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Master of Architecture – Sustainable Design

Activated carbon window filters for reducing carbon dioxide and improving indoor air quality in polluted houses.

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Thesis submitted in partial fulfillment of requirements of the degree Master of Architecture-Sustainable Design

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Activated carbon window filters for reducing carbon dioxide and improving indoor air quality in polluted houses.

Aysha Amer Hamdan

ABSTRACT

This study investigates the viability of improving indoor air quality (IAQ) by means of a window filter model that uses activated carbon generated from locally obtained biomass to absorb carbon dioxide (CO_2) from the air. Using typical window size, three different residential building scenarios were examined in terms of window-to-floor ratio. To evaluate how well-proposed filter configurations capture natural daylighting and ventilation, simulation tests were run in four main directions. Using continuous reactor setups and four biomass waste materials (coffee grains, sunflower seed shells, oak sawdust, and almond shells that were pyrolyzed and potassium hydroxide impregnated), precursor kinds, bed height, and filter ratio were carefully experimentally investigated.

Different biochar yields were found using adsorption tests using fixed bed filters filled with the synthesized activated carbon; almond shells had the highest production (31.9%), followed by oak sawdust (29.78%), sunflower seed shells (23.6%), and coffee grains (22.1%). In light of this, almond shells outperformed oak sawdust, sunflower seed shells, and coffee grains in terms of adsorption capacity and filter efficiency. Continuous breakthrough diagram testing revealed that raising the bed height and filter ratio significantly improved CO_2 filter efficiency and adsorption capacity.

The results of the simulation highlighted the increased ventilation and daylighting factor of higher window-to-floor ratios, which are especially helpful for optimizing interior spaces. In addition, box windows performed better than ordinary window designs, providing better views outside and more effective filtration in every direction.

According to research, choosing the right biomass precursors and maximizing filter ratios can help fine-tune the adsorption effectiveness of synthetic activated carbon and, in turn, the CO_2 filter efficiency. Additionally, adding more filters to box windows or dividing filter sections in regular windows proved to increase airflow, which is consistent with continues ventilation theories and produces acceptable results.

فلاتر للنافذة من الكربون المنشط لتقليل تركيز ثاني أكسيد الكربون وتحسين جودة الهواء الداخلي في المنازل الملوثة.

عائشة عامر حمدان

المستخلص

تتحرى هذه الدراسة جدوى تحسين جودة الهواء الداخلي عبر نموذج فلتر نافذة يستخدم الكربون المنشط الناتج من الكتلة الحيوية الموجودة محليا لامتصاص ثاني أكسيد الكربون من الهواء. تم فحص ثلاث سيناريوهات مختلفة للمباني السكنية من حيث نسبة النافذة إلى الأرضية باستخدام حجم النافذة النموذجي. لتقييم كفاءة تكوينات الفلتر المقترحة في توفير الإضاءة الطبيعية والتهوية الجيدة، أجريت اختبارات المحاكاة في الاتجاهات الأربعة الرئيسية. تم التحقيق تجريبياً في أنواع السلائف وارتفاع الفلتر ونسبة الفلتر المستخدم من خلال إعدادات مستمرة جرت على أربعة مواد من الكتلة الحيوية (حبات القهوة، قشور بذور عباد الشمس، نشارة خشب البلوط، وقشور اللوز التي تم تحللها ومعالجتها بهيدروكسيد البوتاسيوم مخبريا).

تم العثور على مختلف نواتج الفحم الحيوي باستخدام اختبارات الامتزاز باستخدام فلاتر ثابتة مملوءة بالكربون المنشط المركب؛ كانت قشور اللوز أعلى إنتاج (31.9%)، تليها نشارة خشب البلوط (29.78%)، قشور بذور عباد الشمس (23.6%)، ثم حبات القهوة (22.1%). في ضوء ذلك، تفوقت قشور اللوز على نشارة البلوط، قشور بذور عباد الشمس، وحبات القهوة من حيث قدرة الامتزاز وكفاءة الفلتر. كشفت الاختبارات المستمرة أن زيادة ارتفاع الفلتر ونسبة الفلتر حسن بشكل كبير من كفاءة فلترة ثاني أكسيد الكربون وقدرة الامتزاز.

أظهرت نتائج المحاكاة زيادة التهوية وعامل الإضاءة الطبيعية لنسب النافذة إلى الأرضية الأعلى، مما يساعد بشكل خاص في تحسين المساحات الداخلية. بالإضافة إلى ذلك، تفوقت النوافذ الصندوقية على تصميمات النوافذ العادية، مما يوفر مشاهدة أفضل للخارج وترشيحًا أكثر فعالية في كل الاتجاهات. وفقًا للبحث، يمكن أن يساعد اختيار السلائف الحيوية المناسبة وزيادة نسب الفلتر في ضبط فعالية الامتزاز للكربون المنشط، وبالتالي كفاءة فلترة ثاني أكسيد الكربون. علاوة على ذلك، ثبت أن إضافة المزيد من الفلاتر إلى النوافذ الصندوقية أو تقسيم الفلتر في النوافذ العادية الى منطقتين يزيد من تدفق الهواء، وهو ما يتسق مع نظريات التهوية المتقابلة وينتج عنه نتائج مقبولة.

DECLARATION

I declare that the Master Thesis entitled "Activated carbon window filters for reducing carbon dioxide and improving indoor air quality in polluted houses " is my own original work, and herby certify that unless stated, all work contained within this thesis is my own independent research and has not been submitted for the award of any other degree at any institution, except where due acknowledgement is made in the text.

Aysha Amer Hamdan

Signature: ______________________________ Date: ____________________

DEDICATION

I dedicate this work to my family, especially my great partner Munther Manasra , who has always been there for me and has always pushed me up. To my sweetheart Kinda, I only need you to give me the power to keep going and to be strong. I dedicated this work to my parents. I know you are proud of me. I achieved it for my mother because of your well wishes and support; to my sisters and brothers. To my tutors and colleagues at Palestine Polytechnic University.

Aysha A. Hamdan

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Finally, a heartfelt thank you to everyone who helped with this job.

Table of Content

List of Abbreviations

CO_2	Carbon dioxide
ppm	part per million .
µm	micrometers
US	United States
HEF	High Efficiency Filter.
°C	degree Celsius
TiO_2	Titanium dioxide .
NOX	oxides of nitrogen
CO	Carbon monoxide
NH_3	ammonia
SO_2	Sulfur dioxide
VOCs	Volatile organic compounds.
H_2S	Hydrogen sulfide
UV	ultraviolet light
AC	Activated carbon .
ACF	Activated carbon fiber
IAQ	indoor air quality .
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers.
PMV	predicted mean vote .
PPD	predicted percentage of dissatisfied.
m/s	meter per second
WFR%	Window to Floor Ratio.
O_2	dioxygen
IEQ	Indoor environmental quality
EPA	Environmental Protection Agency
DF	daylight factor
HVAC	Heating, ventilating, and air conditioning.
LEED	Leadership in Energy and Environmental Design

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Chapter 1

Introduction.

1.1 Preface .

The growing global interest in sustainability makes it necessary to take care of reducing the negative effects on the environment and the consumption of non-renewable energy while improving indoor air quality (IAQ) to enhance the physical and psychological comfort of users (Hasselaar, 2006) (Tantiwat, 2021). Indoor environmental quality (IEQ), as part of sustainable interior design, must consider various aspects such as thermal performance, natural lighting, and the freeness of indoor air from pollutants to provide a healthy and comfortable environment. while the issue of air pollution has become an urgent issue, especially for those who reside near the main streets.

Many residential buildings directly adjacent to the main streets suffer from many pollution problems resulting from transportation activities , especially smog and carbon dioxide, which pose health risks to humans (Yunus et al., 2012). However, there is a lack of attention to this problem in the design of residential buildings, where residents constantly inhale polluted air, or others resort to relying on artificial lighting and ventilation or maybe not opening windows constantly. This deprives them of insolation and makes them more vulnerable to various diseases (Hasselaar, 2006).

