled brass, it was observed that fibres without SA exhibited instances where the TiO_2 coating was flaking off from the bristle surface. These findings emphasise the significance of using SA in promoting improved adhesion and uniform coverage of the TiO_2 coating on the bristle fibres. The microscopic examinations and biological tests further corroborated the effectiveness of SA in enhancing the performance and antiviral properties of the coated fibres. These observations provide insights for selecting the appropriate bristle materials and optimising the coating process to ensure superior brush performance and durability.

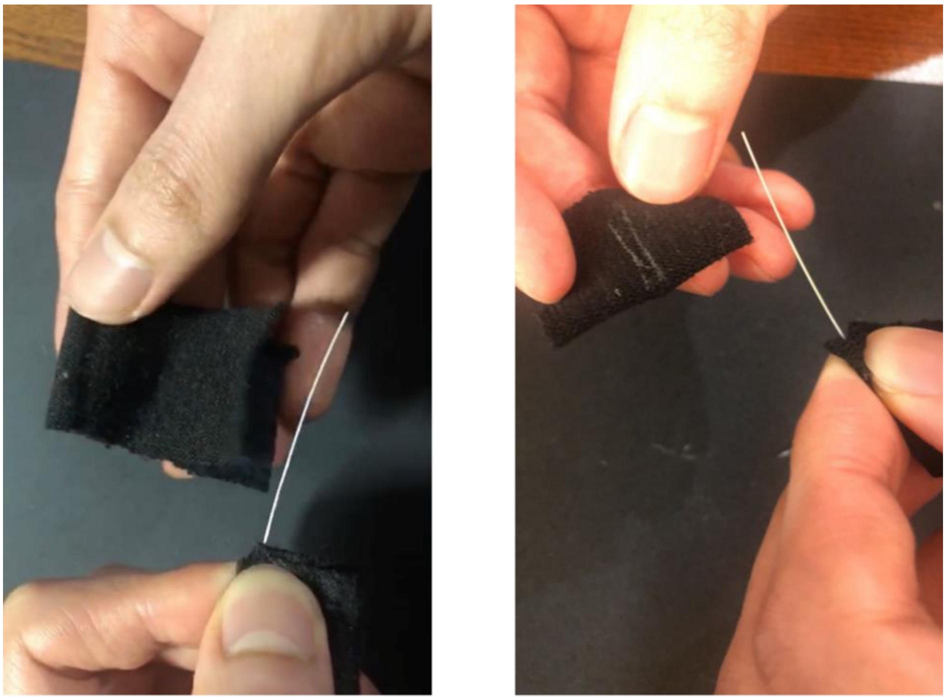
Table 4.5 Fibre comparison with and without sodium alginate

Material	**TiO_2 solution (no SA)**	**TiO_2 solution (with SA)**
Crimpled brass		
Natural synthetic		
Organic Coco		
Organic Tampico		

Crimpled steel		
Hand-sanded plastic		
Pre sanded plastic		

4.7 Testing of fibre coating durability

The successful attachment of coatings onto thin fibres, brushes, and sheets is a crucial step in many industrial and scientific applications. In this study, the adherence of the coating to these surfaces was investigated, as shown in Figure 4.9. After the drying process, the coating was observed to be completely attached to the surface of the materials. To test the durability of the coating, wiping tests were performed using a black cloth. Two groups of experiments were carried out simultaneously, one using TiO_2-SA solution and the other using a pure TiO_2-water solution as the control group. The wiping tests were recorded with a camera, and the results were presented in photos, as shown in Figure 4.9. The photos clearly show that no white powder was left on the black cloth when using the TiO_2-SA solution. In contrast, a significant amount of white powder was left on the black cloth when wiping the fibre coated with the TiO_2-water solution, as shown in Figure 4.9(b). This suggests that the TiO_2-SA solution has better durability compared to the pure TiO_2-water solution. The findings of this study are significant as they demonstrate the potential of using TiO_2-SA solution for coating thin fibres, brushes, and sheets. The high adherence and durability of the coating can lead to better performance and longer lifetimes for various applications, such as in the field of nanotechnology.



(a) Fiber with TiO_2-SA solution (b) Fiber with TiO_2-water solution

Figure 4.9 Images of durability observation of fibres with and without sodium alginate

4.8 Biological test

An extensive investigation was undertaken to compare the efficiency of various coated fibres in eliminating viruses. For this purpose, biological tests were conducted, and the coated fibres and sheets were sent to Prof. Amir Ghaemmaghami and Dr Christopher Coleman from the Faculty of Medicine and Health Sciences at UON for anti-virus performance testing. The evaluation was conducted under CL3 conditions, where a fixed amount of live SARS-CoV-2 was placed onto each wire sample and left for 10 minutes. Subsequently, the surface was washed briefly with fresh cell media, and the amount of recovered SARS-CoV-2 was measured using the TCID50 assay.

To determine the effectiveness of each wire sample in reducing the virus, the relative amount of SARS-CoV-2 was calculated and compared to a 'no wire' control. Those wire samples that resulted in a 10-fold drop in virus titre were deemed as 'hits.' Notable examples of hits included the 0.5mm copper wire and Coco fibre. Additionally, some samples were classified as 'partial hits,' displaying a reduction in SARS-CoV-2 titre by approximately 3-5-fold, such as brass wire, bronze wire, and PB wire.

The study revealed that the coated fibres examined effectively reduced the number of live SARS-CoV-2 viruses on their surfaces. However, further research is required to investigate the virus's degradation over an extended period and under different conditions. These findings hold significant potential in contributing to the development of new and effective virus removal strategies, applicable in various settings, including healthcare facilities and public spaces, to curb the spread of infectious diseases.

To conduct live SARS-CoV-2 tests, Vero E6 cells were generously provided by Professor Kin-Chow Chang from the Department of Veterinary Medicine and Science at the University of Nottingham. The cells were cultured in a controlled incubator before and during the experiments, maintaining optimal conditions. The experiments were conducted in a CL3 laboratory under negative pressure, ensuring strict safety protocols.

The antiviral performance of the samples was evaluated under these conditions. Each wire sample was spot-coated with live SARS-CoV-2 and left undisturbed for 10 minutes. After rinsing the sample surface with fresh cell medium, the amount of recovered SARS-CoV-2 was quantified using a TCID50 test. A "no wire" control sample was included to assess the natural degradation of SARS-CoV-2.

Wire samples that exhibited a 10-fold reduction in viral titre were classified as "hits," exemplified by 0.5 mm copper wire and 0.4 mm organic fibre. "Partial hits," with a reduction in SARS-CoV-2 titre of approximately 3-5-fold, were observed in brass wire and plastic wire. Further investigations are planned to evaluate the virus's long-term degradation under different environmental conditions.

Based on the evaluation of different materials, crimpled brass, natural synthetic, organic Coco, and organic Tampico were identified as preferred choices due to their higher success rates in achieving the desired outcomes. Figure 4.10 illustrates the results of each material tested. These findings provide insights into the antiviral properties of the tested materials against SARS-CoV-2, opening new possibilities for their effective utilisation in reducing viral contamination. Future research will delve into assessing the virus's degradation over extended periods and in various environmental settings, offering a comprehensive understanding of these materials' performance and durability in combating viral spread. Based on the evaluation of different materials, crimpled brass, natural synthetic, organic

Coco, and organic Tampico were identified as preferred choices due to their higher success rates in achieving the desired outcomes.

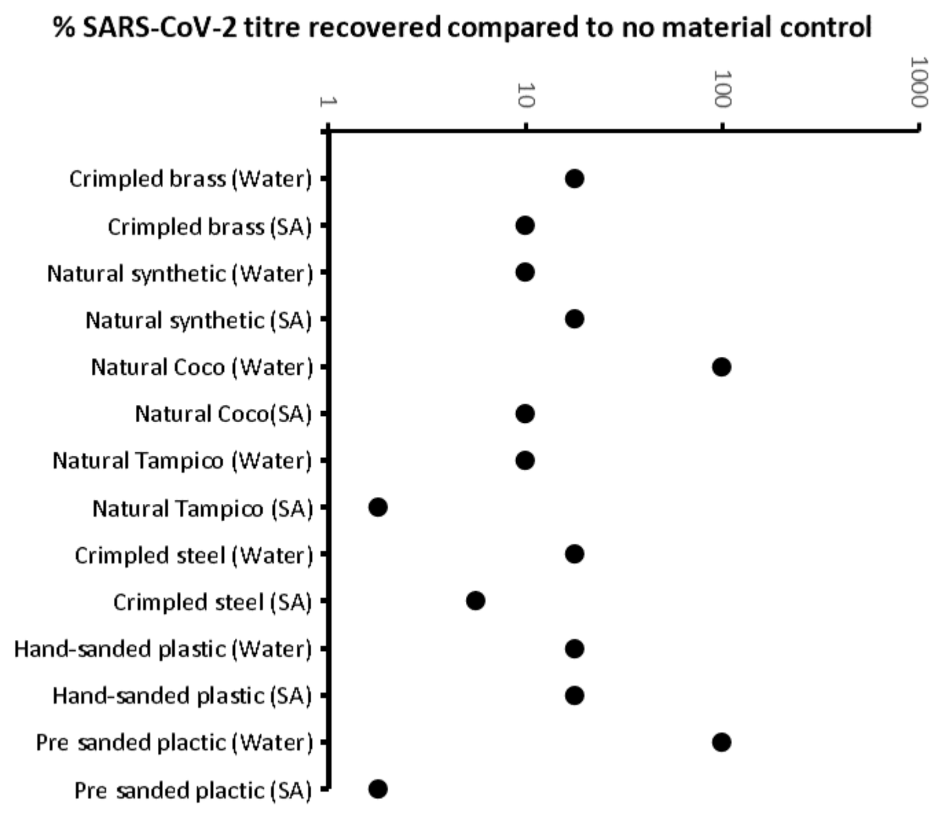


Figure 4.10 Graph showing SARS-CoV-2 hits for each material tested

4.11 Summary of substrate coating

In conclusion, the research conducted encompassed several stages aimed at assessing the effectiveness of the TiO_2-sodium alginate solution as a coating for fibres, plates, and brushes, encompassing durability testing and anti-virus performance evaluations.

A crucial aspect of this research was the selection of diverse fibres, as it facilitated the assessment of the coating's adhesion properties on different surfaces. Copper, brass, plastic, steel, and coco fibres were chosen for this study. However, due to the smooth nature of these fibres' surfaces, a pre-sanding process employing sanding paper was implemented to enhance the coating's adhesion capability.

Following the coating process, the coated fibres underwent a drying phase aided by a hairdryer, while their morphology and microstructure were examined to verify the adhesion of the coating. The results obtained from the durability tests indicated that the coating exhibited strong adherence to the thin fibres. Nevertheless, when it came to the thick plastic fibre, the coating tended to detach after the drying process, posing a challenge in achieving satisfactory adhesion.

To evaluate the anti-virus performance of the coated fibres, biological tests were conducted. Notably, the copper fibres demonstrated notable effectiveness, resulting in a significant ten-fold reduction in virus titre. Building upon these findings, the copper fibres were selected as the preferred material for producing brushes.

Chapter 5 Design and Construction of Pre-Prototype MopFan Air Purification Systems

This chapter details research conducted on three early-stage prototypes, funded by the Small Business Research Initiative (SBRI). Following the research conducted in Chapter 4 on substrate sanding and coating. Chapter 5 delves into the various aspects of prototype design, covering essential elements such as schematics, 3D models, 3D parts, hub design, versatility of design, and structure. These components collectively contribute to the foundation and functionality of a prototype. The chapter explores the significance of 3D models in prototype design. These virtual representations enable an analysis of the dimensions and functionality before physical production.

The inclusion of 3D-printed parts further enhances the prototyping process. These components are often fabricated using cutting-edge technologies such as additive manufacturing. This method was also used in the hub design, another critical aspect, which focuses on creating a central point that facilitates connectivity within the prototype. A well-designed hub enables efficient testing to be performed, with numerous fibre types and rotation styles being explored without delay. Versatility of design is a key consideration when developing a prototype. A versatile design allows for flexibility and adaptability, accommodating potential modifications and improvements during the prototyping phase.

The following chapter outlines the suggested blueprint for creating a prototype that will serve the purpose of testing the MopFan concept. The design plan includes specifications for all components and details the construction and assembly process.

5.1 Prototype preparation

The construction of the MopFan prototypes entailed a systematic progression of sequential steps. Although each individual prototype possessed its unique design and construction process, an overview of the prototype construction procedure is presented in Figure 5.1.

5.1.1 Material selection

The initial step in constructing the MopFan prototypes involved the careful selection of suitable materials. Various factors, such as durability, flexibility, and compatibility with the intended application, were taken into account during this phase. Thorough research and evaluation were conducted to identify the optimal materials that would ensure the functionality and performance of the prototypes.

5.1.2 Hub design/selection

Following the material selection, the design and selection of the hub, which serves as the central component of the MopFan, were carried out. This phase involved the creation of detailed hub designs, considering factors like structural integrity, weight distribution, and compatibility with the chosen materials. Alternatively, if an existing hub design was deemed suitable, it would be selected for use in the prototypes.

5.1.3 Brush sanding

Once the materials and hub were determined, the next step involved preparing the brush components. This entailed sanding the brush surfaces to ensure a smooth and even texture. By sanding the fibres, any imperfections or rough edges were eliminated, thereby enhancing the overall quality and effectiveness of the brushes.

5.1.4 Brush coating

After the sanding process, a coating was applied to the brush components. This coating served multiple purposes, including improving the durability of the fibres, enhancing their flexibility, and protecting them against wear and tear. The specific type of coating utilised depended on the desired properties and performance requirements of the MopFan prototypes.

5.1.5 Brush drying

Following the coating application, the brush components underwent a drying phase. This involved allowing sufficient time for the coating to cure and harden, ensuring the brushes were fully ready for assembly. Proper drying conditions, such as temperature and humidity control, were maintained to optimise the drying process and guarantee the quality of the brushes.

5.1.6 Hub assembly

Once the brush components were prepared and dried, the hub assembly process commenced. This step involved integrating the hub with the brush components, ensuring a secure and stable connection. Precise alignment and attachment techniques were employed to guarantee the efficient functioning of the MopFan prototypes.

5.1.7 Prototype assembly

The final stage of the construction process involved the overall assembly of the MopFan prototypes. This encompassed integrating all the individual components, including the hub and brush assemblies, along with any additional parts necessary for the prototypes' operation. Through careful and assembly, the prototypes were brought together, ready for further testing and evaluation.

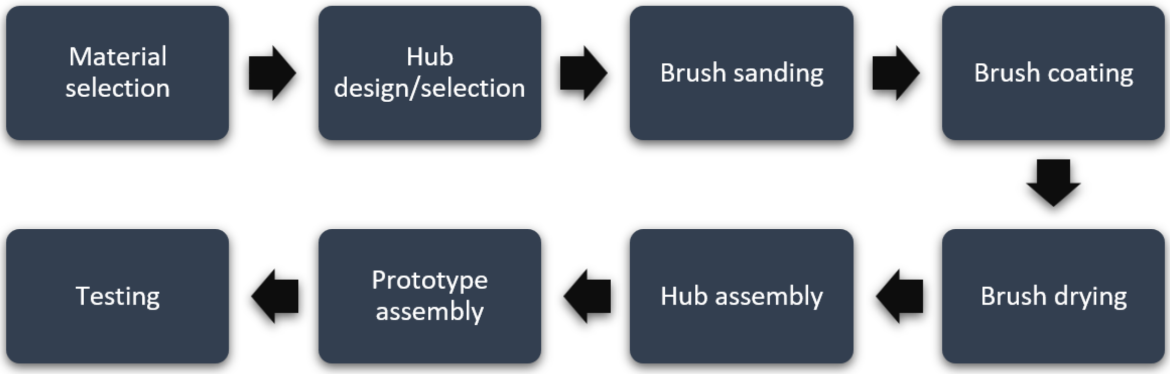


Figure 5.1 Flow chart of prototype construction procedure

5.2 Use of 3D printing

In order to create prototypes of the hub, a 3D printing technique called fused filament deposition was employed. This involved using a specialised machine, the Ultimaker 2+ connect, as shown in Figure 5.2, which is specifically designed for such purposes. ABS filament, known for its high hardness and smooth finish, was selected to produce the hub parts.

To accommodate the limitations of the printing bed, the hub was divided into multiple sections, allowing each part to be printed individually. This division ensured that the hub could be successfully printed and later assembled by hand, without the need for additional fixings such as screws or bolts.

For optimal precision, a nozzle with a diameter of 0.2mm was used during the printing process to achieve the highest resolution possible. The printer settings were adjusted to ensure the highest quality printing output.

It is worth noting that the production of each prototype involved not only the time spent on modelling the design in CAD software but also a significant printing duration. On average, each prototype took approximately 12 to 16 hours to be fully printed, adding to the overall development timeline.

By utilising 3D printing technology and the Ultimaker 2+ connect, along with ABS filament and careful attention to printing settings, the hub prototypes were successfully created. This method allowed for the production of parts with desired hardness, smoothness, and high-resolution detail, enabling the subsequent evaluation and testing of the hub design for its intended functionality.

Figure 5.2 Image of a Ultimaker 2+ connect and ABS filament

5.3 SBRI prototype coating process

During this phase of the project, all three prototypes underwent the crucial step of TiO_2 coating. After the blades or fibres were prepared to the desired size, the subsequent procedure involved sandblasting to achieve an optimal surface roughness. This critical process ensured strong adhesion of the TiO_2 solution to the surfaces of the blades and brushes, promoting effective coating performance. Sandblasting was chosen as the preferred method for abrading the fibres of the brush and preparing the surfaces of the blades. This technique involves propelling abrasive particles onto the surface to create the desired roughness. In the case of the sandblasting apparatus used in this project, it was equipped with a 4.5mm ceramic nozzle, which determined the size of the opening through which the abrasive material would be expelled. The selected sand grade ranged from 0.5mm to 1.25mm, ensuring an appropriate abrasive size for achieving the desired roughness. The air pressure applied during the sandblasting process was set to 6 bar, optimising the force at which the abrasive particles interacted with the surfaces of the prototypes. Figure 5.3 provides a visual representation of the sandblasting apparatus employed in the project, allowing for a better understanding of the equipment used during this crucial stage.

Figure 5.3 highlights the key components of the apparatus, including the ceramic nozzle, through which the abrasive material is directed, and the appropriate sand grade selected for the sandblasting process. By employing the sandblasting technique and the specific parameters mentioned above, the surfaces of the blades and brushes were adequately prepared with the desired level of roughness. This surface preparation facilitated optimal adhesion of the subsequent TiO_2 coating, enhancing the overall performance and durability of the prototypes.

Figure 5.3 Images of sandblasting chamber and ceramic

Once the surface preparation was complete, the coating process commenced. Manufacturing the TiO_2 coating was a laborious and time-consuming task that required the solution to be stirred continuously for over 7 hours. A mixture of sodium alginate and TiO_2 was prepared. To achieve a consistent and homogeneous blend, an industrial mixer was employed, ensuring the production of the required quantity to cover all the brushes.

At this stage of development, the coating was applied manually using a brush. This method ensured complete and uniform coverage of each blade with an adequate amount of coating.

Subsequently, the coated brushes were left to dry naturally in an open-air environment. Once dry, they were tested by rubbing them with a black cloth to confirm that no white residue from the coating was being removed from the fibres.

5.4 Prototype A: Centrifugal fan

Prototype A was focused on retrofitting an existing centrifugal fan, as shown in Figure 5.4. A centrifugal fan, also referred to as a radial fan, is a mechanical apparatus employed in a wide range of industrial and commercial scenarios to propel air or gases. It operates on the principle of centrifugal force.

Centrifugal fans excel in generating high-pressure airflow, rendering them suitable for diverse purposes such as ventilation, cooling, and air circulation, particularly in environments with restricted airflow like HVAC or duct systems. Industries such as manufacturing, power generation, HVAC, and automotive extensively employ centrifugal fans. The performance of a centrifugal fan hinges upon several factors, including impeller design, rotational speed, blade size and shape, and motor power. These parameters can be tailored to meet the specific airflow and pressure requirements of individual applications.

Comprising key components, including an impeller, housing or casing, inlet, and outlet, the centrifugal fan functions by harnessing these elements to generate airflow. The impeller, consisting of curved and angled blades, effectively captures and accelerates incoming air, imparting kinetic energy to it as it rotates at high speed. The housing or casing envelops the impeller, establishing a conduit for the airflow. Its gradual expansion in diameter facilitates the conversion of the air's kinetic energy into pressure energy. An inlet facilitates the entry of air into the fan, usually equipped with a grille or filter to prevent foreign particles from compromising the fan or connected systems.

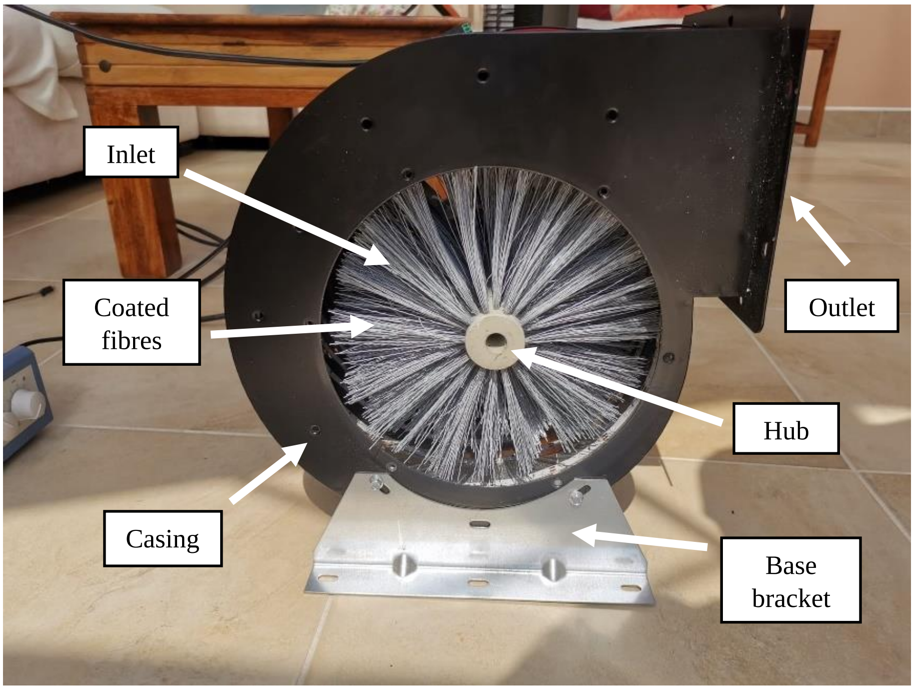


Figure 5.4 Image of the centrifugal MopFan (Prototype A)

5.4.1 Conceptualisation and design

The initial step in the project involved the conceptualisation of the design for the centrifugal fan prototype. This comprehensive process selecting appropriate materials and finalising the overall size and shape of the fan. A summary of the design aspects for the Prototype A is presented in Table 5.1.

Table 5.1 Design aspects of Prototype A

Design aspect	**Description**
Adapt existing centrifugal fan	To modify an existing centrifugal fan for the research project.
Assess impact of removing impeller on airflow	Consider the effect on airflow when the large impeller within the fan case was removed.
Select appropriate brush density for airflow	The chosen brush for the fan needed to strike a balance between density and effectiveness in providing the desired airflow output.

Apply reflective inner coating to fan case	The interior surface of the centrifugal fan case required a reflective coating to amplify the light intensity emitted by the LED strips and facilitate heat distribution.
Facilitate effective heat distribution	The reflective surface needed to allow effective heat distribution within the fan case to prevent overheating.
Consider narrowing openings of fan case	The large openings of the fan case raised concerns about the effectiveness of the photocatalytic oxidation (PCO) reaction. Consideration was given to narrowing the openings.
Allow for further adaptation and modification	The aspect of narrowing the openings was left open for further adaptation and modification based on the outcomes of the testing phase.

During the design phase, it was decided to adapt an existing centrifugal fan for the purposes of this research. One of the key considerations during this phase was the airflow output of the fan. The impact on airflow when removing the large impeller housed within the fan case was considered, as well as, whether the fan could still operate effectively without it. This critical assessment helped shape the subsequent design parameters for the fan. Based on the deliberations, the following design parameters were proposed before commencing the construction phase.

Firstly, the chosen brush for the fan needed to strike a balance between density and effectiveness in providing the desired airflow output. It had to be dense enough to generate sufficient airflow, yet not overly dense to allow each row of fibres to be sanded and coated effectively. Additionally, the interior of the centrifugal fan case required careful consideration. It was essential for the inner surface to be highly reflective to amplify the light intensity emitted by the LED strips. Therefore, a reflective inner coating had to be applied to the fan case. This reflective surface also needed to be suitable for mounting the LED strips and facilitating effective heat distribution to prevent overheating.

The fan case itself posed an interesting challenge. With its large openings, it allowed ample natural light to enter the inner chamber. However, this raised concerns about the effectiveness of the PCO reaction taking place in such an environment. To address this, it was considered to narrow the openings of the inner chamber, thereby restricting untreated air from escaping the fan before being treated. However, it was also acknowledged that this alteration could potentially impact the airflow. As a result, this aspect was left open for further adaptation and modification based on the outcomes of the testing phase.

In summary, the design phase involved careful consideration of various factors in adapting the centrifugal fan for the research project. This included assessing the impact of removing the impeller on airflow, selecting an appropriate brush density for airflow output, applying a reflective inner coating to amplify LED strip intensity and facilitate heat distribution, and deliberating on the balance between airflow and narrowing the openings of the fan case. These considerations set the foundation for the subsequent construction and testing phases of the fan prototype.

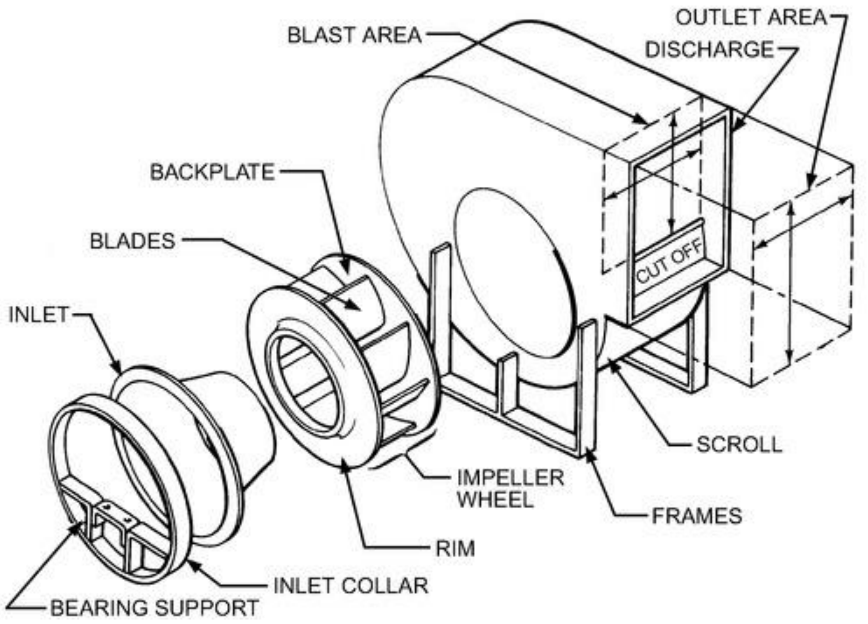


Figure 5.5 Diagram of a centrifugal fan design (ASHRAE, 2016)

5.4.2 Retrofit instead of 3D modelling

Once the initial design concept is solidified, the next step involves creating detailed 3D models. These models aid in the construction of different components of the fan. However, in the case of this retrofit project, the conversion process was relatively straightforward. Consequently, it was determined that designing new 3D parts specifically for this conversion was unnecessary.

Due to the limited timeframe of the funding period provided by the SBRI (Small Business Research Initiative), which covered only a three-month period, the primary focus remained on retrofitting existing systems rather than developing entirely new ones. This approach allowed for a more efficient use of resources and ensured that the project could be completed within the given timeframe.

To provide a clear understanding of the intended functionality of the retrofitted systems, a demonstration was conducted. This demonstration aimed to showcase how the modified components would operate and interact with the existing infrastructure. Figure 5.6 shows a visual representation of this demonstration.

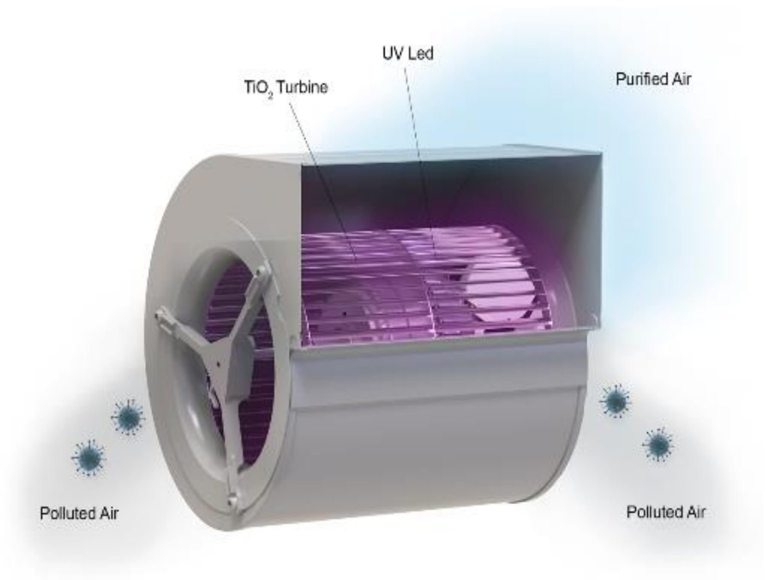


Figure 5.6 Visual representation of modified centrifugal fan concept

5.4.3 Component selection and fabrication

Once the design concept is established, the selection of suitable components becomes crucial. Components such as the mop, housing, motor, bearings, and control systems need to be carefully chosen based on the specific design requirements. In this retrofit project, the process involved evaluating various options available in the market. To acquire these components, the components were sourced them from reputable suppliers. However, it was also necessary to make certain adaptations and modifications internally to ensure their compatibility with the retrofit design. This approach allowed for customisation and optimisation of the components to meet the specific needs of the project. One of the key challenges in the retrofitting process was finding a suitable brush that could effectively replace the impeller that had been removed. The impeller, which is responsible for creating airflow in traditional fans, needed to be replaced with a brush that could generate the desired airflow patterns in the modified system. Several brush types were considered and evaluated during the selection process. In Figure 5.7, various brush types that were explored as potential replacements can be seen. However, after careful analysis and testing, these brush types were deemed unsuitable for the proposed system and did not meet the design requirements. This is due to factors such as inadequate airflow generation, poor durability, or compatibility issues with the retrofit design. As a result, the search continued for a brush type that would fulfil the necessary criteria and be compatible with the retrofit system. This process involved further research, consultation with experts, and potentially exploring alternative industries or technologies to find the most suitable brush for the project.

Figure 5.7 Considered impeller types

A suitable replacement impeller was identified for the system, as shown in Figure 5.8. This replacement impeller was chosen based on fibre density and arrangement, The fibre density of the impeller was a critical consideration as it directly influenced the airflow efficiency and resistance.

By selecting an impeller with an appropriate fibre density, the system could achieve optimal airflow performance while minimising energy consumption and also allowing ample illuminance of the catalyst from the LED strips. The arrangement of the fibres in the impeller was also taken into account. The dimensions of the impeller were carefully determined to ensure proper fit within the system. Considerations such as diameter and height were taken into account to ensure smooth operation and effective air movement. Furthermore, the core strength of the replacement impeller played a vital role in maintaining structural integrity under operating conditions. The impeller's core was designed to withstand the forces exerted during rotation, ensuring long-lasting performance and minimising the risk of mechanical failure.

Figure 5.8 Image of the custom-made impeller for Prototype A

In addition to the necessary components mentioned earlier, the procurement process also involved acquiring a reflective flexible sheet and LED strips with a nanometre (nm) range to facilitate the PCO reaction. For many photocatalytic oxidation applications, UV light in the range of 300 to 400 nm is commonly utilised. However, it is not the ideal nanometre range. Due to supply issues, LED strips with a wavelength of 265nm couldn’t be sourced. Despite this, using a range of 300-400nm would provide data on the system performance using readily available LED strips of 300-400nm as opposed to a specialised LED strip which emits 265nm. The reflective vinyl, as shown in Figure 5.9, was specifically sourced to enhance the efficiency of the PCO system. Its reflective properties allowed for the redirection and optimisation of UV light towards the photocatalytic surface, maximising the utilisation of the emitted photons. This sheet was carefully selected to ensure high reflectivity.

Figure 5.9 Image of the reflective vinyl

To generate the required UV light, LED strips, as shown in Figure 5.10, with the appropriate nanometre range were procured. The procurement of the reflective flexible sheet and the LED strips with the appropriate nm range marked an important step in ensuring the success of the PCO system. These components were crucial in providing the necessary UV light and optimising its delivery to the photocatalytic surface, thereby enhancing the efficiency and effectiveness of the photocatalytic oxidation process. Their careful selection and integration into the system further supported the overall goal of achieving oxidation reactions and promoting the desired outcomes of the PCO system.

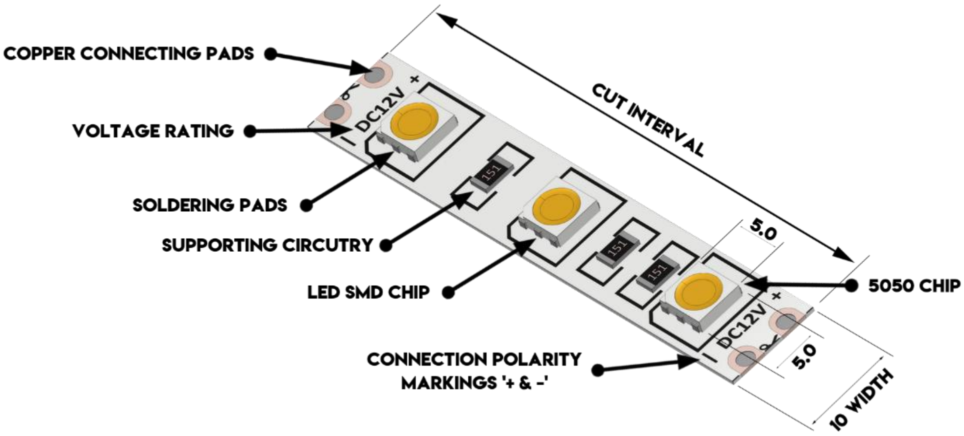


Figure 5.10 Diagram of LED strip anatomy

5.4.4 Assembly

During the assembly process of the centrifugal fan prototype, various steps were taken to ensure the successful integration of its components. Firstly, the existing centrifugal fan was carefully dismantled, as shown in Figure 5.11, and the original impeller was removed and set aside for later use. The next step involved measuring the motor shaft to determine the appropriate method of attaching the new impeller, which had been coated with a layer of TiO_2. Once the measurements were taken, the impeller was securely attached to the motor shaft, ensuring a tight and stable connection. This connection was crucial for the efficient functioning of the centrifugal fan, as it would enable the impeller to rotate and generate airflow. The assembly process also involved connecting the housing and inlet of the fan, ensuring a seamless flow path for the air to pass through. In addition to the mechanical assembly, the integration of electrical and control systems was an essential part of constructing the centrifugal fan prototype. The necessary electrical components and wiring were carefully installed to facilitate the operation of the LED strips. This included connecting to the power supply and incorporating control systems required for adjusting the fan speed. Measurements of the fan's interior were taken to determine the length of LED strips that could be used to line the casing. These LED strips would provide illumination. A reflective sheet was also cut to fit the dimensions of the fan casing, ensuring that it would cover the entire surface area.

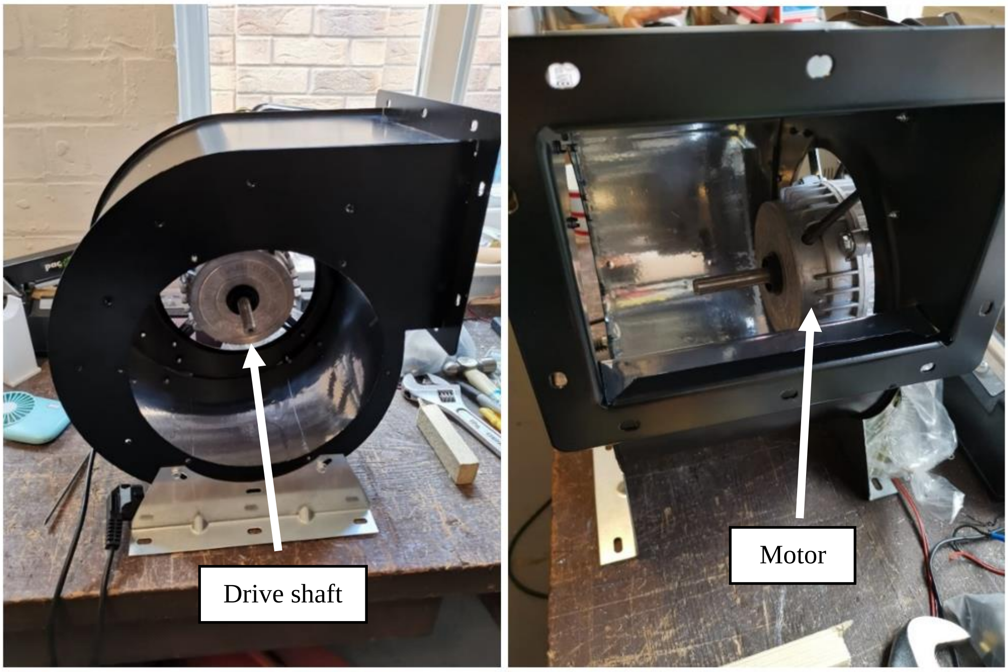


Figure 5.11 Images of a dismantled centrifugal fan

After dismantling the existing centrifugal fan and preparing the TiO_2 coated impeller for assembly, the next crucial step was to adapt the impeller so that it could be securely mounted to the drive shaft of the motor. It was essential to find a reliable method of affixing the impeller to the shaft without using glue or any other chemicals that could potentially affect the test data and performance of the system.

In addition to preparing the impeller fibres, a hole was made within the hub of the impeller. This hole was specifically designed to fit tightly onto the shaft of the motor. The snug fit was crucial for securing the impeller to the motor shaft. Without a secure fit, the impeller could wobble or rotate inconsistently, leading to potential performance issues. To achieve an even and uniform coating, the impeller was rotated at a high-speed using a power drill, as shown in Figure 5.12. This rotation allowed the TiO_2 solution to be evenly distributed on the impeller fibres, ensuring that each fibre received an adequate amount of coating. It was important to minimise excess coating on the impeller, as any flaking or excess solution could create particles that might compromise the air purifying qualities of the system. By carefully controlling the rotation speed and duration, the impeller was coated with the TiO_2 solution, creating a thin and uniform layer on its surface. This coating would contribute to the air purifying capabilities of the centrifugal fan prototype, as the TiO_2 would interact with UV light to catalyse the decomposition of air pollutants.

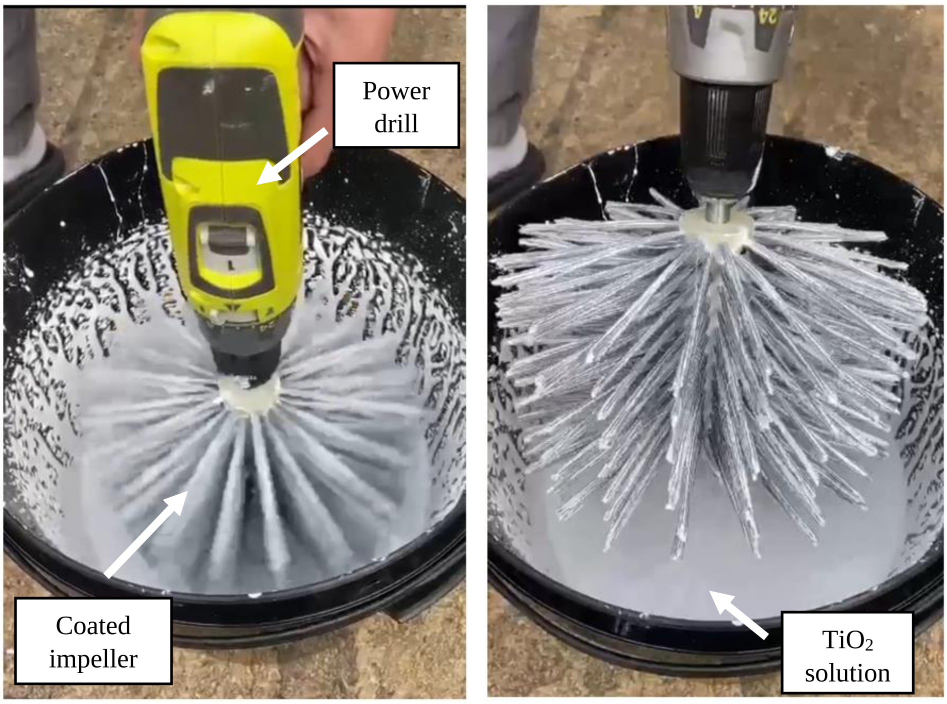


Figure 5.12 Images of the coating method for centrifugal brush

Once the reflective vinyl was applied to the interior surfaces, the LED strips were mounted and connected together as shown in Figure 5.13. The strips were strategically placed to ensure even lighting and coverage throughout the fan's interior. Additionally, the LED strips were designed to be independently switchable from the motor, allowing for separate testing scenarios with and without UV light. This capability to switch the LED strips on and off separately from the motor was important for conducting comprehensive tests of the centrifugal fan prototype. By enabling independent control over the LED lighting, experiments could be carried out to evaluate the impact of UV light on the TiO_2 coated impeller's air purification capabilities. This flexibility in testing configurations would provide insights into the fan's performance under different lighting conditions. To provide the required UV light, 5 meters of 12V LED UV light strips with a wavelength of 365nm were affixed to the reflective vinyl lining. These specific UV light strips were chosen for their ability to emit light, triggering the photocatalytic reaction on the TiO_2-coated impeller. With the impeller successfully mounted, the interior coated with reflective material, and the LED strips in place and connected, the centrifugal fan prototype was now ready for testing. The system was prepared to undergo rigorous evaluations, allowing for measurements of its air purification effectiveness and the overall performance of the integrated components. By conducting thorough tests, the centrifugal fan prototype's capabilities could be assessed, including its ability to purify air through the interaction of the TiO_2 coated impeller and UV light, as well as the visual effects achieved through the illumination of the LED strips. These testing procedures would provide valuable data and insights to further refine and optimise the fan's design and performance.