1.2 Research Significance .

Since the majority of people spend 90% of their time inside buildings, indoor air quality (IAQ) is a significant concern for this study(Samet, 1993). They are more exposed to air pollution, which has been linked in many studies to have harmful effects on human health. Higher particles and air population levels have been linked in studies conducted in the US, Brazil, and Germany to an increased risk of respiratory, cardiovascular, and cancer-related mortality as well as pneumonia, lung function loss, hospitalizations, and asthma(Khader and Hasan, 2015). The rapid spread of allergic responses, as well as infections of the eyes, nose, lungs, and throat, and even skin conditions and fever, affect cognitive function (Cincinelli and Martellini, 2017). Therefore, research is needed to develop window air filters that can capture pollutant gas from outdoor air when there is natural ventilation to address this problem. These windows are essential to ensuring that the air inside homes is cleaner and healthier from CO_2 gas, in addition to having good natural lighting and ventilation capabilities.

1.3 Research problem .

Many studies indicate that the residential buildings that are adjacent to the main streets have various pollution issues as a result of the cars' emissions, particularly carbon dioxide, which is harmful to people's health, particularly that of children and the elderly (Alatawneh et al., 2022). Considering the importance of this issue, it has received little attention in Palestine, where car traffic is the main source of air pollution. Road transportation is just responsible for a 54% of air pollution (Colvile et al., 2001), highlighting the urgent need to address indoor air quality issues, especially in light of the spread of infectious diseases.

Adding to the complexity of the problem is the disproportionate energy consumption of residential buildings, which constitute a substantial 70% of technological installations. The majority of this energy is used by heating, cooling, and ventilation systems (Corlan et al., 2021), which highlights the critical need for creative ways to reduce these energy requirements while also addressing air quality problems. However, the situation is made worse by the neglect of residential buildings, which gives residents few ways to protect their indoor air quality. The issue gets worse when energy-intensive solutions are used, such as window closing and continuous air conditioning, which reduce indoor air quality and the visual connection to the outside world.

As a result, it becomes important to deal with this complex issue in all its facets. This means combining energy efficiency, human health, and air quality issues to create more sustainable and healthy living conditions. It is feasible to create practical solutions that not only lessen the negative effects of carbon emissions on indoor air quality but also improve the residents' general well-being by giving research and innovation in this field top priority.

1.4 Research Questions.

It is hypothesized that adding carbon dioxide filters to windows in residential buildings can provide good filtration capacity that may enhance indoor air quality. In addition it also provides natural daylighting and good ventilation of the spaces.

This leads directly to the main question of the current study:

- Is it feasible to improve indoor air quality by adding a carbon dioxide filter model for windows?

Consequently, the following sub-questions were raised:

- What is the best way to design a window filter model that reduces carbon dioxide emissions entering homes while maintaining environmental sustainability?
- What are the effective filter characteristics that provide the best possible carbon dioxide filtering with sufficient natural ventilation and daylighting?
- What is the effect of the type of activated carbon and filter thickness on the removal efficiency of carbon dioxide emissions
- To what extent do the characteristics of the addition filter affect the carbon dioxide emissions while maintaining the best possible ventilation and natural lighting conditions?

1.5 Research Objectives .

Despite the different benefits of cars and how they improve human transportation, the emissions specifically carbon dioxide generated by them still affect the quality of life. Therefore, this study takes into account the recommendations of previous studies and aims at improving the indoor air quality of homes and save energy by designing an air filter model. As a result, the main objective of this research is: to investigate the technical feasibility of enhancing IAQ through the use of a window filter model.

while the sub-objectives are as follows:

1. To propose different design approaches to determine the best way to create a window filter model that both meets with environmental sustainability and efficiently reduces carbon dioxide emissions in residential buildings.
2. To investigate the effect of type of activated carbon and filter thickness on the removal efficiency of carbon dioxide.
3. To examine how various filter characteristics affect the reduction of carbon dioxide emissions while maintaining good ventilation and natural daylighting factor. Quantify the trade-offs to help choose filter specifications that strike the best balance between indoor comfort and environmental effectiveness.

1.6 Research Limit .

This study focuses on residential buildings that suffer from many air pollution problems, specifically CO_2, in terms of analysis and evaluation of the problem to reach recommendations for designing a model that can be applied to the windows of houses to improve indoor air quality and make it purer.

The model is limited to residential buildings with high CO_2 pollens in a Mediterranean climate. The solutions must respect the constraints of location, abundant solar radiation, case orientation, ventilation, window dimensions or room proportions, etc.

1.7 Research limitation .

1. Lack of sufficient information about the practical experiences of this research.
2. Availability of materials to produce the required model.
3. The general situations that have come up since the war, have made it more difficult to complete the practical part.
4. Apply the model to the housing case to take readings continuously to generalize the research application.

1.8 Research Structure .

This research was divided into four parts as shown in figure (1.1) :

The first part: The first part: is the conceptual study of the thesis, which is covered through Chapter 1. It gives a brief introduction to the research and indicates the conceptual model upon which the research is based. The conceptual study is mainly based on the justification behind the need to balance the filtration-efficient use of window filters in residential buildings in Palestine with the related natural daylight considerations and natural ventilation. It discusses the research background and then presents the research's Significance, problem, questions, objectives, limits, and limitations. The chapter ends by giving a complete overview of the research structure.

The second part: The theoretical study in the second and third chapters was devoted to reviewing the required literature and its definitions. The second chapter presents the theory, applications, and advancements in air filtration are explored, explaining the workings and constituents of filtration systems aimed at enhancing indoor air quality (IAQ). It also looks at various filtration materials and variables that affect filtration quality, such as Computational fluid dynamics and specialized gas filtration technologies like adsorption and activation. In the third chapter, the relationship between IAQ and energy consumption is discussed, taking into account variables like ventilation, daylighting, and occupant behavior. It is especially pertinent in Palestine, where IAQ is a major concern.

The third part: The practical study covered in Chapters Four and Five constitutes the core of the thesis. The research methodology was presented in Chapter 4, and the results were presented and discussed in Chapter 5, where three cases of residential buildings were studied based on the window-to-floor ratio with commonly used window measurement located in the city of Jerusalem, which represents a case of the Mediterranean climate. Activated carbon is prepared from raw materials, first to evaluate the performance of the filter, and second to perform simulations on different models in the four directions to compare the effectiveness of the proposed filter scenarios of natural daylighting and ventilation.

The fourth part: The final chapter includes final reflections and recommendations of the present study to provide a scientific process and filter model scenarios when adding similar scenarios.

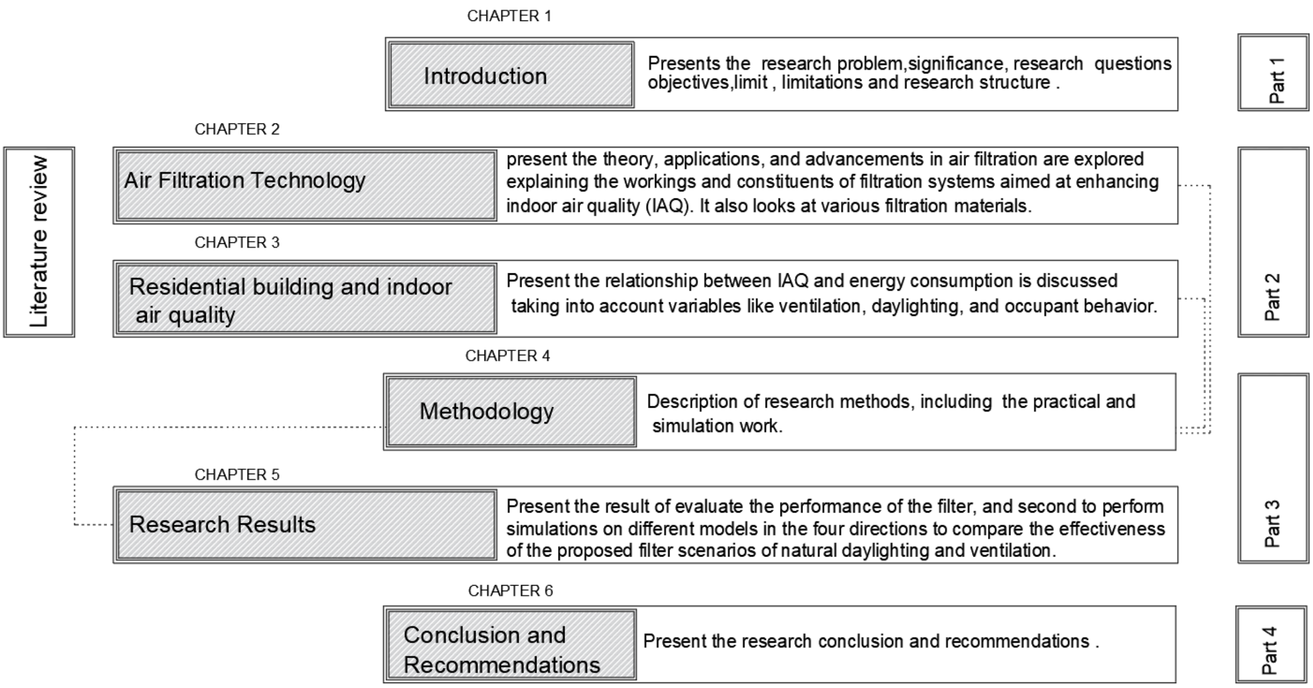


Figure (1.1): The main four parts of the research Structure.