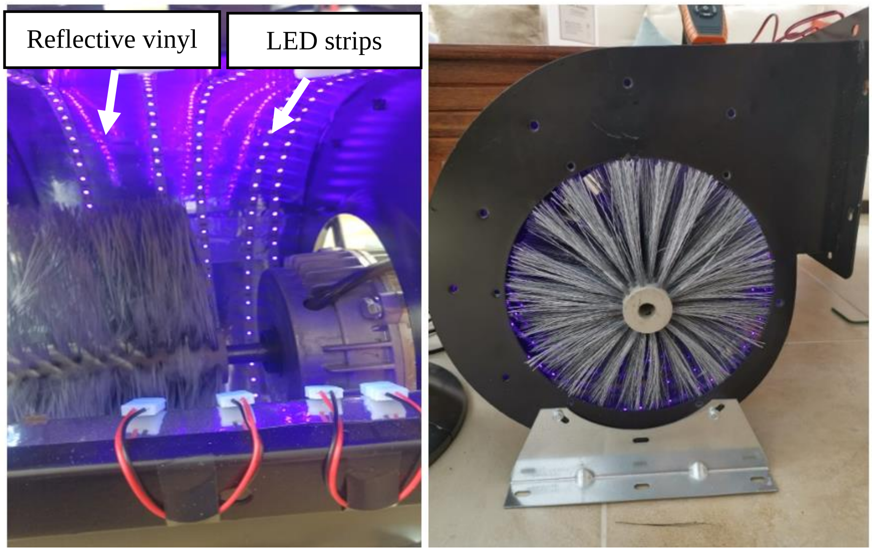


Figure 5.13 Images of the LED arrangement and completed prototype

5.5 Prototype B: Commercial tower fan

Prototype B adapted an existing commercially available tower fan to become a MopFan system, as shown in Figure 5.14. Tower fans are a type of electric fan known for their tall and slender design, resembling a tower or column. They are highly regarded for their compact nature, making them well-suited for a variety of settings such as homes, offices, and indoor spaces where space is limited. Typically, tower fans consist of a vertically-oriented housing that encloses the fan mechanism. This housing is commonly made of plastic and incorporates vertically aligned vents or grilles, enabling the fan to draw in and expel air. The primary advantage of tower fans lies in their ability to generate a consistent and steady airflow. This is achieved by a vertically positioned motor and fan assembly within the housing. The motor drives the fan blades, effectively pulling air from the surroundings and propelling it upwards or outwards through the vents.

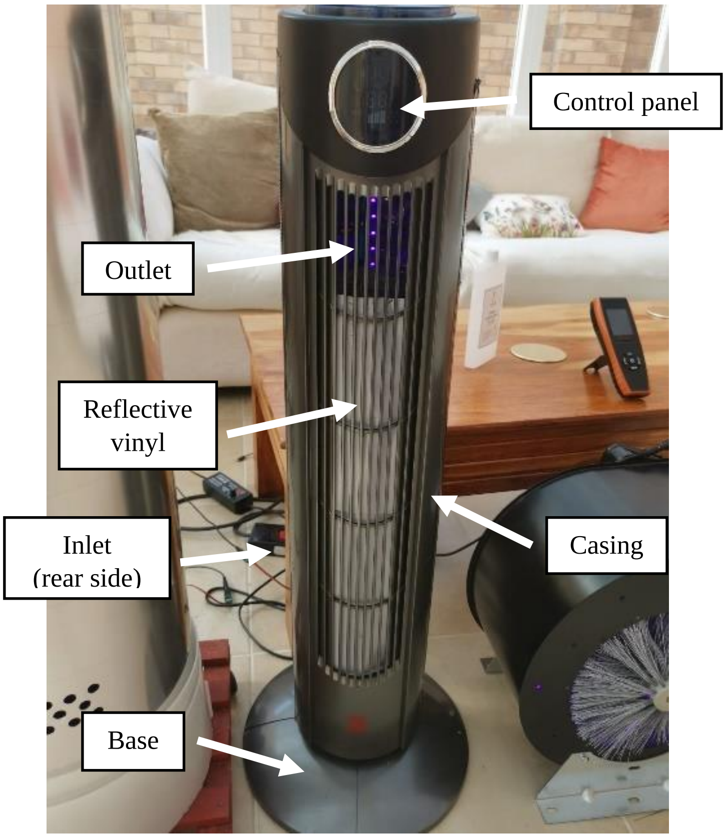


Figure 5.14 Image of the commercially adapted tower fan (Prototype B)

5.5.1 Design and conceptualisation

The first step in the process is to conceptualise and design the tower fan prototype. This involves selecting appropriate materials and finalising the overall size and shape of the fan. Although the concept of adaptation was relatively straightforward, completely changing the hub of the system would likely impact the performance of the motor. The original hub was lightweight, but the new hub would need to be considerably heavier to accommodate the increased number of fibres and copper strips used. One of the critical considerations in the design of this system revolves around the need to achieve an optimal balance between the speed of the rotating brushes and the ability to retain contaminated air within the apparatus for a sufficient period. This balance is crucial as it directly impacts the effectiveness of the photocatalytic reaction used for air purification. While high brush rotation speed is necessary to ensure an adequate volume of air is pushed through the system, excessively high speeds can hinder the desired retention of contaminated air. To address this challenge, a strategic approach was taken by focusing on minimising the weight of the brush assembly. By reducing the weight, greater control over the motor speed can be achieved, allowing for a fine-tuning of the rotation rate. This optimisation helps strike the right balance between air volume displacement and the exposure time for effective purification through the photocatalytic process. However, reducing the weight of the brush strips themselves was not a viable option. Instead, the design solution involved an innovative approach in the construction of the hub. The hub was specifically engineered to be hollow inside, with the brushes secured only at the ends and in the centre. This configuration not only minimised the overall weight but also introduced a unique advantage—light transmission. The hub's design, consisting of three separate parts, enables the passage of light from one side to the other. This feature ensures that the photocatalytic reaction can take place effectively throughout the entire system, enhancing the purification process. Several criteria were considered during the design phase:

5.5.1.1 Achieving adequate fan speed

It was essential to design the fan to achieve a high enough speed to effectively circulate the air within the system, ensuring proper treatment of the air.

5.5.1.2 Providing sufficient space for reflective lining and LED strips

The design needed to allow enough room for the interior of the casing to be lined with reflective material and accommodate the installation of LED strips. This would help maximise illumination and visual effects.

5.5.1.3 Strong and adaptable hub design

The hub design needed to be robust and durable to withstand the operational demands. Additionally, it was important to create a hub design that could be easily removed, minimising downtime between tests and allowing for swift adjustments or replacements. Table 5.2 lists a breakdown of the design aspects of Prototype B.

Table 5.2 Design aspects of Prototype B

Aspect	**Importance**
Fan Speed	Crucial for effective air circulation and proper system treatment
Casing Design	Allocate space for reflective lining and enhance light utilisation
Reflective Lining	Maximise light dispersion and enhance visual effects
LED Strips	Proper positioning and attachment for optimal lighting effects
Hub Design	Ensure strength, adaptability, and endurance for system
Removal and Installation	Easy maintenance and quick adjustments or replacements

5.5.2 Retrofit and 3D modelling

Once the design concept of the tower fan prototype is finalised, the next step involves creating 3D models. In the case of the tower fan, one critical component that required specific design attention was the hub. The hub served as the central connecting piece responsible for attaching the fan blades and transferring the rotational force generated by the motor. To ensure its strength and adaptability to withstand the operational demands placed on it, the hub was designed to be 3D printed using advanced manufacturing techniques.

The 3D printing process allowed for precise control over the design and fabrication of the hub. It was divided into several sections that could be printed separately and then assembled. This modular approach facilitated ease of manufacturing and allowed for adjustments or modifications if needed. Each section of the hub was designed with intricate details and slots to accommodate additional structural reinforcements. To enhance the structural integrity of the hub, aluminium and copper sheets were incorporated into the design. These metal sheets were precisely fitted into the slots within the 3D printed sections, providing additional strength and stability to the hub. The use of aluminium and copper, known for their durability and heat conductivity properties, not only reinforced the hub but also helped dissipate any heat generated during operation, ensuring optimal performance.

By combining the precision of 3D printing technology with the integration of aluminium and copper sheets, the hub design achieved a balance between strength, adaptability, and structural integrity. This design, as shown in Figure 5.15, approach enabled the hub to endure the forces generated during operation, including high-speed rotations and potential vibrations, while maintaining its functionality and longevity. Furthermore, the modular nature of the hub design allowed for easy removal and installation. This feature greatly facilitated maintenance and repairs, as any necessary adjustments or component replacements could be carried out efficiently. With minimal downtime, the tower fan could quickly be restored to optimal working conditions, ensuring uninterrupted airflow and effective air circulation.

Figure 5.15 Visualisation of 3D printed hub design

The system achieves an equilibrium between brush rotation speed and the retention of contaminated air, resulting in an efficient and effective air purification process. One of the key factors in achieving this balance is the optimisation of the brush weight. The brush, a crucial component of the system, is designed to capture and retain airborne contaminants as the fan circulates the air. By carefully calibrating the weight of the brush, it can effectively attract and trap pollutants, such as dust particles, allergens, and other airborne impurities. The optimal weight ensures that the brush maintains contact with the passing air while allowing it to rotate smoothly without excessive resistance.

In addition to the brush weight optimisation, the hollow hub design plays a vital role in the system's performance. The hub is specifically engineered to facilitate the transmission of light. The hollow hub design allows light to pass through its interior, reaching the substrate surface.

This is achieved by carefully shaping and structuring the hub to minimise obstructions or interference with the light path. By maximising the transmission of light to the brush, the system optimises the activation of the photocatalytic coating, enhancing its ability to break down and neutralise harmful substances present in the air.

The efficient and effective photocatalytic purification process enabled by the optimised brush weight and the hollow hub design ultimately leads to improved air quality. As the contaminated air is circulated through the system, the brush captures pollutants, while the photocatalytic coating breaks them down at a molecular level. This process effectively eliminates or neutralises harmful substances, ensuring that the air released back into the environment is purified. To visually represent this concept, Figure 5.16 provides a detailed illustration of the system. It showcases the optimised brush weight, the hollow hub design, and their combined contribution to the overall purification process.

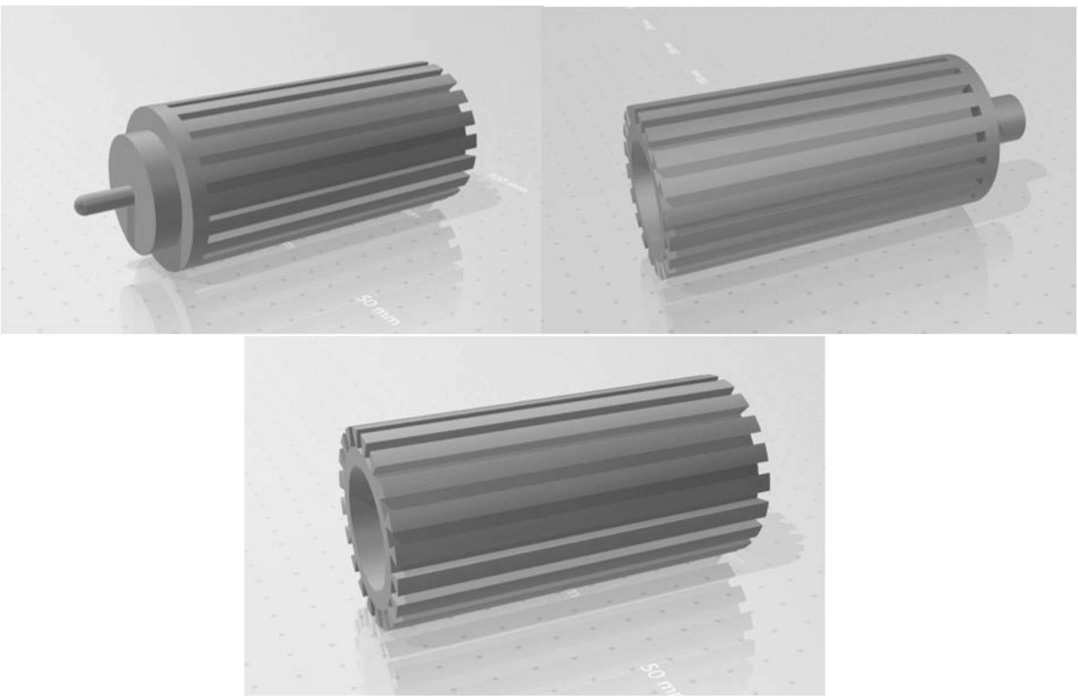


Figure 5.16 Visualisations of 3D printed hollow hub design

Since this tower fan prototype was another adaptation of an existing system, the main focus was on sourcing and incorporating applicable components into the design. This approach ensured that proven and reliable components were utilised, minimising the risk of unforeseen issues during operation. Careful consideration was given to selecting components that aligned with the design requirements and performance expectations of the tower fan system.

The process of sourcing components involved extensive research and evaluation of available options in the market. To begin with, a comprehensive review of existing tower fan systems and their components was conducted. Key factors such as compatibility, efficiency, durability, and cost-effectiveness were taken into account when selecting the components. Compatibility was a critical consideration to ensure that the chosen hub could seamlessly integrate with the existing system design. This involved assessing factors such as dimensions, electrical requirements, and communication protocols. Components were assessed for their build quality, materials used, and their ability to withstand the operational demands and environmental factors. The careful consideration of compatibility, efficiency, durability, and cost-effectiveness resulted in a well-rounded design that met the performance expectations and design requirements of the tower fan prototype. Table 5.3 provides a summary of the considerations during modelling of Prototype B.

Table 5.3 Considerations during modelling of Prototype B

Aspect	**Description**
Focus	Sourcing and incorporating suitable components into the tower fan prototype.
Component Sourcing	- Researching and evaluating available options in the market.
	- Reviewing existing tower fan systems and components.
	- Considering compatibility, efficiency, durability, and cost-effectiveness of components.
Compatibility	Ensuring chosen components seamlessly integrate with the system design.
Durability	Selecting components with sturdy construction, resistance to corrosion, and long-term reliability.
Cost-effectiveness	Striking a balance between performance and budget, selecting affordable components without compromising quality.
Evaluation	Reviewing technical specifications, consulting manufacturers and suppliers, and testing compatibility.

5.5.3 Component selection and fabrication

Suitable components like the impeller, housing, motor, bearings, and control systems are chosen based on the design. These components can be obtained from suppliers or fabricated internally if feasible. To facilitate the construction of the tower fan prototype, copper and aluminium sheets with a thickness of 0.4mm were procured. These materials were selected based on their suitability for the intended purpose, cost-effectiveness, and availability within the supply chain for potential future manufacturing. By using these sheets, a observation in airflow could be made as an alternative to using coated brushes. The copper and aluminium sheets were cut to the required dimensions for the creation of the MopFan blades using tin snips, ensuring precise sizing and shape, as shown in Figure 5.17. These blades would serve as integral components of the tower fan prototype.

Figure 5.17 Aluminium and copper strips

After cutting the sheets to the desired dimensions, the MopFan blades underwent a sanding process, as shown in Figure 5.18, to smooth and prepare their surfaces. This step ensured that the blades were free from any imperfections or irregularities that could affect their performance. Following the sanding process, the blades were coated as part of the component fabrication. This coating would further enhance the functionality and effectiveness of the blades during operation. By incorporating the copper and aluminium sheets as the materials for the MopFan blades, the tower fan prototype could be tested for its operational concept, functionality, and the effectiveness of these chosen materials. This testing phase would provide insights into the overall performance and suitability of the design, contributing to the refinement and optimisation of the tower fan prototype.

Figure 5.18 Image of rotary sanding of aluminium strip in preparation for coating

Furthermore, as part of the tower fan prototype design, a brush hub design was carefully prepared to ensure optimal air purification performance. To accomplish this, a helix brush made of brass was sourced and selected for integration into the system. The helix brush, depicted in Figure 5.19, possessed specific characteristics that made it an ideal component for the tower fan's purification mechanism. The helix brush was composed of high-quality brass material, known for its durability and corrosion resistance. Its robust construction ensured longevity and reliable performance in the tower fan system. The brush featured a helical structure with densely packed fibres, to effectively capture and retain airborne contaminants during operation. To enhance the brush's purification capabilities, a specialised coating was applied to its fibres.

To ensure smooth and efficient operation, multiple helix brushes were mounted in tandem. The brushes were coupled together using a sturdy steel coupler, enabling synchronised rotational movement. This configuration maximised the surface area of the brush system, enhancing its ability to capture and treat a larger volume of air within the tower fan. The distribution of fibres and fibre density on the helix brush played a crucial role in its effectiveness. The fibres were evenly distributed along the helical structure, ensuring uniform contact with the passing air. The fibre density, carefully optimised during the brush's design, allowed for an optimal balance between air flow resistance and effective filtration. This balance ensured that the tower fan could maintain efficient air circulation while effectively capturing and retaining airborne contaminants. In addition to the distribution of fibres, the dimensions of the brush were carefully considered to make it a suitable component for the tower fan. The brush's length, diameter, and overall size were designed to align with the tower fan's specifications and air circulation. These dimensions were chosen to maximise the brush's contact area with the passing air, facilitating enhanced purification performance. By incorporating the brass helix brush with its specialised coating and utilising a robust steel coupler, the tower fan prototype aimed to achieve superior air purification capabilities. The optimised distribution of fibres and fibre density, along with the carefully chosen dimensions, ensured that the brush effectively captured and treated airborne contaminants. This design element contributed to the overall functionality and effectiveness of the tower fan system in improving air quality.

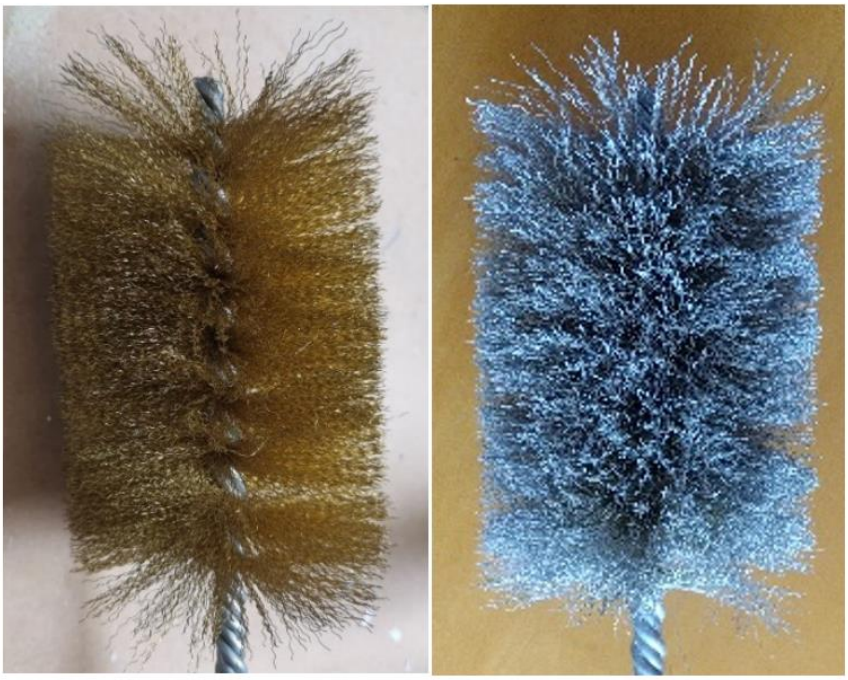


Figure 5.19 Images of helix brush before and after coating

5.5.4 Assembly

Once all the individual components are prepared, the assembly process begins to construct the tower fan prototype. This process involves carefully connecting the various components to create a functional and operational unit, ensuring that each element works together seamlessly. To start the assembly, the impeller is securely attached to the motor shaft. This crucial step ensures that the impeller, responsible for generating airflow, is properly aligned and connected to the driving force of the motor. By securely fastening the impeller to the motor shaft, the assembly ensures that rotational energy is efficiently transferred, allowing the impeller to propel air effectively. Next, the housing and inlet are connected, enclosing the internal components of the tower fan. The housing provides a protective casing that not only houses the impeller and motor but also serves to direct and channel the airflow within the system.

This connection ensures that the airflow is directed in the desired manner, optimising the tower fan's performance and enhancing its ability to circulate air effectively. The integration of the necessary electrical and control systems is another crucial aspect of the assembly process. Wiring, switches, and control mechanisms are carefully connected to ensure proper functionality and ease of operation for the user. This includes connecting the power supply to the motor, enabling the tower fan to be powered and controlled efficiently. The wiring and connections are carefully organised to maintain safety standards and ensure reliable operation. For this particular tower fan prototype, a commercial fan unit served as the base, as shown in Figure 5.20. This base unit was modified to allow for easy replacement of the hub, providing flexibility and adaptability in the design. This design element ensures that the hub, a critical component responsible for connecting the fan blades and transferring rotational energy, can be readily adjusted or replaced without significant downtime or complex procedures.

Figure 5.20 Images of alternative hubs (Aluminium, copper and brass brush)

Throughout the assembly process, attention to detail and precision are maintained to ensure that all components are properly aligned, securely connected, and functionally integrated. Thorough testing and quality checks are conducted to validate the assembly, verifying that the tower fan prototype functions as intended and meets the design specifications.

By assembling the components, including attaching the impeller to the motor shaft, connecting the housing and inlet, integrating electrical and control systems, and incorporating a replaceable hub design, the tower fan prototype aims to deliver reliable and efficient performance.

This comprehensive assembly process ensures that the tower fan operates effectively, providing optimal air circulation and purification for improved air quality. The prototype of the tower fan boasts a versatile array of features, including a diverse range of blade options that cater to various airflow requirements. Among these options are copper blades, renowned for their heat conductivity and efficient performance.

The incorporation of copper blades allows for rigorous testing and facilitates a comprehensive comparison of their airflow characteristics, ensuring the optimal choice for specific cooling needs. In addition to the copper blades, the prototype also integrates aluminium blades. Aluminium, widely recognised for its lightweight nature and corrosion resistance, presents an alternative option for users seeking a balance between performance and durability. Reflective vinyl is applied to the inner walls of the housing, enhancing the reflection and distribution of UV light within the system. This helps optimise the photocatalytic air purification process. A UV LED strip is affixed to the reflective vinyl, providing a consistent and targeted light source to activate the TiO_2 coating and facilitate the decomposition of air pollutants.

The hub for this prototype is 3D printed in five sections, allowing for ease of assembly and accommodating the insertion of the blades, as shown in Figure 5.21. As for the brass brushes, a separate hub is not required as only the axes of the brushes need to be coupled. With LED’s, reflective vinyl and two variants of internal hub, the tower fan was ready for testing.

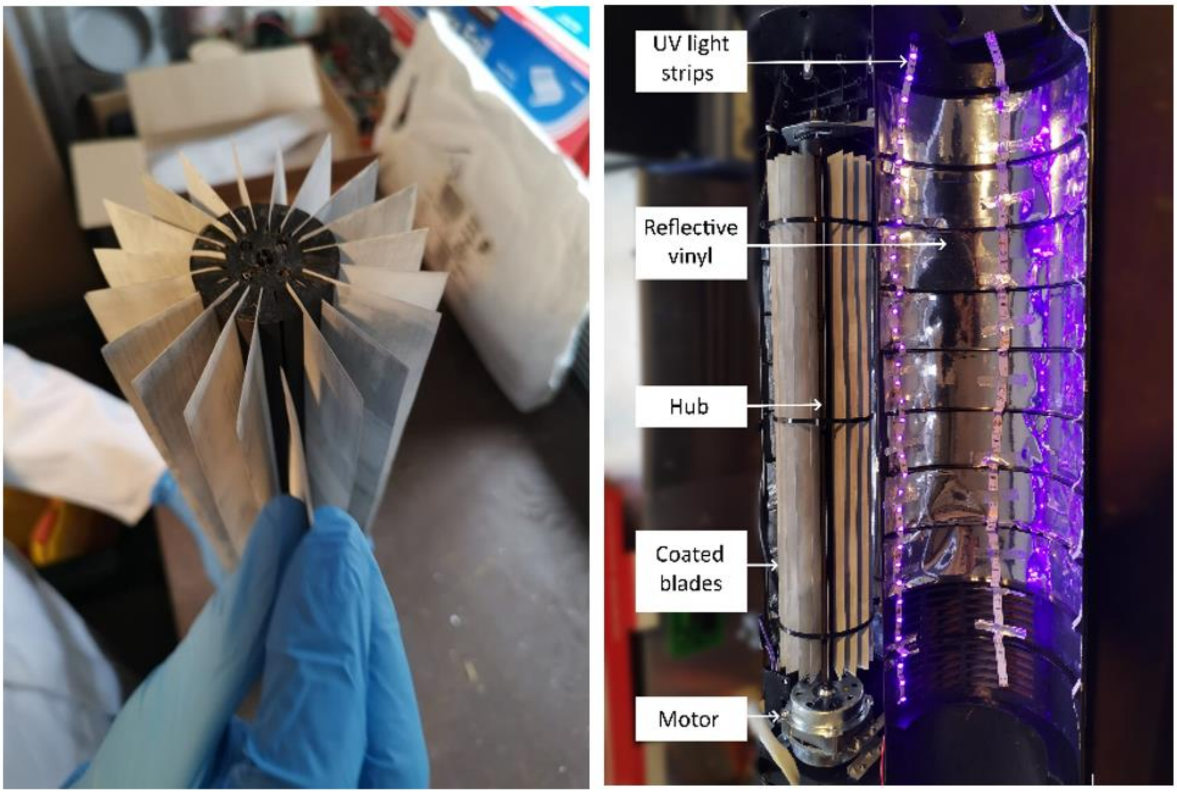


Figure 5.21 Images depicting insertion of blades and component breakdown

5.6 Prototype C: Custom built tower fan

Prototype C, as shown in Figure 5.22, set itself apart from the other prototypes by being designed entirely from scratch, without relying on any existing system. The design of this prototype presented a multitude of challenges, making it stand out in comparison to its counterparts. Moreover, it happened to be the largest among the prototypes, adding to the complexity of the project. One significant consideration during the design process was the ease of movement and transportation. To address this concern and reduce wear and tear on the system, a wheeled base was incorporated. This addition allowed for convenient mobility, ensuring that the prototype could be transported without difficulty. When it came to sourcing the components, it was imperative to be resourceful due to limited budget and time constraints imposed by SBRI. Many suppliers were approached to acquire the necessary parts and even resorted to improvising with unconventional materials. As an example, the lid of the system was repurposed from the bottom of a plastic bucket. Given the constraints in both time and budget, the complexity and functionality achieved in Prototype C. Despite the challenges posed, a functional tower fan system that met the desired objectives was achieved. The creativeness and unique component choices added an element of innovation to Prototype C. The ability to think outside the box and make the most of the available resources was evident throughout the project. Despite the complexities involved in designing and assembling the prototype, it exhibited impressive functionality.

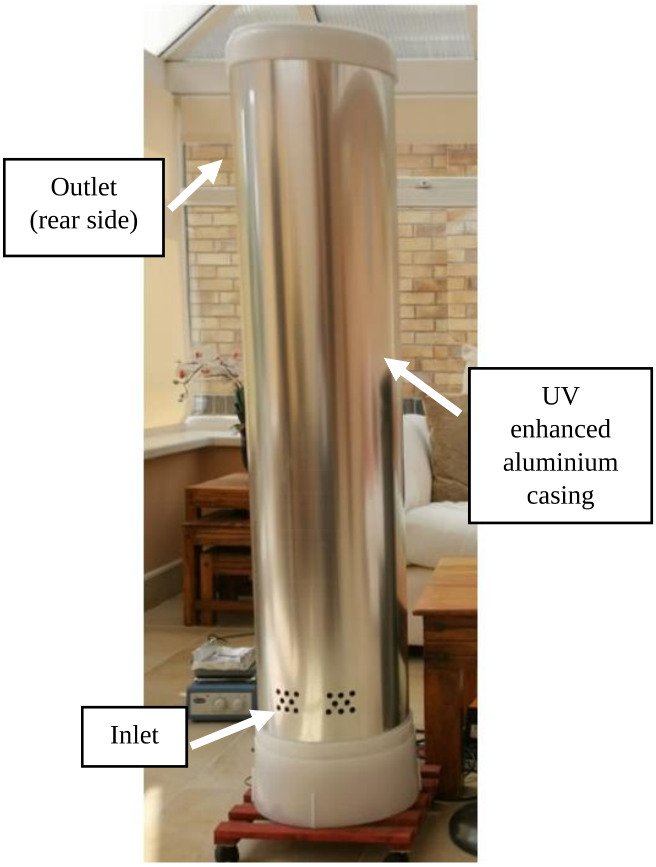


Figure 5.22 Image of completed custom built tower fan (Prototype C)

5.6.1 Design and conceptualisation

The development of the custom-built tower fan prototype begins with the crucial step of conceptualising its design. This entails taking into account several factors such as the required airflow and pressure, selecting appropriate materials, and finalising the overall size and shape of the fan. For Prototype C, the design concept was centred around replicating the successful aspects of Prototype B but on a larger scale. The objective was to create an optimal environment for the PCO reaction to occur, with the anticipation of achieving improved results.

One notable improvement in Prototype C was the incorporation of UV enhanced aluminium as the casing, instead of using reflective vinyl as in the previous prototypes. This decision was made with the intention of maximising the intensity of illumination within the system. The UV enhanced aluminium, possessing its reflective properties, would enhance the distribution of UV light and ensure that a higher level of illumination reached the interior of the tower fan. Consequently, this would amplify the effectiveness of the PCO reaction by promoting the activation of the TiO_2 coating and facilitating the decomposition of air pollutants. By emulating the design principles of Prototype B and scaling them up for Prototype C, it was aimed to create a more optimised environment for the air purification process. The larger size of Prototype C allowed for increased airflow and greater contact between the air and the TiO_2-coated surfaces, potentially improving the overall air purification efficiency. Table 5.4 displays a summary of the different design aspects of Prototype C.

Table 5.4 Design criteria for Prototype C

Aspect	**Action**
Fan Speed	Use additional fan at base of rotating hub to improve airflow
Casing Design	Use highly reflective UV enhanced aluminium as structure
Reflective Lining	UV enhanced aluminium will provide a much higher reflectivity compared to vinyl
LED Strips	Proper positioning and attachment for optimal lighting effects
Hub Design	Ensure strength, adaptability, and endurance for the system
Removal and Installation	Easy maintenance and quick adjustments or replacements
Increase overall air purification efficiency	Scale up design principles from Prototype B

5.6.2 3D modelling

Once the initial design concept for the custom-built tower fan prototype was established, the next step involved creating detailed 3D models. Unlike the previous prototypes, which were relatively straightforward in their design, this particular prototype required more complex considerations. To meet these demands, the design employed the use of CAD software. This software offered powerful tools for precise modelling and visualisation, greatly facilitating the overall design process.

By utilising CAD software, highly accurate and detailed designs that served as the definitive blueprints for constructing the custom-built tower fan prototype were produced. These designs provided a clear roadmap for assembling the different components, ensuring that the final product would align perfectly with the desired specifications and objectives. One significant advantage of incorporating CAD software into the design process was the ability to iterate and refine the prototype's design efficiently. Before moving on to the physical construction phase, virtual modifications to the CAD models could be made, allowing time to fine-tune the design and address any potential issues or challenges. This iterative approach helped minimise the likelihood of errors or the need for extensive rework, ultimately saving valuable time and resources. The software-enabled a systematic approach to the design process, ensuring that every aspect of the custom-built tower fan prototype was carefully considered and optimised. To visualise the design concept and highlight the systematic approach taken, Figure 5.23 was created. This visual representation effectively showcases the various components of the tower fan and the thoughtful design choices made throughout the process.

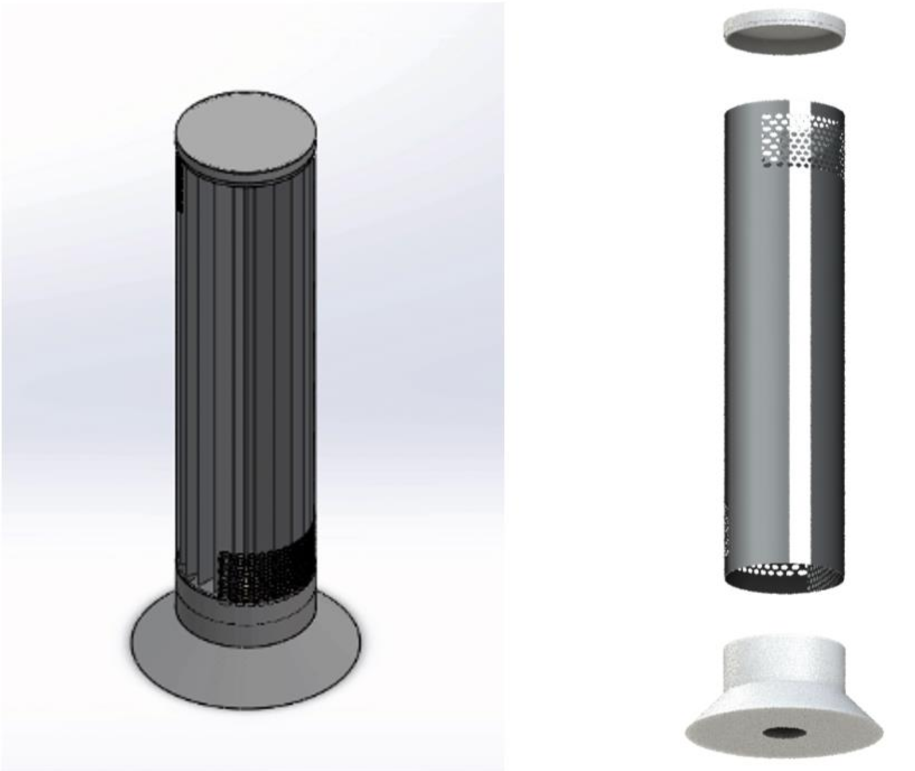


Figure 5.23 Visualisations of the CAD model for Prototype C

5.6.3 Component selection and fabrication

Suitable components like the impeller, housing, motor, bearings, and fibres are chosen based on the design. These components were be obtained from suppliers or fabricated internally if feasible.

A comprehensive analysis and investigation were conducted on numerous fibres to assess their compatibility and durability when coated with a TiO_2 solution. Initially, the fibres chosen for evaluation included copper wires with diameters of 0.1mm, 0.3mm, 0.4mm, and 0.5mm, brass fibres measuring 0.5mm, 0.6mm, and 1.1mm, steel wires, and plastic fibres. Each fibre type was carefully examined to determine its suitability for the desired coating.

To facilitate the sanding process, specific brushes similar to the one depicted in Figure 5.24 were utilised. These brushes were selected for their ability to effectively abrade the fibre surfaces and promote better adhesion of the TiO_2 solution. The sanding procedure helped overcome the initial adhesion challenges and prepared the fibres for subsequent coating application.

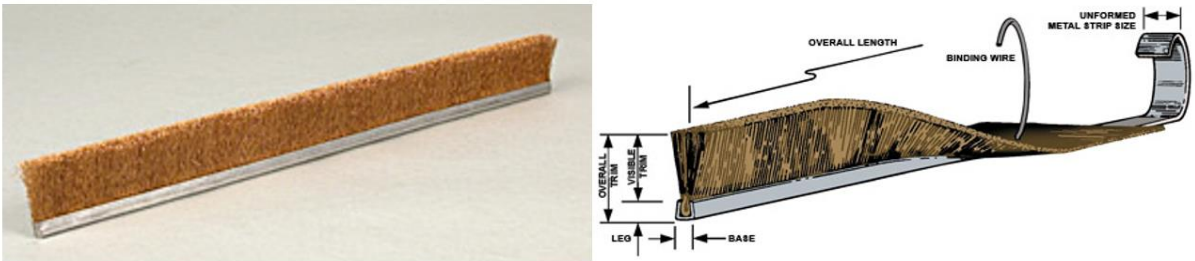


Figure 5.24 Depiction of strip design

In order to secure the fibres during the coating process, a structure resembling the one shown in Figure 5.24 was employed. This structure consisted of a steel rib designed to firmly clamp the fibres in place. The choice of this rib design was based on its established effectiveness in securely holding fibres, as it is a commonly used method in the industry. By adopting this design, the clamping strips required for the project could be produced with the assistance of a commercial manufacturer. This manufacturer would supply the appropriate material in the form of strips, ensuring consistency and ease of use. A total of 20 strips of each fibre material were provided for the experimentation, as shown in Figure 5.25. However, due to manufacturing constraints, it was necessary to sand and coat the fibres after they had been affixed to the steel rib. This sequencing ensured that the fibres were securely clamped in place during the sanding and coating processes. Although it added an extra step to the workflow, it was a necessary adjustment to accommodate the manufacturing limitations and ensure the successful implementation of the TiO_2 coating on the fibres.

To ensure an ample supply of fibres, brushes with 1 meter length and 8-10cm long fibres were utilised. The brush strips were selected, sanded and coated in the TiO_2 solution. Part of the design of the prototype was to ensure that strips could be easily affixed and removed from the prototype. This allowed shorter preparation time between experiments with more fibre types being tested. After each experiment has been completed. The prototype could be partially dismantled with a new fibre material installed and ready for the next set of tests. While the prototype did still take time to affix each brush strip correctly, the design worked reasonably well and all experiments could be performed within an acceptable timeframe.

Figure 5.25 Images of the brush strips used for Prototype C

To effectively cover the entire circumference of a cylinder, a total of 10 brushes will be affixed to a hub. The hub itself consists of three distinct pieces that work together to securely hold the brushes and form a cylindrical shape with exposed fibres. This design ensures that the brushes are evenly distributed around the hub, providing optimal coverage. The upper section of the hub is specially designed with a spindle, which allows for aligned rotation of the brushes. This feature ensures that the brushes rotate in synchronisation, resulting in a smooth and efficient operation of the fan. To achieve a fan with a diameter of 200mm, specific dimensions for the hub are required. The exact dimensions and configuration of the hub can be visualised in the accompanying Figure 5.26. This attention to detail in the hub's design guarantees that the fan operates with the desired diameter and achieves the intended functionality.

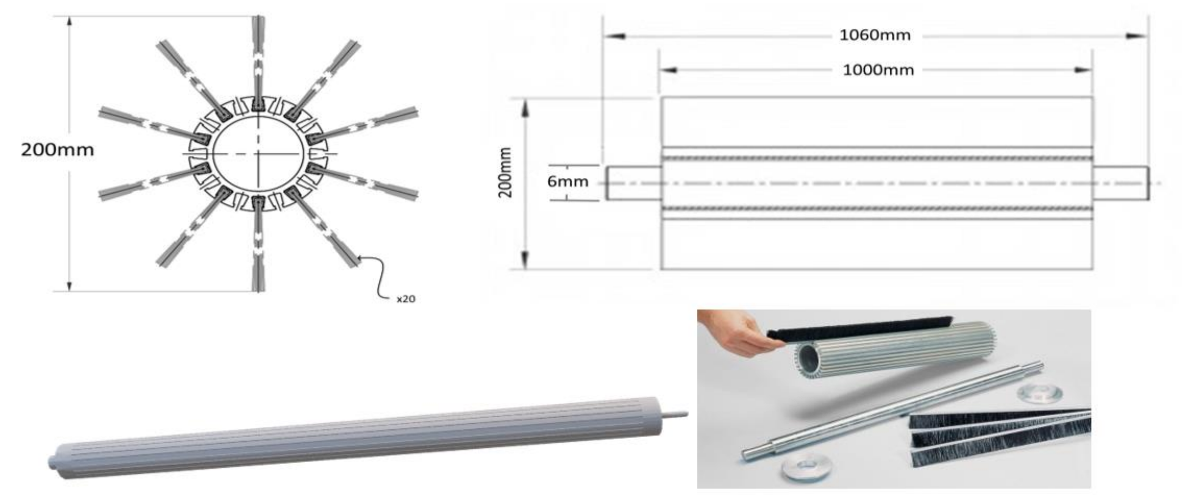


Figure 5.26 Drawing of hub and dimensions

The lower section of the hub plays a vital role in connecting the hub to the motor, which will ultimately rotate the entire assembly. This section contains a coupling mechanism that securely attaches the hub to the motor shaft, ensuring a stable and reliable connection. The coupling allows for the transfer of rotational motion from the motor to the hub, enabling the brushes to spin and perform their intended function. In addition to the lower section, there are intermediate parts within the hub design. These intermediate parts primarily serve a structural purpose, helping to maintain the straightness and stability of the brushes during rotation. By incorporating these structural components, the brushes are effectively supported and aligned, ensuring smooth and consistent operation. For a better understanding of the hub's design, a model of the part can be observed in Figure 5.27. This visual representation provides a clear depiction of the various sections and components within the hub, illustrating their roles and how they come together to form a cohesive unit. An important consideration in the design of this hub is the deliberate avoidance of adhesives in its construction. This adhesive-free approach is crucial for several reasons. Firstly, the use of adhesives can introduce VOCs and other pollutants into the system. These substances can have a detrimental impact on the overall performance and efficiency of the fan, as they can interfere with the airflow and potentially compromise the air quality. Furthermore, adhesives may degrade or weaken over time, especially when exposed to heat or continuous rotation. By eliminating the need for adhesives, the hub design ensures a more durable and reliable construction, minimising the risk of component failure or degradation.

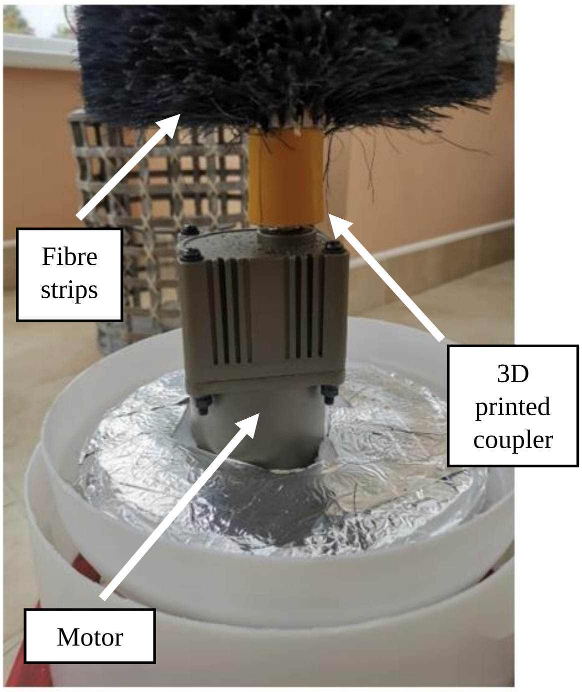


Figure 5.27 Image of base view of Prototype C

The air purification system prototype incorporates UV light with a wavelength of 365 nm, which was chosen due to its widespread availability in the market. To optimise the system's design, UV LED strips with a density of 60 LEDs per meter were employed, as depicted in Figure 5.28. These LED strips operate on 12 V DC and consume only 4.8W of power per meter, resulting in minimal additional power requirements. The utilisation of UV LED strips offers several advantages. Firstly, it allows for the generation of a high intensity of UV light within a relatively small space, ensuring efficient photocatalytic reactions for air purification. The density of 60 LEDs per meter ensures uniform coverage and effective illumination of the target area. Furthermore, the UV LED strips provide flexibility in adjusting the luminescence during the testing phase. If higher light intensity is required for optimal purification performance, additional LED strips can be easily incorporated into the system's design. This adaptability allows for fine-tuning and optimisation based on specific purification needs. In the process of air purification through photocatalysis, it is crucial not only to provide the necessary light but also to effectively displace the purified air. To address this requirement, a cylindrical brush will be utilised, which will be driven by a motor commonly found in tower fans. This configuration enables the rotation of the brush, facilitating the movement of air and allowing for efficient air circulation and purification within the designated area.

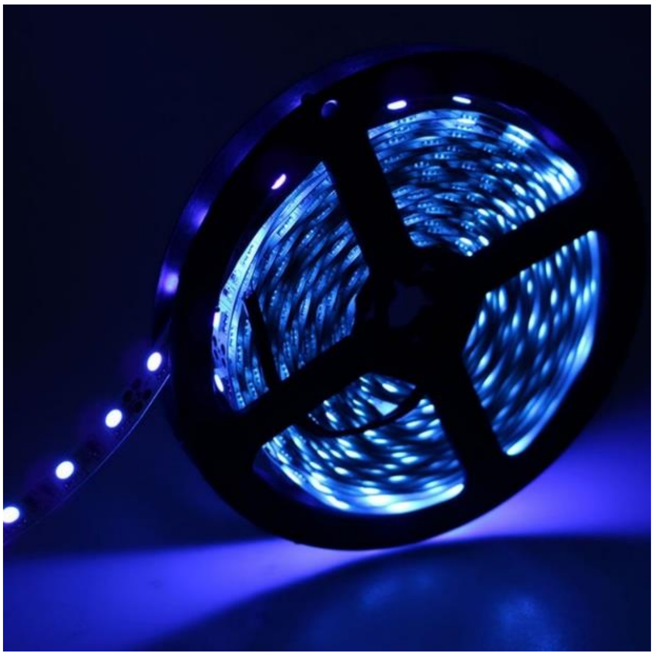


Figure 5.28 Image of LED strip reel

For the current air purification system prototype, a motor with an AC 220V power supply and a power rating of 50W has been chosen, as depicted in Figure 5.29. This motor is specifically selected to meet the requirements of the system and ensure its optimal performance. The motor's maximum rotating speed is 1250 RPM, which can be regulated using a variac to achieve the desired rotation speed.

The selected motor is well-suited for the air purification system as it provides sufficient rotational speed to generate an appropriate displacement of the air. This rotation speed is crucial for effectively circulating the air and facilitating the purification process within the system.

Figure 5.29 displays the compact size and design of the chosen motor. Its compact nature makes it suitable for integration into the air purification system, occupying minimal space. Furthermore, the motor operates efficiently, consuming only 50W of power. This energy-efficient characteristic helps to minimise the power requirements of the system, contributing to its overall sustainability.

One advantage of selecting this particular motor is its compatibility with the commonly available AC 220V power supply. This compatibility simplifies the electrical setup of the system and allows for easy connection to the power source. Additionally, the motor's power rating and operating voltage make it widely accessible in the market, ensuring convenient availability for procurement.

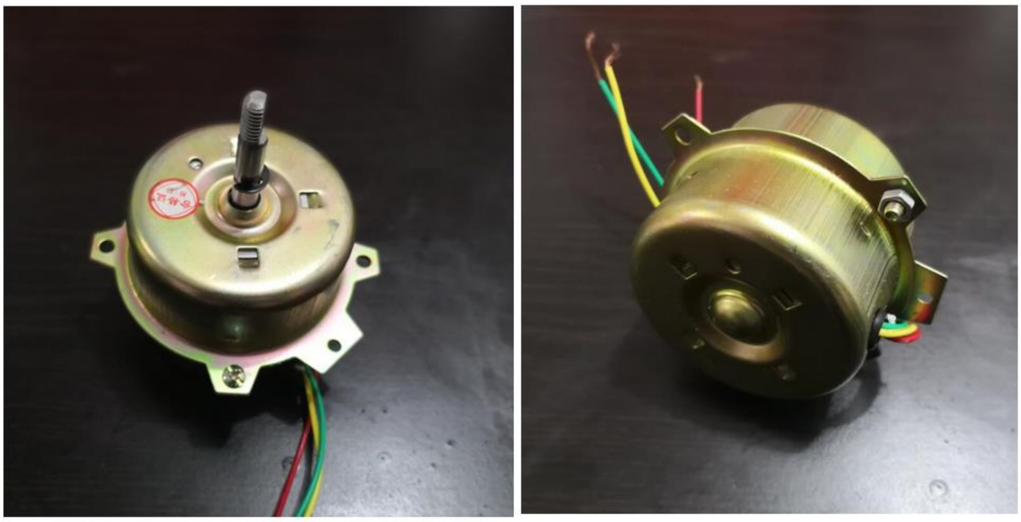


Figure 5.29 Images of 220V AC motor

In summary, the air purification system requires an effective displacement of purified air. To achieve this, a cylindrical brush will be rotated using a motor typically found in tower fans. The selected motor operates at a voltage of 220V AC and consumes only 50W of power, providing sufficient rotational speed to generate an adequate displacement of the air. The compact size and easy availability of the motor make it an ideal choice for the current prototype.

The lower part of the shell will be the base, which will be made of wood or 3D printed material to hold the motor and support the prototype. This part needs to be the heaviest of the three elements, to ensure that the centre of gravity is located in the lower half of the fan body. This will provide better balance and stability to the system. The base is an essential component that holds the entire system together, and its design should be robust and durable. The intermediate part of the air purification system, also referred to as the body, plays a crucial role in the overall functionality of the system. Figure 5.30 demonstrates this component, which consists of a reflective tube made of metal. One of the primary functions of the body is to provide light reflection within the system. The reflective nature of the metal tube ensures that the UV light generated by the UV LED strips is effectively distributed throughout the interior. This reflection enhances the exposure of air passing through the system to the UV light, optimising the photocatalytic reactions that occur during air purification. In addition to its role in light reflection, the body also serves as the housing that contains the fan and other system components. Its cylindrical shape provides a suitable enclosure, maintaining the integrity of the system and protecting the internal components. This design ensures that all the necessary elements of the air purification system are securely housed and properly aligned for optimal performance. To facilitate the flow of air through the system, the body is designed with perforations. These perforations allow air to enter the system from the bottom and exit from the top, creating a controlled airflow path. By implementing this airflow configuration, the body ensures that the air passing through the system is effectively exposed to the purifying brush. The perforations in the body enable a sufficient volume of air to flow through the system, providing ample contact time between the air and the purifying brush.

Figure 5.30 Image of UV enhanced aluminium casing

The last part, located at the upper end of the system, is the lid. This part could be 3D printed and will serve to block and direct the air flow, leading it to the outlet. The lid is an essential component that helps in the efficient flow of purified air out of the system. In summary, the shell of the air purification system will be composed of three main structural elements, namely the base, body, and lid. The base will be made of wood or 3D printed material to hold the motor and support the prototype. The intermediate part, made of reflective metal, will serve as the housing that will contain the fan and have perforations to ensure proper airflow. The lid will be 3D printed and will serve to block and direct the air flow, leading it to the outlet. This shell design will ensure the stability, durability, and efficiency of the air purification system.

5.6.4 Assembly

Once all the individual components are prepared, they are carefully assembled to construct the tower fan prototype. This crucial step involves the precise attachment of the impeller to the motor shaft, the proper connection of the housing and inlet, and the integration of the necessary electrical and control systems. To ensure the brush strips remain securely in place during operation, a design approach has been employed. The ribs of the brush strips have been specifically shaped into a triangular form. This unique design feature allows the brush strips to fit tightly into the grooves of the hub. The grooves themselves are crafted to accommodate the brush strips with precision. In order to provide maximum stability and retention, the grooves are tapered towards the outer surface of the hub. This tapering design enhances the grip and ensures a firm hold on the fibres or blades of the brush strips. This construction allows for the reliable performance of the tower fan prototype.

One notable advantage of this design is its ability to facilitate the easy exchange of brush strips for the purpose of testing different materials. The triangular ribs and corresponding grooves allow for straightforward removal and insertion of the brush strips, enabling the quick and convenient switching between different fibre or blade compositions. This flexibility is invaluable for conducting experiments and evaluating the performance of various materials. For a comprehensive visual representation of the process involved in inserting the brush strips into the hub, as shown in Figure 5.31. This illustrative guide provides a step-by-step demonstration of the precise assembly technique, ensuring that the brush strips are securely and accurately positioned within the hub for optimal performance of the tower fan prototype.

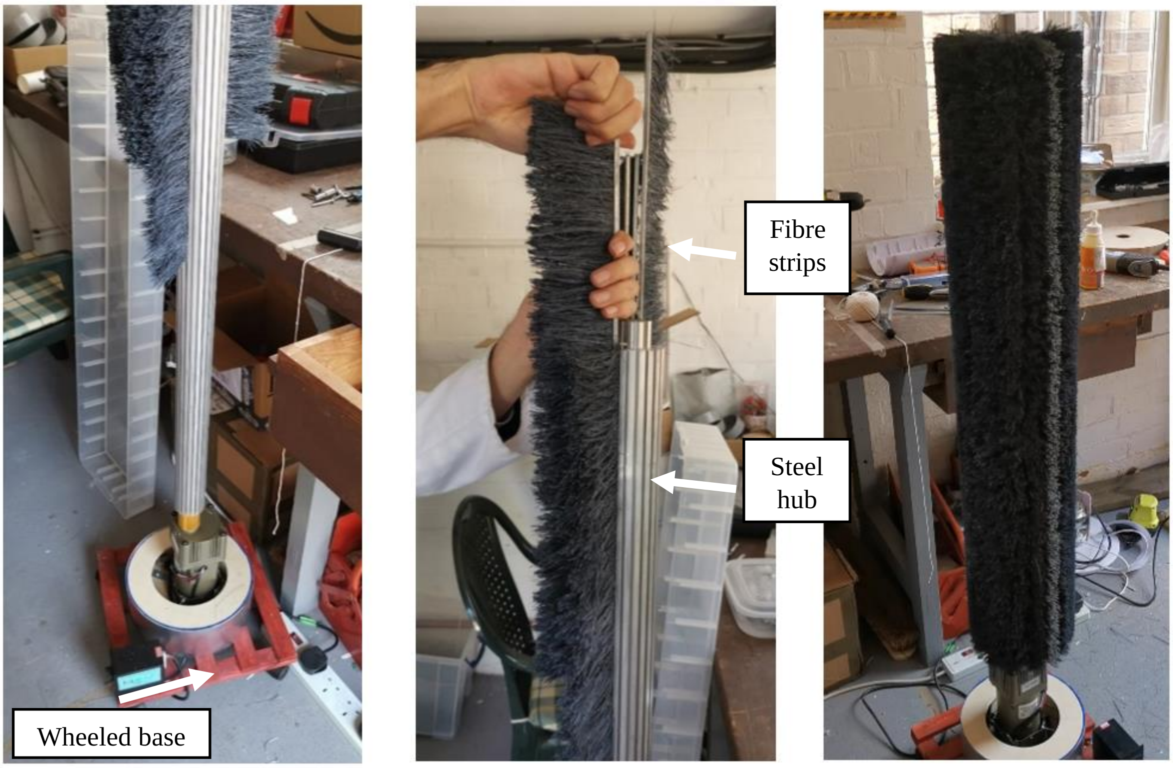


Figure 5.31 Images depicting method of inserting fibre strips into hub

Once all the brush strips were successfully inserted into the hub and securely mounted to the motor, the next step involved the insertion of the outer casing, which in this case was a UV enhanced aluminium. The base of the tower fan prototype was specifically designed with grooves to facilitate the easy mounting of the UV enhanced aluminium. With the UV enhanced aluminium properly positioned on the base, it was further secured using screws to enhance the overall structural integrity of the system.

To ensure optimal air treatment, sixteen inlet holes were carefully created at the base of the UV enhanced aluminium, as shown in Figure 5.32. These inlet holes served as entry points for the polluted air to enter the tower fan prototype. Conversely, sixteen outlet holes were strategically made at the top of the UV enhanced aluminium, enabling the treated air to be expelled from the system. This configuration allowed for extended exposure of the polluted air within the UV enhanced aluminium, maximising the effectiveness of the air purification process.

To enhance the interior illumination and maximise the photocatalytic reaction, the UV enhanced aluminium was lined with LED strips. Each LED strip was connected to ensure consistent and uniform lighting throughout the UV enhanced aluminium. Notably, the lighting system was powered separately from the motor, allowing for independent control and testing of the tower fan prototype with and without UV light.

This careful integration of the UV enhanced aluminium, LED strips, and separate power supply for lighting demonstrates the comprehensive design considerations given to create an efficient and adaptable tower fan prototype for air treatment purposes.

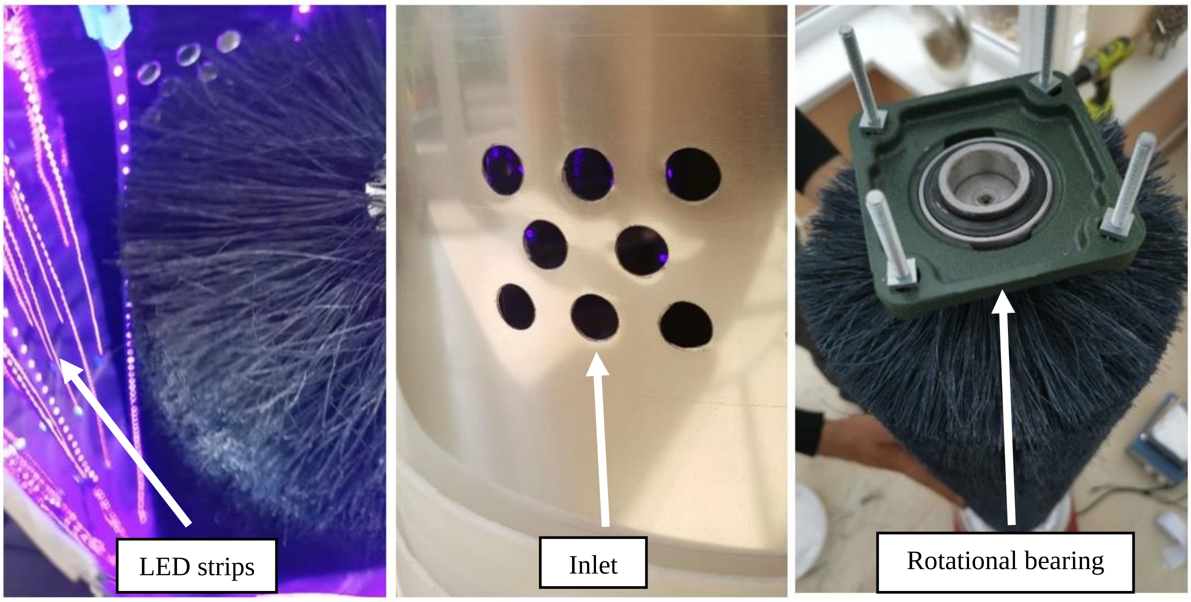


Figure 5.32 Images displaying interior view of casing, inlet holes and rotational bearing

At the hub's summit, a wooden plate and bearing was used. The rotational bearing, as shown in Figure 5.32, would hold the hub in place but also allow it rotate smoothly. As this prototype would need to be dismantled so that the brush fibres could be changed for different testing criteria, the top of the prototype and casing could be removed easily to allow for this. The bearing was fixed to the lid and the prototype was complete.

Chapter 6 Field Testing of Pre-Prototype MopFan Air Purification Systems

This chapter provides a comprehensive account of the field testing carried out on three early-stage MopFan prototypes. Throughout the course of this project, three distinct prototypes were constructed and subjected to a series of rigorous tests under real-world conditions. The primary objective of these tests was to evaluate the effectiveness of the prototypes in removing VOCs, with a particular focus on the removal of formaldehyde—a widely recognised and potentially harmful pollutant.

The testing process encompassed a wide range of parameters and variables, with each prototype undergoing an array of assessments and measurements. An analysis was conducted to gauge the efficacy of pollutant removal, carefully examining the concentration of pollutants in the air before and after the operation of the prototypes. The airflow dynamics within the testing environment were closely monitored to assess the ability of the prototypes to efficiently circulate and filter the air, thus facilitating effective pollutant removal.

In addition to pollutant removal efficacy, the system performance of the prototypes was thoroughly evaluated. Detailed metrics and measurements were collected to assess factors such as noise levels, power consumption, and operational stability. A comprehensive testing comparison was also conducted, comparing the performance of the three prototypes to identify any variations or disparities in their respective capabilities.

Beyond the examination of pollutant-related aspects, other critical environmental factors were taken into account during the testing phase. The levels of CO_2 were closely monitored to ensure that the prototypes maintained adequate ventilation and minimised any potential risks associated with high CO_2 concentrations.

Throughout the testing process, opportunities for improvement were identified, providing insights into enhancing the performance and functionality of the SBRI MopFan prototypes. These reflections encompassed areas such as design modifications, system optimisation, and the incorporation of advanced technologies to further enhance pollutant removal efficiency.

By documenting the extensive testing conducted on the SBRI MopFan prototypes and providing an in-depth analysis of the results, this chapter serves as a valuable resource for understanding the performance, capabilities, and potential areas of development for these innovative air purification solutions.

6.1 Preliminary observations

During the initial stage of the experimental tests, the primary objective was to assess the effectiveness of the concept under scrutiny, as shown in Figure 6.1. To achieve this, a natural sponge was carefully chosen and prepared by applying a specialised coating of TiO_2 solution. This innovative approach aimed to leverage the photocatalytic properties of TiO_2. To control the photocatalysis process and create an ideal testing environment, the coated sponge was strategically placed inside a sturdy plastic box. This box served as a containment vessel, ensuring that the experiment could be conducted under controlled conditions. The box was specifically designed to accommodate two meters of ultraviolet light LED strips, emitting a precise wavelength of 420nm, known for its optimal interaction with the TiO_2 coating.

To harness the maximum potential of the ultraviolet light, the interior of the box was lined with reflective vinyl. This reflective surface acted was used to enhance the distribution and intensity of the UV light throughout the entire enclosure, thereby providing the coated sponge with the most favourable conditions for its photocatalytic activity.

By implementing these measures, the experimental setup aimed to optimise the efficiency and reliability of the concept being investigated. This comprehensive approach aimed to provide a solid foundation for subsequent stages of the testing process, where the performance of the coated sponge under different conditions and variables would be thoroughly examined. The results of these observations were not recorded and were carried out using an impromptu air quality monitor. The monitor indicated a reduction in VOC within the test box which indicated an PCO reaction was occurring.

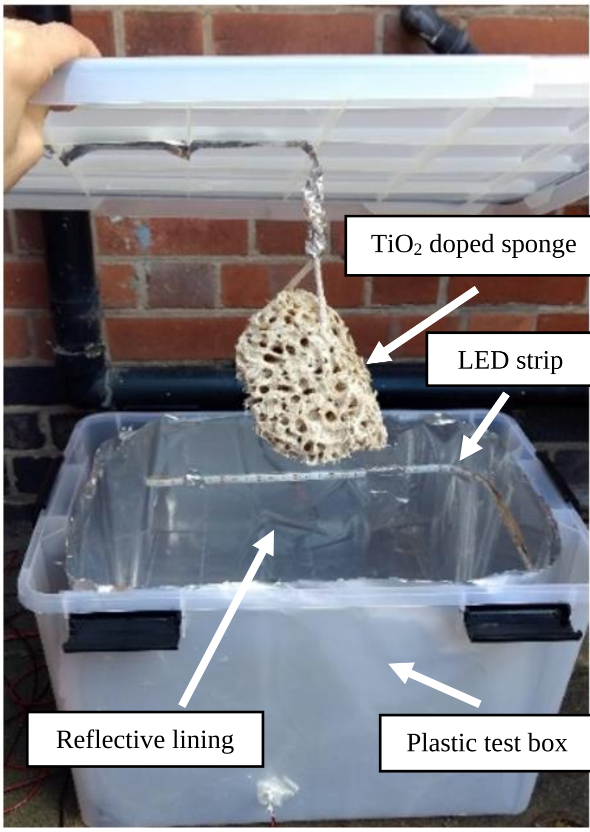


Figure 6.1 Image displaying preliminary testing of PCO reaction with TiO_2 doped sponge

6.2 Particle removal tests

In order to assess the performance of the prototype in capturing and filtering suspended particles, a comprehensive test was conducted. To generate a variety of particle sizes, a burning smudge stick was chosen as the source of PM particles. The continuous combustion of the smudge stick ensured a steady supply of particles throughout the test. Table 6.1 displays a summary of the particle removal testing methodology.

Table 6.1 Particle removal testing methodology

Testing Methodology	**Description**
Objective	To assess the performance of the prototype in capturing and filtering suspended particles
Particle Source	Burning smudge stick chosen to generate a variety of particle sizes

Particle Supply	Continuous combustion of the smudge stick ensured a steady supply of particles
Test Setup	Transparent chamber used for all experiments
Access Door	Strategically placed on one side of the chamber to facilitate easy access and sample replacement
Test Procedure	Prototype subjected to the flow of particles generated by the burning smudge stick
Filtration Process	Prototype's filtration system captured and removed suspended particles from the air
Measurement of Filtration Efficiency	Particle concentration measured before and after passing through the prototype
Observation Capability	Transparent chamber allows visual assessment of particle behaviour and filtration process
Sample Replacement	Access door enables smooth replacement of samples for multiple tests
Insights and Adjustments	Results obtained provide insights for evaluation and potential improvements
Data Analysis	Analyse collected data to evaluate filtration efficiency across different particle sizes
Goal	Ensuring prototype's effectiveness in improving indoor air quality by removing harmful particulate matter

The filtration efficiency of the prototype in removing PM particles was measured using a specialised apparatus, as depicted in Figure 6.2. This apparatus was specifically designed to evaluate the effectiveness of the prototype's filtration system. The test setup involved a transparent chamber where all the experiments took place. To facilitate easy access and sample replacement, an access door was strategically placed on one side of the chamber.

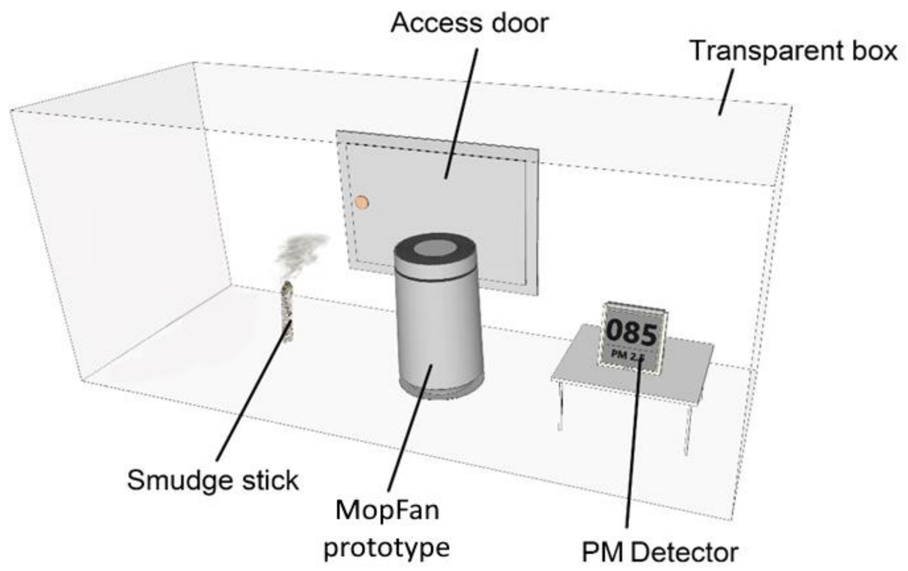


Figure 6.2 Diagram of pollutant removal testing apparatus

During the test, the prototype was subjected to the flow of particles generated by the burning smudge stick. As the particles were generated within the transparent chamber, the prototype's filtration system went into action, aiming to capture and remove the suspended particles from the air. By measuring the concentration of particles before and after passing through the prototype, the filtration efficiency could be quantified. This testing methodology ensured a controlled and consistent environment to evaluate the prototype's performance in capturing and filtering PM particles.

The transparent chamber allowed a visual observation the behaviour of the particles and assess the effectiveness of the prototype's filtration process. The access door facilitated the smooth replacement of samples, enabling multiple tests to be conducted efficiently. The results obtained from this testing procedure provide insights into the prototype's ability to capture and filter suspended particles. This testing methodology serves as a crucial step in the development and optimisation of the prototype, ensuring its effectiveness in improving indoor air quality by removing harmful particulate matter.

6.2.1 Results and discussion

Following the passage through the Prototype C, a significant proportion of PM 2.5 and PM 10 particles were effectively intercepted by the brush component. However, some particles of varying sizes managed to bypass the brush and were subsequently captured for measurement using a PM detector, specifically the LKC-1000S+ model from TEMTOP, a multifunctional air quality meter. The PM detector played a crucial role in quantifying the concentration of remaining particles that were not captured by the brush. It provided accurate measurements of both PM 2.5 and PM 10 mass concentrations. As shown in Figure 6.3 and 6.4, with Prototype C activated, the PM10 and PM2.5 concentrations reduced at a faster rate, with the eventual decreased concentration of each PM at the end of the test. During the PM10 test, an eventual decrease of 89% removal rate efficiency was observed. In the PM2.5 test, a 92% removal rate efficiency was found. It is important to note that there were certain limitations associated with the equipment used in this experiment. One limitation pertained to the maximum PM concentrations that the equipment could accurately measure. These limitations should be taken into consideration when interpreting the results and drawing conclusions from the experiment. To provide a visual representation of the findings, the results obtained from the PM detector and recorded mass concentrations of PM 2.5 and PM 10 are presented in Figures 6.3 and 6.4, respectively. As shown in both graphs, the flat line section is where the particle monitor reached the limit of its range, as the testing chamber was heavily polluted by the particles released from the smudge stick. The smudge stick stopped burning after 30 minutes, the particles within the polluted smoke began to settle at the bottom of the sealed chamber, explaining the drop in PM concentration that is witnessed even with MopFan switched off.

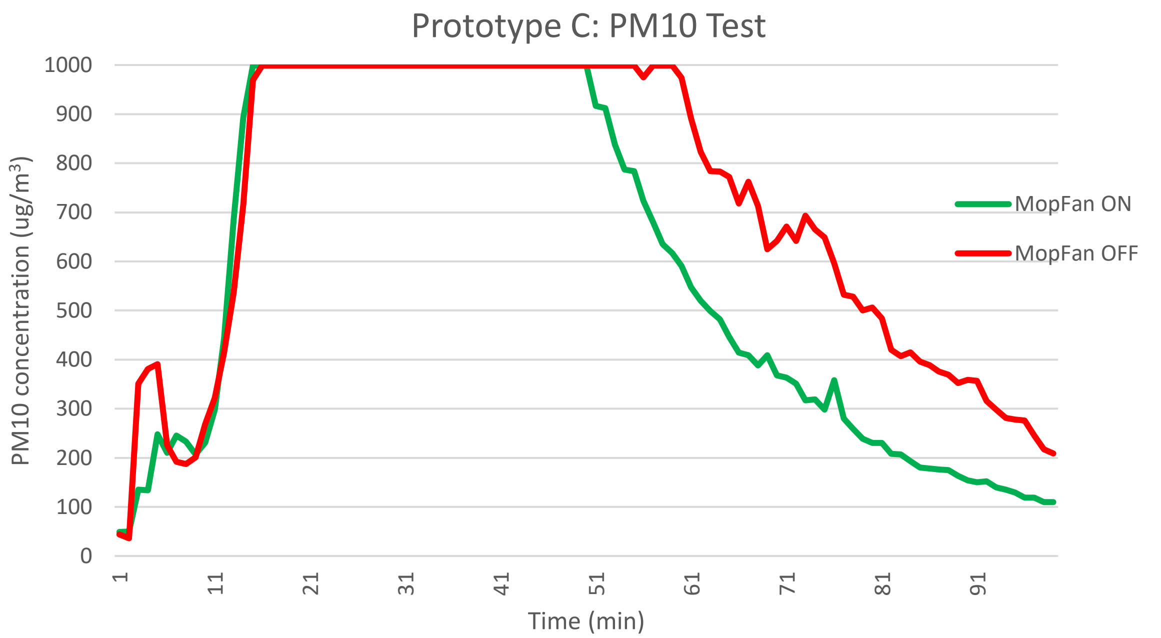


Figure 6.3 Graph of PM10 concentration variation (Prototype C)

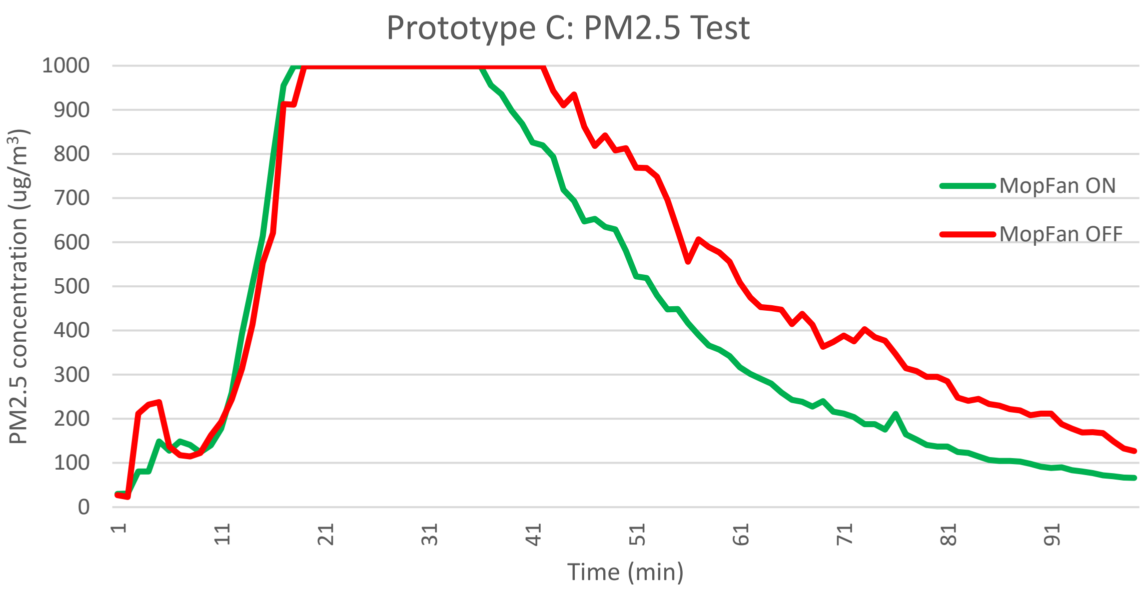


Figure 6.4 Graph of PM2.5 concentration variation (Prototype C)

6.3 Field tests

For the experimental testing, a real room was selected. The chosen room had an approximate size of 45m^2, providing a realistic environment for evaluating the prototype's performance, as shown in Figure 6.5. To ensure flexibility and proper ventilation between tests, the room chosen was a conservatory. During the testing phase, measures were taken to maintain isolation and prevent any external interference. Windows and doors were securely shut and sealed to prevent any potential leakage that could compromise the accuracy of the results. This isolation ensured that the test environment remained consistent throughout the experimentation process.

To ensure the reliability of the results, multiple tests were conducted before recording the data. This approach allowed for a thorough assessment of the prototype's performance and minimised the impact of external factors. The repetition of tests ensured that any variations in results were accurately captured and accounted for. This was crucial in maintaining the integrity of the experimental setup and obtaining reliable data specific to the prototype's performance.

The testing process was further streamlined through the utilisation of Smart Plugs, enabling remote control of the room's ventilation. This feature allowed adjustment to the ventilation levels remotely, ensuring a safe environment for re-entry without exposing themselves to high pollutant levels. By using Smart Plugs, the remote regulation of the ventilation system was possible, striking a balance between maintaining a controlled environment and ensuring safety.

The comprehensive approach taken in selecting a real room, implementing isolation measures, conducting repeated tests, and utilising remote control capabilities contributed to the accuracy and reliability of the experimental results. This rigorous testing methodology strengthens the validity of the data obtained and facilitates a comprehensive evaluation of the prototype's performance in a real-world setting.

Figure 6.5 Image of testing room for SBRI prototypes (conservatory)

6.3.1 Air quality monitor

To evaluate the effectiveness of the prototypes developed, an air quality monitor was utilised. This monitoring device played a crucial role in collecting and recording precise measurements of VOCs and HCHO at regular intervals. These measurements served as vital indicators for assessing and evaluating the overall air quality in the environment. The air quality monitor used for this purpose was the Temtop Air Quality Monitor Particle Detector, as shown in Figure 6.6. This specialised device is designed to measure and monitor indoor air quality by detecting and analysing various types of PM present in the air. These particles can include dust, pollen, smoke, and other pollutants suspended in the environment. Equipped with advanced sensors, the air quality monitor provides real-time measurements of particulate matter levels. It categorises particles into two main categories: PM2.5 and PM10, based on their respective sizes. PM2.5 refers to particles with a diameter of 2.5 micrometres or smaller, while PM10 includes particles with a diameter of 10 micrometres or smaller. The air quality monitor's sensors detect and quantify these particulate matter levels, allowing users to gain insights into the air quality of their surroundings. By providing numerical values, usually in micrograms per cubic meter ($\mu g/m^3$), the device presents a clear representation of the concentration of particulate matter present in the air. The availability of real-time measurements and accurate detection capabilities offered by the Temtop Air Quality Monitor Particle Detector allows an assessment of the air quality in the given environment. The utilisation of the air quality monitor in evaluating the prototypes provides valuable data on the levels of VOCs, HCHO, and particulate matter in the air. This information helps in understanding the effectiveness of the prototypes in purifying and improving the air quality.

Figure 6.6 Image of Temtop Air Quality Monitor Particle Detector

6.3.2 Testing methodology

To ensure consistent and comparable results, a standardised methodology was employed across all tests, including those conducted with different prototypes. The testing procedure began by arranging all the components in their designated positions. A thermal plate was positioned one meter away from the air purifier. This plate was set to a constant temperature of 80 °C and served as a means to evaporate 1ml of methanol. Methanol is commonly used to create VOCs in experiments due to its safety, moderate volatility, stability, versatility, accessibility, and cost-effectiveness. It allows for controlled and precise generation of VOCs, is relatively safe to handle. Concurrently, the fan was activated to simulate normal operating conditions. In cases where UV testing was part of the experiment, the UV light was switched on. It is important to note that the absence of UV light implies the absence of any photocatalytic reaction, while the presence of UV light enables UV- TiO_2 interaction, facilitating the desired process.

Throughout each test, air quality readings were recorded every minute for a duration of two hours. This monitoring allowed for a comprehensive analysis of the performance and effectiveness of the prototypes. Subsequently, the room was ventilated, allowing a minimum gap of 2 hours between each test to ensure proper air circulation and to avoid any residual impact from the previous experiment.

Multiple tests were conducted for each material, ensuring a thorough evaluation of their capabilities. Table 6.2 provides for a summary of the testing methodology used for the SBRI prototypes.

Table 6.2 Summary of the testing methodology for the SBRI prototypes

Step	**Description**
Standardised Methodology	Consistent and comparable results achieved by employing a standardised methodology for all tests conducted with different prototypes.
Component Arrangement	All components arranged in their designated positions for testing.
Thermal Plate Setup	A thermal plate placed one meter away from the air purifier, set to a constant temperature of 80 °C, used to evaporate 1ml of methanol.
Fan Activation	The fan activated to simulate normal operating conditions during testing.
UV Testing (if applicable)	UV light switched on to enable UV-TiO_2 interaction and facilitate the desired photocatalytic process.
Air Quality Readings Recording	Air quality readings recorded every minute for a duration of two hours during each test.

Monitoring	Comprehensive analysis of prototype performance and effectiveness through monitoring of air quality readings.
Ventilation	Room ventilated between each test, allowing a minimum gap of 2 hours to ensure proper air circulation and prevent residual impact from previous experiments.
Multiple Tests	Multiple tests conducted for each material to ensure thorough evaluation of capabilities.
Presentation of Results	Notable and significant results selected and presented in this document, offering a concise overview of achieved outcomes.

6.3.3 Prototype A: Centrifugal fan

After the construction of the centrifugal fan prototype, as shown in Figure 6.7, was completed, the next crucial step was to subject it to comprehensive testing. This testing phase aimed to evaluate the performance, functionality, and efficiency of the prototype under various operating conditions. The testing process involved subjecting the centrifugal fan to simulated real-world usage. This included assessing its airflow capacity, power consumption, noise levels, and overall effectiveness in providing adequate ventilation and air circulation.

Additionally, the prototype underwent testing to assess its durability and reliability. This involved subjecting the fan to extended periods of operation to observe its performance under continuous use. Throughout the testing phase, data and observations were carefully recorded and analysed. Any issues or areas for improvement identified during testing were documented and used to refine and optimise the design of the centrifugal fan prototype.

Figure 6.7 Image of centrifugal fan (Prototype A) prior to testing

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6.3.3.1 Testing and iteration

The assembled prototype of the system undergoes a series of rigorous performance tests to evaluate its airflow, pressure, and overall efficiency. These tests are crucial in assessing the prototype's capabilities and identifying any areas that require adjustments or modifications to enhance its performance. During the testing phase, specific attention is given to the concentration of HCHO present in the air. To measure the effectiveness of the system in removing HCHO, an air quality monitor was utilised and the test data was carefully recorded and analysed. The hot plate burning switched on from the beginning of the test till the end.

The results obtained from these tests are graphically represented in Figure 6.8, providing insights into the reduction of HCHO concentration. Each line represents different testing conditions, UV on and UV off. With “UV on” a reduction in the peak concentration is recorded. Furthermore, the HCHO value at the completion of testing shows a 0.41mg/m^3 reduction compared to when “UV off”. The data in Figure 6.8 clearly illustrates the decrease in HCHO concentration as the photocatalytic reaction occurs within the system. The concentration of HCHO steadily decreases from an initial value of 0.65 mg/m^3, ultimately reaching a low value of 0.24 mg/m^3 at the completion of the test. This reduction demonstrates the efficiency and effectiveness of the prototype in purifying the air by eliminating HCHO. The compelling evidence presented in Figure 6.8 reinforces the potential of the photocatalytic process as a reliable method for removing HCHO from indoor environments. The successful breakdown and conversion of HCHO into less harmful substances highlight the positive impact of the prototype in improving air quality and creating a healthier living or working environment. This outcome holds great promise for addressing indoor air quality concerns, particularly in environments where HCHO emissions are a prevalent issue, such as newly furnished spaces or areas exposed to high levels of off-gassing. The monitored results presented in Figure 6.8 offer tangible evidence of the successful implementation of the centrifugal fan in conjunction with the photocatalytic process. This combination proves to be an effective means of combatting HCHO pollution, leading to improved air quality and a healthier living or working environment.

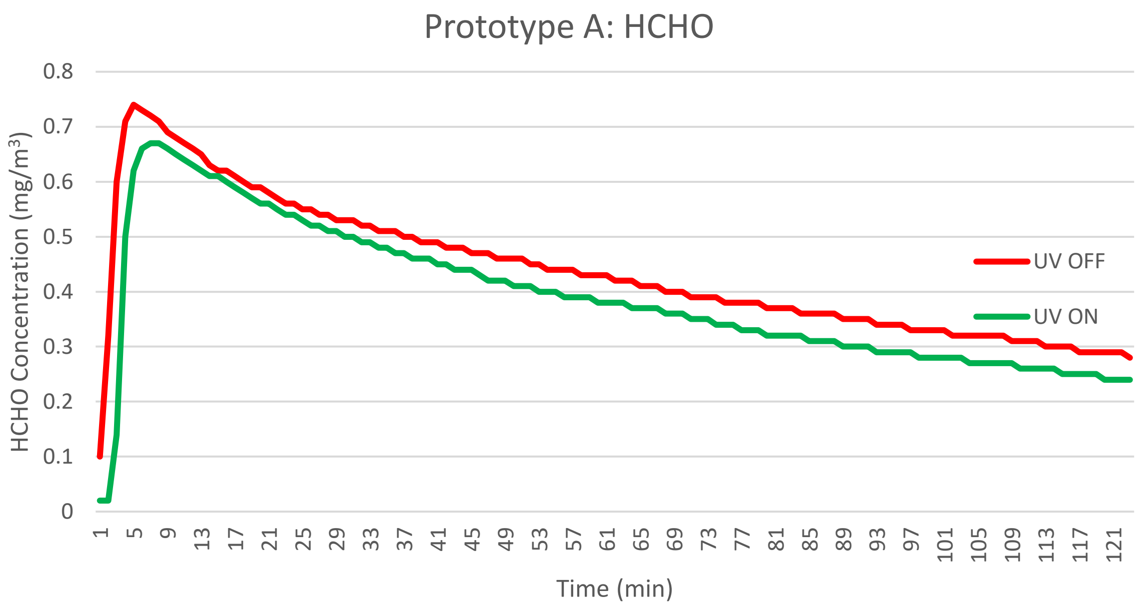

Figure 6.8 Graph displaying variation in HCHO concentration (Prototype A)

Figure 6.9 provides a visual representation of the data collected during the tests conducted using the centrifugal fan, specifically monitoring the concentration of VOCs. The recorded results reveal a substantial reduction in the level of VOCs concentration within the testing environment, with the concentration dropping to approximately 0.85 mg/m^3 after a duration of 2 hours from an initial value of 2.25 mg/m^3. A reduction in the concentration peak is recorded, with VOC concentration in ‘UV on’ decreasing faster. The findings presented in Figure 6.9 serve as compelling evidence of the effectiveness of the centrifugal fan in actively reducing

VOCs within the surrounding environment. This reduction in VOCs concentration is a noteworthy accomplishment, considering the potential adverse effects that these compounds can have on indoor air quality and human health. The monitored results not only demonstrate the successful implementation of the centrifugal fan but also validate the efficiency of its associated air purification mechanism. Through a combination of effective air circulation and the action of the purification system, the concentration of VOCs is visibly diminished over the course of the 2-hour testing period. The reduction in VOCs concentration showcased in Figure 6.9 underscores the importance of employing proper air purification technologies and systems to combat the negative impact of volatile organic compounds.

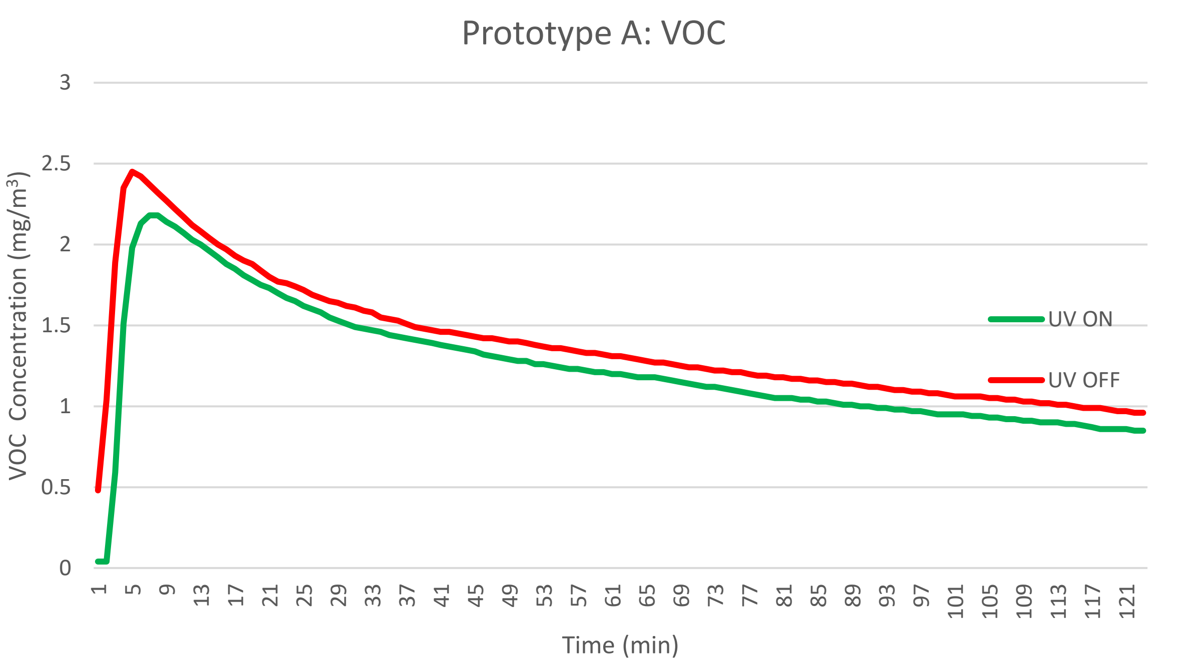

Figure 6.9 Graph displaying variation in VOC concentration (Prototype A)

6.3.3.2 Discussion

After analysing the test results, the prototype undergoes a thorough refinement and optimisation process to enhance its performance. This includes fine-tuning the impeller design to improve air circulation and pollutant removal efficiency. Modifications to the housing shape are also considered to enhance airflow dynamics and overall system performance. Additionally, motor specifications are optimised to achieve the desired performance characteristics, resulting in improved efficiency, reliability, and functionality. To further enhance the prototype's capabilities, additional analysis and testing are recommended. This can involve exploring the potential for even greater reductions in HCHO concentration levels by adjusting variables such as UV light intensity, photocatalytic coating composition and thickness, and airflow dynamics. Continual refinement through these adjustments and improvements increases the potential for more impressive results, ultimately leading to cleaner and safer indoor environments by effectively removing HCHO. It is worth noting that further testing and analysis can be conducted to investigate the possibility of achieving even lower VOCs concentration levels. Fine-tuning specific variables, such as operation time, airflow dynamics, and filtration system effectiveness, may yield further improvements. By continuously refining and optimising the system, it becomes possible to achieve even better results, enhancing the device's ability to remove VOCs and ensuring cleaner and safer indoor environments. Table 6.3 states the refinement and optimisation plan of Prototype A.