Chapter 2

Air Filtration Technology.

2.1 Preface

Poor indoor air quality can hurt the comfort and health of occupants. A recent study found that indoor air pollution results in almost 5.5 million deaths worldwide each year.(Amos, 2016). For example, inhaling small liquid or solid pollutant particles increases the risk of heart disease, cancer, stroke, and respiratory symptoms(Cincinelli and Martellini, 2017). Air pollution ranks fourth among the most dangerous factors after smoking, high blood pressure, and nutritional risks, according to Global Burden of Disease (GBD) research(Smith et al., 2002).

According to recent surveys, people now spend about 90% of their time indoors (Sodiq et al., 2023) (Zou et al., 2022) (Wang et al., 2011) human exhalation is an important source of indoor air pollution, as it contributes 37 micrograms of carbon dioxide per hour per person(Wang et al., 2011). In addition to the rate of carbon dioxide entering houses from the outside adjacent to the main streets, especially from car pollutants (Yang et al., 2010, Ang et al., 2020). Research has indicated that increased CO_2 concentrations can have a noticeable impact on personality psychology and productivity (Hassan et al., 2020). It has been found that human cognitive and behavioral performance is reduced by 6/9 and 7/9, respectively, when exposed to CO_2 concentrations of 1000 ppm and 2500 ppm, versus exposure to 500 ppm. Therefore, it is necessary to keep indoor air quality under adequate control (Tran et al., 2020).

Keeping the indoor environment clean from carbon dioxide requires proper ventilation. However, due to poor residential system design, distribution, Continuous pollution, etc., since air purification techniques only eliminate indoor air pollutants, they do not provide an alternative to traditional methods to reduce energy consumption and operating expenses, so a system that Purifies the air entering the space also provides a way to achieve sustainability Theory of air filtration technology(Raub et al., 2000).

2.2 Air filtration technologies

Filtration theory evolved from the early classical filtration theory of the 19th century to the modern filtration theory and microporous filter theory. The term "Brownian motion" refers to the movement of fine particulates suspended in a liquid, which was initially noticed by botanist Brown in the early 19th century(Liu et al., 2017). A mathematical theory for the microporous structure of fiber filters was proposed by Pickaar and Clarenburg in 1967 .According to Payet, Boulaud, Madelaine, and Renoux (1992), adding correction factors to classical theory could improve the theory's fit to experimental data when the gas slides over a single fiber. (2001), air filters under blocking conditions were studied theoretically and experimentally. They then presented a model for calculating the air filter's pressure loss and efficiency while accounting for filter cake. Numerous researchers have made significant progress in recent years in their theoretical simulations and experiments on the formation and mechanism of filter(Pich, 2017).

The filtration mechanism of conventional filtering materials is the product of several types of synthesized effects, of which the first three are primarily governed filtration mechanisms. These effects include inertial, diffusion, interception, electrostatic, gravity, thermophoresis, and Van der Waals forces. The mass of the particles has a direct bearing on the inertia capture mechanism. When particles move with the flow of air, the inertia effect takes place. When the flow changes, the fiber surface will arrest particulate matter that is outside of the airflow streamline. the wind speed has a significant impact on it. Both the inertia and the inertia efficiency will increase with increasing particle size(Liu et al., 2017, Pich, 2017).

When tiny particles are caught by the fiber surface through gas molecule collisions and random movement, the diffusion capture mechanism takes place. The significance of this mechanism increases for particles smaller than 1 μm. The random movement is more intense and the diffusion efficiency is more visible at smaller particle sizes. Studies reveal that when the particle size is less than 0.1 μm, the theoretical calculation value of the diffusion capture efficiency increases to more than 80%(Montgomery, 2015). It is acceptable to disregard other capture efficiencies in these conditions. When particles follow the direction of airflow and the distance between their centerline and the centerline of the fiber is less than or equal to the total of the fiber and particle radii, an interference capture mechanism takes place(Jin et al., 2022, Frederick, 1980).

2.3 Air filtration system .

The main component of an air filter system is, unsurprisingly, the air filter itself. Air filter systems are designed to remove particulate matter and contaminants from the air, improving indoor air quality or protecting equipment and processes in industrial settings. The air filter is the critical element responsible for capturing and retaining particles (Sodiq et al., 2023).

2.3.1 Classification of air filtration materials.

Architects and engineers are increasingly being supplied with high-performance filtering materials. More solutions to problems associated with filtration systems. In addition to jobs Protecting against pollutants harmful to human health, these materials also have an economic function that reduces heavy dependence on energy use(Montgomery, 2015).

The filtration materials used vary from country to country and are often due to availability Local materials and their suitability to the environment and local climate in the region. Material Preferences and material properties must be understood by policy makers, architects and engineers, And manufacturers to create more sustainable models in the future (Liu et al., 2017).

The most commonly used materials for air filtration are fiber glass, activated carbon, Nanofibers, cloth, titanium dioxide, etc. (Frederick, 1980).

- **Fiberglass& clothes.**

Fiberglass air filter material first appeared in the United States and obtained a US patent in 1940. It has developed rapidly since then(Frederick, 1980). Using ultra-fine fiberglass paper, the HEF (High Efficiency Particulate Air Filter) can achieve 99.9998% efficiency for dust with a particle size of less than 0.3 micrometers by the 1970s. Also use cloth or non-woven fabric as it is gradually becoming more popular in dust filtration and air conditioning industries due to its advantages of high filtration efficiency (higher than 99.9% for submicron dust), low resistance (30%-40% lower than traditional filter material), Long service life (up to 2-5 times that of traditional filter material), high temperature resistance (up to 280°C) and high dust peeling rate(Zou et al., 2022).

In this study, the use of fiberglass and cloth as new materials was not studied, as they have the ability to eliminate dust and particles, but not the ability to filter gases.

- **Nanofibers.**

With the advent of nanotechnology in the late 1980s. Nanofibers are the primary type of nanomaterials used in the air filtration industry. Since nanometer fibers have higher specific surface areas, surface energies, and surface tensions, more airborne particles will be deposited on their surfaces, improving filtration efficiency. The resistance is reduced, the filtration efficiency is increased, and the service life is extended because nanofibers have a greater direct interception and inertial impact compared with traditional plant fibers under the same pressure loss (Wang et al., 2011) ,Table (2.1) preview the advantages and disadvantages of nanofibers

Table (2.1)-An overview of the advantages and disadvantages of nanofibers as air filtration materials.

Reference .(Graham et al., 2002)

Advantages	Disadvantages
Nanofibers have an extremely high surface area per unit mass, which enhances their filtration efficiency.	The production of nanofibers can be more expensive than traditional fibers, impacting the overall cost of the filtration material.
Nanofibers can create a fine and dense pore structure in filter media, leading to effective filtration of submicron particles.	Some nanofibers may be more fragile than larger fibers, making them susceptible to damage during handling or use.
Nanofibrous materials often have high porosity, allowing for efficient air or liquid flow through the filter while maintaining good filtration performance.	Nanofibers may have a tendency to agglomerate, which could affect the uniformity of the filter material and its filtration performance.
Nanofibers can be produced from a variety of materials, including polymers, ceramics, and carbon, making them versatile for diverse filtration needs.	Depending on the material used to produce nanofibers, they may have limited resistance to certain chemicals.
	The fine structure of nanofibers may make them more prone to surface fouling or clogging.