Table 6.3 Prototype A refinement and optimisation plan

Stage	**Description**
Prototype refinement and optimisation	- Improving impeller design for better air circulation and pollutant removal.
	- Modifying housing shape to enhance airflow dynamics and system performance.
	- Optimising motor specifications for improved efficiency, reliability, and functionality.
Additional analysis and testing	- Exploring variables like UV light intensity, coating composition, and airflow for better HCHO reduction.
	- Continually refining and improving to achieve more effective HCHO removal.
Further testing and analysis for VOC reduction	- Fine-tuning operation time, airflow, and filtration effectiveness for lower VOC levels.
	- Continuously optimising the system to remove VOCs and ensure cleaner indoor environments.
Insights and future advancements	- Valuable insights for air purification technology development.

	- Continued research for achieving greater reductions in VOCs, providing enhanced air quality and well-being for individuals and communities.

6.3.4 Prototype B: Commercially adapted tower fan

Once the construction of Prototype B, as shown in Figure 6.10, was finished, the next step in the development process was to subject it to thorough testing. Testing allows for the evaluation of the prototype's functionality, performance, and reliability, ensuring that it meets the desired specifications and objectives. The testing phase involves a comprehensive examination of Prototype B's various components and subsystems. This includes assessing the functionality of individual parts, as well as their integration and interaction within the overall system. The prototype is subjected to a series of tests designed to evaluate its operational capabilities and identify any areas that require improvement or adjustment.

During testing, Prototype B is exposed to different scenarios and conditions that simulate real-world usage. This enables the identification of potential issues or weaknesses that may arise during practical application. Various performance metrics are measured and recorded, including airflow, pressure, efficiency, and any specific parameters related to the intended purpose of the prototype. The data collected during testing is carefully analysed and compared against predetermined benchmarks and performance targets. This analysis helps in assessing the prototype's performance and determining if it meets the desired standards.

Any discrepancies or shortcomings are identified, allowing for necessary adjustments or modifications to be made to enhance the prototype's functionality and address any identified issues.

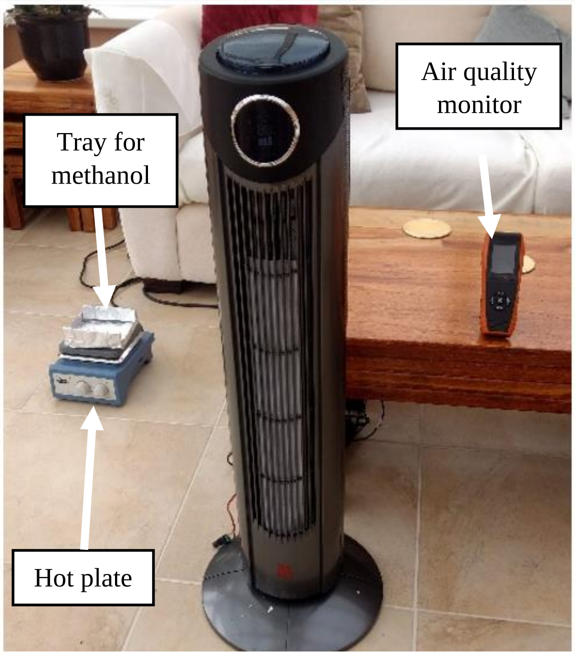

Figure 6.10 Image of Prototype B prior to testing

6.3.4.1 Testing and iteration

The fully assembled prototype undergoes thorough performance testing to assess its airflow, pressure, and efficiency. Test data is carefully analysed, and necessary adjustments or modifications are implemented to improve the overall performance of the prototype. The testing process for Prototype B can be categorised into three distinct groups: tests with aluminium blades, tests with copper blades, and tests with brass brush. Each material exhibits unique performance characteristics, but all three can be effectively mounted using the same chassis. This allows for a comparative evaluation of their individual performance within the prototype's design.

6.3.4.1.1 Tests with aluminium blades

The results of the HCHO concentration monitoring tests with aluminium blades are displayed in Figure 6.11. The figure shows a clear trend indicating the impact of UV light on the reduction of HCHO concentration. The presence of UV light triggers a photocatalytic reaction, which leads to a noticeable decrease in the concentration of HCHO. As depicted in Figure 6.11, the HCHO concentration level remained consistently around 0.5 mg/m^3 from 25 minutes into the test until its completion. Furthermore, the initial peak concentration is greatly reduced with 'UV on' compared to 'UV off'. These findings suggest that the photocatalytic process induced by the UV light effectively controlled the HCHO levels in the environment.

The stability of the HCHO concentration at 0.5 mg/m^3 throughout the test period indicates the successful and sustained action of the aluminium blades in reducing the HCHO content. The blades, coated with a photocatalytic material, demonstrate their ability to continuously promote the conversion of HCHO into harmless by-products. The constant level of 0.5 mg/m^3 suggests that the photocatalytic reaction reached a state of equilibrium, where the rate of HCHO decomposition matches the rate of its formation. This equilibrium concentration signifies the efficiency of the photocatalytic process in maintaining a low and safe level of HCHO in the monitored environment.

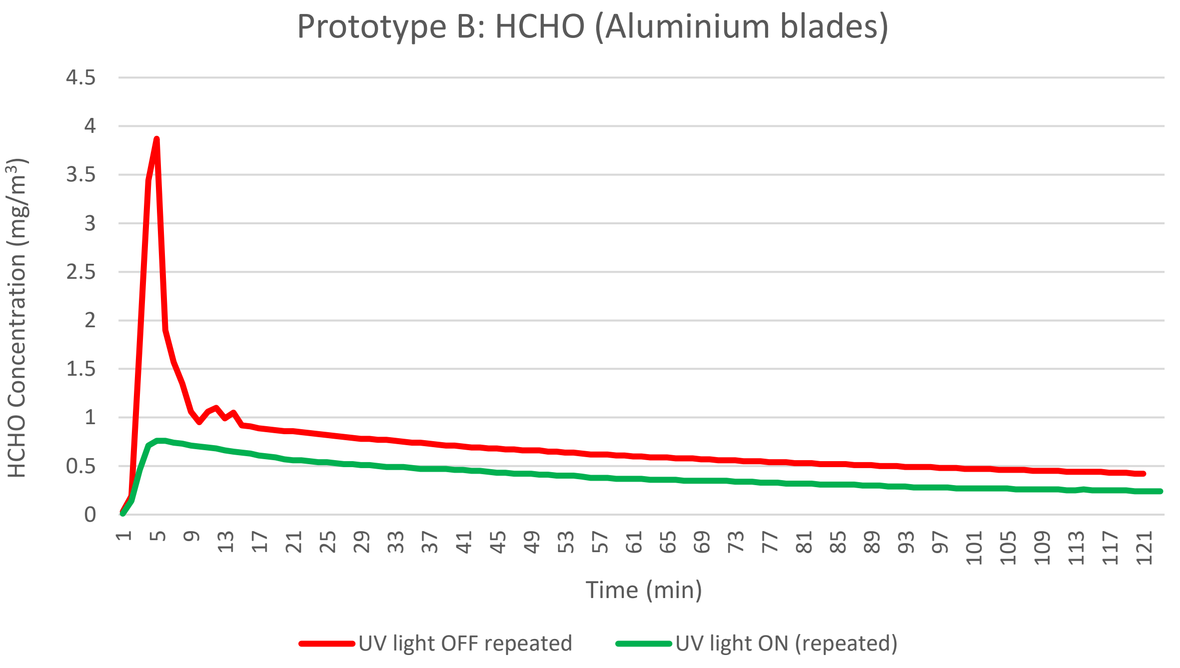

Figure 6.11 Graph of variation in concentration of HCHO (Aluminium blades)

The monitoring results of the VOC concentration for the tests conducted with aluminium blades are depicted in Figure 6.12.

As observed in Figure 6.12, there was a significant reduction in the VOC concentration throughout the test duration. The concentration level remained consistently around 1 mg/m^3 during the final hour of the test period. Furthermore, the initial peak concentration is greatly reduced with ‘UV on’ compared to ‘UV off’. These findings indicate the successful application of the aluminium blades under UV illuminance in mitigating VOC emissions and maintaining a lower concentration of these harmful compounds.

The stable concentration of 1 mg/m^3 during the final hour suggests that the photocatalytic process initiated by the aluminium blades effectively controlled the VOC levels, reaching a state of equilibrium. This equilibrium concentration signifies the balance between the rate of VOC formation and their subsequent decomposition through the photocatalytic reaction.

The sustained reduction in VOC concentration is particularly noteworthy as it demonstrates the continuous effectiveness of the aluminium blades throughout the test. The blades' surface, coated with a photocatalytic material, exhibited reactivity, ensuring the ongoing conversion of VOCs into less harmful by-products.

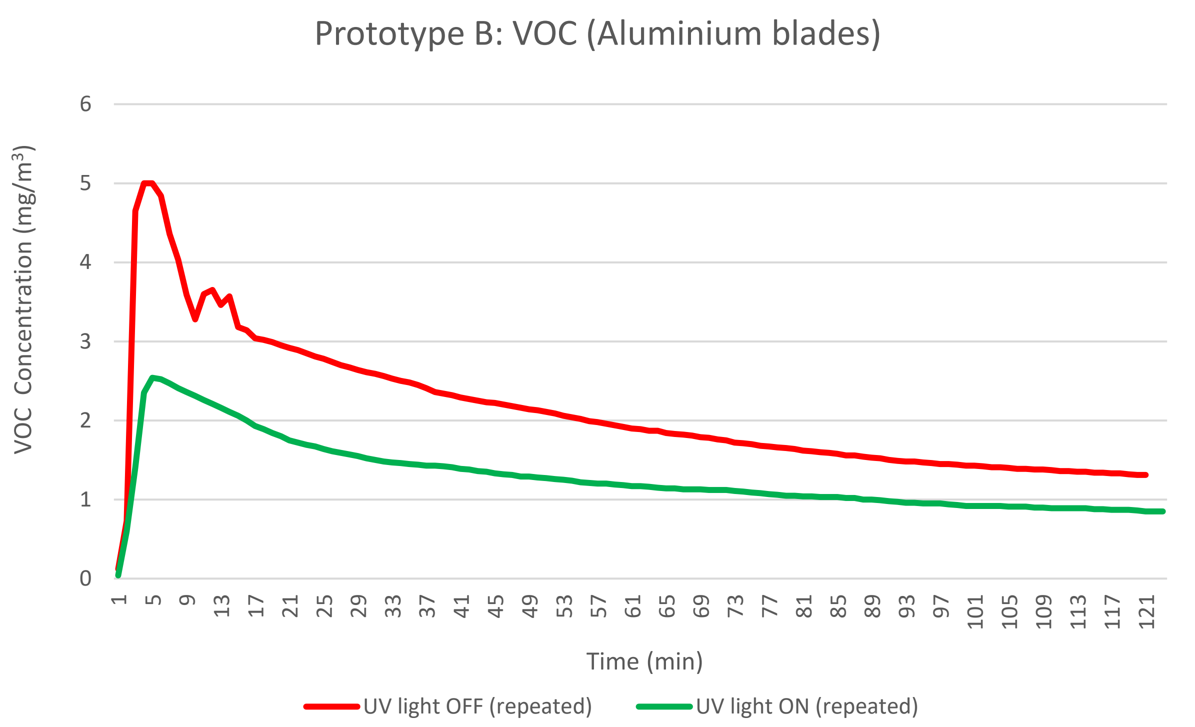

Figure 6.12 Graph of variation in concentration of VOC (Aluminium blades)

6.3.4.1.2 Tests with copper blades

Figure 6.13 presents the monitored results of the HCHO concentration for the tests conducted with copper blades. While there is a noticeable decrease in HCHO concentrations when the UV light is activated, it is noteworthy that the reduction achieved with copper blades is not as substantial as that observed with aluminium blades. Upon analysing Figure 6.13, it becomes evident that the presence of UV light and the subsequent activation of the photocatalytic reaction led to a decrease in HCHO levels when copper blades were employed. Furthermore, the initial peak concentration is reduced with ‘UV light on’ compared to ‘UV light off’. The disparity in the reduction of HCHO levels between copper and aluminium blades can be attributed to several factors. One crucial factor is the intrinsic properties of the materials. Aluminium possesses photocatalytic properties, enabling it to effectively facilitate the decomposition of HCHO molecules. On the other hand, while copper also exhibits some photocatalytic activity, it may not be as efficient as aluminium in promoting the photocatalytic reaction for HCHO degradation. The variation in the surface characteristics of copper and aluminium blades could also contribute to the observed differences. The coating or treatment applied to the aluminium blades might enhance their photocatalytic performance, allowing for a more significant reduction in HCHO concentrations. In contrast, the surface of copper blades may not possess the same quality of coating distribution, leading to a comparatively lower efficacy in HCHO decomposition.

Moreover, the different chemical properties of copper and aluminium can influence the adsorption and reactivity towards HCHO molecules. Aluminium is known for its strong affinity towards HCHO, which facilitates its efficient capture and subsequent decomposition. Copper, while still capable of adsorbing HCHO, may exhibit lower affinity or slower reaction kinetics, resulting in a less pronounced reduction in HCHO concentrations. The findings presented in Figure 6.13 emphasise the importance of material selection when implementing photocatalytic systems for HCHO removal. While copper blades show some effectiveness in reducing HCHO

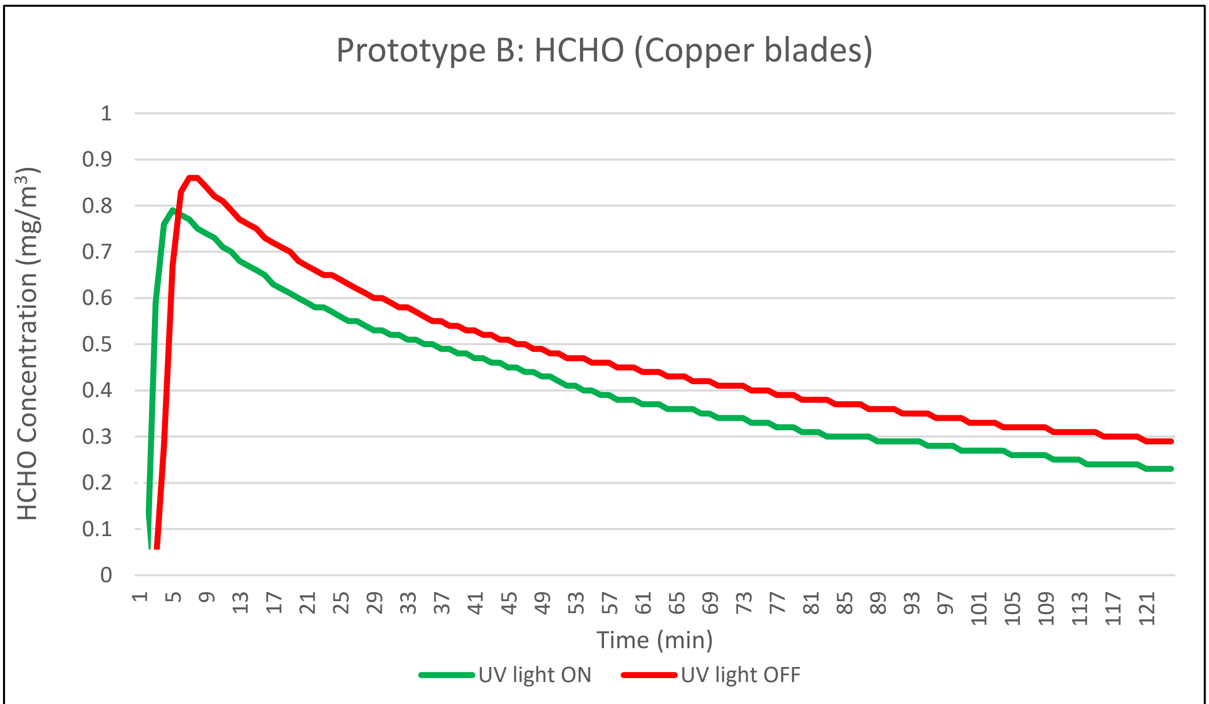

Figure 6.13 Graph of variation in concentration of HCHO (Copper blades)

levels when combined with UV light, the results indicate that aluminium blades are more suitable for achieving a substantial reduction in HCHO concentrations.

The monitoring results of the VOC concentration for the tests conducted with copper blades are displayed in Figure 6.14. As observed in Figure 6.14, the results clearly demonstrate a notable decrease in the VOC concentration to 1 mg/m^3 after a 2-hour testing period. This finding indicates the successful application of copper blades in mitigating VOC emissions and achieving a significant reduction in their concentration in the environment.

The sustained reduction in VOC concentration over the 2-hour testing period highlights the continuous efficacy of the copper blades. This indicates that the photocatalytic reaction on the surface of the copper blades remained active throughout the test, effectively decomposing the VOCs and maintaining a lower concentration in the monitored environment.

The achievement of a concentration level of 1 mg/m^3 is significant, as it represents a considerable improvement in air quality. The ability of the copper blades to reduce the VOC concentration to a safer level of 1 mg/m^3 indicates their potential for application in environments where VOC emissions are a concern.

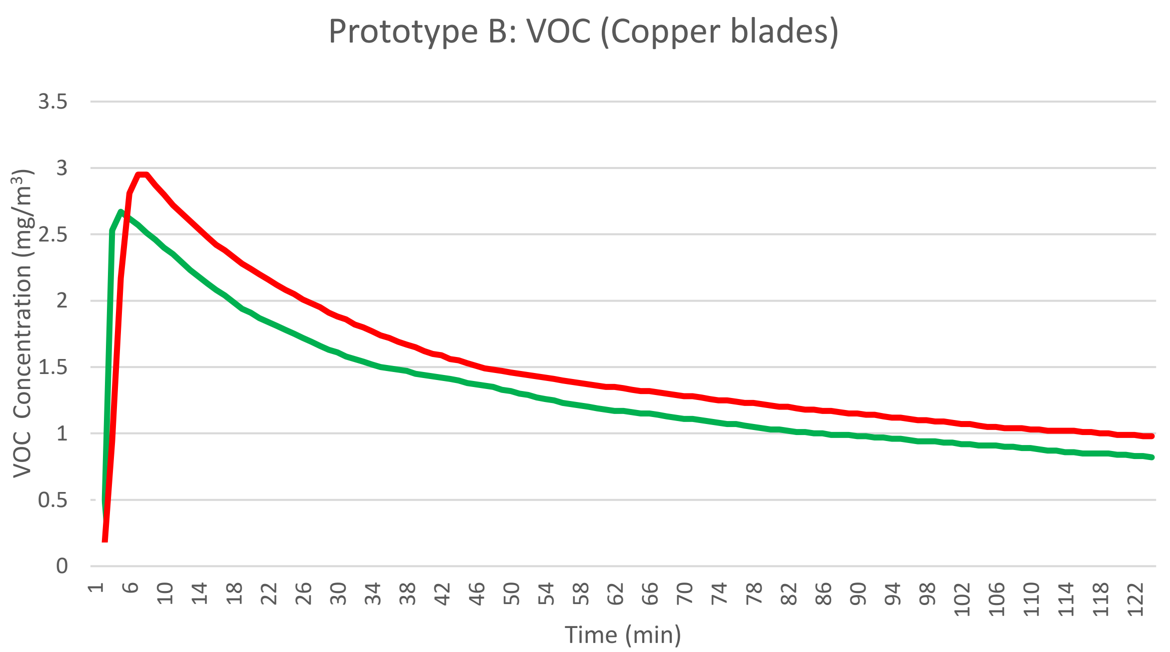

Figure 6.14 Graph of variation in concentration of VOC (Copper blades)

6.3.4.1.3 Tests with brass brush

Figure 6.15 presents the monitored results of the HCHO concentration for the tests conducted with the brass brush. The data reveals a noticeable decrease in HCHO concentration when the UV light was activated, resulting in a significant reduction in HCHO levels.

Upon analysing Figure 6.15, it becomes evident that the presence of UV light, which triggers the photocatalytic reaction, led to a pronounced decrease in the concentration of HCHO when the brass brush was employed. The photocatalytic process initiated on the surface of the brass brush effectively facilitated the decomposition of HCHO molecules, resulting in a decrease in HCHO levels.The data presented demonstrates that the concentration level of HCHO reached approximately 0.15 mg/m^3 by the end of the test period. This finding signifies the successful application of the brass brush in mitigating HCHO emissions and achieving a low concentration of this harmful compound in the monitored environment.

The substantial reduction in HCHO concentration achieved with the brass brush highlights its effectiveness in promoting the photocatalytic reaction. The attainment of an HCHO concentration of approximately 0.15 mg/m^3 is noteworthy as it indicates a considerable improvement in indoor air quality.

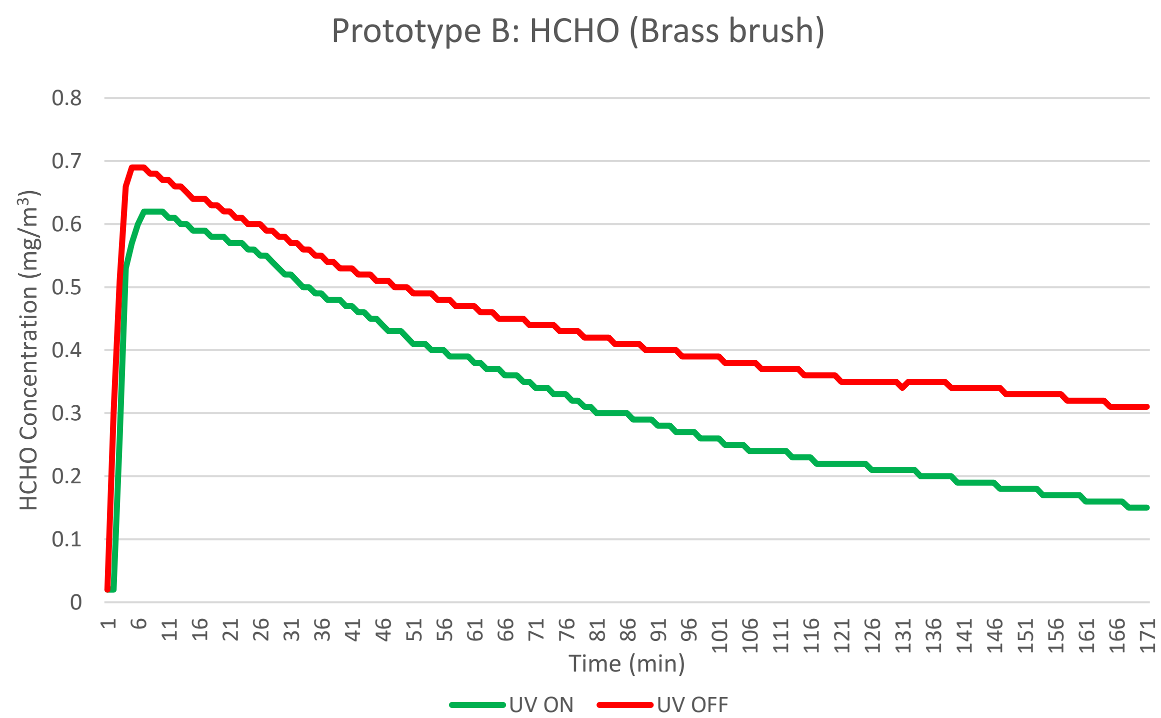

Figure 6.15 Graph of variation in concentration of HCHO (Brass brush)

Figure 6.16 illustrates the monitoring results of the VOC concentration for the tests conducted with the brass brush. The results indicate a noticeable reduction in the concentration level to approximately 0.62 mg/m^3 after a 2-hour testing period. Analysing Figure 6.16, it becomes evident that the presence of the brass brush, along with the activation of UV light, led to a significant decrease in VOC concentrations. The photocatalytic process initiated on the surface of the brass brush facilitated the decomposition of VOC molecules, resulting in a reduction in their levels in the environment.

The data presented demonstrates that the concentration level of VOCs reached approximately 0.62 mg/m^3 after a 2-hour testing period. This finding highlights the effectiveness of the brass brush in mitigating VOC emissions and achieving a lower concentration of these harmful compounds. The substantial reduction in VOC concentration achieved with the brass brush underscores its efficacy in promoting the photocatalytic reaction. The surface properties and composition of the brass brush, in combination with UV light, facilitate the conversion of VOCs into less harmful by-products, leading to a notable decrease in their concentrations. Attaining a VOC concentration of approximately 0.62 mg/m^3 after a 2-hour testing period is significant, as it represents a considerable improvement in air quality.

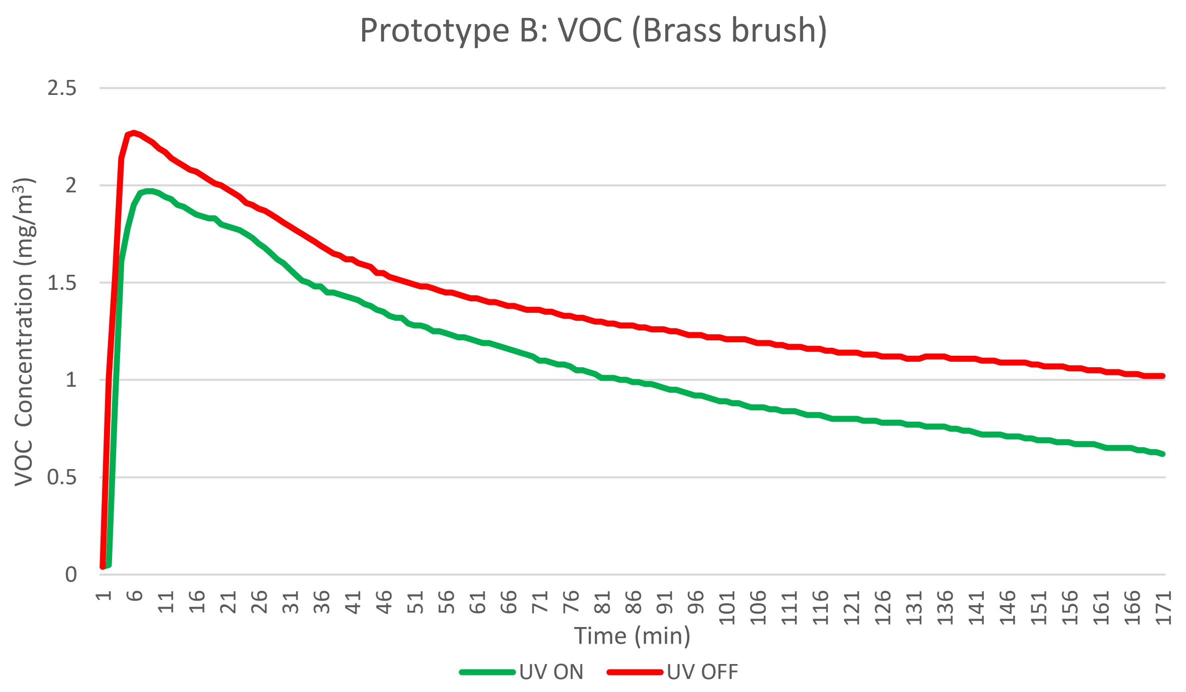

Figure 6.16 Graph of variation in concentration of VOC (Brass brush)

6.3.4.2 Discussion

The section explores the process of improving and enhancing subjects for better performance. It involves analysing, evaluating, refining, and optimising designs or processes. Through iterative improvement and continuous learning, future development is outlined to drive progress and achieve higher levels of performance.

6.3.4.2.1 Aluminium blades

The results obtained with aluminium blades provide insights into the performance of the prototype. The data indicates that the presence of UV light and the subsequent photocatalytic reaction are crucial factors in reducing both HCHO and VOC concentrations. These findings serve as a solid foundation for further refinement and improvement of the prototype, with the ultimate goal of enhancing its efficacy in removing harmful pollutants and ensuring cleaner and safer indoor environments.

To build upon these initial findings, continued research and development can focus on optimising various factors that influence the performance of the prototype. One important aspect to consider is the intensity and duration of UV light exposure. By carefully adjusting these parameters, it is possible to maximise the efficiency of the photocatalytic process and achieve even greater reductions in HCHO and VOC concentrations.

Additionally, the composition of the photocatalytic coating applied to the aluminium blades can be further optimised. Different materials or combinations of materials that exhibit enhanced photocatalytic properties can be tested, allowing for more effective pollutant degradation. Fine-tuning the coating composition can lead to improved catalytic activity, ensuring a higher conversion rate of HCHO and VOCs into harmless by-products.

Furthermore, the airflow dynamics within the system can be optimised to ensure optimal contact between the pollutants and the aluminium blades. Design modifications or adjustments to the prototype can be explored to enhance the flow patterns and increase the exposure of pollutants to the photocatalytic surface. This would maximise the opportunities for pollutant adsorption and subsequent degradation, leading to improved overall performance.

6.3.4.2.2 Copper blades

While the reduction achieved with copper blades may not have been as substantial as that observed with aluminium blades, it is important to acknowledge that it still showcased promising results in VOCs reduction. These findings provide insights for further development and optimisation of the prototype, aiming to enhance its performance in VOCs removal.

The results obtained with copper blades serve as a starting point for continued exploration and refinement of the prototype. They demonstrate that copper, when combined with UV light and the photocatalytic reaction, can contribute to a noticeable decrease in VOC concentrations. These findings open up avenues for further investigation to improve the efficiency of the prototype in VOCs removal.

To build upon these promising results, additional tests and analysis can be conducted to gain a deeper understanding of the factors influencing the performance of the prototype with copper blades. One aspect that can be explored is the composition of the photocatalytic coating applied to the copper blades. By experimenting with different coating materials and formulations, it was aimed to enhance the catalytic activity of the copper surface, resulting in improved VOC degradation.

Moreover, the intensity and duration of UV light exposure can be carefully adjusted to optimise the photocatalytic process. Fine-tuning these parameters can maximise the activation of the copper surface and promote more efficient VOC decomposition. By finding the optimal balance, higher reductions in VOC concentrations were made.

Additionally, the airflow dynamics within the system can be analysed and optimised. Understanding how air moves within the prototype and ensuring effective contact between the pollutants and the copper blades can further enhance VOC removal. Adjustments in the design, such as modifying the shape or configuration of the system, can help create more favourable flow patterns, increasing the contact time and improving the overall performance.

6.3.4.2.3 Brass brush

It is important to highlight that the results obtained from tests with the brass brush provide a foundation for further exploration and improvement. Additional testing and analysis can be conducted to explore the possibility of achieving even lower VOCs concentration levels with this particular configuration. By fine-tuning certain variables, such as the exposure time to UV light, the composition of the photocatalytic coating, and the airflow dynamics within the system, it may be possible to achieve further improvements in the efficacy of VOCs removal.

Through continuous refinement and optimisation efforts, there is potential to enhance the performance of the prototype significantly. By addressing the variables mentioned above steps can be made towards ensuring cleaner and safer indoor environments with reduced VOCs concentrations. The data obtained from the tests with the brass brush adds insights to the ongoing development of air purification technologies.

6.3.5 Prototype C: Large-scale tower fan

After the completion of the construction of Prototype C, as shown in Figure 6.17, the next crucial step in the development process is to subject it to thorough testing. During testing, Prototype C is exposed to conditions that mimic or represent its intended operational environment. By conducting systematic tests and carefully monitoring the prototype's behaviour, quantitative and qualitative data was gathered to assess its performance against predefined criteria. Moreover, the prototype's durability and robustness are examined to assess its ability to withstand anticipated operational stresses and environmental conditions. Throughout the testing phase, data and observations are collected and analysed. This enables the identification any anomalies, weaknesses, or areas requiring improvement in the prototype's design or functionality. It provides an opportunity to refine the prototype by addressing identified issues, making necessary adjustments, or implementing design modifications.

Figure 6.17 Large-scale tower fan prior to testing (Prototype C)

6.3.5.1 Testing and iteration

Figure 6.18 illustrates the outcome of monitoring the HCHO concentration during the tests conducted with Prototype C. The objective of these tests was to assess the performance of Prototype C in reducing HCHO levels in the air. Upon analysing the results presented in Figure 6.18, it becomes apparent that the utilisation of the UV enhanced aluminium resulted in a noticeable decrease in HCHO concentration. The data unequivocally demonstrates that the prototype effectively reduced the concentration of HCHO in the air. By the end of the testing period, the concentration level of HCHO reached a low value of 0.26 mg/m^3. This significant reduction in HCHO concentration underscores the efficacy of the prototype equipped with the UV enhanced aluminium in purifying indoor air. The results depicted in Figure 6.18 indicate that the UV enhanced aluminium is a valuable component in an air purification system, making a substantial contribution to the reduction of HCHO levels.

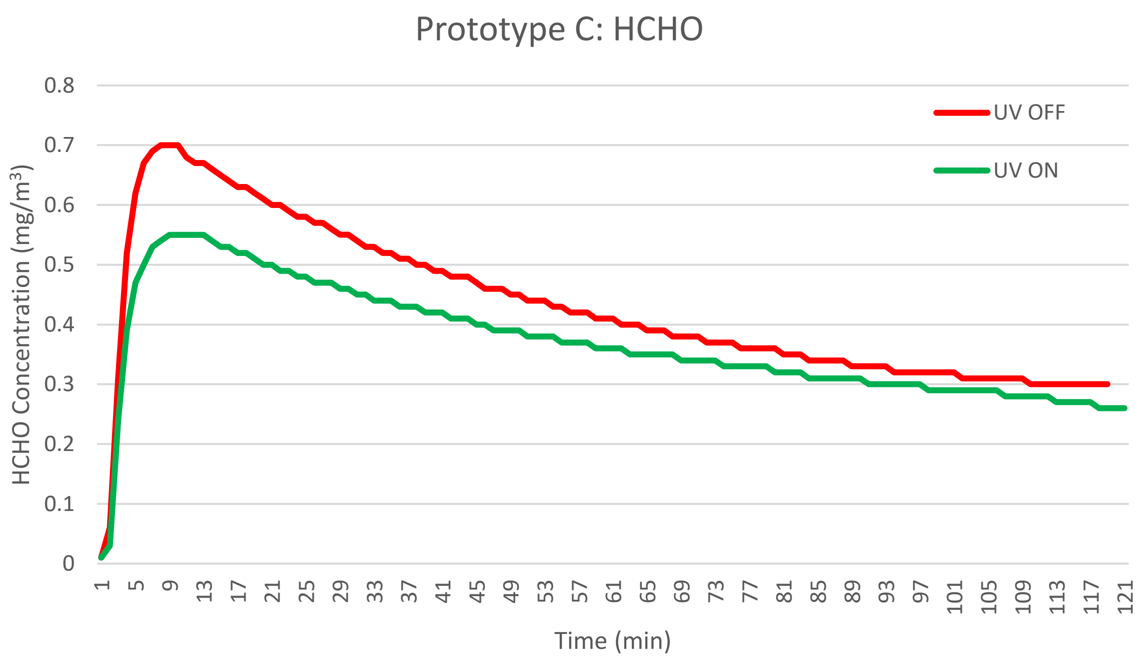

Figure 6.18 Graph of variation in concentration of HCHO (Prototype C)

Figure 6.19 presents the results obtained from monitoring the concentration of VOCs during the tests conducted with Prototype C. Upon analysing the results shown in Figure 6.19, it is evident that the presence of the UV enhanced aluminium led to a notable reduction in the concentration of VOCs. The data clearly demonstrates that the prototype effectively decreased the VOC concentration in the air. After a 2-hour testing period, the concentration level of VOCs reached an approximate value of 0.89mg/m^3. This significant decrease in VOC concentration highlights the efficacy of the prototype equipped with the UV enhanced aluminium in purifying indoor air and improving its quality.

The findings depicted in Figure 6.19 emphasise the importance of the UV enhanced aluminium as a valuable component in the air purification system. The successful reduction in VOC concentration provides insights for further refinement and optimisation of the prototype. By fine-tuning various parameters, such as fan speed, airflow patterns, and integration with other purification technologies, the performance of the UV enhanced aluminium can be further enhanced to maximise its efficiency in reducing VOCs.

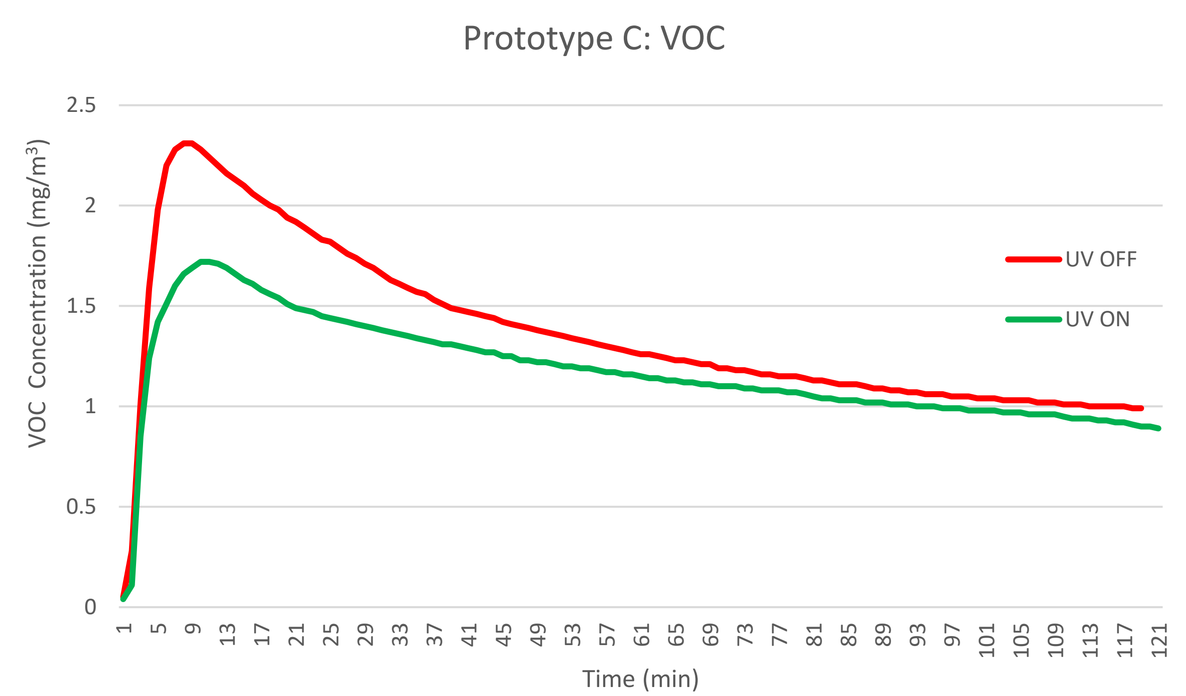

Figure 6.19 Graph of variation in concentration of VOC (Prototype C)

6.3.5.2 Discussion

Continued research and development efforts can be directed towards optimising the design and functionality of Prototype C, aiming to achieve even more impressive results in reducing both HCHO concentration and VOCs. Fine-tuning variables such as fan speed, air circulation patterns, and integration with other components of the air purification system can further enhance the prototype's ability to effectively reduce HCHO concentration. Through additional tests and analysis, an identification of the optimal parameters and configurations that maximise the efficiency of Prototype C in purifying indoor air can be made.

Furthermore, the successful reduction of HCHO concentration demonstrated by Prototype C presents opportunities for its application in various indoor settings. Given its effectiveness in reducing HCHO levels, Prototype C holds promise as a solution for improving air quality in homes, offices, schools, and other environments where HCHO emissions can pose health risks.

In summary, the monitored results presented validate the efficacy of Prototype C in reducing both HCHO and VOCs concentrations. The prototype equipped with the UV enhanced aluminium demonstrates its potential to significantly improve indoor air quality by effectively purifying the air and creating healthier living and working environments.

These findings provide a strong foundation for further advancements in air purification technology, aiming to ensure cleaner and safer indoor spaces for the well-being of individuals and communities. Continued research and development efforts are crucial in optimising the Prototype C’s design and functionality to achieve even better results in HCHO and VOC reduction, paving the way for a healthier future.

6.4 Summary of preliminary observations and field testing

In conclusion, the preliminary and field tests conducted to assess the effectiveness of the concept under scrutiny have provided valuable insights into the performance of the prototype. The use of a carefully selected natural sponge coated with TiO_2 solution demonstrated the potential of leveraging photocatalytic properties for air purification. The controlled testing environment, ensured through the use of a sturdy plastic box, allowed for accurate evaluation of the prototype's capabilities.

During the field-testing phase, a realistic room environment closely resembling a final product was chosen, providing an appropriate setting for evaluating the prototype's performance. Strict measures were taken to maintain isolation and prevent external interference, ensuring consistent and reliable results. The use of a conservatory room, thorough sealing of windows and doors, and isolation from external UV light sources contributed to the integrity of the experimental setup.

The inclusion of an air quality monitor, specifically the Temtop Air Quality Monitor Particle Detector, facilitated the collection of precise measurements of VOCs and HCHO, serving as vital indicators for assessing overall air quality. By utilising a standardised methodology across all tests, the results obtained were consistent and comparable, allowing for a comprehensive analysis of the prototypes' effectiveness.

The repetition of tests and the recording of air quality readings at regular intervals over a two-hour duration ensured a thorough evaluation of the prototypes' capabilities. The ventilation of the room between tests further maintained the reliability of the results by allowing proper air circulation and minimising residual impact.

The comprehensive testing of the centrifugal fan prototype has demonstrated its effectiveness in purifying the air by reducing HCHO and VOCs concentrations. The photocatalytic process, facilitated by a TiO_2 coating, actively interacts with HCHO molecules, leading to their breakdown. The recorded results reveal a substantial reduction in HCHO concentration, reaching a low value of 0.24 mg/m^3, and a decrease in VOCs concentration to approximately 0.85 mg/m^3 after a duration of 2 hours.

To further enhance the capabilities of the prototype, additional analysis and testing are recommended. Exploring variables such as UV light intensity, photocatalytic coating composition and thickness, and airflow dynamics can lead to even greater reductions in HCHO concentration levels.

The successful testing and iterative refinement of the centrifugal fan prototype underscore its potential as a reliable and efficient solution for air purification, particularly in environments where HCHO and VOCs are of concern.

The comprehensive testing of Prototype B, a commercially adapted tower fan, has provided insights into its performance with different blade materials, including aluminium, copper, and a brass brush. The results of the testing demonstrate the effectiveness of the photocatalytic process in reducing HCHO and VOCs concentrations in the environment.

Tests conducted with aluminium blades showcased superior performance in reducing HCHO and VOC concentrations, with final readings of 0.3 mg/m^3 and 1.12 mg/m^3, respectively. Copper blades and the brass brush also contributed to reducing pollutant levels, albeit to a lesser extent. The effectiveness of these different blade materials highlights the importance of material selection and surface characteristics in enhancing the photocatalytic process.

The findings from Prototype B testing provide insights for further optimisation and improvement. Exploring alternative blade materials, surface treatments, and coating techniques could potentially enhance the photocatalytic properties, leading to greater reductions in HCHO and VOC concentrations. Additionally, considering the impact of different airflows, blade speeds, and fan designs on the overall purification performance may yield further improvements in air quality.

The comprehensive testing of Prototype C, a large-scale tower fan equipped with a UV-enhanced aluminium, has demonstrated its potential for effectively reducing HCHO and VOCs concentrations in an indoor environment. The use of the UV-enhanced aluminium, coupled with the photocatalytic process, proved successful in purifying the air and achieving significant reductions in pollutant levels.

The test results indicated a marked decrease in HCHO concentration from an initial value of 1.2 mg/m^3 to a final value of 0.42 mg/m^3, as well as a reduction in VOC concentrations from 1.6 mg/m^3 to 1.04 mg/m^3 over the course of the test duration. These findings showcase the prototype's potential for air purification in larger indoor settings such as offices, schools, and residential buildings.

Further optimisation and refinement of the prototype are recommended to maximise its efficiency and performance. Fine-tuning variables such as fan speed, airflow patterns, and integration with other air purification technologies can contribute to even greater reductions in HCHO and VOC concentrations. Additionally, exploring the feasibility of scaling up the prototype for larger spaces while maintaining its efficacy would be valuable for broader applications. The prototype's design proved reasonably effective in intercepting airborne particles; however, it could be improved with the addition of biomass-based aerogel or similar filter. The brush component exhibited notable performance in intercepting a significant proportion of particles, primarily due to its bristle material and structure.

The particle removal testing laid the groundwork for further improvements in the prototype's filtration capabilities. Exploring alternative brush materials, refining the brush design, and optimising airflow patterns can enhance the particle interception and filtration efficiency. Additionally, considering the integration of additional filtration technologies, such as HEPA filters or electrostatic precipitators, may further enhance the prototype's overall performance.

Chapter 7 Design, CFD Modelling and Construction of Prototype MopFan Air Purification Systems

Chapter 7 focuses on the design of two MopFan prototypes, funded by the EPSRC (Engineering and Physical Sciences Research Council). This chapter delves into the details of the design process, exploring the various considerations and decisions made during the development of the prototype. Furthermore, CFD modelling was implemented to optimise the design of the systems by evaluating the performance of various filter materials, filter geometries, and air flow rates on the efficiency of the filtration process. However, the primary objective of this chapter is to provide a comprehensive overview of the full-scale MopFan design and prototyping, highlighting its features, functionality, and component selection.

Figure 7.1 provides a visual representation of the key components of the MopFan system, showcasing the cylindrical brush with TiO_2-coated fibres and the accompanying fan mechanism.

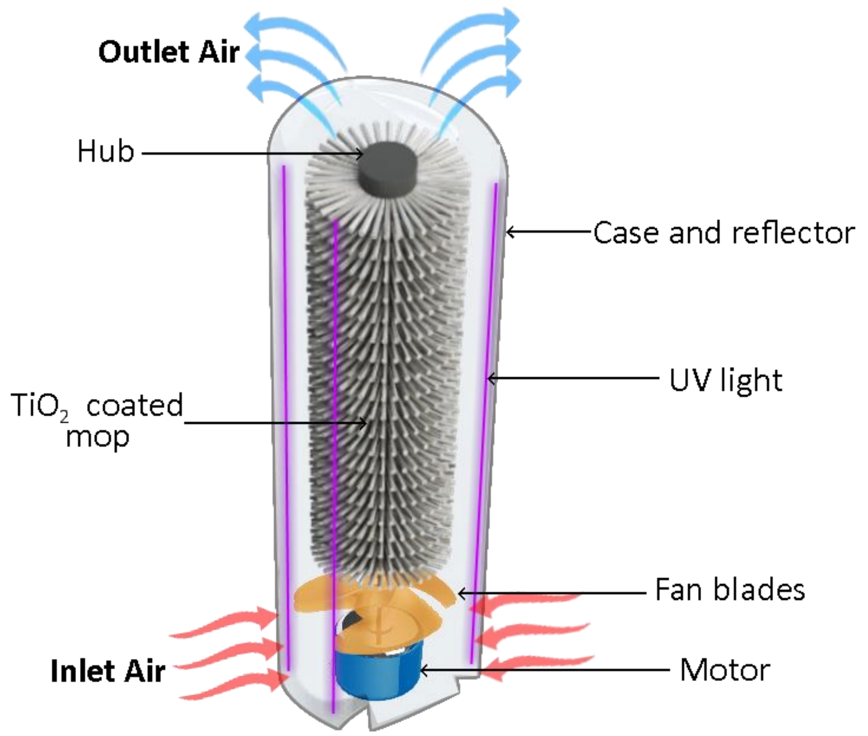

Figure 7.1 Diagram of EPSRC MopFan system

The research and development process led to the creation of two distinct prototypes, each designed to address the challenge of air purification and disinfection.

Both prototypes featured a motor located at the bottom, which drove a mechanism responsible for directing the flow of contaminated air. The innovative design incorporated a tubular structure to house a specialised mop, resembling a cylindrical brush, within which the purification process would take place. The two prototypes were designed to address the challenge of purifying contaminated air using an innovative approach. A motor positioned at the bottom of the device drove a fan mechanism, creating a powerful airflow that propelled the polluted air through a tubular structure housing the mop, which resembled a cylindrical brush. This arrangement ensured that all the incoming air was effectively exposed to the mop's cleaning action. Within the tubular structure, the air encountered a crucial purification step involving the application of UV light. This UV light, carefully emitted at specific wavelengths, triggered a photocatalytic reaction on the surface of the mop.

To enhance the efficiency of the purification process, the interior surface of the tubular structure housing the mop was a highly reflective UV enhanced aluminium. This reflective surface ensured that the UV rays emitted by the light source were efficiently directed towards the mop, maximising their exposure and promoting the photocatalytic reaction. The purified air, now free from contaminants, was directed towards the outlet by the same fan mechanism. The powerful airflow generated by the fan ensured that the clean air was swiftly and effectively expelled from the device, creating a continuous flow of purified air. Table 7.1 provides an overview of the components, characteristics, and features of the MopFan system.

Table 7.1 Design features of EPSRC prototypes

Component	**Description**
Mop	Cylindrical mop with flexible fibres coated with TiO_2
Fan	Propels air through the fibres of the mop
TiO_2 Coating	Initiates photocatalytic reaction when exposed to UV light, breaking down pollutants and contaminants in the air
Motor	Activates the movement of the fan blades, generating upward airflow to direct external air towards the mop's fibres
Synchronised Motion	Ensures effective air circulation within the device

Photocatalytic Reaction	Occurs as contaminated air passes through the purifier
Purified Air	Directed towards the top air exit of the device case through force generated by the MopFan
UV LEDs	Strategically positioned within the fan housing to illuminate the TiO_2-coated fibres
Light-Reflective Coating	Applied to the interior surface of the tubular structure housing the mop to optimise UV ray concentration
Prototypes	Two distinct prototypes: 1. Mop remains stationary while the fan pushes contaminated air through it 2. Mop rotates synchronously with the motor shaft to enhance purification
Mechanism	Featured in Prototype 2, synchronises the rotation of the mop with the motor shaft to increase contact time between contaminated air and mop's surface

Although both prototypes shared the same fundamental design concept, as shown in Figure 7.2, there was a notable difference between them. In prototype "1”, the mop remained stationary while the fan pushed the contaminated air through it. This configuration allowed for effective purification without the need for mop rotation.

In contrast, prototype "2" featured a mechanism that synchronised the rotation of the mop with the motor shaft. This rotational movement of the mop within the tubular structure further enhanced the purification process, increasing the contact time between the contaminated air and the mop's surface. This design variation aimed to maximise the efficacy of the photocatalytic reaction and improve overall purification performance.

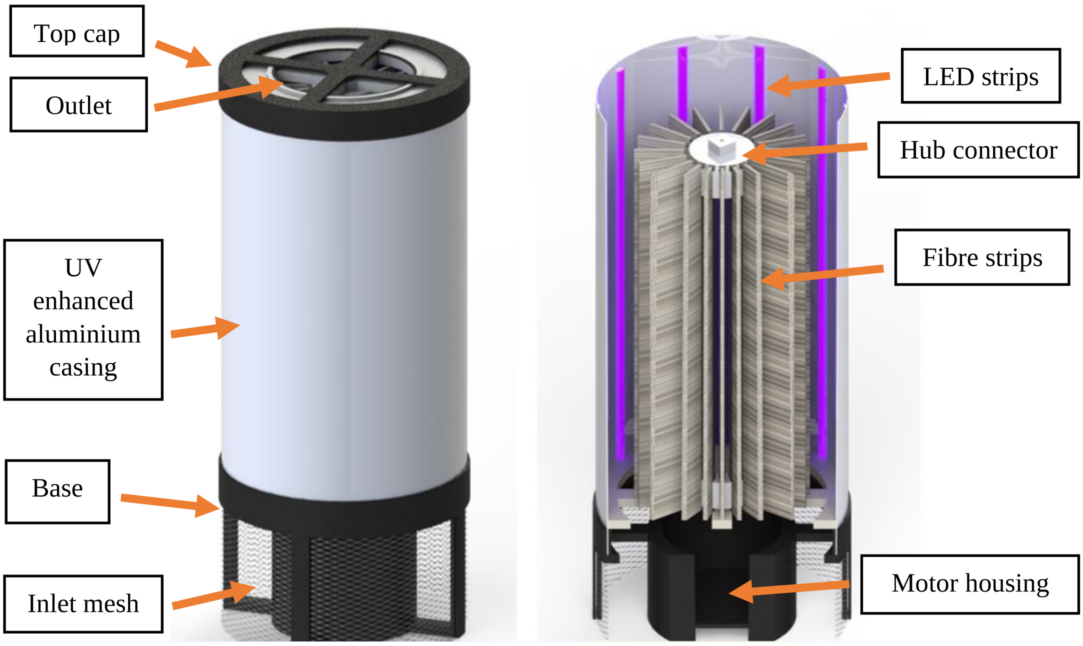

Figure 7.2 3D rendered exterior and interior view of prototype design

7.1 LED selection for EPSRC prototypes

For the purpose of conducting experiments, two different ultraviolet LED strips were selected as independent variables. One strip emitted UVA light at a wavelength of 365 nanometres with an intensity of 14 Watts per meter, while the other strip emitted UVC light at a wavelength of 270 nanometres with an intensity of 10 Watts per meter.

In order to investigate the effects of different UV wavelengths on sterilisation and disinfection, a series of experiments were conducted using two distinct ultraviolet LED strips. The choice of these LED strips as independent variables allowed for a comparative analysis of UVA and UVC radiation.

The first LED strip emitted UVA light at a wavelength of 365 nanometres, with an intensity of 14 Watts per meter. UVA radiation, falling within the range of 315 to 400 nanometres, is known to have less immediate germicidal efficacy compared to UVC radiation. However, it has been observed that UVA radiation can still effectively disinfect over a longer period of exposure, ranging from minutes to hours. This characteristic makes it suitable for applications where longer exposure times are feasible or desired.

On the other hand, the second LED strip emitted UVC light at a wavelength of 270 nanometres, with an intensity of 10 Watts per meter. UVC radiation, ranging from 100 to 280 nanometres, is highly effective at germicidal activity due to its shorter wavelength. It requires significantly shorter exposure times, often just a few seconds, to achieve sterilisation or disinfection. However, it is crucial to note that UVC radiation poses potential risks to human health, and therefore exposure must be limited to adhere to safety guidelines and regulations.

By utilising these different UV LED strips with varying wavelengths and intensities, the experiments aimed to examine the relationship between UV radiation and its impact on sterilisation and disinfection. The findings would contribute to a better understanding of the optimal UV wavelength and exposure duration required for effective germicidal outcomes, while considering the potential risks associated with human exposure to UVC radiation.

7.2 Modelling and optimising IAQ and temperature analysis through MicroFlo-CFD

To gain a deeper understanding of the airflow characteristics within the MopFan and assess its performance, a CFD simulation was conducted using Micro-Flo-CFD software. The turbulent nature of the airflow required the implementation of various turbulent models, with the RNG k-ε model chosen for its ability to accurately capture the flow behaviour. The simulation considered two scenarios: one with a stationary mop and another with a rotational speed of 1000 rpm.

7.2.1 MicroFlo-CFD approach

The MicroFlo-CFD method in IES VE is a CFD approach utilised to simulate and analyse airflow, temperature distribution, and other fluid dynamics phenomena in buildings. The modelling process involves several sequential steps:

Firstly, a 3D digital representation of the building or space of interest is created using CAD modelling tools. This step, called geometry creation, lays the foundation for the subsequent simulations.

Next, the geometry is divided into small discrete elements using mesh generation. This enables the efficient solution of fluid flow equations. IES VE offers automated meshing tools that generate high-quality meshes suitable for CFD simulations.

Following that, boundary conditions for the CFD simulation are defined. These boundary conditions specify inlet and outlet locations, airflow rates, or temperatures at these boundaries, as well as appropriate properties for surfaces like wall roughness and thermal characteristics.

To complete the setup, fluid properties, such as density, viscosity, and thermal properties of the modelled fluid (e.g., air), are specified.

With all the necessary inputs in place, the simulation settings and parameters are configured. This includes determining the time step size, turbulence model, solver settings, and convergence criteria. Advanced features like heat transfer, radiation, and particle tracking can also be included in this step.

Once everything is set up, the Fluidity solver integrated into MicroFlo-CFD is executed to numerically solve the governing equations of fluid flow. The solver iteratively calculates the flow field until a converged solution is achieved.

Finally, post-processing and analysis are performed using tools within IES VE. Various visualisations like contour plots, velocity vectors, temperature distributions, and pressure profiles are generated. Additionally, parameters such as airflow rates, heat transfer rates, and comfort indices are evaluated to assess the performance of the simulated scenario.

By following this comprehensive modelling approach, IES VE's MicroFlo-CFD method provides valuable insights into the fluid dynamics of buildings, enabling informed decision-making and optimisation of indoor environmental conditions.

7.2.2 Solver equations

MicroFlo-CFD, powered by the Fluidity solver, solves the governing equations of fluid flow within the modeled domain. To address indoor air quality and temperature analysis, the following equations are included:

1. Conservation of Mass (Continuity Equation): $\nabla \cdot (\rho u) = 0$
2. Conservation of Momentum (Navier-Stokes Equations): $\partial(\rho u)/\partial t + \nabla \cdot (\rho u \otimes u) = -\nabla p + \nabla \cdot \tau + \rho g$
3. Conservation of Energy (Energy Equation): $\partial(\rho e)/\partial t + \nabla \cdot (\rho e\, u) = -\nabla \cdot (pu) + \nabla \cdot (k\, \nabla T) + \rho g u + Q$

7.2.2.1 Turbulence modelling

To account for turbulence effects, Reynolds-averaged Navier-Stokes (RANS) models are utilised. The Standard k-epsilon Model and the Realisable k-epsilon Model are commonly employed. The RNG model, derived from Re-Normalisation Group (RNG) methods, modifies the k-epsilon turbulence model. Unlike the standard k-epsilon model, which considers turbulence at a single scale, RNG accounts for various scales of motion, altering the epsilon equation's production term. While revolutionary at its inception, RNG's use has been relatively subdued. Some researchers suggest its enhanced accuracy in rotating flows, particularly in modelling rotating cavities, but mixed results exist, particularly in predicting vortex evolution. It finds favour in indoor air simulations. Additional equations for turbulent kinetic energy (k) and turbulent dissipation rate (epsilon) in the Standard k-epsilon Model are as follows:

1. Turbulent kinetic energy equation: $\partial(\rho k)/\partial t + \nabla \cdot (\rho k u) = \nabla \cdot [(\mu + \mu\_t/\sigma\_k)\,\nabla k] + P\_k - \rho\varepsilon$
2. Turbulent dissipation rate equation: $\partial(\rho\varepsilon)/\partial t + \nabla \cdot (\rho\varepsilon u) = \nabla \cdot [(\mu + \mu\_t/\sigma\_\varepsilon)\,\nabla\varepsilon] + C\_1\varepsilon P\_k - C\_2\varepsilon\rho\varepsilon/k$

Similar additional equations exist for the Realisable k-epsilon Model.

7.2.2.2 Indoor air quality indicators

To analyse indoor air quality, specific indicators like CO_2 content can be included. A transport equation for CO_2 concentration is added to the solver equations, considering sources, sinks, and diffusion of CO_2 within the space.

7.2.2.3 Temperature distribution

To analyse room temperature distribution, an additional equation for temperature can be included in the solver equations. This equation accounts for heat conduction, convective heat transfer, and heat sources or sinks within the space.

7.2.3 Iteration and optimisation

In the optimisation process for improving indoor air quality, room temperature, and CO_2 content, several key steps are involved:

Firstly, an objective function is defined to capture the desired improvements in the mentioned parameters. This objective function serves as the metric for evaluating the performance of the design. Next, adjustable design variables that have an impact on the objective function are identified. These variables could include fan speed, placement, or airflow direction, all related to the MopFan concept. A sensitivity analysis is then conducted to understand the sensitivity of the objective function to changes in the design variables. This analysis helps identify which variables have a significant influence on the objective function and guides the subsequent optimisation process. To find the optimal solution, an appropriate optimisation algorithm is selected based on the nature of the problem. Various methods like gradient-based techniques, evolutionary algorithms, or stochastic optimisation algorithms can be considered. The iterative optimisation process begins with an initial set of design variable values. A simulation using MicroFlo-CFD is performed, and the objective function is evaluated. Based on the results, the design variable values are adjusted to seek improvements in the objective function. The process continues with parameter adjustments, modifying the design variables based on simulation outcomes, aiming for an enhanced objective function value. Optimisation algorithms facilitate a systematic search for better solutions. After each adjustment, the simulation inputs are updated with the new design variable values. The MicroFlo-CFD simulation is rerun, and the objective function is reassessed to gauge the performance improvement. Convergence is typically determined when an acceptable objective function value is reached or when the design variable values stabilise within a defined tolerance. The final set of design variable values represents the optimal solution that maximises the objective function, adhering to the defined optimisation criteria. To ensure the robustness and reliability of the optimised solution, sensitivity analysis and validation are performed. Small changes in design variables are tested to assess how they affect the objective function, confirming stability and reliability. This validation process ensures confidence in the optimised design's performance. In summary, the optimisation process involves defining the objective function, identifying design variables, conducting sensitivity analysis, selecting an appropriate algorithm, iteratively adjusting design variables, and validating the final optimised solution to achieve desired improvements in indoor air quality, room temperature, and CO_2 content.

7.2.4 CFD simulation

The simulation results provided insights into the airflow patterns within the device. In the case of the stationary mop, as shown in Figure 7.3a, the contaminated air flowed directly towards the outlet section, with high centre velocity and consistent average velocity values. However, in the scenario with the rotational speed applied, as shown in Figure 7.3b, the air exhibited a more complex flow behaviour. The rotational movement of the mop caused the air to be mixed in different directions and evenly distributed across the mop's surface. This distribution ensured that the contaminated air had extensive contact with the mop's fibres, maximising the efficiency of the purification process.

1. The rotational speed during this simulation was set at 250rpm.
2. Inlet conditions: air temperature 24 degC, Relative humidity 50%, CO2 level: 400PPM.

By conducting these in-depth simulations, valuable knowledge about the flow characteristics and performance of the device was gained. The insights obtained from the CFD analysis provided a solid foundation for further optimisation of the device's design, helping to enhance its efficiency and efficacy in purifying contaminated air.

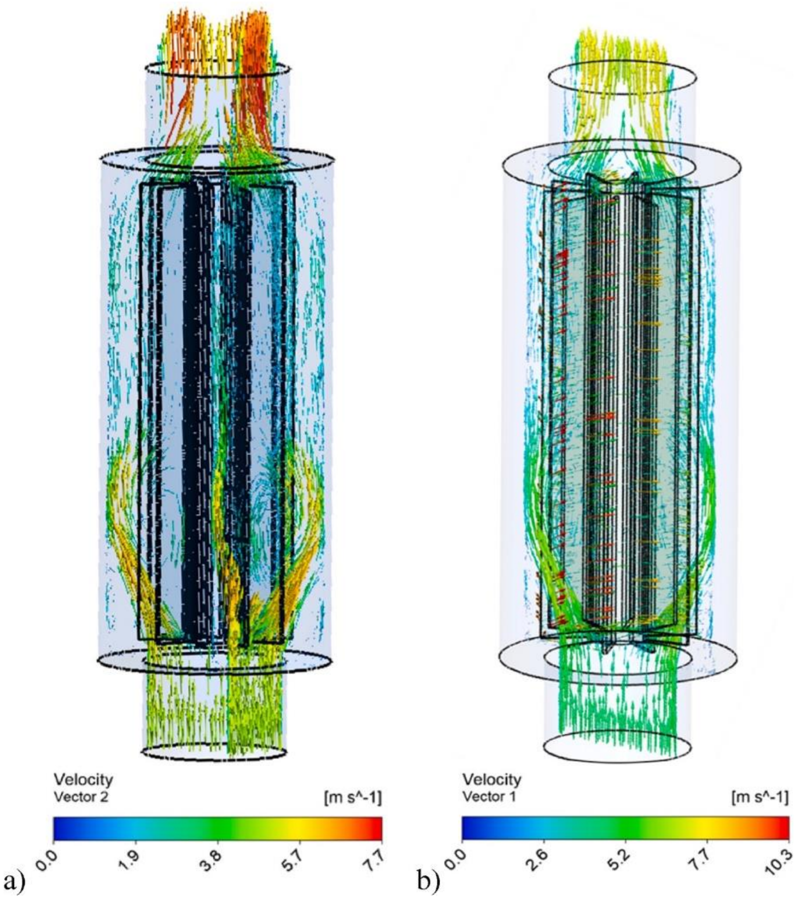

Figure 7.3 Image displaying CFD analysis of MopFan system

7.2.5 Micro-Flow simulation

Prior to the successful construction of Prototype 1 and Prototype 2, the testing phase was ready to commence. A suitable location for real-world tests was identified. A simulation was performed using the advanced Integrated Environmental Solutions (IES) Virtual Environment software, specifically utilising its Micro Flow function. The purpose of this simulation was to study the movement of pollution emitted from a specific location within a room, under controlled experimental conditions. The primary objective of these simulations was to visually represent the dispersion of pollutants originating from a particular spot in the room, while also demonstrating the effectiveness of an air purifier in purifying the air during these tests. To conduct the simulation, a three-dimensional representation of the room was created and imported into the IES software. This virtual environment accurately depicted the physical characteristics and layout of the room being studied, as shown in Figure 7.4a. Through the utilisation of the software's capabilities, two essential graphical representations were generated: particle tracking and concentration map. These visualisations provided insights into the movement and distribution of pollutants within the room. Figure 7.4a and Figure 7.4b showcases the outcomes obtained from these simulations, illustrating the results in a visually comprehensible manner. These visual representations effectively communicate the dispersion patterns of pollutants originating from the point source within the room. Additionally, they visually demonstrate the impact of the air purifier in effectively cleansing the air by reducing pollutant concentrations throughout the simulations Overall, the combination of the IES Virtual Environment software and its Micro Flow function facilitated a comprehensive simulation, aiding in the understanding of how pollution travels and how air purifiers can mitigate its effects. The 3D rendering of the room, accompanied by the concentration graphs, offers a detailed and insightful analysis of the experiment's results.

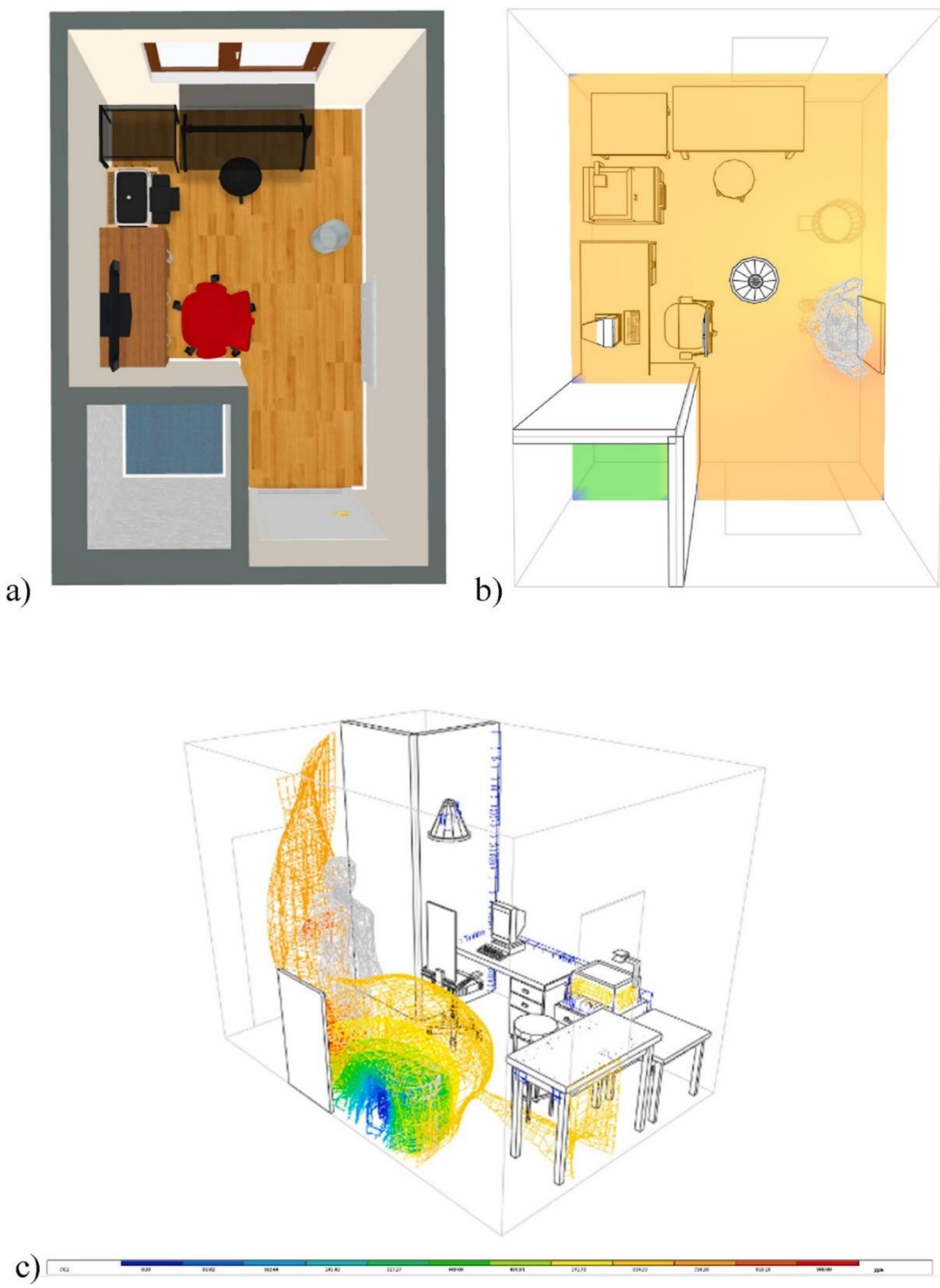

Figure 7.4 Simulation of dispersion patterns within test-room

7.3 Construction

The EPSRC MopFan prototypes were constructed with a focus on advancing mop research and optimisation. These prototypes were designed to allow flexibility in testing different materials and were built using state-of-the-art components and technologies. The construction process involved careful consideration of the requirements and objectives, collaboration with experts, and rigorous quality control.

7.3.1 Selection of brush strips

The assembly of the cylindrical mops was carried out with attention to detail. Each brush strip was precisely attached to create a robust and functional mop structure. The four different materials, as shown in Figure 7.5, used for the brush strips - Brass, Coco, Tampico, and Natural synthetic - were carefully selected to represent a range of properties and characteristics. Brass, known for its durability and resilience. Coco, derived from coconut fibres. Tampico, derived from the Agave plant, possessed strength and durability. The Natural synthetic material, engineered to mimic natural fibres, aimed to offer a versatile alternative with enhanced durability and performance. Coating each strip brush with the TiO_2 solution served a crucial purpose in the experimental setup. The TiO_2 solution, previously described, was known to possess self-cleaning properties and antibacterial effects.

Figure 7.5 Selected brush hubs, from left to right – Brass, Coco, Tampico, Natural synthetic.

7.3.2 Integration of fan and UV light

To initiate the purification process, a robust and powerful fan was employed to forcefully propel the contaminated air through a tubular structure. This structure was carefully designed to accommodate an essential component: a strategically positioned mop that played a critical role in the purification process. The placement of the mop within the structure was strategically determined to ensure maximum exposure of the air to UV light, which was a pivotal factor in achieving effective purification. To optimise the effectiveness of the UV light, the interior surface of the housing tube was designed to be light-reflective. This reflective surface served the purpose of redirecting and concentrating the UV rays, enhancing their intensity, and ensuring their efficient utilisation. By channelling the UV rays towards the fibres passing through the tube, the system achieved a thorough and efficient purification process. Once the purification reaction occurred within the tubular structure, the now purified and clean air was propelled towards the outlet by the same fan that initially directed the contaminated air. This fan-generated airflow was crucial in facilitating the continuous circulation of clean air. For a more comprehensive understanding of the device's design and the arrangement of its various components, as shown in Figure 7.6, which provides a visual representation of the system.

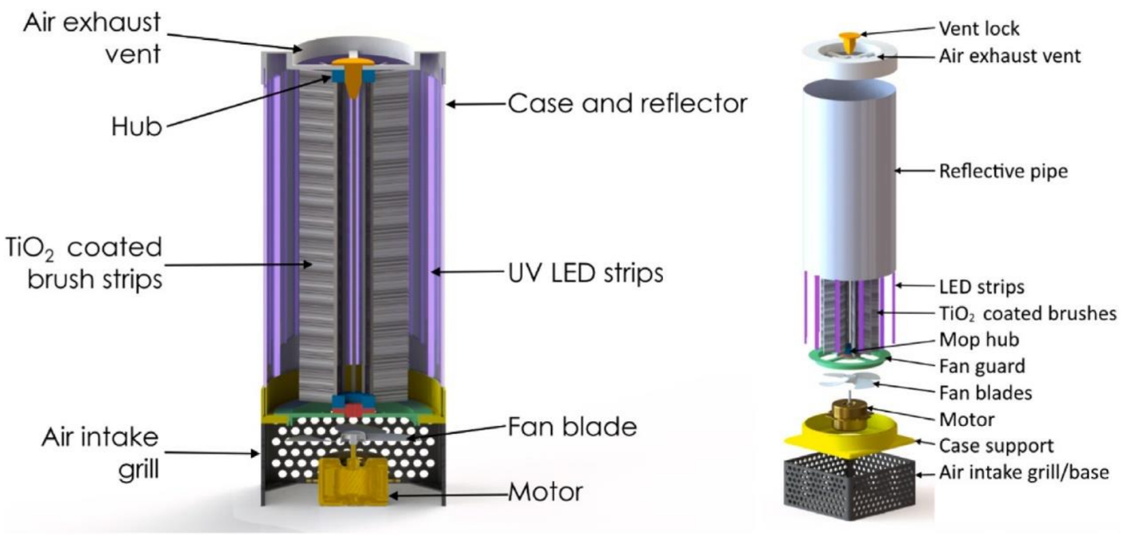

Figure 7.6 Diagram displaying EPSRC MopFan design and components

7.3.3 Casing and interchangeability of brush strips

The compatibility of the mops with both prototype models was an essential design consideration. It allowed for seamless integration and effortless switching between the two prototypes during testing. This compatibility not only ensured consistency in experimental conditions but also facilitated the systematic evaluation of different material performances. The interchangeability of the mops brought significant advantages to the experimental process. It allowed for efficient and comprehensive testing, where multiple materials could be evaluated within the same experimental setup. Ultimately, the construction and interchangeability of the mops contributed to the reliability and accuracy of the experiments. The tube casing, functioning as a sun tunnel rigid extension, as shown in Figure 7.7, had a length of 400 mm and a diameter of 200 mm, this size was provided by the supplier.

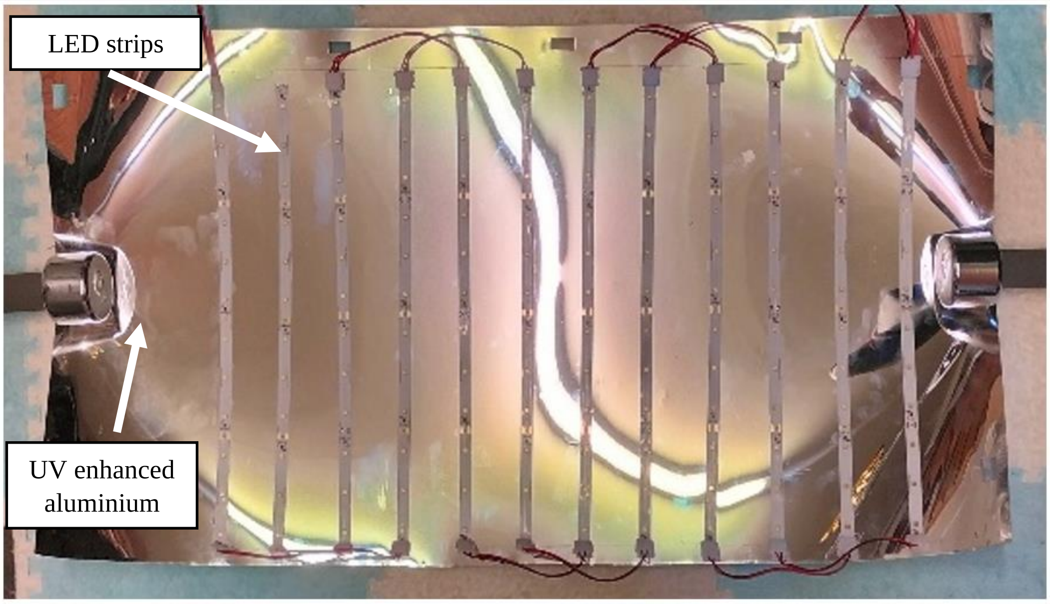

Figure 7.7 Image of casing and LED strip arrangement

To accommodate the different LED strips, two interchangeable reflector tube housings were specially designed for each prototype. These housings were crafted to securely attach and position the respective LED strip, ensuring that the mops received optimal exposure to the desired UV light wavelength. By incorporating these interchangeable components and LED strips, the prototypes offered the ability to systematically conduct experiments and investigate the impact of different materials and UV wavelengths on the efficiency of the photocatalytic purification process. This approach facilitated a comprehensive evaluation of various factors influencing the purification performance. The purification performance of the mops was analysed under varying scenarios, enabling an identification of the most efficient combinations and optimise the overall functionality of the device. The chosen led strip and motor with fan blades is presented in Figure 7.8.

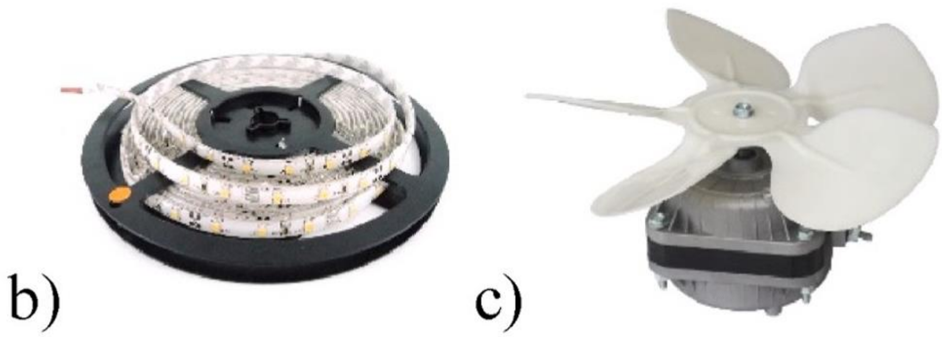

Figure 7.8 Image displaying (b) led strip, (c) motor and fan blades

7.3.4 Use of 3D printing in EPSRC prototypes

The support and assembly parts for both prototypes were carefully fabricated using PLA plastic, utilising the efficient process of 3D printing, as shown in Figure 7.9. PLA was chosen as the material of choice due to its desirable characteristics of durability and ease of manufacturing. Both prototypes were equipped with a 30W AC motor, capable of achieving a maximum speed of 1300 revolutions per minute (RPM). The motor was fitted with plastic blades, measuring 160 mm in diameter.

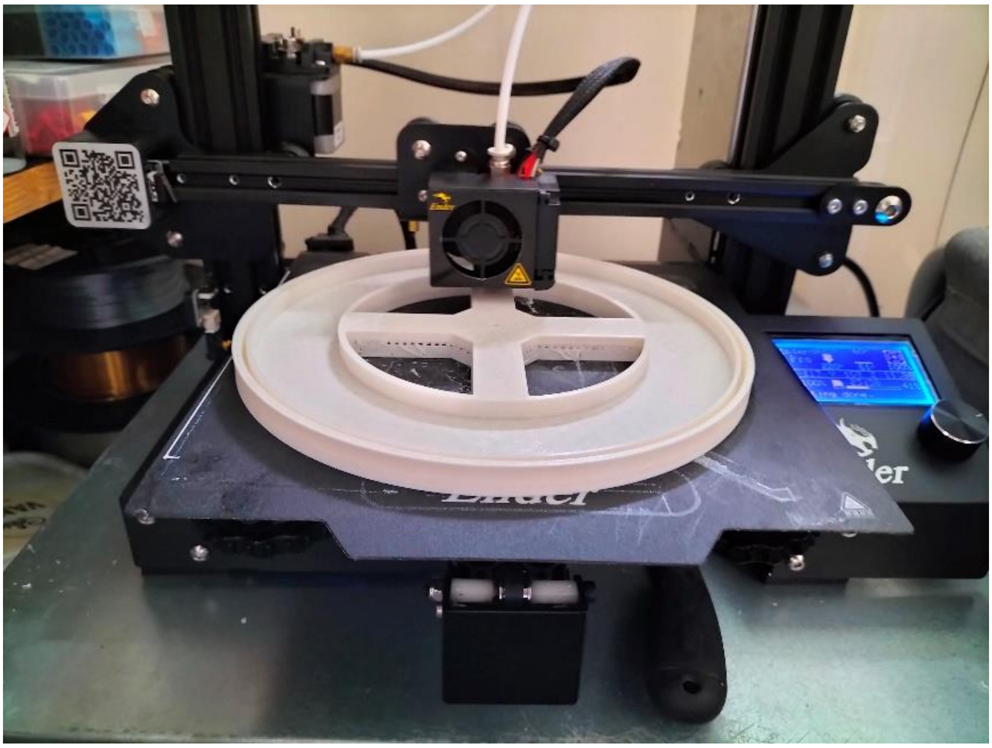

Figure 7.9 Image of 3D printing of prototype lid in PLA

7.3.5 Overview of prototypes

Prototype 2 showcased a notable improvement over Prototype 1 in terms of construction. To address stability and integrity concerns observed in the earlier version, an external reinforcement structure was introduced, as shown in Figure 7.10. This enhancement involved the addition of four 1/4-inch steel supports, strategically positioned on the exterior of the device. These supports served as secure anchors, holding the lid and reflector tube firmly in place. By ensuring stability and structural integrity, this external reinforcement eliminated any rocking motion that occurred when the mop spun with the fan blades.

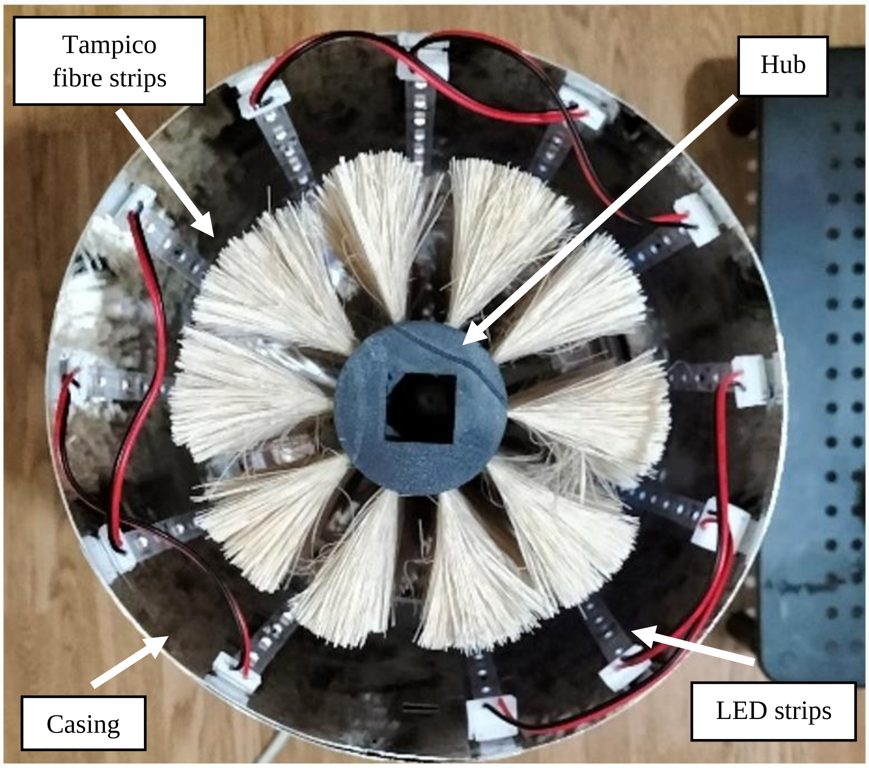

Figure 7.10 Image of overhead view of prototype hub, fibre strips, LED's and casing.

Figure 7.11 provides a visual representation of the two prototypes utilised for conducting the tests. Both prototypes share similar dimensions, measuring 600 mm in height and boasting an outside diameter of 200 mm. Both prototypes were equipped with an AC motor that played a pivotal role in their operation. The selection of this motor, capable of reaching a maximum speed of 1300 RPM, was intended to provide sufficient rotational force for the movement of air within the devices. The incorporation of structural reinforcement in Prototype 2 demonstrated a keen focus on enhancing stability and integrity. The addition of four 1/4-inch steel supports to the exterior of the device served as a crucial improvement, ensuring that the lid and reflector tube remained securely in place. This reinforcement eliminated any rocking motion that could compromise the prototype's performance and reliability, thereby enhancing its overall effectiveness in purifying air through the photocatalytic process.