- **Titanium dioxide (TiO_2).**

One of the materials that emerged in the twenty-first century to remove hazardous gases is the photocatalytic material titanium dioxide (TiO_2). After the material absorbs ultraviolet radiation, ultraviolet excitation energy occurs. This triggers a redox reaction, which forms superoxide anionic radicals and strong oxidative hydroxyl radicals. These radicals can efficiently decompose gases such as NOx, CO, NH_3, SO_2, and VOCs into H_2O, CO_2, and other corresponding inorganic elements. This reaction, which occurs at room temperature and pressure, sterilizes the air and removes any secondary pollutants. Moreover, since it includes different composite materials, additional purification of indoor air can be performed ,Table (2.2) preview the advantages and disadvantages of titanium dioxide.

Table (2.2)-An overview of the advantages and disadvantages of titanium dioxide as air filtration materials.

Reference .(Haider et al., 2019).

Advantages	Disadvantages
TiO_2 exhibits photocatalytic properties when exposed to ultraviolet (UV) light. This property allows TiO_2 to interact with organic and inorganic pollutants, breaking them down into harmless byproducts. This can contribute to the overall removal of contaminants from the air.	The photocatalytic activity of TiO_2 relies on exposure to UV light. In the absence of light, such as during nighttime or in spaces with limited natural light, the effectiveness of TiO_2 coatings diminishes.
TiO_2 is effective in neutralizing or breaking down certain odorous compounds. This makes TiO2-coated filters useful in applications where the removal of unpleasant smells is a priority.	The photocatalytic activity of TiO_2 is often more effective against smaller particles. Larger particles may not be as readily affected, and the effectiveness can vary depending on the specific pollutants present.
TiO_2 coatings can contribute to the self-cleaning properties of filters. The photocatalytic process can help break down accumulated organic matter on the filter surface.	TiO2 coatings can add to the cost of air filtration systems. While the benefits may justify the expense in certain applications, cost considerations should be taken into account.
	While TiO_2 photocatalysis generally breaks down pollutants into harmless substances like carbon dioxide and water, there is a possibility of the formation of intermediate byproducts, some of which may be undesirable.
	Over time, TiO_2 coatings may become coated with debris, reducing their effectiveness. Regular cleaning or replacement may be necessary to maintain optimal performance.
	In some cases, TiO_2 photocatalysis may lead to the generation of ozone, which is a respiratory irritant and a potential health concern. Proper engineering and design are required to minimize this risk.

- **Activated Carbon (AC)**

Since the 1950s, the world's manufacturing sector has expanded rapidly, ushering in a new era for air filter materials. Japanese researchers began to develop activated carbon fiber (ACF) using rayon, polypropylene nitrile, and other raw materials. Because of its many benefits, including rich profile, easy regeneration, short adsorption journey, uniform pore size distribution, high stripping speed, large adsorption capacity, and more, ACF is considered one of the best air purification materials in the 21st century, Table (2.2) preview the advantages and disadvantages of activated carbon.

Table (2.3)-An overview of the advantages and disadvantages of activated carbon as air filtration materials.

Reference .(Roegiers and Denys, 2021).

Advantages	Disadvantages
It can be produced from any carbonaceous raw material containing high carbon con- tent which is non-expensive resources	The porosity of the AC de- pends on various factors like temperature and agent. Hence an optimum process needs to be developed to achieve the maximum sur- face area.
Separating of AC from the process is relatively very easy.	Sometimes, only normal AC is not sufficient to capture CO_2 from post-combustion pro- cess. So foreign martial needs to be added to increase the selectivity of CO_2.
AC can operate under a wide range of pH.	
Activated carbons can be pre- pared in the form of gran- ules, powders, fibers, or beads from suitable.	
AC dose not react with various chemicals easily and hence it can resist corrosion.	
AC is hydrophobic in nature which eliminates the extra step of removing moisture from the flue gas mixture.	
Thermosetting precursors by either physical or chemical means.	
Manufacture of AC is not a cumbersome process. There are two methods: physical and chemical activation.	
Easy to regenerate.	

2.4 The relationship between filtration technology and indoor air quality (IAQ).

Air quality is rated as the most important by building occupants compared to visual comfort,
Acoustic comfort and thermal comfort. It also has the greatest impact on the quality of the indoor environment compared to other conditions.

The most important element in air quality factors is the gain or loss of pollutants, which are:
It is directly affected by the characteristics of the filter that is used, especially the ability to absorb pollutants. This value depends on the type of materials used, which affects the energy consumption of air purification.

Absorption capacity is the ability of materials to store harmful gases between their molecules at different temperatures through the passage of pollutants through the filter. This depends on the physical and chemical nature of the material. And Various properties such as humidity, temperature, and atmospheric pressure.

2.4.1 Filtering performance.

An expanded definition of comfort includes the perception of air "quality." Occupants may perceive indoor air as heavy, stale, smelly, unpleasant, refreshing, or crisp. As the air is sensed, many attributes are integrated its temperature, moisture content, odor, and chemical properties(Fanger, 2006). Materials and educational supplies emit odorous compounds as do dirty filters and ducts, cleaning agents, kitchens, bathrooms, gymnasiums, art rooms, moldy surfaces, computers, and copying machines(Liu et al., 2017, Fanger, 2006). Discusses perceived air quality and ventilation requirements in the context of indoor sensory pollution loads from occupants and materials. or what is added from the outside, and this is what constitutes the most dangerous aspect, which can be controlled, by committing to using techniques that help filtration the air entering the spaces in homes. This means that the relationship is direct. Between the use of air filtration systems and high indoor air quality(Pich, 2017).

2.4.2 Energy and Economic Behavior.

Energy, economic behavior, and filtration technology have a complex and connected relationship. By minimizing the energy consumption of HVAC systems and improving airflow dynamics, advanced filtering technologies can improve energy efficiency. Additionally, they make HVAC equipment last longer, which reduces maintenance expenses and the need for costly repairs or replacements(Alavy and Siegel, 2019). Furthermore, using filtering technology can enhance indoor air quality, which can increase productivity and reduce absenteeism among occupants, thereby improving economic consequences for enterprises and organizations. However, the initial cost of advanced filtering systems may be costly, especially in situations where funds are limited(Fanger, 2006).

2.4.3 Thermal comfort.

Human perception of the thermal environment depends on four parameters: air temperature, radiant temperature, relative humidity, and air speed. Perception is modified by personal metabolic rates and the insulation value of clothing. Thermal comfort standards are essentially based on a set of air and radiant temperatures and relative humidity levels that will satisfy at least 80 percent of the occupants at specified metabolic rates and clothing values(Swamy, 2021).

ASHRAE has codified the air temperature, relative humidity, radiant temperature, and air movement conditions under which occupants should feel "thermally neutral" Guidance is found in ASHRAE Standard 34-2019, "Thermal Environmental Conditions for Human Occupancy," which provides a range of temperatures and relative humidity for winter and summer conditions(Faulkner, 2001).

Improving indoor air quality by controlling carbon dioxide concentration using ventilation and Filtration system. That is, by focusing on environmental parameters (air temperature, relative humidity) by measuring humidity, air velocity, PMV, PPD, and CO_2) and comparing them to the ASHRAE standard. The recommended PMV value range for homes is (-0.5 to 0.5) and the PPD value is less than 20%, as shown in figure (2.1) (Kabrein et al., 2017, Olesen, 2004, Jadhav, 2018).