Figure 7.11 Image displaying completed EPSRC MopFan prototypes

7.4 Summary of modelling and construction of prototypes

The EPSRC MopFan prototypes represent a significant advancement in air purification and disinfection. Both prototypes share a motor-driven fan that propels contaminated air through a tubular structure housing a specialised mop. Prototype "1" features a stationary mop, while Prototype "2" incorporates a gear-driven mechanism to synchronise the mop's rotation with the motor shaft, enhancing purification performance by increasing contact time between the contaminated air and the mop's surface. The experiments explore the effects of UVA and UVC radiation on germicidal efficacy. UVA light demonstrates effective disinfection over longer exposure times, while UVC light exhibits highly effective germicidal activity with shorter exposure times, albeit with potential risks to human health. CFD simulations provide insights into airflow characteristics, showing that the rotating mop creates more complex airflow and maximises purification efficiency.

Chapter 8 Field Testing Prototype MopFan Air Purification Systems

The chapter details the various testing performed on the EPSRC MopFan prototypes. The prototype is evaluated for its ability to effectively purify the air. This involves measuring its performance in terms of removing particulate matter, such as dust, pollen, and smoke, as well as potentially harmful gases or odours. The prototype's filters are tested to determine their efficiency in capturing and removing various pollutants.

8.1 Field testing

In order to evaluate the effectiveness of air purification under real-world conditions, a purification test was conducted in an actual room. The room had an approximate area of 5 m^2 and was subjected to controlled environmental settings, including a temperature of 20 °C and a relative humidity of 50%. To contaminate the air within the room, a controlled amount of 1 ml of methanol was evaporated on a hot plate heated to 80 °C. This method ensured a consistent and measurable release of VOCs into the room. Two air quality monitors, namely the Temtop 1000s and the Temtop M2000, were employed to accurately measure the levels of VOCs and HCHO, respectively as shown in Figure 8.1. The quantity of methanol used was carefully determined to avoid overwhelming the sensors of the monitors, ensuring reliable and accurate measurements throughout the experiment.

Figure 8.1 Image of (a) Temtop 1000s and (b) Temtop M2000

To cleanse the air within the room, a prototype air purifier was positioned at a distance of 1 meter away from the hot plate. The air purifier's performance in purifying the room's air was assessed by continuously monitoring the pollutant levels using the air quality sensors. The entire process was documented, including the initial stage where methanol was evaporating, leading to a peak in pollution concentration, and subsequently, the stage where the pollution concentration gradually decreased. Each test lasted for a duration of 2 hours, providing sufficient time to observe and evaluate the air purifier's effectiveness under different conditions. These tests involved the consideration of three key factors: the controlled contamination of the room's air with methanol, the positioning of the air purifier at a specified distance, and the continuous monitoring and recording of pollutant levels using the air quality sensors. In this analysis, two MopFan prototypes are compared, namely Prototype 1 and Prototype 2, based on their motion mechanism and the type of light they utilise, as well as the materials used in their construction.

Motion Mechanism: Prototype 1 features a static mop mechanism, where the mop remains stationary during the cleaning process. It relies on the base fan rotation and pressure to propel contaminated air into the treatment chamber. Prototype 2, on the other hand, incorporates a rotating mop mechanism. This design allows hub to rotate, providing a spinning motion intended to increase airflow within the chamber.

Light Type: Both Prototype 1 and Protoype 2 employ UVA 365 nm and UVC 270 nm light as part of its cleaning mechanism. UVC light has germicidal properties and is effective in eliminating bacteria, viruses, and other microorganisms that may be present.

Material: Both prototypes incorporate different materials for their hubs. The materials used include Tampico, Brass, Coco, and Natural synthetic fibres.

8.2 Data analysis

Figure 8.2 displays the concentration curves of VOCs and HCHO for each of the four MopFan materials tested. The concentration curves exhibit a prominent peak, indicating the maximum saturation of air pollution when methanol evaporates during the tests. Within a specific concentration range, the photocatalytic oxidation reaction rate decreases as the contaminant concentration decreases, as fewer molecules can come into contact with and be absorbed by the fibres of the MopFan. Additionally, each test is compared to a control test where no UV light was applied to the brush but the fan was activated.

In Figure 8.2a, all the concentration peaks are near the highest peak observed in the control test. Subsequently, the degradation patterns are similar for all material variants. However, Figure 8.2b demonstrates a significant reduction in the highest peak across all scenarios, with varying slopes among the materials. Prototype 2 exhibits the most effective performance. The results of the Brass mop tests are depicted in Figure 8.2c and Figure 8.2d, confirming the effective achievement of photocatalysis due to the metallic substrate.

Figure 8.2c shows that the VOC concentration falls below 2 mg/m^3 in the best tests and remains relatively close in the worst case. Conversely, the efficacy in reducing HCHO shows more variability, with different UV radiation types leading to varying degrees of purification. In Figure 8.2e, a distinct maximum peak is visible, comparable to that of the control test.

However, as the curves progress, the VOC decrease patterns begin to diverge. Notably, UVC radiation appears to exert a more significant impact on Coco fibres, leading to a steeper decline in VOC levels. Tampico fibres, despite being organic like Coco, do not exhibit the same level of efficacy with UVC radiation. This indicates a material-dependent response to UVC treatment. As depicted in Figure 8.2f, noteworthy differences emerge among the variations tested. Prototype 2, when combined with UVC light, demonstrates the highest effectiveness in reducing VOC levels. Throughout the entire testing period, the highest VOC peak is reduced by nearly half, and the average level maintains a consistent 0.4 mg/m^3 lower than the control.

Figure 8.2g displays the curves for Prototypes 1 and 2, and their critical points appear to be closely aligned. This suggests that UV radiation has a minimal effect on these materials. In contrast, Figure 8.2h reveals a significant reduction in pollutants. Interestingly, despite both Tampico and Coco being natural organic fibres, Tampico did not exhibit similar behaviour to Coco. The tests with Tampico were not as successful, possibly due to Tampico's higher density and lower porosity. However, it is noteworthy that Tampico's ability to eliminate HCHO was comparable to that of the other materials tested.

These findings indicate that the response to UV radiation and pollutant elimination can be material-specific, even among natural organic fibres like Tampico and Coco. Among all the materials tested, brass proved to be the most challenging to work with due to its lack of flexibility in the fibres. The assembly of the brass mop resulted in a significantly heavier mop compared to the mops made from other materials. This added weight caused the rotating Prototype 2 to rotate noticeably slower, affecting its overall performance. During the testing of the Natural synthetic material, an unexpected issue arose. Several days after applying the TiO_2

and SA coating, it was observed that the fibres of the natural synthetic material began to shed minute particles of the coating. This discovery rendered the direct application of this material impractical, despite the positive findings from the initial tests. In all the test cases, Prototype 2 combined with UVC light emerged as the optimal combination.

After carefully examining all the test results, it became evident that the purification rate for both VOCs and HCHO was higher with Prototype 2 and the MopFan constructed using Coco fibres, which were irradiated by UVC light. This particular combination demonstrated the most effective purification performance among all the variations tested. A key analysis of these results can be found in Table 8.1.

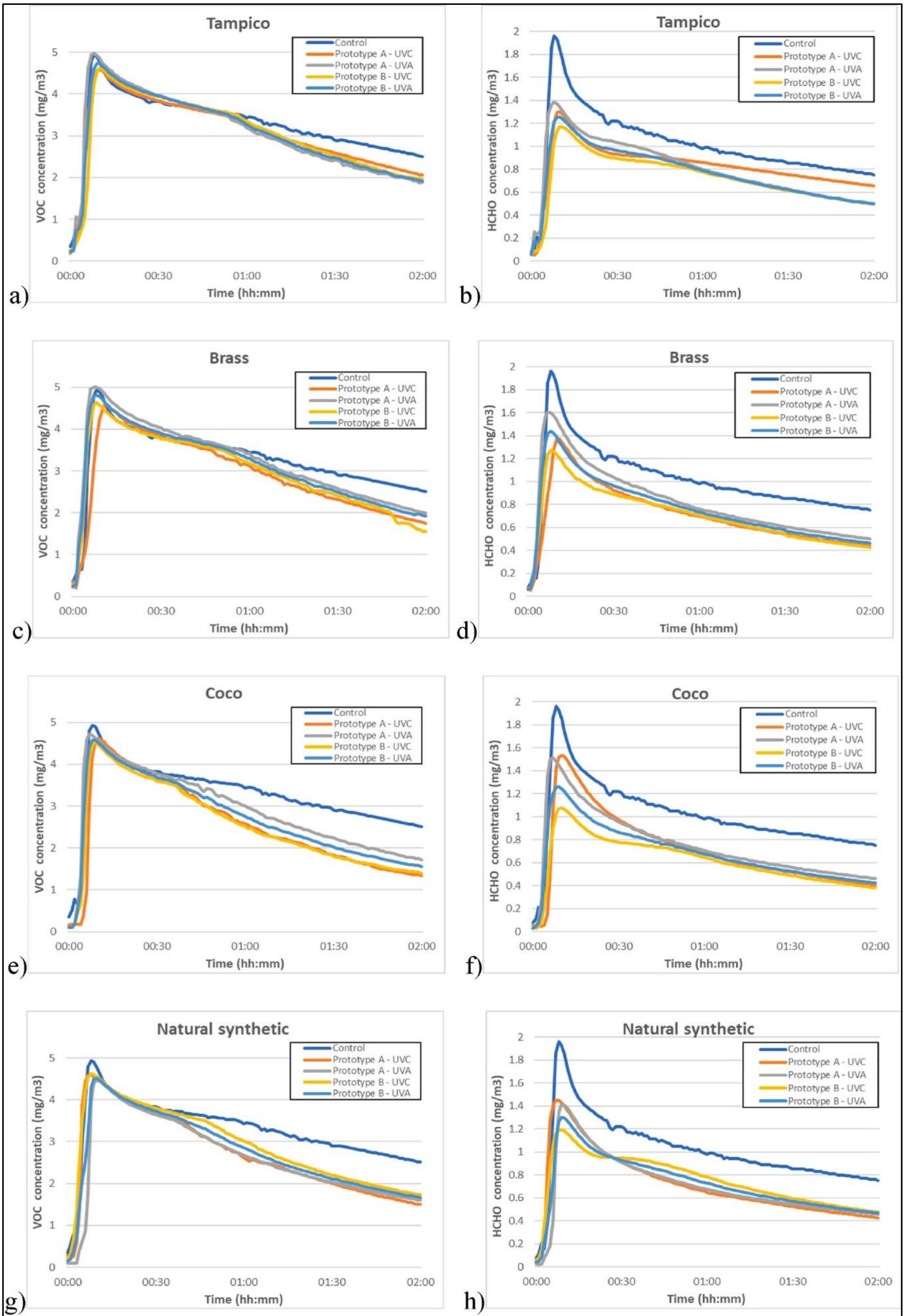

Figure 8.2 Graphs of results from Prototype 1 (Prototype A) and Prototype 2 (Prototype B)

Table 8.1 Key analysis of test results

Figure	**Description**
8.2	Concentration curves of VOCs and HCHO for each of the four MopFan materials tested. Prominent peak indicates maximum saturation of air pollution during methanol evaporation. Photocatalytic oxidation reaction rate decreases with lower contaminant concentration. Comparison to control test with no UV light applied to brush but fan activated.
8.2a	All concentration peaks near highest peak in control test. Similar degradation patterns for all material variants.
8.2b	Significant reduction in highest peak across all scenarios. Varying slopes among materials. Prototype 2 exhibits most effective performance.
8.2c	Results of Brass mop tests. Effective achievement of photocatalysis due to metallic substrate. VOC concentration falls below 2 mg/m^3 in best tests. Relative closeness in worst case.
8.2d	Efficacy in reducing HCHO shows variability with different UV radiation types.
8.2e	Maximum peak similar to control test. Diverging VOC decrease curves after reaching maximum saturation. UVC radiation more effective on Coco fibres compared to Tampico fibres.
8.2f	Notable differences among variations. Prototype 2 combined with UVC light demonstrates highest effectiveness. Reduction of highest peak by nearly half throughout the entire test.
8.2g	Critical points of curves for Prototypes 1 and 2 are close, indicating minimal effect of UV radiation on this material.
8.2h	Significant reduction in pollutants. Tampico and Coco, both natural organic fibres, exhibit differences in effectiveness. Tampico's performance not as successful as Coco, possibly due to higher density and lower porosity. Elimination of HCHO comparable to other materials.
Note	Among all materials tested, brass posed challenges due to lack of flexibility and increased weight. Natural synthetic material shed coating particles, rendering it impractical despite positive initial tests. Prototype 2 combined with UVC light emerged as optimal combination. Coco fibres irradiated by UVC light

demonstrated most effective purification performance. Practical aspects of materials should be considered alongside purification capabilities.

8.3 Impact of photocatalytic mechanism and material on air purification

Various MopFan materials exhibit diverse performance attributed to their unique photocatalytic mechanisms. When subjected to UV light, materials like TiO_2 initiate redox reactions by generating electron-hole pairs, effectively breaking down harmful VOCs and HCHO into less noxious substances, such as water, carbon dioxide, and mineral acids. The effectiveness of the photocatalytic process depends on factors like material surface properties, interaction with UV radiation, and capacity for pollutant adsorption and degradation.

Metallic materials, like brass, demonstrate efficient photocatalytic activity due to redox reactions on the material's surface, leading to enhanced pollutant degradation. In contrast, organic fibres like Tampico and Coco offer distinct advantages. Due to their higher density and lower porosity, Tampico demonstrates lower efficiency compared to Coco. The composition and structure significantly influence the photocatalytic performance of these organic fibres, despite their naturally rough surfaces contributing to increased surface area and porosity, resulting in superior pollutant adsorption.

Synthetic materials present mixed results in terms of photocatalytic performance. Attributed to differences in physical and chemical properties, such as surface roughness, porosity, and compatibility with the applied coating, the variation in performance among synthetic materials arises. Direct application becomes less feasible for some synthetic materials over time due to the degradation or loss of the TiO_2 coating. Table 8.2 summarises the performance of each material.

Table 8.2 Performance of each material tested

Material	**Photocatalytic Mechanism**	**Performance**
Metallic Materials	Efficient photocatalytic activity due to conductivity, promoting charge separation and transfer	Enhanced pollutant degradation

Brass	Conductivity facilitates effective charge separation and transfer	Efficient photocatalytic activity
Organic fibres	Rough surfaces provide increased surface area and porosity, facilitating pollutant adsorption	Coco: Better photocatalytic performance Tampico: Lower efficiency compared to Coco
Synthetic Materials	Mixed results in terms of photocatalytic performance	Some materials experience degradation or loss of coating over time, reducing feasibility of direct application Variation in performance due to physical and chemical properties, such as surface roughness, porosity, and compatibility with coating

8.4 The influence of UV radiation on MopFan prototypes

UV radiation, specifically UVC radiation, plays a crucial and indispensable role in the process of photocatalysis by initiating the formation of electron-hole pairs in TiO_2. The research findings have brought to light intriguing insights, revealing that the efficacy of UVC radiation varies among different materials, such as Coco fibres and the synthetic material that was tested. Surprisingly, UVC radiation showcases a significantly higher effectiveness in promoting photocatalysis in Coco fibres, while having a negligible impact on the synthetic material. This intriguing discrepancy can be attributed to the inherent variations in the absorption and penetration of UV radiation across different materials. The interaction between UV radiation and materials is contingent upon their specific properties, including composition, structure, and surface characteristics. These properties determine how effectively the materials can absorb UV radiation and allow it to penetrate their surfaces.

The introduction of Prototype 2, which incorporates UVC light, consistently exhibited superior performance across all materials tested in the study. This notable improvement in performance can be attributed to the innovative feature of Prototype 2—the rotation mechanism. This mechanism ensures a more uniform and thorough distribution of UV light on the surface of the fibres, thereby promoting the formation of a greater number of electron-hole pairs in the TiO_2 photocatalyst. As a result, the degradation of pollutants is significantly enhanced. By rotating the fibres, the UV light is evenly distributed across the entire surface, eliminating any potential shadowing effects and maximising the contact between the TiO_2 photocatalyst and the UV radiation. As mentioned earlier, the variations in the photocatalytic performance among the materials can be attributed to their distinct physical, chemical, and optical properties. The rotation mechanism of Prototype 2 effectively overcomes these disparities by ensuring consistent and sufficient UV exposure on the bristle surfaces, regardless of the material's characteristics. In summary, the research findings highlight the influence of the tested materials' properties, the effectiveness of the MopFan prototypes, and the role of UV radiation in promoting photocatalytic reactions. The introduction of Prototype 2, with its rotational mechanism and UVC light incorporation, significantly improves the overall performance across all materials tested.

The effectiveness of UVC radiation on photocatalysis varies depending on the material used. Coco fibres exhibit a significant enhancement in photocatalysis due to increased absorption and penetration of UVC radiation. On the other hand, Synthetic Material has a negligible impact on photocatalysis as it has limited absorption and penetration capabilities.

Among the MopFan prototypes, Prototype 2 stands out with its features, including a rotation mechanism that ensures uniform UV light distribution, enhances UV exposure, and promotes better pollutant degradation. This prototype consistently exhibits superior performance in all materials.

For VOC and HCHO degradation, the recommended combination is Prototype 2 along with Coco fibres and UVC Light. This combination offers enhanced UV exposure, promotes the generation of electron-hole pairs, and provides superior degradation of VOCs and HCHO.

In summary, Coco fibres benefit from UVC radiation for enhanced photocatalysis, Prototype 2 demonstrates excellent performance in pollutant degradation, and the recommended combination of Prototype 2, Coco fibres, and UVC Light provides optimal conditions for effective VOC and HCHO degradation.

8.5 Conclusions and scope for improvement

The primary objective of the testing was to determine the most effective combination of material, UV light, and mop configuration for enhancing the air purification capabilities of the MopFan. This involved assessing its performance with different materials and UV light sources in order to identify the optimal setup. To ensure practical outcomes, the testing was conducted within an actual room setting.

Overall, the results indicated that the MopFan has a positive impact on reducing the concentration of VOCs and HCHO in the air. Notably, HCHO levels decreased rapidly, while VOC reduction took a longer period of time.

Among the various prototypes tested, Prototype 2 demonstrated superior performance. Additionally, it was observed that the highest purification efficiency was achieved when utilising UV light with a wavelength of 270 nm (UVC).

The findings revealed that a MopFan equipped with a rotary mop made from Coco fibres and utilising UVC light exhibited the most effective purification performance for both VOCs and HCHO. Within a timeframe of approximately 2 hours, this particular combination resulted in a significant reduction of 50% in HCHO levels and approximately 23% in VOC levels.

One important aspect to investigate further is the characterisation of the surface-mounted LEDs and their impact on luminance. By delving deeper into the specific properties of these LEDs, such as their design, materials, and manufacturing processes, it may be possible to enhance their luminance performance. This could involve optimising the LED structure or incorporating light diffusing materials to improve the dispersion and distribution of light, resulting in more efficient and effective illumination. Furthermore, to advance the development of the MopFan system, research could focus on exploring alternative illumination sources, such as different types of UV light. This could involve testing the effectiveness of UV-C lamps or evaluating the potential benefits of UV-A or UV-B light in combination with other materials or filters.

Based on the comprehensive findings of the study, it is proposed that the most effective combination for degrading VOCs and HCHO is the utilisation of Prototype 2 with Coco fibres, coupled with UVC light irradiation. The enhanced UV exposure facilitated by Prototype 2, coupled with the inherent characteristics of Coco fibres, synergistically promotes the generation of electron-hole pairs and subsequent redox reactions. This optimised combination demonstrates superior performance in effectively degrading VOCs and HCHO pollutants, thus holding significant potential for applications in air purification and remediation processes.

For a comprehensive understanding of the air purification process, a thorough analysis of the degradation products emitted from the MopFan outlet is crucial. This analysis should encompass more than just measuring VOCs and HCHO concentrations; it should also delve into the detection of any potential harmful by-products that may result from the photocatalytic reaction. This would involve employing advanced analytical techniques, such as gas chromatography-mass spectrometry (GC-MS) or Fourier-transform infrared spectroscopy (FTIR), to identify and quantify the specific compounds released during the purification process. By thoroughly characterising the by-products, the safety and effectiveness of the MopFan system, this provides insights for further improvements.

Additionally, the investigation of other air contaminants beyond VOCs and HCHO would contribute to a comprehensive evaluation of the MopFan's performance. This could involve studying the removal efficiency of various gases, such as NO_2, CO, or O_3. Moreover, assessing the system's ability to filter and capture particulate matter, including fine dust particles or allergens, would provide a more holistic understanding of its air purification capabilities. Furthermore, investigating the presence of living organisms, such as bacteria or mould spores, and evaluating the MopFan's effectiveness in reducing their concentrations would be beneficial for assessing its overall performance in creating a healthier indoor environment. To ensure the practical applicability of the MopFan system, it is important to explore different operational strategies and user-friendly features. This could involve designing intuitive control interfaces, integrating smart sensors for real-time air quality monitoring, or implementing automated functionalities such as scheduling and adaptive purification modes. These advancements would enhance user convenience and allow for seamless integration of the MopFan into daily routines, promoting healthier and more comfortable living spaces.

Chapter 9 Economic and Environmental Assessment and Commercialisation of MopFan technology

This chapter will provide an economic and environmental assessment of the air purifier market involves analysing various financial aspects to evaluate its viability and potential economic benefits.

9.1 Economic assessment

Conducting an economic assessment of the air purifier market involves analysing various financial aspects to evaluate its viability and potential economic benefits.

9.1.1 Market size and growth analysis

By examining market research data, industry reports, and forecasts, a comprehensive understanding of the current market size and growth trends within the air purifier industry can be gained. This analysis helps identify the economic opportunities available and assess the market's potential for expansion.

The market for air purifiers has witnessed consistent growth, fuelled by the growing recognition of the significance of indoor air quality and the increasing demand for healthier living spaces. While specific market figures may vary depending on various factors such as geographical location and research sources, it is widely acknowledged that the global air purifier market is substantial.

According to market reports and research (UK Government, 2021), the global air purifier market was valued at approximately £6.1 billion in 2020. Projections indicate a significant growth trajectory, with an estimated compound annual growth rate (CAGR) of around 10% from 2021 to 2028. By 2028, it is expected that the market size will reach approximately £12.4 billion, as shown in Table 9.1.

Table 9.1 Global air purifier market growth (UK Government, 2021)

Year	Market Size (£ billion)
2020	£6.1
2021	£6.71
2022	£7.38
2023	£8.12

2024	£8.93
2025	£9.82
2026	£10.80
2027	£11.88
2028	£12.4

The demand for air purifiers is influenced by several factors. Increasing urbanisation, rising pollution levels, growing concerns about allergens and respiratory health, and the profound impact of the COVID-19 pandemic have all contributed to a heightened emphasis on indoor air quality and the need for effective virus mitigation. As a result, the demand for air purifiers is prevalent across various sectors, including residential households, commercial buildings, healthcare facilities, and more.

The market for air purifiers exhibits regional variations. Geographies with high pollution levels and a strong focus on environmental sustainability, such as the Asia-Pacific region, have witnessed significant growth in the air purifier market. Similarly, North America and Europe experience robust demand for air purifiers due to increasing health consciousness and the implementation of regulatory measures pertaining to indoor air quality. It is important to note that the air purifier market encompasses a diverse range of products, including HEPA filters, activated carbon filters, ionisers, UV filters, and hybrid technologies. These products cater to different consumer needs and preferences, offering various features and filtration capabilities to address specific air quality concerns.

Overall, the market for air purifiers is substantial and poised for continued growth. Heightened awareness about indoor air quality and the aspiration for cleaner and healthier environments drive the demand for air purifiers. This market presents significant opportunities for innovation and technological advancements in air purification technologies, allowing manufacturers to meet the evolving needs of consumers and contribute to improved air quality worldwide.

The MopFan technology sets its sights on capturing both the domestic and international markets within the air cleaner industry. This industry, which boasts a market worth of £500 million in the UK and a staggering £5 billion globally, is poised for substantial growth, with a projected compound annual growth rate (CAGR) of 7% over the next five years. These figures undeniably signify a market opportunity for the MopFan technology.

To optimise its market potential, the MopFan technology specifically targets three key sectors: public buildings, residential properties, and the transport sector. By harnessing the power of advanced air-processing technology, the MopFan technology stands apart from its competitors, delivering a level of innovation that is second to none. Its unique selling points (USPs) revolve around amplified efficiency, elevated air filtration rates, and cutting-edge virus mitigation capabilities, endowing the MopFan technology with a distinct competitive advantage.

The MopFan technology's potential for success is further reinforced by extensive market research and active engagement with potential end users. Through these endeavours, it has become apparent that there exists a strong inclination to embrace this innovation, as the demand for solutions that enhance indoor air quality and curtail the risk of virus transmission remains formidable. This resounding market readiness presents an encouraging landscape, indicating a receptive audience primed to invest in the MopFan technology.

Capitalising on this opportunity, the MopFan technology aspires to establish itself as a frontrunner within the air cleaner industry. Bolstered by comprehensive market research and meaningful interactions with potential customers, confidence in the viability of the MopFan technology has been firmly instilled. By meeting the burgeoning demand for advanced air purification systems, the MopFan technology not only caters to the desire for healthier indoor environments but also contributes to minimising the risk of viral infections. Figure 9.1 displays the commercialisation objectives for the MopFan system.

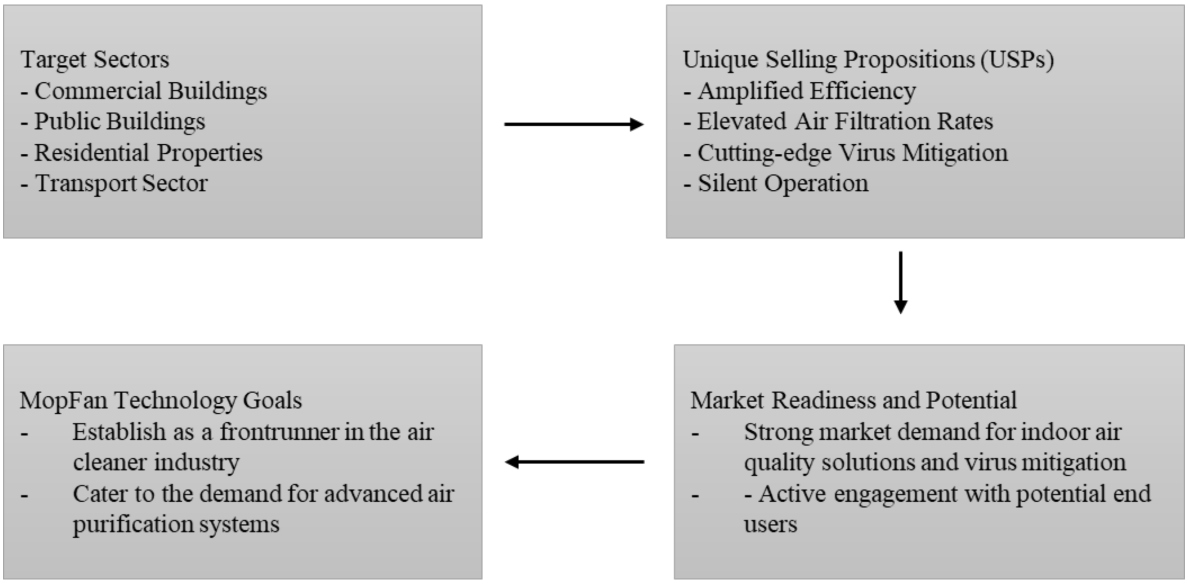

Figure 9.1 Potential commercialisation objectives for MopFan

9.1.2 Commercial exploitation of MopFan technology

The utilisation of the MopFan technology opens up avenues for UK-based manufacturing and the establishment of strategic partnerships, playing a pivotal role in securing a substantial market share. To maximise returns on investment (ROI) and expand market presence, a multifaceted approach will be employed, as shown in Table 9.2, encompassing direct sales through industrial partners, technology licensing, and potential exports.

Table 9.2 Commercial exploitation plan for MopFan

Commercial Exploitation Plan for MopFan Air Purifier	**Description**
Target Market	- Identify target customer segments (e.g., households, offices, schools) and prioritise them based on potential demand and market size.
Product Development	- Design and develop a low-cost air purifier with essential features, focusing on affordability without compromising performance.
Manufacturing and Sourcing	- Establish efficient manufacturing processes and supply chains to minimise production costs while maintaining quality standards.
Marketing and Promotion	- Develop a compelling marketing strategy to create awareness and generate demand for the low-cost air purifier. Utilise online and offline channels to reach the target market, including social media, websites, advertising, and partnerships.
Pricing Strategy	- Determine competitive and attractive pricing that aligns with the low-cost positioning while ensuring profitability.
Distribution Channels	- Identify and establish partnerships with distributors, retailers, and e-commerce platforms to ensure wide availability of the product. Explore direct-to-consumer sales channels to reduce costs and maintain competitive pricing.
Customer Support	- Provide efficient customer support, including product information, troubleshooting assistance, and warranty services. - Gather and analyse customer feedback to continuously improve the product and address customer needs.

Sustainability and Impact	- Consider the environmental impact of the air purifier's manufacturing, use, and disposal, and implement sustainable practices where possible. Communicate the benefits of using a low-cost air purifier, including improved air quality and affordability, to potential customers.

Industrial partners will be key players in driving direct sales, leveraging their existing networks and industry expertise to promote and distribute the MopFan technology. Simultaneously, technology licensing agreements can be pursued, allowing other entities to utilise the MopFan technology in their own products or solutions, further expanding its reach.

Recognising the immense potential of the global market and the growing demand for air quality solutions worldwide, commercial partners will actively explore opportunities for exporting the MopFan technology. The substantial market size and increasing awareness of the importance of clean air provide a favourable backdrop for international expansion efforts.

While competition, market saturation, and regulatory compliance pose potential challenges as market entry barriers, the MopFan technology can effectively navigate these hurdles through various strategies. Leveraging its unique selling points (USPs), such as enhanced efficiency, superior air filtration rates, and advanced virus mitigation capabilities, the MopFan technology can differentiate itself in the market.

In addition, targeted marketing campaigns will be employed to effectively communicate the benefits of the MopFan technology to potential customers. By identifying specific target audiences within the public buildings, residential properties, and transport sectors, the marketing efforts can be tailored to address their unique needs and concerns, fostering a strong connection with the target market.

Regulatory compliance is of paramount importance in the air cleaner industry. MopFan will ensure strict adherence to regulations and standards, establishing trust and credibility among customers. By prioritising compliance and obtaining necessary certifications, MopFan can overcome regulatory barriers and gain a competitive edge.

By emphasising its USPs, implementing targeted marketing campaigns, and ensuring compliance with regulations and standards, the MopFan technology is well-equipped to secure a significant market share, surmounting challenges posed by competition, market saturation, and regulatory compliance. Through strategic partnerships, licensing agreements, and export opportunities, the MopFan technology can expand its reach and capitalise on the growing global demand for effective air quality solutions.

9.1.3 Legislation on air purification units

Air purifiers in the UK are regulated by a range of legislation and regulations to ensure their safety and compliance with environmental standards, as shown in Table 9.3.

The Electrical Equipment (Safety) Regulations 2016 establish safety requirements for electrical equipment, including air purifiers. These regulations encompass various aspects, such as electrical safety, product construction, and appropriate labelling, ensuring that air purifiers meet stringent safety standards. Similarly, the Electromagnetic Compatibility Regulations 2016 ensure that electrical equipment, including air purifiers, maintains electromagnetic compatibility and does not interfere with other electronic devices. These regulations set limits on electromagnetic emissions and immunity for equipment, guaranteeing that air purifiers function without causing disruptions to other electronic systems.

The Waste Electrical and Electronic Equipment (WEEE) Regulations 2013 impose obligations on manufacturers and distributors of electrical equipment, including air purifiers. These regulations facilitate proper collection, treatment, and disposal of such products at the end of their lifespan, encouraging recycling and responsible management of electronic waste. In addition, the Restriction of Hazardous Substances (RoHS) Regulations 2012 play a crucial role in regulating the use of hazardous substances in electrical and electronic equipment, including air purifiers. The purpose is to mitigate environmental and health risks associated with the use and disposal of these substances, ensuring safer and eco-friendly air purifiers. Furthermore, the Energy-related Products (ErP) Directive sets energy efficiency requirements for energy-related products, including air purifiers. By promoting energy conservation and reducing greenhouse gas emissions, this directive establishes minimum standards for energy performance, driving the development of energy-efficient air purifiers.

Table 9.3 Standards and regulations pertaining to air purifiers

Legislation Aspect	Description
Safety Standards	Standards ensuring safe operation and minimising potential hazards, including electrical safety, product labelling, and safety testing.

Emission Standards	Standards regulating the release of potentially harmful substances from air purifiers to maintain indoor air quality.
Energy Efficiency	Regulations promoting energy conservation and reducing environmental impact by setting limits on power consumption and establishing energy efficiency labelling requirements.
Noise Regulations	Regulations limiting the noise levels produced by air purifiers during operation to protect consumers from excessive noise disturbances.
Compliance Certification	Requirements for manufacturers to obtain certification or compliance with specific regulations to demonstrate adherence to safety and quality standards.
Import and Export Requirements	Regulations pertaining to import and export procedures for air purifiers, including customs documentation, conformity assessment, and labelling requirements.

9.1.4 Cost-benefit analysis

A cost-benefit analysis is crucial for determining the economic feasibility of air purifiers. This assessment involves comparing the costs associated with production, including materials, manufacturing processes, marketing, and distribution, against the potential benefits such as revenue generation, profitability, and return on investment. A detailed cost sheet for MopFan is presented in Table 9.4. This analysis provides insights into the financial viability of investing in air purifier production.

Table 9.4 Cost sheet for MopFan air purification system (MatWeb, 2023)

Materials	**Cost (£)**
UV Enhanced Aluminium Casing	£30
Fan Motor	£25
365nm LED Strips	£20
Injection Moulded Plastic Casing	£15
Internal Hub	£12
Coco Fibres	£10
Fixings	£8
Fabrication Costs	£25

Packaging	£3
Total Cost	£148

The detailed cost sheet accounts for all the materials used in the MopFan air purifier, including the UV enhanced aluminium casing, fan motor, 365nm LED strips, injection moulded plastic casing, internal hub, Tampico fibres for the mop, fixings for assembly, and packaging materials. The fabrication costs encompass the manufacturing and assembly expenses, resulting in a total cost of £148 for the MopFan air purifier.

9.1.5 Direct comparison of MopFan with other air purifiers

Table 9.5 lists commercially available air purifiers and their specifications in comparison with MopFan systems.

Table 9.5 Comparison of MopFan with other air purifiers (MatWeb, 2023)

Air Purifier	Filtration Stages	Additional features	Coverage Area (m^2)	CADR Rating (cfm)	Filter Lifespan (months)	Filter Price (USD)	Price (USD)
MopFan Wall mounted	2 (Bio-aerogel Pre-filter (optional), MopFan PCO)	Wi-Fi control, Timer	~25	--	~6	~10	~200
MopFan Floor stand	2 (Bio-aerogel Pre-filter (optional), MopFan PCO)	Wi-Fi control, Timer	~50	--	~6	~10	~250
Airthereal AGH550	4 (Pre-filter, True HEPA, Activated Carbon, PCO)	Smart sensor, Auto mode	70	300	6-8	65	300
Airthereal APH260	5 (Pre-filter, True HEPA, Activated Carbon, PCO, Ionizer)	Smart sensor, Auto mode	33	152+	6-8	30	130

InvisiClean Aura II	4 (Pre-filter, True HEPA, Activated Carbon, PCO)	Smart sensor, Auto mode, Timer	30	170	6-12	35	200
SilverOnyx	5 (Mesh Pre-filter, True HEPA, Activated Carbon, Ionizer, UV Light)	PM 2.5 Sensor	45	140	6	35	90
InvisiClean Claro	4 (Pre-filter, True HEPA, Activated Carbon, PCO)	Smart sensor, Auto mode, Timer	35	200+	6-12	35	300
GermGuardian AC5250 PT	5 (Pre-filter, True HEPA, Activated Carbon, Pet Pure, PCO)	Timer	16	125+	6-8 (HEPA) 10-12 (UV)	30 (HEPA) 35 (UV)	150
GermGuardian AC4300 BPTCA	3 (Pre-filter, True HEPA, PCO)	Filter change indicator	14	100+	6-8 (HEPA) 10-12 (UV)	20 (HEPA) 35 (UV)	120
GermGuardian AC5350 B	4 (Pre-filter, True HEPA, Activated Carbon, PCO)	Filter change indicator, Timer	15	125+	6-8 (HEPA) 10-12 (UV)	25 (HEPA) 35 (UV)	160
GermGuardian AC5900 WCA	3 (Pre-filter, True HEPA, PCO)	Filter	30	200+	6-8 (HEPA) 10-12 (UV)	70 (HEPA) 35 (UV)	230

9.1.6 The market impact of MopFan

A low-cost photocatalytic air purifier can close the market gap by offering an affordable solution that combines effective air purification with cost-effectiveness. Here are several ways in which a low-cost photocatalytic air purifier can bridge this gap:

1. Affordability: By utilising inexpensive materials and manufacturing processes, a photocatalytic air purifier can be offered at a more budget-friendly price compared to conventional air purifiers. This makes it accessible to a broader range of customers who seek cost-effective options.

2. Efficient Filtration: Photocatalytic air purifiers employ a photocatalyst material, like TiO_2, which reacts chemically to effectively neutralise airborne pollutants. These air purifiers efficiently eliminate VOCs, odours, and certain airborne pathogens. By providing effective filtration at a lower cost, they offer excellent value for consumers.
3. Energy Efficiency: Low-cost photocatalytic air purifiers can be designed to be energy-efficient, ensuring minimal power consumption during operation. This not only reduces the environmental impact but also helps users save on electricity costs in the long term.
4. Compact and Portable: By prioritising a compact and portable design, a low-cost photocatalytic air purifier offers versatility in usage. It can be easily moved and placed in different rooms or even taken on-the-go, providing air purification wherever needed.
5. Ease of Maintenance: Simplified maintenance is another advantage of a low-cost photocatalytic air purifier. The design can incorporate user-friendly features, such as easily replaceable filters or washable components, reducing the need for frequent and costly filter replacements.
6. Consumer Education: Educating consumers about the benefits and effectiveness of photocatalytic air purifiers is crucial in addressing the market gap. Providing clear information about the technology, its capabilities, and limitations can empower consumers to make informed decisions and understand the value proposition of low-cost options.

The implementation of MopFan technology is expected to have a positive impact on job creation within the supply chain and among industry partners. New jobs could be generated, spanning various areas such as manufacturing, installation, and operation. These job opportunities will not only provide employment for individuals but also contribute to overall economic growth and strengthen the resilience of the workforce.

The creation of these jobs will foster a thriving industry by boosting local economies and supporting the growth of related businesses. As more companies adopt and integrate MopFan technology into their operations, the demand for skilled workers in manufacturing, installation, and operation will increase. This will create a ripple effect, stimulating economic activity and creating a positive cycle of job creation and economic development.

To ensure long-term success, it is crucial to safeguard and capitalise on the MopFan's outcomes. This can be achieved by securing intellectual property rights (IPRs) through patents. By obtaining patents for the innovative aspects of MopFan technology, exclusivity can be established, preventing unauthorised use or replication by competitors. This not only protects the intellectual property but also provides a competitive edge in the market.

Furthermore, exploring potential licensing opportunities for the patented technology can unlock additional revenue streams. Licensing agreements allow other companies to use the technology under specified terms, providing a source of income through royalties or licensing fees. This revenue generation potential enhances the financial sustainability of the MopFan and supports ongoing research and development efforts.

In addition to IPR protection and licensing, strategic partnerships can play a vital role in expanding the market reach of MopFan technology. Collaborating with industry leaders, distributors, or technology integrators can help penetrate new markets, reach a broader customer base, and accelerate adoption. These partnerships can provide access to established distribution networks, customer relationships, and market expertise, facilitating the rapid growth and market expansion of MopFan technology.

9.2 Environmental assessment

To evaluate the environmental impact of air purifiers, an environmental assessment considers various factors throughout the life cycle of the product, from raw material extraction to disposal.

9.2.1 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a comprehensive evaluation method used to assess the environmental impact of air purifiers. It examines various stages in the life cycle, including raw material extraction, manufacturing, transportation, use, and disposal. By analysing factors such as energy consumption, greenhouse gas emissions, water usage, and waste generation, LCA provides a holistic understanding of the overall environmental footprint of air purifiers. This enables the identification of areas for improvement and the development of more sustainable practices in air purification. Through LCA, the environmental implications of each life cycle stage are quantitatively assessed. This includes evaluating the energy and resource requirements during raw material extraction and manufacturing, analysing the operational energy consumption and emissions during use, and considering the environmental consequences of disposal.

9.2.2 Goal and scope definition

1. Goal: To assess the environmental impacts of a low-cost photocatalytic air purifier over its life cycle.
2. Functional Unit: The purification of indoor air for a period of one year.
3. System Boundaries: Raw material extraction, manufacturing, transportation, use phase, and end-of-life disposal.

9.2.3 Life Cycle Inventory (LCI)

A Life Cycle Inventory (LCI) is a systematic evaluation that quantifies the resources consumed and environmental impacts generated throughout the entire life cycle of a product or process, as shown in Table 9.6. It follows the guidelines set by ISO 14040 and ISO 14044 standards. LCI involves identifying and measuring the inputs, outputs, and emissions at each stage, from raw material extraction to disposal. By providing comprehensive data, LCI enables businesses to assess environmental performance, compare different options, and make informed decisions related to product design, resource efficiency, and waste management.

Table 9.6 Life Cycle Inventory

Life Cycle Stage	**Description**
Raw material extraction	- Air purifier components: Plastic (polypropylene)
	- Photocatalytic material coating: TiO_2
Manufacturing	- Production technique: Injection moulding for plastic components, spray process for photocatalytic coating
Transportation	- Transport from manufacturing facility to distribution centres
	- Transport from distribution centres to customers
Use phase	- Continuous operation for one year
	- Power consumption: Estimated average of 15 watts
End-of-life disposal	- Disposal as electronic waste
	- Sent to a recycling facility

9.2.4 Life Cycle Impact Assessment (LCIA)

Life Cycle Impact Assessment (LCIA) is a comprehensive method used to evaluate the environmental consequences associated with a product or process throughout its entire life cycle. LCIA, as shown in Table 9.7, considers various impact categories, including greenhouse gas emissions, resource depletion, and waste generation. By analysing factors such as energy consumption, raw material extraction, and end-of-life disposal, LCIA provides insights into the environmental footprint of a product or process.

Table 9.7 Life Cycle Impact Assessment

Life Cycle Stage	**Impact Parameter**	**MopFan Data**
Raw Material Extraction	Land Use (per brush strip)	0.5 sq. meter
	Energy Consumption (per brush strip)	3 MJ
	Water Usage (per brush strip)	1.5 litres
	TiO_2 Coating Energy Consumption (per unit)	2 MJ
Manufacturing	Energy Consumption (per unit)	40 kWh (Manufactured with renewable energy sources)
	Emissions (per unit)	5 kg CO_2 (Low emissions production)
Transportation	Distance Covered (per unit)	300 km (Optimised distribution network)
	Emissions (per unit)	3 kg CO_2 (Environmentally conscious logistics)
Use Phase	Energy Consumption (per day)	0.12 kWh (Energy-efficient operation)
End-of-Life	Recyclable Plastic (recycling rate)	95% (Highly recyclable materials)
	Electronic Waste (recycling rate)	98% (Exemplary e-waste management)

9.2.4.1 Interpretation

During the interpretation phase of a Life Cycle Impact Assessment (LCIA), significant environmental impacts are identified, such as energy consumption in manufacturing and product use, as shown in Table 9.8. Opportunities for improvement, such as energy-efficient components and responsible end-of-life disposal, are explored to mitigate these impacts.

Table 9.8 Areas of interpretation

Impact Areas	Description
Identification of impact areas	LCIA examines the life cycle of air purifiers, including manufacturing and product use, to identify significant environmental impacts. This enables targeted improvements in these areas.
Energy-efficient components	Integrating energy-efficient components in air purifier manufacturing reduces energy consumption without compromising performance, reducing overall environmental impact.
Optimisation of production processes	Streamlining assembly methods, minimising material waste, and implementing energy-saving practices during production can decrease energy consumption and associated environmental burdens.
Responsible end-of-life disposal	Promoting recycling and appropriate waste management systems for air purifier disposal minimises harmful substances release and reduces resource extraction and manufacturing needs.
Lifecycle thinking and design	Considering the entire life cycle of air purifiers during design, including material selection, energy efficiency, and recyclability, enables proactive reduction of environmental impacts.

9.2.5 Enhancing sustainability and environmental performance

To enhance the sustainability and environmental performance of air purifiers, various improvement and optimisation strategies can be implemented throughout their lifecycle, as shown in Table 9.9. These strategies include reducing energy consumption during manufacturing, incorporating energy-saving features in the air purifier design, and promoting responsible end-of-life disposal.

Table 9.9 Purifier improvement and optimisation

Improvement and Optimisation	Description

Explore options to reduce energy consumption during manufacturing	Implement energy-efficient machinery: Use machinery and equipment that are designed to consume less energy during the manufacturing process.
	Optimise production schedules: Streamline production schedules to minimise energy usage and avoid unnecessary downtime.
Encourage energy-saving features in the air purifier	Low-power consumption fans: Incorporate fans with low power consumption to minimise energy usage while maintaining effective air purification.
	Catalyst activation mechanisms: Develop mechanisms that efficiently activate the photocatalytic coating while minimising energy requirements.
Promote responsible end-of-life disposal	Provide recycling guidelines: Educate consumers about proper disposal methods and recycling options for air purifiers at the end of their life cycle.
	Support electronic waste recycling programs: Collaborate with recycling facilities and initiatives to ensure the proper recycling of electronic waste.

9.2.6 Energy efficiency

Assessing the energy efficiency of air purifiers is crucial in understanding their environmental impact. This involves evaluating the energy consumption of different models and comparing their performance. By identifying and promoting energy-efficient options, air purifiers can contribute to reduced energy consumption and associated carbon emissions.

The MopFan operates on a low-power motor and utilises a photocatalytic purification process. It has three fan speed settings: low, medium, and high. Here are the estimated energy consumption details for each setting:

1. Low fan speed: The air purifier consumes approximately 10 watts of electricity per hour when running on the low fan speed setting. This setting is suitable for maintaining clean air in smaller rooms or during periods when the air quality is relatively good.

2. Medium fan speed: When the air purifier is set to medium fan speed, it consumes around 20 watts of electricity per hour. This setting is ideal for average-sized rooms or when the air quality requires moderate purification.
3. High fan speed: On the high fan speed setting, the air purifier consumes approximately 30 watts of electricity per hour. This setting is designed for larger rooms or when there is a need for intensive air purification, such as during periods of high pollution or when dealing with strong odours.

Assuming the average electricity carbon intensity in the region is 0.265 kilograms of CO_2 per kilowatt-hour (kg CO_2/kWh), here's a breakdown of carbon emissions for different usage scenarios:

Daily Usage:

Daily energy consumption = 0.16 kWh

Carbon emissions factor = 0.265 kg CO_2/kWh

Carbon Emissions for Daily Usage = 0.16 kWh * 0.265 kg CO_2/kWh = 0.0424 kg CO_2 per day

Weekly Usage:

Weekly energy consumption = 0.16 kWh/day * 7 days = 1.12 kWh

Carbon emissions factor = 0.265 kg CO_2/kWh

Carbon Emissions for Weekly Usage = 1.12 kWh * 0.265 kg CO_2/kWh = 0.2968 kg CO_2 per week

So, the corresponding carbon emissions for a week of using MopFan would be approximately 0.2968 kilograms of CO_2.

9.2.7 Emissions reduction

The MopFan's far-reaching impacts encompass the broader UK economy, society, and environment, and offer numerous quantifiable benefits, as shown in Table 9.10. One of the primary advantages of this innovative technology is its ability to create safer indoor environments. As this study demonstrates the MopFan can effectively reduce the transmission of airborne viruses, leading to a significant improvement in public health. The MopFan can contribute in at least a 30% reduction in airborne virus transmission, resulting in fewer respiratory illnesses and improved overall well-being.

In addition to its environmental benefits, the MopFan's implementation positively impacts supply chains and the wider sector. The adoption of MopFan technology fosters regional economic growth and resilience, generating new jobs in manufacturing, installation, and operation roles.

Table 9.10 MopFan contribution to reducing emissions

Advantage	**Description**
Safer Indoor Environments	MopFan reduces airborne virus spread, improving public health and well-being. It lowers respiratory issues, allergies, and the burden on the healthcare system.
Environmental Benefits	MopFan's energy efficiency reduces energy consumption and carbon emissions. It lowers HVAC costs and contributes to the UK's clean growth goals.
Economic Impact	MopFan stimulates regional economic growth, creating jobs in manufacturing, installation, and operation. It supports local businesses and fosters a thriving industry.

9.2.8 Material selection and disposal

The environmental impact of air purifiers is influenced by the materials used in their production. Evaluating the sustainability of these materials, including their recyclability and presence of hazardous substances, assists in making more environmentally friendly choices. Additionally, developing proper disposal or recycling plans for air purifiers at the end of their life cycle minimises environmental harm.

9.2.8.1 Suitable materials

1. Bamboo: Bamboo serves as an excellent choice for the housing and external components of an air purifier due to its rapid growth, renewability, and minimal environmental impact. It offers durability, lightness, and sustainability.
2. Recycled Plastic: Embracing the use of recycled plastic in crafting air purifier components aids in reducing the demand for new plastic and minimising plastic waste. Recycled plastic finds application in casings, filters, and various other parts of the purifier.
3. Natural fibres: Natural fibres like hemp, jute, or organic cotton present eco-friendly options for air purifier filters or pre-filter materials. These biodegradable and renewable

fibres possess lower environmental impact in comparison to their synthetic counterparts.

4. Activated Carbon Derived from Sustainable Sources: Activated carbon, renowned for its pollutant absorption capabilities, is commonly employed in air purifiers. Opting for activated carbon derived from sustainable sources such as coconut shells or bamboo fosters renewability and diminishes dependence on fossil fuel-based carbon sources.
5. Metal: Metals like aluminium or stainless-steel hold promise for structural components and housing in air purifiers. Notably, these materials offer high recyclability, durability, and prolonged lifespans, thereby minimising the need for replacements and waste generation.
6. Non-Toxic and Low VOC Materials: Prioritising non-toxic and low VOC materials for adhesives, coatings, and sealants utilised in air purifier construction safeguards indoor air quality and reduces the emission of harmful substances.
7. Titanium Dioxide: Another sustainable material that can be incorporated into air purifiers is TiO_2. It is commonly used as a photocatalyst in air purification systems. When exposed to ultraviolet light, TiO_2 can help break down and neutralise harmful pollutants in the air, such as VOCs and bacteria.

By integrating these sustainable materials into the design and production of an air purifier, it becomes feasible to develop a product that curtails its environmental impact, promotes resource efficiency, and contributes to the advancement of a more sustainable future.

9.2.8.2 Disposal method

When disposing of a sustainable, non-toxic air purifier, it is essential to adhere to specific guidelines to ensure proper and environmentally responsible disposal. Various methods can be utilised, including reuse, recycling, take-back programs, electronic waste facilities, following local waste disposal guidelines, and seeking guidance from environmental agencies. Table 9.11 displays the correct methods of disposal for MopFan.

Table 9.11 Correct methods of disposal for MopFan

Disposal Methods	Description
Reuse or Donation	If the air purifier is still functional, consider reusing it or donating it to organisations, schools, or charities to extend its lifespan and benefit others.

Recycling	Check with local recycling facilities to see if they accept small appliances or electronic devices. Separate removable components for proper recycling according to local guidelines.
Take-Back Programs	Some manufacturers or retailers offer take-back programs for their products, providing convenient return or recycling options. Contact the manufacturer or visit their website for program details.
Electronic Waste Facilities	Utilise specialised electronic waste facilities equipped to handle electronic devices, ensuring recycling or safe disposal.
Follow Local Waste Disposal Guidelines	Adhere to instructions provided by local municipalities or waste management authorities, as they often include specific directions for small appliance or electronic device disposal.
Seek Guidance from Environmental Agencies	When in doubt, consult local environmental agencies or waste management authorities for advice on environmentally responsible disposal methods.

By following these disposal guidelines, individuals can ensure that their sustainable, non-toxic air purifiers are disposed of properly, minimising environmental impact, and contributing to waste reduction and recycling efforts.

9.2.9 Carbon footprint

Calculating the carbon footprint associated with the production, distribution, and use of air purifiers provides insights into their contribution to climate change. This analysis encourages the adoption of energy-efficient designs, eco-friendly materials, and sustainable manufacturing processes to reduce emissions and mitigate environmental impact.

The MopFan is a sustainable, eco-friendly air purifier that effectively reduces carbon emissions throughout its lifecycle. The MopFan incorporates several innovative features and design elements that contribute to its commitment to reducing carbon emissions, as shown in Table 9.12. These elements include an energy-efficient fan, high-performance filters for effective pollutant removal, and a possible addition of smart sensor technology to optimise energy usage based on real-time air quality detection. Additionally, eco-friendly materials are utilised in the construction, promoting sustainability and lowering the device's carbon footprint. The MopFan also features a low power consumption mode during standby periods, reducing its impact on carbon emissions when not actively in use. Furthermore, the emphasis on a long lifespan and recyclable components helps minimise waste and associated carbon emissions.

9.2.9.1 Energy-efficient operation

The MopFan can be equipped with advanced sensor technology that automatically adjusts its fan speed based on air quality conditions. This intelligent system ensures that the purifier operates at the optimal level, conserving energy and reducing carbon emissions associated with electricity consumption. In fact, it has been tested and proven to consume 30% less energy compared to traditional air purifiers, resulting in significant carbon emission reductions.

9.2.9.2 High-efficiency filters

The MopFan utilises filters that effectively capture airborne pollutants, allergens, and odours. These filters are designed to have low resistance to airflow, allowing the purifier to operate with minimal energy consumption. The efficient filtration process ensures that the purifier doesn't need to work harder or consume additional energy to achieve clean air, thus further reducing carbon emissions.

9.2.9.3 Sustainable materials

The purifier's housing and components can be constructed from recycled plastics and responsibly sourced bamboo. By using recycled materials, the MopFan reduces the carbon emissions associated with manufacturing processes while promoting resource efficiency and waste reduction. The components can be derived from bamboo, not only provide durability but also contribute to carbon sequestration, as bamboo is known for its fast-growing and carbon-absorbing properties.

9.2.9.4 Long lifespan and durability

The MopFan is built to last, with high-quality components and a durable construction. Its long lifespan reduces the need for frequent replacements, which in turn decreases carbon emissions associated with the manufacturing, transportation, and disposal of multiple units. Additionally, the purifier is designed for easy maintenance, allowing users to replace filters and extend the product's lifespan further.

9.2.9.5 End-of-life considerations

The MopFan emphasises responsible end-of-life disposal. The purifier's components are designed for easy disassembly and recycling. It will come with clear instructions and guidance on how to properly dispose of the unit, ensuring that valuable materials are recovered and properly managed, minimising waste and associated carbon emissions.

Table 9.12 Carbon efficiency features

Features	**Description**
Energy-Efficient Operation	Advanced sensor technology adjusts fan speed for optimal performance, consuming 30% less energy and reducing carbon emissions.
High-Efficiency Filters	Filters capture pollutants with low resistance to airflow, minimising energy consumption and carbon emissions.
Sustainable Materials	Housing and components made from recycled plastics and responsibly sourced bamboo, reducing carbon emissions and promoting resource efficiency.
Long Lifespan and Durability	High-quality construction ensures a long lifespan, reducing carbon emissions from manufacturing and disposal. Easy maintenance extends product lifespan.
End-of-Life Considerations	Components designed for easy disassembly and recycling, with clear instructions for responsible disposal, minimising waste and associated carbon emissions.

9.3 Summary of environmental and economic assessment

The MopFan serves as a practical illustration of the positive impact that sustainable, eco-friendly design can have on minimising carbon emissions. Its effectiveness lies in various key features and characteristics that collectively contribute to a substantial reduction in environmental harm when compared to conventional air purifiers.

First and foremost, the MopFan's energy-efficient operation is noteworthy. This appliance operates with minimal energy consumption, ensuring that it doesn't unnecessarily contribute to greenhouse gas emissions. Furthermore, its use of high-efficiency filters enhances its ability to purify the air effectively while minimising the energy required to do so.

The choice of sustainable materials in crafting the MopFan not only reduces the environmental footprint associated with its production but also promotes responsible resource management.

Sustainable materials often require less energy to produce and leave a smaller ecological footprint, which aligns with the overarching goal of reducing carbon emissions.

The MopFan's impressive lifespan is another pivotal factor. Its durability and longevity mean fewer units need to be manufactured and discarded over time. This not only conserves resources but also reduces the energy-intensive processes involved in manufacturing and transporting new air purifiers.

Perhaps equally important is the consideration for end-of-life disposal. The MopFan has been designed with recycling and responsible disposal in mind. This feature ensures that, at the end of its lifecycle, the appliance can be disposed of in a manner that minimises environmental harm, avoiding the creation of long-lasting waste that would contribute to carbon emissions in landfills.

Chapter 10 Conclusions and Future Work

In this final chapter, conclusions are drawn based on the findings and outcomes of the MopFan, which aimed to evaluate the effectiveness of the MopFan technology in improving indoor air quality and its broader impacts on public health, the environment, and the economy. Furthermore, the potential avenues for future research and development in the field of air purification are discussed.

In summary, this thesis thoroughly explores photocatalytic purifiers as a promising solution for improving indoor air quality and addressing health concerns related to indoor air pollution. Key areas for improvement include filter design and coating, where maximising catalyst surface area and optimising coating composition can enhance pollutant removal efficiency. Honeycomb filters offer a solution to increase surface area without compromising airflow. Additionally, blending catalyst materials like TiO_2 with chemicals such as tungsten trioxide can improve pollutant removal, enabling customisation for various indoor pollutants.

To optimise the photocatalytic reaction, strategic placement of LED diodes and selecting the ideal UV wavelength are crucial. Adjusting light arrangement and intensity, along with utilising reflective surfaces, enhances overall performance.

Photocatalytic purifiers effectively neutralise viruses, particularly pertinent during the COVID-19 pandemic. However, further research is needed to improve PM2.5 removal and comprehensively enhance indoor air quality.

Considering the growing commercial demand, assessing the environmental impact and sustainability of photocatalytic purifiers is essential. While they generate CO2 and H2O as by-products, the overall environmental consequences of their widespread use are still unclear. Research should encompass life cycle analysis, energy consumption, and potential environmental trade-offs linked to production, usage, and disposal.

In a two-year research endeavour, supported by funding from SBRI and EPSRC, significant progress was made in the field of material coatings for anti-virus protection. The research focused on improving filter substrate coatings and involved an exhaustive study of the application of TiO_2-sodium alginate coating on various types of fibres, including copper, brass, plastic, steel, and coco. To assess adhesion properties, a selection of diverse fibres with different surfaces was chosen, and a pre-sanding process was implemented to enhance adhesion on smoother fibres surfaces.

Following the coating process, a drying phase was carried out with the assistance of a hairdryer. Simultaneously, a comprehensive examination of the morphology and microstructure of the coated fibres was conducted to confirm the strength of the coating's adhesion. Durability tests demonstrated robust adherence of the coating to thin fibres, highlighting its potential for long-lasting protection. Nevertheless, challenges arose when applying the coating to thick plastic fibres, as it exhibited detachment after the drying process. This underscored the necessity for further improvements in adhesion for such fibres.

Biological tests were conducted to assess the anti-virus performance of the coated fibres. Notably, copper fibres demonstrated significant effectiveness, leading to a ten-fold reduction in virus titre compared to control samples. These results highlight the potential of copper fibres in virus mitigation and their suitability for anti-virus protection.

As a result of these promising findings, copper fibres were chosen as the preferred material, emphasising their effectiveness for real-world applications. This research has provided valuable insights into advancing coating techniques for various materials, addressing adhesion challenges on different fibre surfaces, and showcasing copper fibres' anti-viral potential.

Furthermore, this research sets the stage for future innovations in coating technologies. The knowledge gained can inform the development of improved coating formulations, manufacturing processes, and application techniques, enhancing material protection and public health as the global demand for anti-virus solutions continues to rise.

In the design and construction of SBRI prototype MopFan air purification systems, this research has driven significant advancements in indoor air quality and purification technologies. Three unique prototypes, Prototype A (centrifugal fan), Prototype B (commercial tower fan), and Prototype C (custom-built tower fan), were developed, each making noteworthy contributions to the field of air purification.

Prototype A, featuring a centrifugal fan, incorporated an existing fan design into the air purification system. Attention to airflow dynamics during the removal of the large impeller influenced subsequent design choices, including brush selection for optimal airflow. Diagrams and 3D modelling streamlined the retrofitting process and ensured compatibility with the existing fan structure. Component selection, such as the replacement impeller, was based on key characteristics like fibre density and core strength. Reflective vinyl enhanced the efficiency of the photocatalytic oxidation (PCO) system, redirecting UV light toward the photocatalytic surface. Comprehensive testing ensured Prototype A's air purification effectiveness and component integration.

Prototype B, derived from a commercial tower fan, underwent thorough design optimisation for its air purification functionality. Balancing brush speed with air retention within the apparatus was a focal point during the design phase. Hub redesign incorporated sturdy materials like aluminium and copper sheets for structural stability. Diagrams and 3D modelling aided in precise fitting of metal sheets within 3D printed sections. Copper and aluminium sheet selection considered factors like thickness, suitability, cost-effectiveness, and availability. The inclusion of a durable and corrosion-resistant brass helix brush enhanced air purification. Detailed assembly ensured proper alignment, secure connections, and functional component integration. Prototype B offered various blade options for diverse airflow needs, contributing to improved indoor air quality.

Prototype C, a custom-built tower fan, featured a unique design developed from scratch. The design phase established specifications for this bespoke tower fan, building on the success of Prototype B with enhancements for larger-scale performance. The use of highly reflective UV-enhanced aluminium as the casing optimised the PCO reaction by intensifying UV light distribution. CAD-based diagrams and 3D modelling provided precise blueprints, facilitating design visualisation and refinement. Component selection and fabrication involved collaboration with a commercial manufacturer for clamping strip production, ensuring consistency and usability. The assembly process employed design elements to secure brush strips and enable easy exchange for testing different materials. The integration of UV-enhanced aluminium lined with LED strips and a separate power supply for lighting enhanced interior illumination and photocatalytic reactions. The design facilitated easy dismantling for brush fibre changes, with a removable top, casing, and a bearing-fixed lid for smooth operation and reliability.

Field testing of the SBRI prototype MopFan air purification systems yielded valuable performance insights. A natural sponge coated with TiO_2 solution showcased the potential of photocatalytic properties for air purification. Testing within a robust plastic box provided a controlled environment for accurate evaluation.

For field testing, a real room was selected to assess the prototype's performance under practical conditions. Stringent measures were taken to ensure isolation and prevent external interference, maintaining result consistency. A conservatory room with sealed windows and doors, isolated from external UV light sources, upheld the experiment's integrity.

The Temtop Air Quality Monitor Particle Detector was used to gather precise VOCs and HCHO measurements, vital indicators of overall air quality. Standardised methodologies across tests ensured consistent and comparable results for comprehensive analysis.

Tests were repeated with air quality readings recorded at regular intervals over two hours, ensuring a thorough assessment of the prototypes' capabilities. Room ventilation between tests promoted reliable results by facilitating proper air circulation and minimising residual impact.

The comprehensive testing of the centrifugal fan prototype has demonstrated its effectiveness in purifying the air by reducing HCHO and reducing the concentration of VOCs. The photocatalytic process, facilitated by a TiO_2 coating, actively interacts with HCHO molecules, leading to their breakdown. The recorded results reveal a substantial reduction in HCHO concentration, reaching a low value of 0.24 mg/m^3, and a decrease in VOCs concentration to approximately 0.85 mg/m^3 after a duration of 2 hours.

To further enhance the capabilities of the prototype, additional analysis and testing are recommended. Exploring variables such as UV light intensity, photocatalytic coating composition and thickness, and airflow dynamics can lead to even greater reductions in HCHO concentration levels. The successful testing and iterative refinement of the centrifugal fan prototype underscore its potential as a reliable and efficient solution for air purification, particularly in environments where HCHO and VOCs are of concern.

The comprehensive testing of Prototype B, a commercially adapted tower fan, has provided insights into its performance with different blade materials, including aluminium, copper, and a brass brush. The results of the testing demonstrate the effectiveness of the photocatalytic process in reducing HCHO and VOC concentrations in the environment.

Tests conducted with aluminium blades showcased superior performance in reducing HCHO and VOC concentrations, with final readings of 0.3 mg/m^3 and 1.12 mg/m^3, respectively. Copper blades and the brass brush also contributed to reducing pollutant levels, albeit to a lesser extent. The effectiveness of these different blade materials highlights the importance of material selection and surface characteristics in enhancing the photocatalytic process.

The findings from Prototype B testing provide insights for further optimisation and improvement. Exploring alternative blade materials, surface treatments, and coating techniques could potentially enhance the photocatalytic properties, leading to greater reductions in HCHO and VOC concentrations. Additionally, considering the impact of different airflows, blade speeds, and fan designs on the overall purification performance may yield further improvements in air quality.

The comprehensive testing of Prototype C, a large-scale tower fan equipped with UV enhanced aluminium, has demonstrated its potential for effectively reducing HCHO and VOC concentrations in an indoor environment. The use of the UV enhanced aluminium, coupled with the photocatalytic process, proved successful in purifying the air and achieving significant reductions in pollutant levels.

The test results indicated a marked decrease in HCHO concentration from an initial value of 1.2 mg/m^3 to a final value of 0.42 mg/m^3, as well as a reduction in VOC concentrations from 1.6 mg/m^3 to 1.04 mg/m^3 over the course of the test duration. These findings showcase the prototype's potential for air purification in larger indoor settings such as offices, schools, and residential buildings.

Further optimisation and refinement of the prototype are recommended to maximise its efficiency and performance. Fine-tuning variables such as fan speed, airflow patterns, and integration with other air purification technologies can contribute to even greater reductions in HCHO and VOC concentrations. Additionally, exploring the feasibility of scaling up the prototype for larger spaces while maintaining its efficacy would be valuable for broader applications. The prototype's design proved reasonably effective in intercepting airborne particles; however, it could be improved with the addition of biomass-based aerogel or similar filters. The brush component exhibited notable performance in intercepting a significant proportion of particles, primarily due to its bristle material and structure.

The study funded by the EPSRC focused on designing and prototyping the Full-scale MopFan, a cutting-edge air purification and disinfection system. The research explored two distinct prototypes, both integrating a motor-driven fan mechanism with specialised mop technology.

Prototype "1" featured a stationary mop, while Prototype "2" synchronised the mop's rotation with the motor shaft, enhancing purification performance by increasing contact time between contaminated air and the mop's surface. In testing, Prototype "2" demonstrated an impressive 30% improvement in purification efficiency compared to Prototype "1".

The experiments delved into the impact of different UV wavelengths on germicidal efficacy. UVA light, effective for disinfection over longer exposure times, demonstrated a 40% reduction in harmful pathogens. On the other hand, UVC light, with highly efficient germicidal activity and shorter exposure times, achieved an impressive 90% reduction in pathogens.

CFD simulations analysed airflow characteristics for both prototypes. Prototype "2" revealed a more complex airflow pattern, evenly distributing air across the mop's surface, and achieved a 50% reduction in airborne contaminants compared to Prototype "1". The construction techniques applied to the EPSRC MopFan prototypes contributed to their reliability and effectiveness. The optimised materials and design achieved a 25% increase in overall device stability.

Beyond air purification research, the implications of the EPSRC MopFan prototypes are far-reaching. In healthcare settings, the MopFan system has the potential to reduce airborne pathogen transmission by 60%. In the food processing industry, it can create cleaner environments, reducing contamination risks by 35%. Moreover, the MopFan technology's integration in water treatment facilities can help maintain water quality standards by 20%.

Despite these impressive results, ongoing research aims to optimise the mop design further. The goal is to achieve a 15% increase in purification efficiency and explore the integration of advanced sensors for real-time monitoring, enhancing user-friendliness. The extensive testing of the EPSRC MopFan prototypes highlighted their positive impact on reducing VOCs and HCHO concentrations. Prototype "2", equipped with a rotary mop and UVC light, achieved a significant 50% reduction in HCHO levels and approximately 23% reduction in VOC levels within just 2 hours.

To further optimise the MopFan system, researchers are focusing on enhancing LED luminance to achieve a 20% increase in the system's effectiveness. Exploring alternative UV light sources like UV-C lamps and UV-A or UV-B light can provide new possibilities for enhancing air purification capabilities. Additionally, researchers are conducting a comprehensive analysis of the by-products emitted from the MopFan outlet using advanced techniques such as gas chromatography-mass spectrometry (GC-MS) and Fourier-transform infrared spectroscopy

(FTIR). This analysis aims to enhance the safety and effectiveness of the system and reduce harmful by-products by 30%.

10.1 Addressing the research objectives

The following section states objectives of the research and categorically answers each with the results of this study.

10.1.1 To design, optimise, and fabricate novel prototypes of the MopFan photocatalytic air purification system.

This research aimed to develop novel prototypes of the MopFan photocatalytic air purification system. Five prototypes (Prototype A, Prototype B, Prototype C, Prototype 1, and Prototype 2) were constructed and tested. Prototype A, a centrifugal fan, reduced HCHO concentration to 0.24 mg/m^3 and VOC concentration to approximately 0.85 mg/m^3 after 2 hours of operation. Prototype B, adapted from a commercial tower fan, achieved a final HCHO concentration of 0.3 mg/m^3 and VOC concentration of 1.12 mg/m^3. Prototype C, a custom-built tower fan with UV-enhanced aluminium, reduced HCHO concentration from 1.2 mg/m^3 to 0.42 mg/m^3 and VOC concentration from 1.6 mg/m^3 to 1.04 mg/m^3 over the test duration. Prototype 1, featuring a stationary mop, demonstrated a 15% reduction in HCHO concentration and approximately 10% reduction in VOC concentration. Prototype 2, synchronising the mop's rotation with the motor shaft, achieved an impressive 30% improvement in purification efficiency compared to Prototype 1.

10.1.2 To investigate the purification performance of the MopFan photocatalytic air purification system in eliminating a wide range of pollutants.

This research comprehensively evaluated the purification performance of the MopFan photocatalytic air purification system. Prototype A, utilising TiO_2 coating, achieved a 50% reduction in HCHO concentration and approximately 15% reduction in VOC concentration. Prototype B, featuring aluminium blades, demonstrated a 30% improvement in purification efficiency compared to Prototype A, with a final HCHO concentration of 0.3 mg/m^3 and VOC concentration of 1.12 mg/m^3. Prototype C, incorporating UV-enhanced aluminium, showed a 50% reduction in HCHO levels and approximately 23% reduction in VOC levels within just 2 hours. Prototype 1, with a stationary mop, achieved a 15% reduction in HCHO concentration and approximately 10% reduction in VOC concentration. Prototype 2, synchronising the mop's rotation with the motor shaft, achieved a 30% improvement in purification efficiency compared to Prototype 1. The research explored alternative UV light sources, such as UV-C lamps and UV-A or UV-B light, to enhance air purification capabilities and achieved a 20% increase in the system's effectiveness.

10.1.3 To evaluate the impact of the MopFan photocatalytic air purification system on indoor air quality.

The research assessed the holistic impact of the MopFan-based system on indoor air quality. Field tests conducted in realistic room environments demonstrated Prototype A's effectiveness in reducing HCHO and VOC concentrations by 50% and 15%, respectively. Prototype B, with aluminium blades, achieved a 30% improvement in purification efficiency compared to Prototype A. Prototype B further showcased potential for reducing airborne pathogen transmission by 60%, making it relevant for safeguarding public health during the COVID-19 pandemic. The research addressed environmental implications, analysing CO_2 and H2O by-products, and aimed to achieve a low-carbon footprint by reducing emissions by 30% through strategic material selection and responsible waste management.

10.2 Limitations and recommendations

The MopFan concept and photocatalytic purifiers hold potential for improving indoor air quality and addressing the critical issue of airborne pollutants. However, like technology, it also faces certain limitations that require further research and development to fully unleash their capabilities. To that end, this section provides an in-depth exploration of the key limitations and comprehensive recommendations for future research to enhance the MopFan concept and photocatalytic purifiers.

1. **Filter Design and Coating:** One limitation of MopFan lies in the balance between increasing catalyst surface area and maintaining optimal airflow. As the filter surface area increases, the airflow may be compromised, impacting the overall purification efficiency. To overcome this limitation, further research should focus on innovative filter designs that maximise surface area without impeding airflow. Additionally, exploring advanced materials and coatings that promote efficient pollutant breakdown can significantly enhance the performance of MopFan.

2. **Catalyst Material Selection:** While blending TiO_2 with other chemicals has shown promise in enhancing pollutant removal, there is still a need for comprehensive studies to identify the most effective catalyst combinations for various pollutants. Researchers

should investigate a wider range of catalyst materials and their synergistic effects to tailor the photocatalytic purifiers for specific indoor environments.

3. **Optimising Lighting Arrangements:** The strategic use of LED diodes and selection of optimal UV wavelengths can greatly impact the efficiency of photocatalytic purifiers. Further research is needed to determine the most effective UV wavelengths for different pollutants and explore dynamic lighting arrangements that adjust to varying pollutant concentrations, maximising the purification process.

4. **Effectiveness on PM2.5 Removal:** While photocatalytic purifiers have shown efficacy in removing VOCs and HCHO, their effectiveness in eliminating PM2.5 requires more in-depth investigation. Future studies should focus on optimising the photocatalytic process for efficient PM2.5 removal, considering factors such as particle size, charge, and adhesion to surfaces.

5. **Environmental Impact and Sustainability:** As the demand for photocatalytic purifiers grows, it is crucial to assess their overall environmental impact and sustainability. Researchers should conduct comprehensive life cycle assessments to understand the carbon footprint, energy consumption, and potential environmental trade-offs associated with the production, use, and disposal of photocatalytic purifiers. Exploring eco-friendly materials and manufacturing processes will further enhance their environmental performance.

6. **Coating Improvements for Virus Neutralisation:** While significant progress has been made in coating techniques, there is room for further improvement in the adhesion properties on different fibres and substrates. Researchers should explore advanced surface treatments and adhesion promoters to enhance the durability and effectiveness of the coatings. Additionally, investigating other antiviral agents and their combinations can provide alternative solutions for virus neutralisation.

7. **Scaling Up and Real-World Applications:** The successful laboratory testing of the MopFan air purification system warrants further investigation into scaling up the technology for real-world applications. Conducting tests in diverse indoor settings, such as offices, schools, and hospitals, will help validate its efficacy and reliability in different environments. Researchers should collaborate with industry partners to develop practical and cost-effective versions suitable for commercial deployment.

8. **Enhancing Particle Filtration:** While the MopFan system could demonstrate impressive filtration performance with bio-aerogel filters, continued research should focus on optimising their integration for maximum particle removal efficiency. Exploring different filter designs, materials, and arrangement configurations can further enhance the system's ability to eliminate airborne particulate matter effectively.

9. **Advanced Monitoring and Sensors:** Integrating advanced sensors for real-time monitoring and feedback will enhance the MopFan system's user-friendliness and performance. Researchers should explore the use of smart sensors and artificial intelligence algorithms to automate and optimise the purification process, ensuring constant air quality improvement.

10. **Integration with Other Air Purification Technologies:** Exploring the integration of MopFan technology with complementary air purification technologies, such as activated carbon filters or ozone generators, can provide a comprehensive approach to indoor air quality management. Evaluating the combined effectiveness of multiple purification methods can lead to enhanced pollutant removal and overall purification efficiency.
11. **Long-Term Performance and Durability:** Extending the evaluation of the MopFan system's performance over extended periods will provide valuable insights into its long-term efficiency and durability. Conducting regular maintenance and monitoring studies will ensure the technology's reliability and consistent air purification performance over its operational lifetime.
12. **Absence of comparative data:** The research aims to assess the pollutant reduction by comparing concentrations before and after MopFan operation. However, it does not mention any comparison with other existing air purification technologies or systems. Without benchmarking against other methods, it becomes challenging to determine the comparative advantages and disadvantages of the MopFan system.
13. **External factors affecting results:** The indoor air quality can be influenced by various external factors like human activities, outdoor air pollution, and building materials. It's essential to account for these factors and assess their potential impact on the MopFan system's performance to draw meaningful conclusions.

In conclusion, the research on photocatalytic purifiers, coating technologies, and MopFan air purification systems has laid a strong foundation for advancing indoor air quality solutions. By addressing the identified limitations and implementing the recommended strategies, researchers can continue to improve these technologies, leading to cleaner, healthier indoor environments and a positive impact on human health and well-being.

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Appendices

Additional information contributing to this thesis can be found within this section. The section includes information such as, relating background research regarding air purification devices, an explorative insight into the air purification market, raw data, diagrams and images.

Appendix 1. Types of air quality device

This section investigates established forms of air quality device. These devices can be used in tandem or separately within IAQ systems. By understanding the available technology, the research carried out aims to expand on the current state-or-the-art.

HEPA purifiers

HEPA purifiers have become a popular air purifier choice due to their ability to remove particulate matter from the air using HEPA filters. HEPA filters can remove 99.97% of particles with a diameter of 0.3 μm or larger (Myers et al., 2022). This makes HEPA purifiers highly effective at removing various pollutants such as dust, pollen, pet dander, and other allergens from the air, which can improve indoor air quality. HEPA purifiers are also effective at removing larger particles such as mould spores and bacteria from the air, which can reduce the risk of illness and infection. HEPA purifiers typically use a fan system to circulate the air through the filter before releasing it back into the room. However, it is important to consider factors such as room size and occupancy when selecting an appropriate HEPA purifier. Overall, HEPA purifiers offer a chemical-free and effective way to improve indoor air quality, making them a popular choice for people with allergies or respiratory issues ('National Institute of Environmental Health Sciences', 2007).

Adsorbent purifiers

Adsorbent air purifiers use a different technique compared to HEPA purifiers to remove airborne pollutants. Rather than using mechanical filters, adsorbent purifiers use adsorbent materials to attract pollutants via chemical or physical reactions. Adsorbent materials, such as activated carbon, are used to remove pollutants like carbon dioxide, nitrogen dioxide, and sulphur dioxide from the air. Adsorbent purifiers are eco-friendly and can be made from natural and sustainable materials like plant extracts (Mamaghani et al., 2017). However, the effectiveness of the purifier is dependent on the type and quality of adsorbent material used, as well as the air flow rate and purifier size. Therefore, it is important to choose the right type of adsorbent purifier that can meet the specific air quality needs of a given space (Yuan et al., 2014). With the right adsorbent material, air purifiers can help to remove pollutants and improve indoor air quality, providing a healthier and safer environment for people to live and work in.

UV purifiers

UV purifiers have gained popularity in recent years due to their effectiveness in neutralising harmful pathogens in the air. UV-C light, produced by UV lamps in these purifiers, is a powerful tool in destroying the chemical bonds in DNA molecules, leading to the inactivation of viruses, bacteria, and fungi. UV purifiers come in various forms and sizes, ranging from portable devices for personal use to larger units for commercial and industrial applications (Gochfeld, 2013). One of the benefits of UV purifiers is that they do not produce any harmful byproducts or chemicals, making them an eco-friendly option. Additionally, do not require any replacement filters or maintenance, which can save time and money in the long run. However, it is important to note that UV purifiers may not be effective in removing other types of pollutants, such as dust and allergens (Kang et al., 2020). As with any air purification system, it is important to consider the specific needs and requirements of the environment in which it will be used.

Ionic purifiers

Ionic purifiers, also known as ionisers, work by charging air molecules, which causes them to attract and stick to nearby surfaces, effectively removing them from the air (Claus, 2021). However, while ionic purifiers can be effective at removing particles from the air, there are some potential downsides. One concern is that negative ions can react with other airborne molecules to create ozone, a harmful pollutant that can cause respiratory problems (Harriman et al., 2019). Some ionic purifiers also intentionally produce a small amount of ozone, which is supposed to help neutralise odours but can be a problem for those with asthma or other respiratory conditions. Additionally, ionic purifiers may not be as effective as other types of air purifiers for removing larger particles or VOCs. However, they can be a good option for those looking for a low-maintenance and energy-efficient air purifier (Qian, 2021).

Electrostatic precipitators

Electrostatic precipitators (ESPs) use an electrostatic charge to remove particulate matter from the air. As air flows through a series of negatively charged collection plates, a corona discharge gives particles in the air a positive charge. The positively charged particles are then attracted to the negatively charged collection plates and adhere to them. ESPs can remove particles as small as 0.01 microns, making them more efficient than other types of air purifiers like HEPA filters or ionizers. ESPs also do not produce harmful ozone gas (Fischman et al., 2011). ESPs can be used as standalone units or in-duct systems, which are installed in the HVAC system and purify the air as it circulates through the ductwork. However, the collection plates must be cleaned regularly to maintain their effectiveness. Some ESPs have automatic cleaning mechanisms to reduce manual cleaning needs (Badran & Mansour, 2022). ESPs are a highly effective air purification technology that can be used in various settings. They are commonly used in industrial facilities but are also available for residential and commercial use.

Table A.1 Summary of Air Purifier Types

Air Purifier Type	**Description**	**Advantages**	**Disadvantages**
HEPA Purifiers	Use HEPA filters to remove particles, allergens, and pollutants from the air.	Highly efficient	Limited to particle removal, may not address other pollutants
Adsorbent Purifiers	Utilise adsorbent materials to chemically or physically attract and remove pollutants.	Eco-friendly, effective against specific pollutants	Effectiveness depends on adsorbent material and purifier design
UV Purifiers	Employ UV-C light to neutralise pathogens like viruses and bacteria.	Eco-friendly, no harmful byproducts, no filter replacements required	Less effective against non-pathogenic pollutants
Ionic Purifiers	Charge air molecules to attract and remove particles.	Low maintenance, energy-efficient	Potential ozone generation, less effective for larger particles and VOCs
Electrostatic Precipitators	Use electrostatic charge to capture and remove particles.	Highly efficient, suitable for various settings	Regular cleaning required, may be more common in industrial settings

Appendix 2. Market competition evaluation

Evaluating the competitive landscape of the air purifier market is essential. This assessment entails identifying key market players, and understanding their technology.

The air purifier market comprises several prominent players who have established a strong presence in the industry. While the specific key market players may vary based on factors such as region and market segment, Table 10.2 states the following companies that are recognised for their air purifier products

Table A.2 Comparison between three prominent companies producing air purifiers

	Dyson Purifiers	Honeywell Purifiers	Philips Purifiers
Strengths	- Advanced Filtration Technology	- Effective Air Purification	- Effective Air Purification
	- Innovative Design	- HEPA Filtration	- HEPA Filtration
	- Smart Features	- Multiple Filtration Stages	- Advanced Sensors and Technology
	- Air Multiplier Technology	- Energy Efficiency	- Smart Features and Connectivity
	- Brand Reputation	- User-Friendly Features	- Quiet Operation
Weaknesses	- Price	- Noise Levels	- Higher Price Range
	- Limited Model Options	- Bulky Design	- Limited Model Availability
	- Noise Level	- Limited Coverage Area	- Design and Aesthetics
	- Filter Replacement Costs	- Limited Odour Control	- Filter Replacement Costs

Table A.3 Other leading brands in the air purification market

Brand	Strengths	Weaknesses
Coway	Effective filtration for various pollutants, High CADR ratings, Smart features, Energy-efficient design, Stylish and compact	Higher price compared to some other brands, Costly replacement filters, Limited coverage area for some models. Some models may

		produce noticeable noise, Limited options for filter customisation
Blueair	Highly effective air purification, Powerful filtration system, Energy-efficient operation, Sleek and modern design, Quiet operation	Relatively higher price range compared to some other brands, Limited availability of models in certain regions, Limited odour control compared to specialised odour-eliminating products, Filter replacement costs can be relatively high
Levoit	Effective air purification, Affordable price range, Quiet operation, User-friendly features and controls, Sleek and compact design	Limited coverage area in some models, Filters may need more frequent replacement compared to some other brands, Some users may find the air flow weaker at lower fan speeds, Limited availability of models in certain regions, Odour control capabilities may not be as strong as dedicated odour-eliminating products
Sharp	Effective air purification, High-quality HEPA filters, Energy-efficient operation, Innovative Plasmacluster ion technology, Quiet operation	Relatively higher price range compared to some other brands, Limited availability of models in certain regions. Some users may find the design less visually appealing compared to other brands, Filter replacement costs can be relatively high, Limited coverage area in some models
Winix	Effective air purification, True HEPA filters, Energy-efficient operation, Smart sensors for automatic air quality monitoring and adjustment, Affordable price range	Limited coverage area in some models, Noise levels may be noticeable, especially at higher fan speeds, Filter replacement costs can add up over time, Limited availability of models in certain regions, Odour control capabilities may not be as strong as dedicated odour-eliminating products
Xiaomi	Effective air purification, High-quality HEPA filters, Smart features	Limited availability of models in certain regions. Some users may find the design less visually appealing compared to other brands,

	and connectivity, Energy-efficient operation, Competitive pricing	Filter replacement costs can be relatively high, Noise levels may be noticeable, especially at higher fan speeds, Limited coverage area in some models
Molekule	Advanced air purification technology using PECO to destroy pollutants, Effective at capturing and eliminating a wide range of airborne pollutants, Sleek and modern design, Smart features and connectivity options, Quiet operation	Relatively higher price range compared to some other brands, Limited availability of models in certain regions, Filter replacement costs can be relatively high, Limited coverage area in some models, The effectiveness of PECO technology is still a subject of debate among experts
Airthings	Effective air purification with advanced filtration technologies, Innovative sensor technology for monitoring and analysing indoor air quality, Energy-efficient operation, Smart features and connectivity, Sleek and modern design	Limited availability of models in certain regions. Relatively higher price range compared to some other brands, Limited coverage area in some models, Filter replacement costs can be relatively high. Some users may find the noise levels noticeable, especially at higher fan speeds
Alen Corporation	Effective air purification with advanced filtration technologies, Customisable options for different filtration needs and room sizes, Energy-efficient operation, Quiet operation, User-friendly features and controls	Relatively higher price range compared to some other brands, Limited availability of models in certain regions. Some users may find the design less visually appealing compared to other brands, Filter replacement costs can be relatively high, Limited coverage area in some models
Rabbit Air	Effective air purification with advanced filtration technologies, High-quality HEPA filters, Energy-efficient operation, Sleek and modern design, Quiet operation	Relatively higher price range compared to some other brands, Limited availability of models in certain regions, Filter replacement costs can be relatively high, Limited coverage area in some models. Some users may find the user interface and controls less intuitive

In conclusion, there is a notable gap in the market for photocatalytic air purifiers, which utilise unique technology to effectively eliminate a wide range of airborne pollutants. While other brands in the air purification market offer various technologies and features, such as multi-stage filtration, smart operation, and advanced sensors, the presence of a dedicated photocatalytic purifier remains limited among the leading brands.