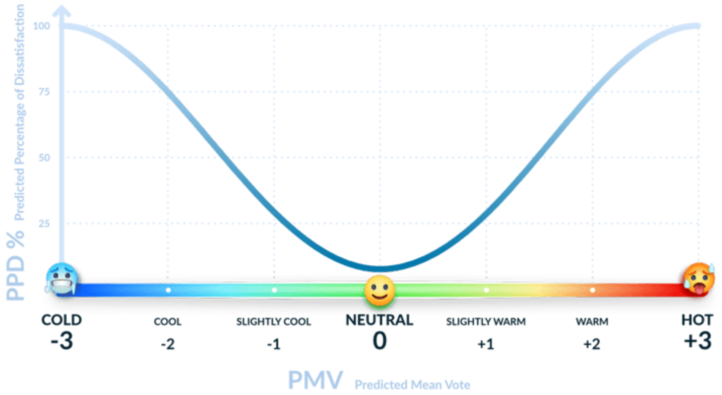


Figure (2.1): Graph showing how PPD is predicted to change with PMV.

Source:(Jadhav, 2018)

Humans have an involuntary thermoregulatory mechanism that adjusts our body temperature. For example, to maintain our thermal balance and prevent discomfort locally, we might perspire in hot weather or shivering in cold weather. The human body has a limited capacity for environmental adaptation; if these limits are reached, the body's reactions are felt as uncomfortable. Fanger's theory as shown in Figure (2.2) developed through climate chamber tests to state that an individual's metabolic rate, garment insulation, and surroundings could all be used to determine their level of thermal comfort.

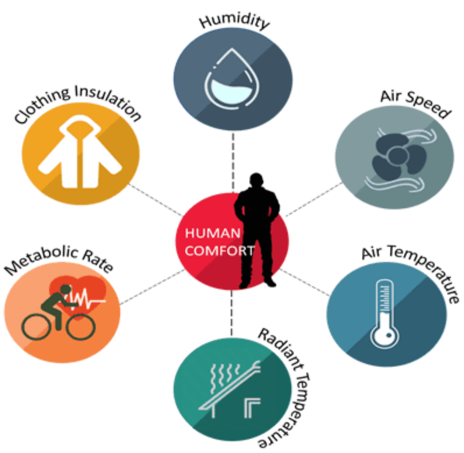


Figure (2.2): Environmental and personal factors that influence thermal comfort.

Source:(Jadhav, 2018)

The measurement results showed good agreement on thermal comfort even when using the filter. Acceptance of thermal comfort as recommended in the ASHRAE standard. If the air temperature achieved in the room was

24°C, while the relative humidity ranged from 69 to 89%. Furthermore, air movement indoor was within the 1 to 2 m/s range of standard ASHRAE recommendations(Alavy and Siegel, 2019, Faulkner, 2001).

2.5 Factors affecting the filtration quality.

The quality of the filter filtration is affected by several factors, including what controls the absorption capacity of the basic material in it, which affects the passage of pollutants through the filter. This depends on the physical and chemical nature of the material. As for the same material, the quality of filtration is affected by the thickness and density of the filter layer used. Filtration is also controlled by various other external factors such as humidity, temperature, and atmospheric pressure. Below are some influencing factors and an explanation of them(Olesen, 2004).

- **Window-to-floor ratio WFR:**

The relationship of ventilation space (windows) is strongly linked to the space that supports it, which affects the quality of ventilation through the following classification (Nedhal et al., 2016):

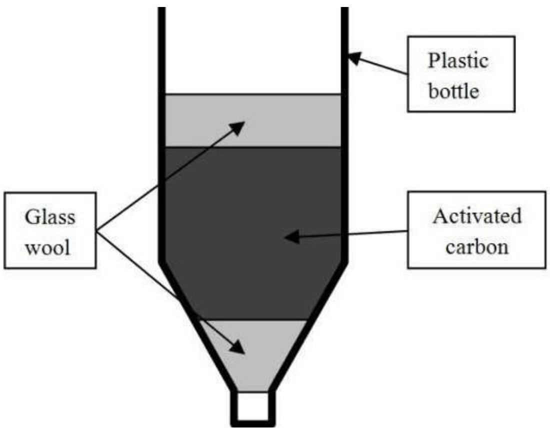
1. Fair: when the window-to-floor area ratio is greater than 20%.
2. Good: when the window-to-floor area ratio is equal to 10–20%.
3. Bad : when the window-to-floor area ratio is less than 10 %.

- **Contact Time:**

The contact time between the CO_2 gas and the activated carbon is important. Longer contact times generally allow for better adsorption, but the flow rate of the gas through the filter needs to be balanced to maintain operational efficiency (Yang et al., 2010).

- **Activated Carbon Bed Depth:**

The thickness or depth of the activated carbon bed in the filter impacts the available surface area for adsorption. A thicker bed may allow for more prolonged contact with the gas and improved filtration efficiency, Figure (2.3) below show the activated carbon bed depth (Ang et al., 2020).



Figure(2.3):Design concept for the activated carbon filter.

Source:(Siong et al., 2013)

- **Pre-Filtering:**

In some applications, pre-filtering to remove particulate matter or other impurities before the gas reaches the activated carbon filter can enhance the overall filtration efficiency.

- **Flow Rate:**

The rate at which the CO_2 containing gas flows through the activated carbon filter is crucial. Balancing the flow rate is essential to achieve the desired filtration quality without compromising the overall system performance (Yang et al., 2010, Hassan et al., 2020).

- **Filter Design:**

The overall design of the activated carbon filter, including the arrangement of filter beds and the flow path, can influence the filtration efficiency for CO_2 gas.

2.6 Gases Filtration Technologies.

In recent years, awareness of climate change has arisen in the international community. It encouraged the study of technologies to reduce greenhouse gas emissions such as carbon oxides, methane, nitrous oxide, and others, which are responsible for the level of atmospheric pollution and climate change. Environmental pollution is a serious issue with the rapid development of urbanization, industrialization, and vehicle traffic. In particular, fossil fuel pollution increases atmospheric CO_2 levels. Carbon monoxide (CO) in indoor air is produced mainly by combustion processes, such as cooking or heating. Besides, CO can also enter indoor environments through infiltration from outdoor air (Tran et al., 2020) . as a result of increased energy demand and increased vehicle numbers in general, making it difficult to reduce. The important sources of indoor CO emissions include unvented kerosene and gas space heaters; leaking chimneys and furnaces; back-drafting from furnaces, gas water heaters, wood stoves, and fireplaces; gas stoves; generators and other gasoline-powered equipment; and tobacco smoke. The average concentration of CO in a building without any gas stoves is about 0.5–5 ppm, while the concentration in areas near gas stoves ranges from 5 to 15 ppm and even 30 ppm or higher(Tran et al., 2020). CO exposure can cause adverse health effects, such as : (1) at low concentrations, there are impacts on cardiovascular and neurobehavioral processes; and (2) at high concentrations, unconsciousness or death (Raub et al., 2000). Carbon dioxide (CO_2), a colorless and odorless gas, is a well-known constituent of the earth's atmosphere and also a major human metabolite (Zhang et al., 2017). The average CO_2 concentration in ambient air is about 400 ppm, which is primarily the result of the combustion of fossil fuels (Zhang et al., 2017, Persily and de Jonge, 2017). Recently, the indoor CO_2 level has been applied as a reference for the assessment of IAQ as well as for ventilation control (Persily and de Jonge, 2017, Emmerich and Persily, 2001). According to the ASHRAE standard, it is recommended that indoor CO_2 concentrations are below 600 ppm to ensure human health(Janssen, 1989). It is established that exposure to a CO_2 concentration of 3000 ppm increases headache intensity, sleepiness, fatigue, and concentration difficulty(Tran et al., 2020).

2.6.1 Carbon dioxide capture technologies and Materials.

There are different technologies to capture carbon dioxide emitted during combustion processes; These techniques include absorption, cryogenics, membrane use, and adsorption.

- **Absorption:**

Absorption involves the use of chemical solvents to capture CO_2 from flue gases. Typically, a solvent such as amine compounds is used to absorb CO_2 from the gas stream, forming a solution. The CO_2 is then stripped from the solution, purified, and compressed for storage or utilization. Absorption is a mature technology commonly used in industrial applications.

- **Cryogenics:**

Cryogenic carbon capture involves cooling flue gases to very low temperatures, causing CO_2 to condense into a liquid or solid phase, which can then be separated from other gases. Cryogenic capture can achieve high purity levels of CO_2 and is suitable for large-scale applications but may require significant energy input for cooling.