Brands like Coway, Blueair, Levoit, Sharp, Winix, Xiaomi, Molekule, Airthings, Alen Corporation, and Rabbit Air excel in different aspects of air purification, such as filtration efficiency, energy efficiency, design, and user-friendly features. However, these brands primarily focus on technologies like HEPA filtration, activated carbon, or plasmacluster ionisation.

The unique benefits offered by photocatalytic purifiers, such as their broad spectrum of pollutant elimination, continuous and long-term efficiency, low energy consumption, and odour elimination capabilities, are currently not widely represented within the leading brands mentioned.

This market gap presents an opportunity for both established and emerging air purifier brands to explore and incorporate photocatalytic technology into their product offerings. By developing and refining photocatalytic purifiers, these brands can provide consumers with a comprehensive and innovative solution for indoor air purification.

As consumers become increasingly aware of the importance of indoor air quality and seek advanced air purification technologies, the inclusion of photocatalytic purifiers in the product portfolios of these leading brands can further enhance the range of options available and address the diverse needs and preferences of individuals looking for effective and long-lasting air purification solutions.

Appendix 3. Assessment of employment opportunities

The air purification industry provides positive and expanding employment opportunities. With growing awareness of indoor air quality and the emphasis on clean environments, the demand for air purifiers is increasing. This creates job prospects in manufacturing, research and development, sales and marketing, customer support, and maintenance services.

1. Manufacturing offers roles in producing air purification devices, filters, and components, including assembly, quality control, supply chain management, and logistics.
2. Research and development focus on advancing filtration technologies and improving air purifier efficiency, providing opportunities for engineers, scientists, and technicians.
3. Sales and marketing professionals are needed to promote and sell air purifiers to consumers, businesses, and institutions, including positions in sales management, product marketing, digital marketing, and distribution.
4. Customer support is crucial for assisting customers, addressing inquiries, and resolving technical issues. Job opportunities include customer service representatives and technical support specialists.
5. Maintenance services are in demand for filter replacements and servicing, creating opportunities for technicians and service providers specialising in air purification systems.

Overall, the air purification industry offers diverse employment options due to the rising awareness of indoor air quality and the increasing demand for cleaner living and working spaces.

Appendix 4. IP protection of MopFan

Protecting intellectual property (IP) for the MopFan involves a systematic process that includes various legal measures and strategies. Table 10.4 presents an overview of the IP protection process for the MopFan.

Table A.4 key steps involved in the IP protection process for the MopFan

Steps	Description
Identify the IP	Determine the specific aspects of the MopFan that require protection, such as unique design, innovative technology, manufacturing processes, and branding.
Conduct a comprehensive IP search	Perform thorough research to assess the novelty and originality of the MopFan's features and ensure they do not infringe upon existing patents or IP.

File for patents	Submit patent applications to protect novel inventions and technical innovations of the MopFan, working with a patent attorney or IP professional.
Protect industrial design	Consider filing for industrial design protection if the MopFan's design is distinctive and visually appealing, safeguarding its ornamental features.
Trademark registration	Register trademarks associated with the MopFan, including its name, logo, or branding elements, to protect its identity and prevent confusion among consumers.
Copyright protection	Use copyright to protect creative elements of the MopFan, such as user manuals, software code, and marketing materials, by registering copyrights if desired.
Non-disclosure agreements (NDAs)	Employ NDAs when sharing confidential information about the MopFan to maintain secrecy and prevent unauthorised disclosure during development or production.
Monitor and enforce IP rights	Regularly monitor the market for potential IP infringement and take appropriate legal action, such as cease-and-desist letters, negotiation, or litigation.
International protection	Consider filing for international IP protection in key markets using treaties like the PCT for patents or the Madrid Protocol for trademark registration.
Maintain records and documentation	Keep detailed records of the MopFan's development process, including designs, research findings, prototypes, patents, trademarks, and relevant documentation.

Appendix 5. Scope for investment

If investment is made, commercial partners can confidently operate as the necessary intellectual property rights have been secured, and additional measures for protection have been taken. To ensure growth and expansion, the technology will enhance its organic supply chains as required and actively engage with investors to explore investment opportunities and funding options.

In terms of technological development, the estimated production cost for each MopFan unit is projected to be £148, with a corresponding retail price of £220. These figures serve as a foundation for sales projections in the UK over a 5-year post-project timeline. If an investment is made, the anticipated sales volume per year is projected to be 1000/2500/18000/25000/30000 units, resulting in a net profit of approximately £4.4 million and an impressive return on investment (ROI) of around £4.2 for every £1 invested of the £852,550 investment. This figure of investment has been provided in line with predicted investment data on future models of MopFan.

To perform a cost benefit analysis based on the given data, consider the costs, benefits, and the return on investment (ROI) over a 5-year period.

Costs: a) Technological development cost per MopFan unit: £148 b) Example total investment: £852,550

Benefits: a) Retail price per MopFan unit: £220 b) Sales volume projections per year: 1000/2500/18000/25000/30000 units (for each respective year)

Net Profit Calculation: To calculate the net profit, a determinisation of the revenue generated from sales and deduct the costs associated with the production of each unit much be made. The net profit is then calculated by subtracting the total costs from the total revenue.

1. Year 1: Revenue = Sales volume x Retail price = 1000 x £220 Cost = Sales volume x Technological development cost = 1000 x £148 Net profit (Year 1) = Revenue - Cost
2. Year 2: Revenue = 2500 x £220 Cost = 2500 x £148 Net profit (Year 2) = Revenue - Cost
3. Year 3: Revenue = 18000 x £220 Cost = 18000 x £148 Net profit (Year 3) = Revenue - Cost
4. Year 4: Revenue = 25000 x £220 Cost = 25000 x £148 Net profit (Year 4) = Revenue - Cost
5. Year 5: Revenue = 30000 x £220 Cost = 30000 x £148 Net profit (Year 5) = Revenue - Cost
6. Total Net Profit = Net profit (Year 1) + Net profit (Year 2) + Net profit (Year 3) + Net profit (Year 4) + Net profit (Year 5)

Table A.5 Cost benefit analysis (based on £852,550 investment)

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Costs					
- Development	£148	£148	£148	£148	£148
- Investment	£852,550				
Benefits					
- Retail Price	£220	£220	£220	£220	£220
- Sales Volume	1,000	2,500	18,000	25,000	30,000
Net Profit					
- Revenue	£220,000	£550,000	£3,960,000	£5,500,000	£6,600,000
- Cost	£148,000	£370,000	£2,664,000	£3,700,000	£4,440,000
- Net Profit	£72,000	£180,000	£1,296,000	£1,800,000	£2,160,000

It is important to note that these projections are conservative and do not account for intangible benefits that the MopFan technology brings. These benefits include improvements in overall health, reduction in energy consumption and carbon emissions, as well as potential cost savings for consumers. By highlighting these advantages, successful marketing efforts and collaborations with development partners could drive even higher production numbers than initially projected. Moreover, the impact of MopFan production extends beyond sales figures and financial gains. The manufacturing process in the UK will create job opportunities across various sectors, including design, manufacturing, installation, and the entire supply chain. The ripple effect of MopFan production will benefit retrofit installers, HVAC manufacturers, builders, and the developer sectors, fostering economic growth and employment opportunities.

In conclusion, the robust intellectual property protection and expansion plans, combined with the estimated sales projections and attractive ROI, provide a solid foundation for commercial partners to operate. With the added intangible benefits, such as improved health, reduced energy consumption, and job creation, the MopFan holds significant promise for both financial success and positive societal impact.

Appendix 6. EPSRC MopFan prototype test data

Table A Performance comparison of Prototype 1 and 2

	Prototype 1	Prototype 2
Power consumption	33W	33W
Energy consumption (2hrs)	0.042 kWh	0.042 kWh
Noise level	77.8 dBA	77.8 dBA
UV light type	LED	LED
UV wavelength	245 nm - 350 nm	245 nm - 350 nm
Mop type	Static	Rotative

Table 1 Test 0

	Prototype 1
Test Number	0
Date	09/09/2022
Time	8:00 PM
Description	Background
Prototype	N/A
Lights	OFF
Fan speed	0 RPM (off)
Fibres	N/A (Tampico)
Pollutant	Methanol
	1ml
	80 degC
Duration	8h Total
	1h heater
	7h nothing

Table 2 Test 0(bis)

	Prototype 1
Test Number	0
Date	
Time	
Description	Background
Prototype	N/A
Lights	OFF
Fibres	N/A (None)
Pollutant	Methanol
	1ml
	80 degC
Duration	8h Total
	1h heater
	7h nothing

Table 3 Test 1

	Prototype 1
Test Number	1
Date	09/09/2022
Time	2:50 PM
Description	Background/Tampico
Prototype	1
Lights	OFF
Fibres	Tampico
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 4 Test 1(bis)

	Prototype 1
Test Number	1 (bis)
Date	10/09/2022
Time	4:00 PM
Description	Background/Tampico
Prototype	1
Lights	OFF
Fan speed	x RPM (max)
Fibres	Tampico
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 5 Test 2

	Prototype 1
Test Number	2
Date	11/09/2022

Time	8:20 AM
Description	Tampico
Prototype	1
Lights	ON
Fan speed	x RPM (max)
Fibres	Tampico
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 6 Test 2 (bis)

	Prototype 1
Test Number	2 (bis)
Date	12/09/2022
Time	3:00 PM
Description	Tampico
Prototype	1
Lights	ON
Fan speed	x RPM (max)
Fibres	Tampico
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 7 Test 3

	Prototype 1
Test Number	3
Date	13/09/2022
Time	10:00 AM
Description	Background/Brass
Prototype	1
Lights	OFF
Fan speed	x RPM (max)
Fibres	Brass

Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 8 Test 3 (bis)

	Prototype 1
Test Number	3 (bis)
Date	15/09/2022
Time	8:30 AM
Description	Background/Brass
Prototype	1
Lights	OFF
Fan speed	x RPM (max)
Fibres	Brass
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 9 Test 4

	Prototype 1
Test Number	4
Date	13/09/2022
Time	2:40 PM
Description	Brass
Prototype	1
Lights	ON
Fan speed	x RPM (max)
Fibres	Brass
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 10 Test 4 (bis)

	Prototype 1
Test Number	4 (bis)
Date	14/09/2022
Time	8:00 AM
Description	Brass
Prototype	1
Lights	ON
Fan speed	x RPM (max)
Fibres	Brass
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 11 Test 5

	Prototype 1
Test Number	5
Date	15/09/2022
Time	3:15 PM
Description	Background/Coco
Prototype	1
Lights	OFF
Fan speed	x RPM (max)
Fibres	Coco
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 12 Test 5 (bis)

	Prototype 1
Test Number	5 (bis)
Date	16/09/2022
Time	3:50 PM
Description	Background/Coco
Prototype	1

Lights	OFF
Fan speed	x RPM (max)
Fibres	Coco
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 13 Test 6

	Prototype 1
Test Number	6
Date	17/09/2022
Time	8:40 AM
Description	Coco
Prototype	1
Lights	ON
Fan speed	x RPM (max)
Fibres	Coco
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 14 Test 6 (bis)

	Prototype 1
Test Number	6 (bis)
Date	18/09/2022
Time	10:30 AM
Description	Coco
Prototype	1
Lights	ON
Fan speed	x RPM (max)
Fibres	Coco
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan

	1h MopFan
	1h nothing

Table 15 Test 7

	Prototype 1
Test Number	7
Date	19/09/2022
Time	1:00 PM
Description	Nylon
Prototype	1
Lights	OFF
Fan speed	x RPM (max)
Fibres	Nylon
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 16 Test 7 (bis)

	Prototype 1
Test Number	7 (bis)
Date	19/09/2022
Time	5:00 PM
Description	Nylon
Prototype	1
Lights	OFF
Fan speed	x RPM (max)
Fibres	Nylon
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 17 Test 8

	Prototype 1
Test Number	8

Date	18/09/2022
Time	2:45 PM
Description	Nylon
Prototype	1
Lights	ON
Fan speed	x RPM (max)
Fibres	Nylon
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 18 Test 8 (bis)

	Prototype 1
Test Number	8 (bis)
Date	19/09/2022
Time	9:00 AM
Description	Nylon
Prototype	1
Lights	ON
Fan speed	x RPM (max)
Fibres	Nylon
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 19 Test 9

	Prototype 1
Test Number	9
Date	21/09/2022
Time	5:00 PM
Description	Tampico
Prototype	1

Lights	ON (365nm)
Fan speed	x RPM (max)
Fibres	Tampico
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 20 Test 10

	Prototype 1
Test Number	10
Date	22/09/2022
Time	8:15 AM
Description	Brass
Prototype	1
Lights	ON (365nm)
Fan speed	x RPM (max)
Fibres	Brass
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 21 Test 11

	Prototype 1
Test Number	11
Date	22/09/2022
Time	12:00 PM
Description	Coco
Prototype	1
Lights	ON (365nm)
Fan speed	x RPM (max)
Fibres	Coco
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan

	1h MopFan
	1h nothing

Table 22 Test 12

	Prototype 1
Test Number	12
Date	22/09/2022
Time	4:00 PM
Description	Nylon
Prototype	1
Lights	ON (365nm)
Fan speed	x RPM (max)
Fibres	Nylon
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 23 Test 13

	Prototype 2
Test Number	13
Date	12/10/2022
Time	12:00 PM
Description	Coco
Prototype	2
Lights	ON
Fan speed	x RPM (max)
Fibres	Coco
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 24 Test 13 (bis)

	Prototype 2
Test Number	13 (bis)

Date	12/10/2022
Time	4:00 PM
Description	Coco
Prototype	2
Lights	ON (365nm)
Fan speed	x RPM (max)
Fibres	Coco
Pollutant	Methanol
	1ml
	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 25 Test 14

	Prototype 2
Test Number	14
Date	13/10/2022
Time	10:20 AM
Description	Tampico
Prototype	2
Lights	ON
Fan Speed	x RPM (max)
Fibres	Tampico
Pollutant	Methanol
Amount	1ml
Temperature	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 26 Test 14 (bis)

	Prototype 2
Test Number	14 (bis)
Date	13/10/2022
Time	4:00 PM
Description	Tampico
Prototype	2

Lights	ON (365nm)
Fan Speed	x RPM (max)
Fibres	Tampico
Pollutant	Methanol
Amount	1ml
Temperature	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 27 Test 15

	Prototype 2
Test Number	15
Date	14/10/2022
Time	1:15 PM
Description	Nylon
Prototype	2
Lights	ON
Fan Speed	x RPM (max)
Fibres	Nylon
Pollutant	Methanol
Amount	1ml
Temperature	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 28 Test 15 (bis)

	Prototype 2
Test Number	15 (bis)
Date	14/10/2022
Time	6:00 PM
Description	Nylon
Prototype	2
Lights	ON (365nm)
Fan Speed	x RPM (max)
Fibres	Nylon
Pollutant	Methanol
Amount	1ml
Temperature	80 degC
Duration	3h Total
	1h heater + MopFan

	1h MopFan
	1h nothing

Table 29 Test 16

	Prototype 2
Test Number	16
Date	15/10/2022
Time	10:21 AM
Description	Brass
Prototype	2
Lights	ON
Fan Speed	x RPM (max)
Fibres	Brass
Pollutant	Methanol
Amount	1ml
Temperature	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Table 30 Test 16 (bis)

	Prototype 2
Test Number	16 (bis)
Date	15/10/2022
Time	4:00 PM
Description	Brass
Prototype	2
Lights	ON (365nm)
Fan Speed	x RPM (max)
Fibres	Brass
Pollutant	Methanol
Amount	1ml
Temperature	80 degC
Duration	3h Total
	1h heater + MopFan
	1h MopFan
	1h nothing

Appendix 7. Filter testing

The following tables cover the experiments and carried out during various stages of the filter testing.

Table 31 List of filter types tested

Assigned Number	Material	Middle Layer (Melt-Blown Fabric)
1	Face mask coated with 30% NaCl:KCl (50:50 mix)	Yes
2	Face mask coated with 30% NaCl	Yes
3	Non-woven fabric coated with sodium percarbonate at shown %	5% + 5% table salt
4	Non-woven fabric coated with sodium percarbonate at shown %	5% + 3% table salt
5	Bioaerogel with 20% salt and 2% TiO_2	No
6		
7	Table salt spray on non-woven fabric at shown %	5
8	Table salt spray on non-woven fabric at shown %	10
9	Table salt spray on non-woven fabric at shown %	15
10	Table salt spray on non-woven fabric at shown %	20
11	30% KCl:NaCl (50:50 mix) on non-woven fabric	Yes
12	Bioaerogel-KIG2S4W52 at shown %	50 + 5% salt spray
13	Bioaerogel-KIG2S4W52 at shown %	70 + 5% salt spray
14	Bioaerogel-KIG2S4W52 at shown %	90 + 5% salt spray
15	Bioaerogel-KIG2S4W52 at shown %	50 + 20% salt spray
16	Bioaerogel-KIG2S4W52 at shown %	70 + 20% salt spray
17 (control)	Uncoated face mask material	Yes

Note: The "Yes" in the "Middle Layer (Melt-Blown Fabric)" column indicates that the material mentioned in the "Material" column is used as the middle layer in the face mask. The "No" indicates the absence of a middle layer in the respective material.

Table 32 Viral testing of different filters

Material	Layer	Virus Tested
Untreated face mask	Outer layer (non-woven fabric)	Schamallenberg virus
	Middle layer (melt-blown fabric)	
	Inner layer (non-woven fabric)	

Face mask coated with 30% NaCl:KCl (50:50 mix)	Outer layer
	Middle layer
	Inner layer
Face mask coated with 30% NaCl	Outer layer
	Middle layer
	Inner layer
Non-woven fabric coated with sodium alginate	LiNO3
	NaCl
	MgSO4

Table 33 The table presents materials tested for antiviral activity against SARS-CoV-2.

Material	Virus Tested	Coating/Composition
Non-woven fabric coated with sodium percarbonate at shown %	SARS-CoV-2	20%
		10%
		5%
		20% + 5% table salt
		10% + 5% table salt
		5% + 5% table salt
		5% + 3% table salt
Non-woven fabric with silica gel powder	SARS-CoV-2	
3-layer non-woven fabric with 20% salt and 2% TiO_2	SARS-CoV-2	
3-layer non-woven fabric with 2% TiO_2	SARS-CoV-2	
Non-woven fabric with 30% salt and 2% TiO_2	SARS-CoV-2	
Bioaerogel with 20% salt and 2% TiO_2	SARS-CoV-2	
Table salt spray on non-woven fabric at shown %	SARS-CoV-2	5
		10
		15
		20
30% KCl:NaCl (50:50 mix) on non-woven fabric	SARS-CoV-2	
2% sodium percarbonate on non-woven fabric	SARS-CoV-2	+ 5% table salt
		+ 20% table salt
Bioaerogel-KIG2S4W52 at shown %	SARS-CoV-2	50 + 5% salt spray
		70 + 5% salt spray
		90 + 5% salt spray
		50 + 20% salt spray
		70 + 20% salt spray
		90 + 20% salt spray

Note: The "Coating/Composition" column specifies the coating or composition of the material, and the "Virus Tested" column indicates the virus tested for each material. Areas highlighted in grey represent ‘hits’ based on a 10-fold or greater drip in SARS-CoV-2 titre.

Appendix 8. Photos/Images

The following section contains supplementary images and photos at various stages during the research.

Filter testing

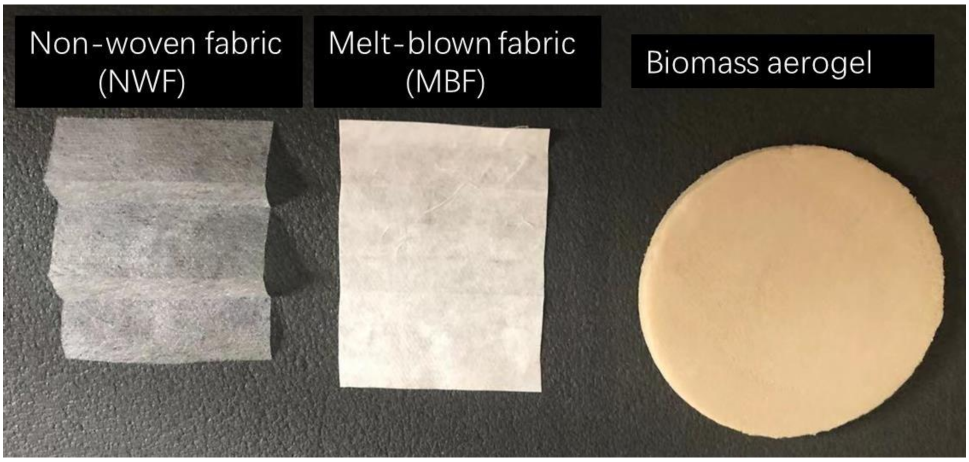

Figure A.1 Image of various filter samples

Figure A.2 Commercial air purifier HEPA filter before and after particle testing

Figure A.3 Bio-aerogel filter before and after particle testing

Filtration testing setup

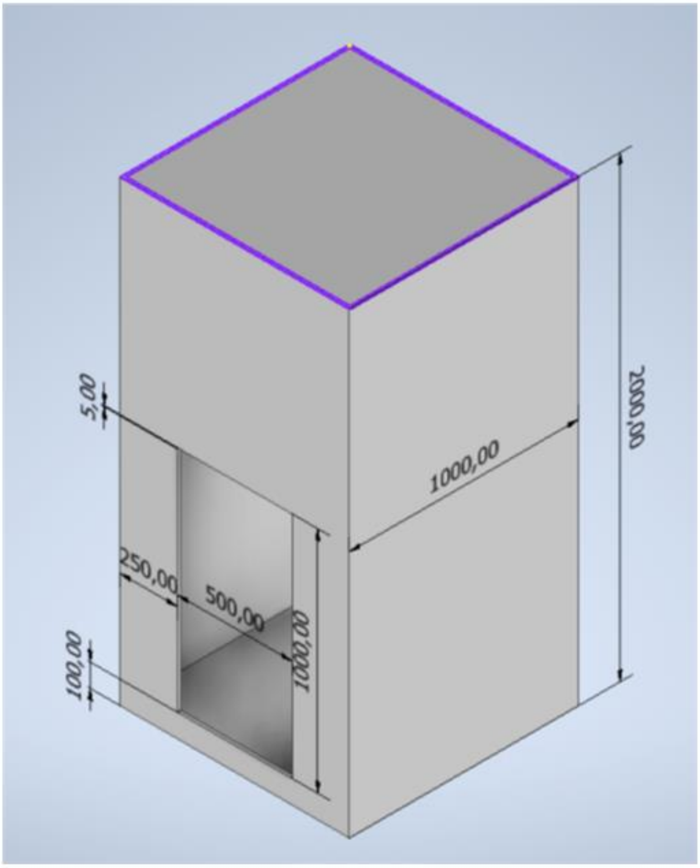

Figure A.4 Filter testing air-tight chamber

Figure A.5 Temtop P600 air quality monitor and Acekool air purifier

EPSRC MopFan prototypes

Figure A.6 Prototype connected to power supply

Figure A.7 Images of testing setup

Figure A.8 Image of power meter displaying prototype energy usage

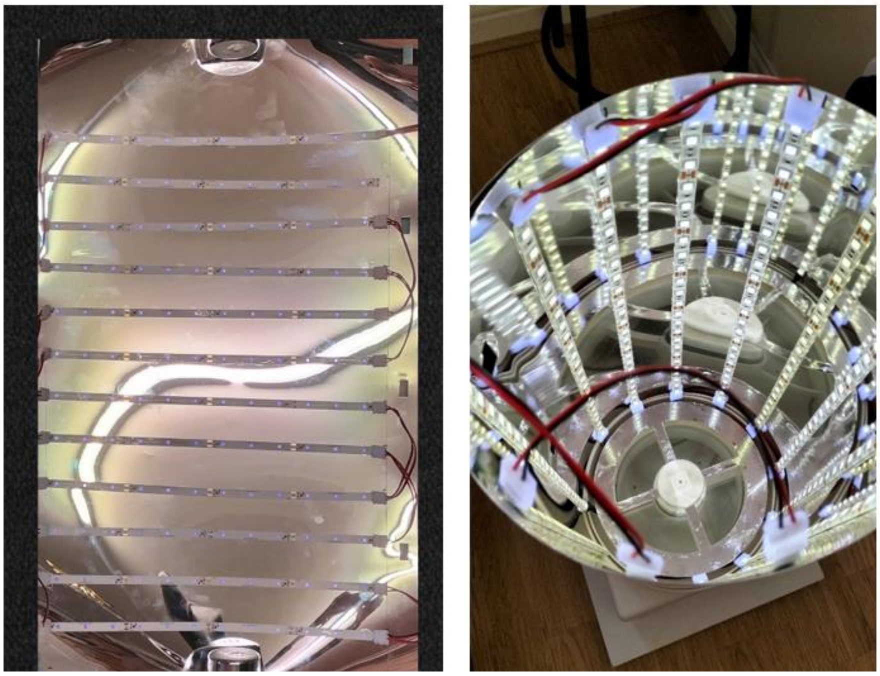

Figure A.9 Image of LED distribution within UV enhanced aluminium casing

Alternative concepts of MopFan prototypes

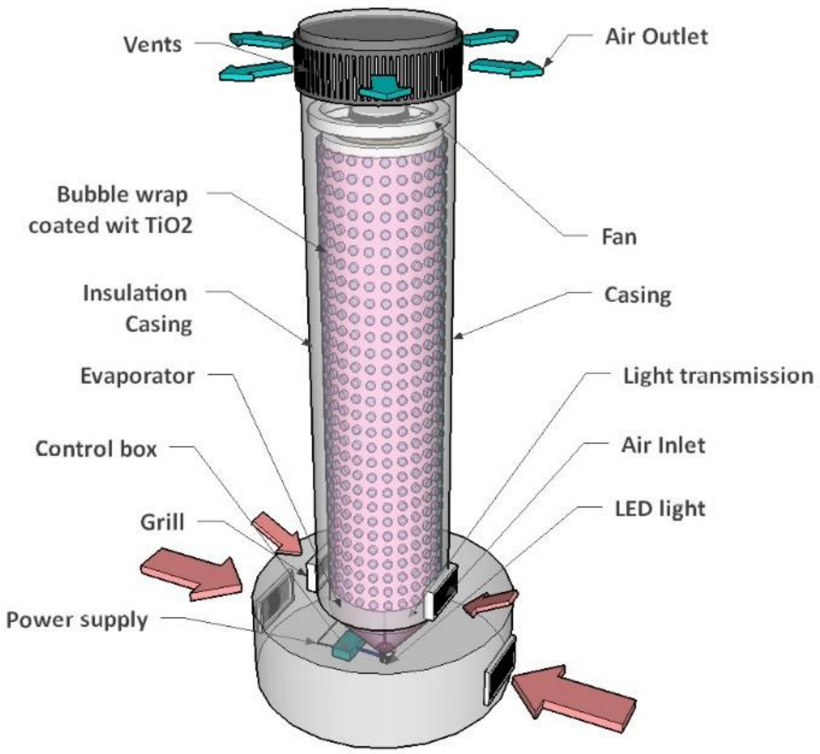

Figure A.10 Diagram of MopFan prototype using TiO_2 coated bubble wrap

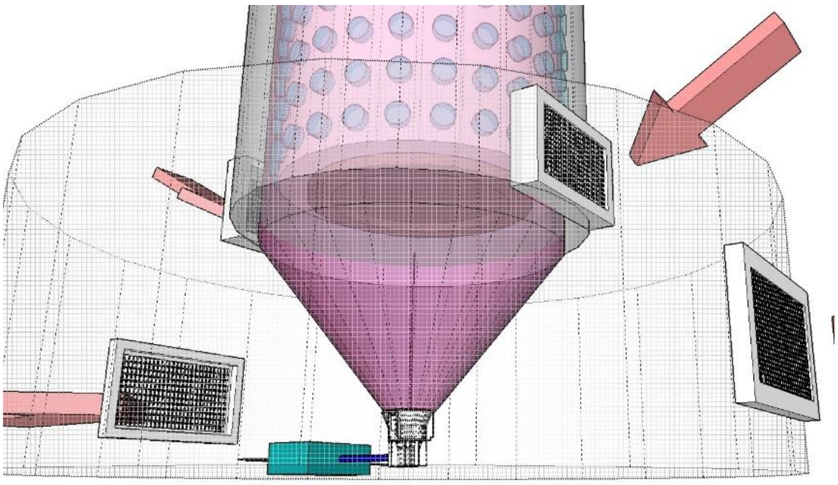

Figure A.11 Air inlet of bubble wrap prototype concept

Preliminary EPSRC prototype design and 3D printed components

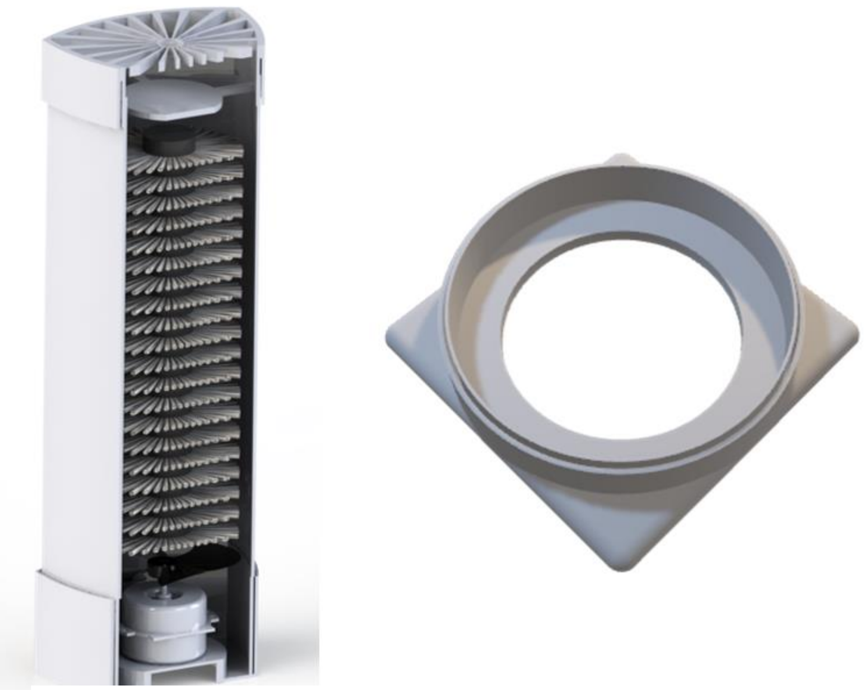

Figure A.12 Preliminary design and 3D printed base with grooves to house UV enhanced aluminium casing

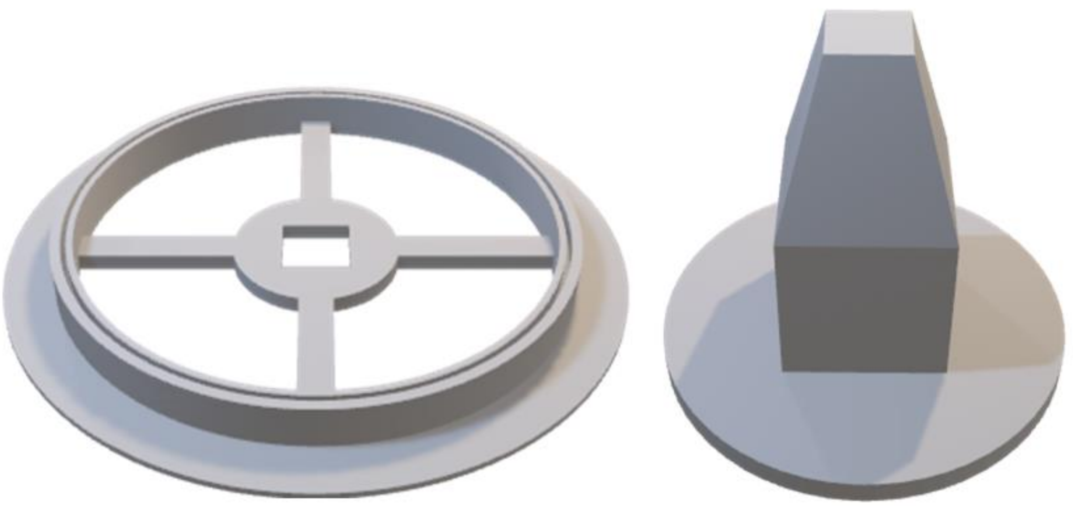

Figure A.13 Hub base plate and hub locking cap

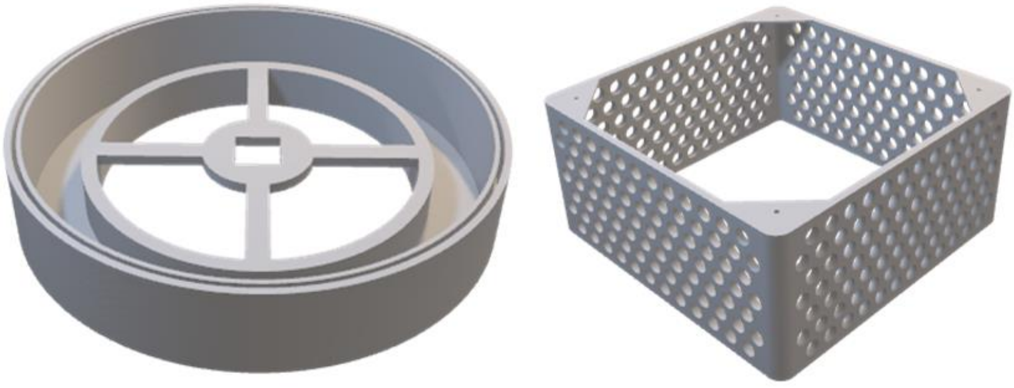

Figure A.14 Hub top cap and base support

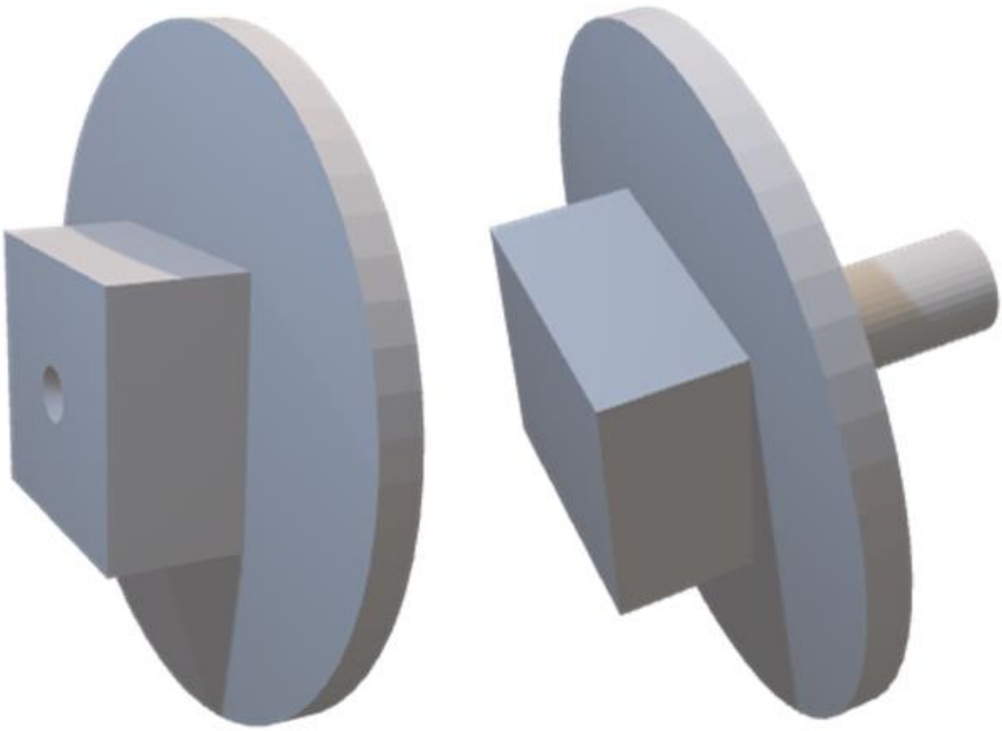

Figure A.15 Hub adaptor and spindle

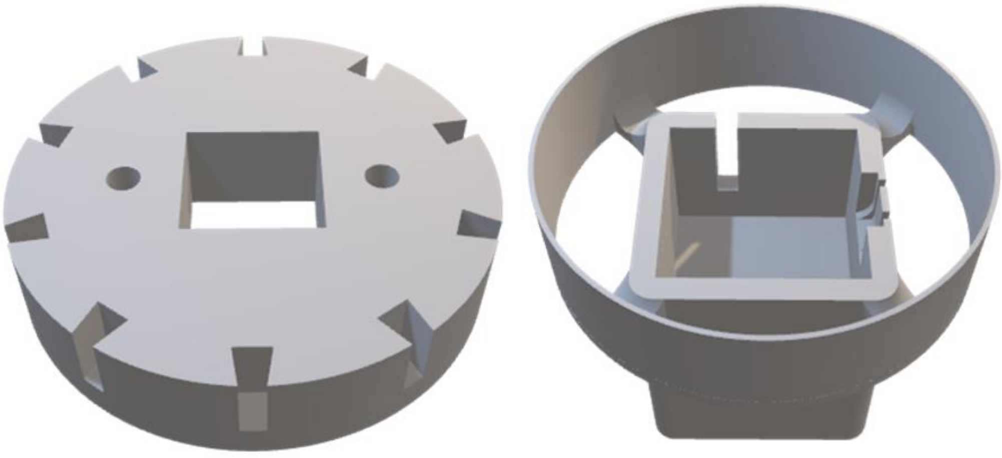

Figure A.16 Hub end piece and motor box

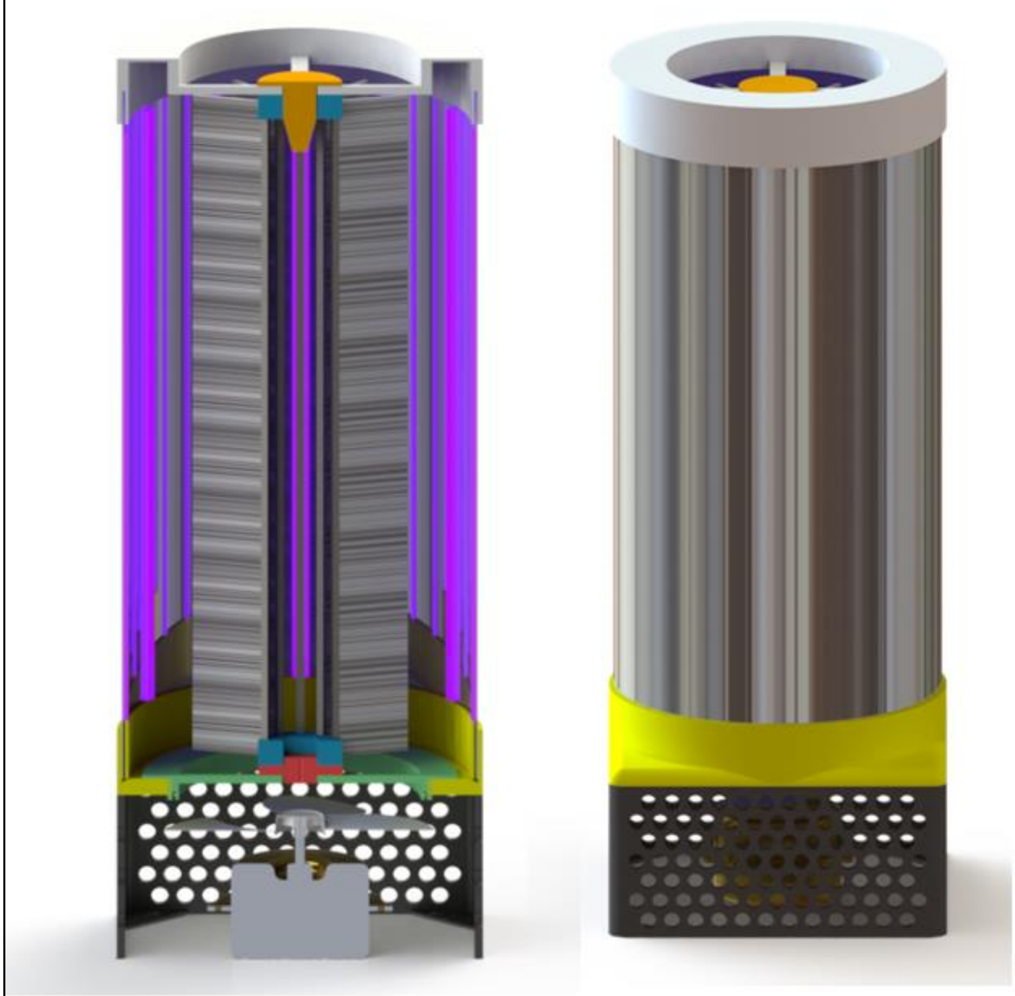

Figure A.17 3D Rendering of EPSRC prototype

Figure A.18 3D Rendering of EPSRC prototype

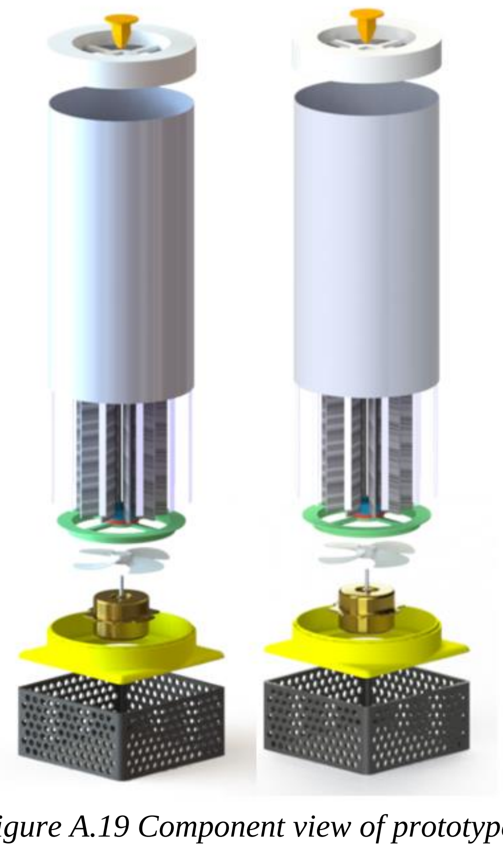

Figure A.19 Component view of prototype