- **Membranes:**

Membrane-based carbon capture involves the use of selectively permeable membranes to separate CO2 from flue gases based on differences in molecular size and solubility. Membrane systems offer the potential for lower energy consumption and reduced equipment footprint compared to other capture technologies but may have limitations in terms of CO_2 purity and scalability (Petersson and Wellinger, 2009).

- **Adsorption:**

Adsorption processes involve the use of solid materials, such as activated carbon or metal-organic frameworks, to adsorb CO_2 from flue gases. The adsorbent materials selectively capture CO_2 molecules, which can then be desorbed under specific conditions for recovery. Adsorption is a versatile technology that can be tailored for different applications and operating conditions. Researchers have widely investigated the adsorption method for CO_2 capture due to its low energy consumption and cost-effectiveness. state that several factors, such as the synthesis method, raw materials, and the ability of the materials to remove CO_2, influence the cost of adsorbents. Therefore lower energy usage often results in lower expenses.

- **Scrubbing technology:**

Using chemical adsorption is one of the most attractive technologies due to its many advantages, including low power requirement due to working at ambient pressure, and high loading of scrubbing liquid. On the other hand, there are disadvantages when using alkylamine compounds, such as monoethanolamide and diethanolamine. In the reduction step, the degradation of amines results in raw material loss and harmful chemical species formation. However, these disadvantages can be overcome using unconventional methods and various alkaline compounds (e.g., aqueous ammonia).

Each purification technology used for gases has strengths and weaknesses. Some resort to combining different technologies and creating a hybrid method that can overcome the limitations. The methods are called hybrid systems, including cryogenic adsorption and cryogenic membranes.

2.7 Adsorption.

The process of adsorption involves separating particles, or adsorbate, from a fluid stream and applying them to a porous solid surface, or adsorbent, that is exposed to the fluid. Following that, the adsorbates are focused on the solid porous surface. To achieve a high adsorption efficiency, the fluid can be run through a fixed bed that is packed with small, highly surface-area solid particles. Adsorption involves the selective adhesion or bonding of one or more mixed components to the surface of a microporous solid, preferably with a large surface area per unit mass.

The primary characteristics of many adsorbents utilized in different separation applications are their porous structure of fine pores, pore size of 50% of total particle volume, and their shape as small particles, beads, or granules with sizes ranging from 0.1 to 12 mm. In solid pores, adsorption typically results in the formation of a monolayer. Multi-layers do, however, occasionally exist.

In addition, due to the acidic nature of carbon dioxide (weak Lewis acid), and Lewis bases are expected to be introduced into it To activated carbon surfaces carbon dioxide may also be preferred for Performance capture. Surface area, pore diameter, and functional groups all come into play An important role in absorbing carbon dioxide. The Surface area and number of pores are interrelated, the greater the number of pores The surface area increases as the number of pores increases. surface area, pore diameter, and pore distribution depend on the temperature AC treatment.

2.7.1 Adsorption capacity.

The total amount of CO_2 adsorbed onto the AC particles was determined by applying mass balance principles on the packed-bed, as shown in Figure(2.4). The general mass balance equation given in Equation (1) was applied.

Total CO_2 accumulation (total amount of adsorbed CO_2):

$$= \text{input- output} \quad (1)$$

Rate of accumulation (R):

$$= (c_o \times Q) - (c \times Q) \quad (2)$$

where c_o is the inlet concentration of CO_2 (g/L), c is the outlet concentration of CO_2 (g/L) and Q is the flow rate (m3/min).

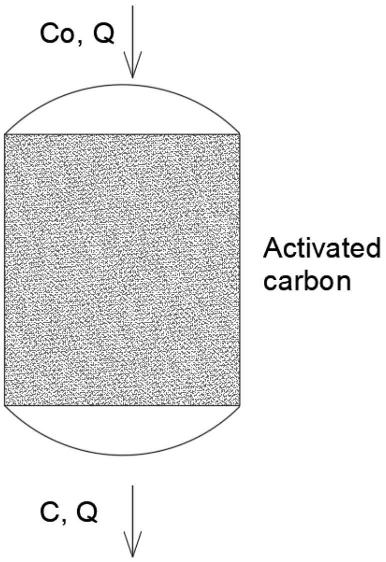


Figure (2.4). Activated carbon-based packed bed (C and Q are the CO_2 concentration and flow rate, respectively).

$$\text{Total accumulation} = \int_{\infty}^{0} (1 - c \div co)dt \quad (3)$$

where t is the adsorption time (min). The integral $\int_{\infty}^{0} (1 - c \div co)dt$ in Equation (3) can be obtained from the shaded area of the breakthrough curve as shown in Figure (2.5).

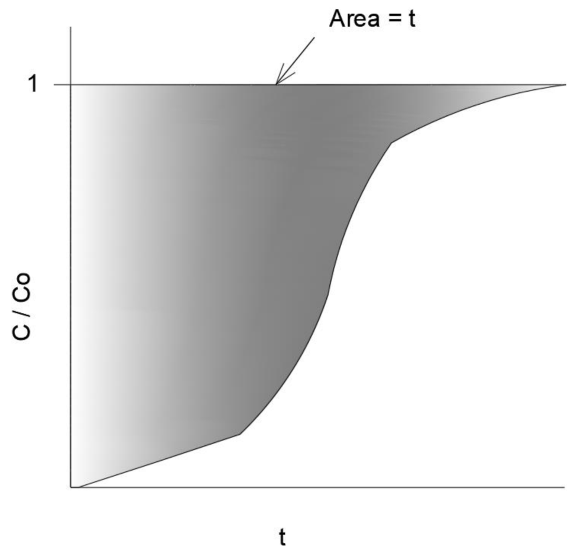


Figure (2.5). Breakthrough curve achieved after CO_2 adsorption.

The adsorption capacity of AC can be obtained from Equation (4) as follows :

$$q = m\,CO2 / m\,AC \quad (4)$$

where q is the adsorption capacity of AC (mg H 2S/g AC), m CO_2 is the total amount of CO_2 (mg) accumulated as given in Equation (3) , and m AC is the mass of AC (g) filled in the adsorption bed .

2.8 Activated Carbon Production.

2.8.1 Carbonization.

Gasification, combustion, and pyrolysis are the three basic processes that can use biomass to convert it into energy. Pyrolysis is the process of thermally breaking down biomass in an oxygen-free media to produce fuel gas, char, and bio-oil, among other energy forms(Tripathi et al., 2016). Gasification is the process of heating biomass in a gaseous medium—such as air, nitrogen, carbon dioxide, oxygen, or steam—to produce a gaseous fuel. It is possible to use the generated gas, which contains CO, CO_2, H_2, and N_2, as a chemical feedstock to make liquid fuels. However, it can also be utilized to power boilers that produce heat or gas engines and turbines made of gas that produce electricity (McKendry, 2002). As for combustion, it is the direct burning of biomass in the presence of oxygen which converts the chemical energy stored in biomass to heat within a temperature range of 800– 1000 °C (Tripathi et al., 2016). Combustion ensures the complete oxidation of the biomass while gasification is a partial oxidation in temperature ranges between 700-900 °C.

2.8.1.1 Pyrolysis.

Without oxygen, it is thermochemical decomposition. Organic waste can benefit from pyrolysis because it has a high concentration of hemicelluloses, cellulose, and lignin, all of which can be broken down by heat. The temperature can rise above the biomass thermal stability point in the absence of oxygen, producing more stable products that do not burn.

Pyrolysis involves a variety of chemical processes that can be categorized into primary and secondary stages. During the initial phase, the biomass suffers partial removal of carbohydrate polymers into short chains of sugar units when heated to approximately 200°C. This process results in species with low water content along with a slow dehydration. Dehydrogenation, or the removal of hydrogen from organic molecules, and devolatilization, or the removal of volatile material, are two of the interactions that take place when the temperature becomes 300° C.

2.8.1.2 Type of Pyrolysis.

The final product is greatly affected by the pyrolysis process's operating conditions. Bio-oil is mostly produced via flash and fast pyrolysis, which operates between 850 and 1250 °C and has a relatively short residence time. with quick pyrolysis, the ratio of bio-oil generated is 60–75%; with flash pyrolysis, however, the ratio rises. Regarding slow pyrolysis, it mostly yields charcoal when heated to 550–950 °C for one to four hours.

Conversely, intermediate pyrolysis strikes a balance between the formation of liquid and solid materials (Tripathi et al., 2016).

Table (2.4) Operating conditions for different types of pyrolysis .

Process	**Slow**	**Fast**	**Flash**	**Intermediate**
Temperature(°C)	550-950	850-1250	900-1200	550-650
Residence time(s)	300-550	0.5-10	<1	0.5-20
Main Products	Bio-char	Bio-oil	Bio-oil	Bio-char +Bio-oil

2.8.2 Biochar.

2.8.2.1 Factors affecting Biochar production.

- **Type of biomass:**

High carbon and low inorganic content agricultural precursors can be used to make biochar. Because it is accessible, has little economic value, has little ash content, is suitable in terms of hardness and rigidity, and its disposal poses an environmental risk, agricultural waste is employed (Dias et al., 2007).

The wastes that are most frequently utilized to make char are bituminous coal, peat, wood, and coconut shells .The type of the starting material will have a major impact on the ultimate qualities of the carbon .Biochar formation is facilitated by the presence of lignin and cellulose. Research indicates that the largest lignin content in biomass waste enhances the creation of biochar, while higher cellulose content improves the production of bio-oil(Kan et al., 2016).

The temperature ranges at which lignin, cellulose, and hemicellulose breakdown vary.

Hemicelluloses break down between 220 and 315 degrees Celsius, whereas cellulose breaks down between 315 and 400 degrees Celsius. Ultimately, lignin breaks down at temperatures higher than 400 °C(Chen et al., 2018). Because cellulose breaks down into a stable hydrocellulose substance at low temperatures, there is more char produced. At high temperatures, it is transformed into volatile products (Tripathi et al., 2016). In conclusion, the main factor contributing to the creation of char is lignin. When olive husk, corncob, and tea trash were compared, the olive husk yielded the highest biochar due to its high lignin content (Tripathi et al., 2016).

- **Temperature:**

Pyrolysis temperature is the most significant factor, followed by pyrolysis residence time and pyrolysis heating rate (Ioannidou and Zabaniotou, 2007). A higher temperature often results in a higher yield of liquids and gases and a lower yield of char. Conversely, higher temperatures result in better-quality char. This can be explained by either secondary breakdown of char residue or substantial original decomposition of biomass at higher temperatures. The production of some non-condensable gaseous compounds from the secondary breakdown of the char at higher temperatures also adds to the increase in gas yield. The residence duration of the primary degradation vapors inside the broken particles must be shortened as the pyrolysis temperature increased (Ioannidou and Zabaniotou, 2007).

- **Heating rate:**

The heating rate has a high influence on products characteristics of biomass pyrolysis. In pyrolysis of rapeseed, when the heating rate increase from 5 to 50 K/min the mass losses increase from 1.1 to 10 mg/min.(Haykiri-Acma et al., 2006) Also in pyrolysis of cherry sawdust the yield of biochar increase from 29.98% to 39.98% when the heating rate decrease from 10 to 5 °c/min (Gheorghe et al., 2009). Fast heating rate leads to quick fragmentation of biomass and produces a high amount of gasses(Kan et al., 2016), while the lower heating rate leads to produce more stable and hydrocellulose and increase char production (Gheorghe et al., 2009).

- **Residence time:**

The biomass needs enough time to respond in order for the elements of the biomass to fully repolymerize. Furthermore, Biochar's macro and micropores form with enough time(Tripathi et al., 2016). Temperature and residence time have an impact on the physical, chemical, spectroscopic, and morphological characteristics of the biochar in addition to its yield. A high-quality charcoal is produced when the time is extended, yielding less volatile materials and the original cell structure while increasing the amounts of C, K, and P (Peng et al., 2011). According to another study, at high temperatures, the yield of biochar rises with residence time; whereas, at low temperatures, the yield of biochar decreases with residence time (Tripathi et al., 2016).

2.8.3 Activation.

2.8.3.1 Physical activation.

At temperatures between 800 and 1100 degrees Celsius, charred material is exposed to oxidizing gases such as steam, carbon dioxide CO_2, air, or a combination of them (Abuelnoor et al., 2021). Because CO_2 is clean, easy to handle, and has a slow reaction rate at 800°C, it is usually used as an activation gas(Ioannidou and Zabaniotou, 2007). Steam, on the other hand, is more effective than CO_2 because it generates a larger surface area and a faster conversion because water molecules' tiny size facilitates diffusion through porous structures more effectively (Nor et al., 2013, Alves et al., 2021).

2.8.3.2 Chemical activation.

The carbonized material is impregnated with an oxidizing agent for dehydration by mixing or kneading with a concentrated solution of acid or base. The commonly activated chemicals are

$ZnCl_2$, H_3PO_4 , NaOH, KOH, and K_2CO_3 (Ioannidou and Zabaniotou, 2007, Abuelnoor et al., 2021). These dehydrating agents prevent tar and other unwanted material to form in carbonization, which produces a higher percentage of carbon content. To acquire the final porous structure, chemical activation must be followed by thermal treatment of inert atmosphere. Chemical activation is performed at a lower temperature and part of the activation chemicals can be recovered, zinc salts and phosphoric acid for instance(Ioannidou and Zabaniotou, 2007).

Comparing between chemical and physical activation, the priority for chemical activation due to lower activation temperatures, shorter treatment time, larger surface area and microporosity, and a higher yield of AC production(Nor et al., 2013, Alves et al., 2021).

2.8.3.3 Physiochemical activation.

A combination of the initial two activation mechanisms (Nor et al., 2013). For example, it is utilized to generate granular activated carbon with a very high surface area and porosity for use in gasoline vapor control applications. Figure (2.6) below show the different between the chemical and physical activation.

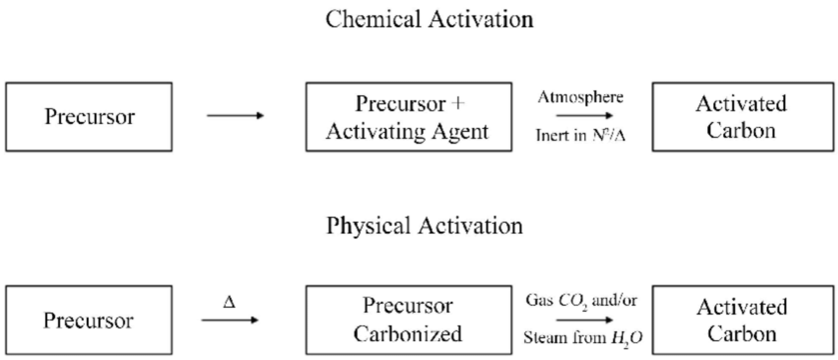


Figure (2.6):The chemical and physical activation.
Source: (Alves et al., 2021).

2.8.4 Activated carbon.

Activated carbon is a good choice to use for carbon dioxide adsorption due to its high adsorption capacity at atmospheric pressure, lower cost, hydrophobic properties, high surface area, thermal stability, ease of reduction, and the ability to modify pore structure and surface performance (Gheorghe et al., 2009). On the other hand, the massive production of agricultural waste and biomass negatively affects the environment, so recycling biowaste into valuable materials is essential economically and environmentally. To recycle and convert biowaste, activated carbon is simply made from a wide range of biomass materials because they have low levels of inorganic compounds (ash content) and high carbon (Peng et al., 2011). Many carbon-based materials, such as peat, wood, lignite, coal, and nutshells, are used to produce commercially activated carbon. OR through carbonization and can be used as suitable gas adsorbents, including CH_4/CO_2 .

Activated Carbon is classified into four main groups according to its structure including granular activated carbon (GAC), powdered activated carbon (PAC), activated carbon fibers

(ACF), and activated carbon cloths (ACC). GAC is usually prepared from hard materials of high rigidity and large particles retained on mesh #80, used as filler in columns, can be regenerated after use. When raw material particles are small, PAC is produced. For having small volumes, highly efficient adsorption occurs, even though settling and removal are slower in PAC than GAC. It's disposed of after use. ACF is manufactured from homogeneous polymeric raw materials and has a monodispersed pore size distribution. The thin fiber shape develops intra-particle adsorption. Therefore, the contact efficiency between the media and the adsorbent is enhanced. ACC were initially developed using as precursors phenolic or viscose rayon and are considered to be excellent adsorbents due to their low-pressure drop during the process, high contact efficiency, and flexibility(Dias et al., 2007) .

2.9 Summary .

This chapter has focused on the discussion of the main issues and definitions related to the research objective:

- ✓ The definition of the filtration system and its objectives, and the relationship between the systems and the internal environment of the residential building.
- ✓ A study of the main materials used for building filtration and the advantages and disadvantages of each material. It was concluded that activated carbon has several advantages depending on the materials used.
- ✓ In order to produce activated carbon that is ready for use as a filter, methods of carbon preparation and activation were studied.

Chapter 3

Residential building and indoor air quality .

3.1 Preface .

Different life activities cause people to spend the majority of their time in different types of buildings, including residences, offices, schools, and restaurants. The air quality in indoor environments is a significant determinant of human health and well-being. Several studies have established links between positive human health impacts and improved indoor environments (Mannan and Al-Ghamdi, 2021) (Colenberg et al., 2021). Low IAQ results in unwanted health conditions, including death in the worst-case scenarios. This highlights the importance of the IAQ of any indoor space.

Modern building regulations are based on promoting energy savings, which entails a reduction in air exchange and therefore increases the concentration of indoor pollutants (Wang and Zhang, 2011). Regulations and recommendations in the field of modern construction should find a compromise between the progress in building tightness and the guarantee of a good IAQ, leading to a parallel decrease in building energy requirements. As regulations for construction and refurbishment of buildings progress, more investment in the development of these technologies is needed. Indeed, biotechnologies have the potential to successfully deal with poor IAQ and the difficulties and limitations associated with this problem. However, more investigation is necessary. First, to develop and optimize the technologies at the laboratory level, and then, to incorporate them in cost-effective systems that can be integrated into indoor spaces combining optimal performance with acceptable aesthetics. The implementation of biotechnologies in indoor spaces would have benefits in IAQ, which in the end would lead to increased comfort and health of the users and a reduction in the energy expenses of the buildings.

3.2 Residential building.

In Palestine residential architecture is diverse and reflects several cultural preferences, architectural styles, and economic factors. Typical varieties include single-family residences, which can range from modern villas to traditional Palestinian homes, and multi-story apartment buildings that are common in cities and provide community facilities(A'rraf, 1985). Townhouses are also popular because they offer a good mix of seclusion and functional space in both urban and suburban environments. Gated communities are becoming more and more common in suburban locations, providing residents with premium living spaces and a range of facilities. There are also informal communities, which pose issues with urban planning, indoor air pollution, and infrastructure(Hadid, 2002, Hamdan, 1996).

3.3 Indoor Environmental Quality (IEQ) in Residential building.

Indoor Environmental Quality (IEQ) refers to the overall quality of the indoor environment within a building or structure. It encompasses various factors that can affect the health, comfort, and well-being of occupants(Mahdavi et al., 2020). IEQ is an important consideration in building design, construction, and operation, as it can impact occupants' productivity, satisfaction, and health.

The building envelope controls the internal environment of the space. Therefore, internal environmental quality factors must be taken into consideration when working on any designs that may be added to the building envelope. Seven factors affect indoor environmental quality (IEQ)(Tran et al., 2020):

Thermal comfort 2) Indoor air quality 3) Visual comfort 4) Acoustic comfort 5) Building factors,6) Occupancy factors and 7) Climatic . These factors are closely related and cannot be treated separately.

3.3.1 Indoor air quality.

To maintain clean and healthy air within the home for a comfortable and healthy living environment, IAQ for residential buildings is a measure of indoor conditions that provide comfort to users of the space while respecting outdoor environmental elements, ventilation, wind, and energy. A building's natural ventilation rates, humidity levels, and concentration of particular chemicals, carbon oxide, and biological pollutants all affect how clean the air within is(Mannan and Al-Ghamdi, 2021). Residential buildings are buildings that are operated over a long period. It is not like other types of buildings that are used for specific hours. These buildings have furniture and appliances as well as occupants who require high air quality. Energy is consumed by operating the appropriate air conditioning and filtration systems to achieve the desired comfort(Tainio et al., 2021).

In recent years, comparative risk studies performed by the Environmental Protection Agency (EPA) and Science Advisory Board (SAB) have consistently ranked indoor air pollution among the top five environmental risks to public health. The importance of indoor air quality is also due to the absolute amount of time that people spend indoors(Wang and Zhang, 2011). Most people spend up to 90% of their time indoors and many spend most of their working hours in an office environment (Mannan and Al-Ghamdi, 2021). It has been estimated that the potential productivity gain by providing better indoor environmental quality are over $40 billion to $200 billion per year in the U.S(Fisk, 2000) . Indoor air quality can be improved by three ways: controlling source, designing ventilation systems to dilute and exhaust contaminated air, and cleaning air(Guo et al., 2003) .

3.3.2 Visual comfort.

Visual comfort in residential buildings refers to the ease, satisfaction, and well-being experienced by occupants in their visual environment. It encompasses various factors related to lighting, glare, contrast, color, and spatial organization, all of which contribute to creating a visually pleasing and functional living environment. Achieving visual comfort in residential buildings is essential for promoting occupants' health, productivity, and overall quality of life(Tabadkani et al., 2021).The most important aspect of visual comfort in residential buildings is the daylight factor: Adequate lighting levels are crucial for ensuring that occupants can see clearly and comfortably perform tasks within the home. Lighting should be sufficient without being overly bright or causing discomfort or glare(Li et al., 1999).

When it comes to daylight factor, it's a measure of the amount of natural light available within a space relative to the amount of artificial light needed. It's expressed as a percentage and is calculated by dividing the illuminance (light level) on a given point in the interior of a building by the illuminance on a horizontal plane outside under an overcast sky. The formula for %DF is derived as follows(Li et al., 1999, Mardaljevic and Christoffersen, 2017):

$$\%DF = Ei/Eo \times 100\%,$$

Where Ei: is the illuminance from daylight at a point on the indoor working plane.

and Eo: is the simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of the sky, as shown in Figure (3.1).

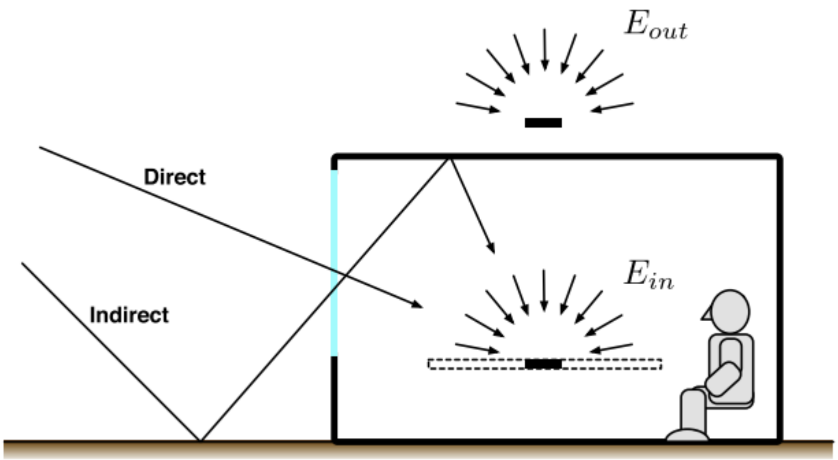


Figure (3.1): Definition of the daylight factor.

Source :(Mardaljevic and Christoffersen, 2017).

Daylight factor requirements or recommendations may vary depending on factors such as building orientation, location, climate, and the specific needs of occupants. However, typical daylight factor recommendations for residential spaces often range from 3% to 5% (3-5 DF) for living areas and bedrooms(Lynes, 1979).

In Palestine, like in many other regions, optimizing daylighting in residential buildings can offer several benefits, including energy savings, visual comfort, and connection to the outdoors(Li et al., 1999). Design strategies to enhance daylighting may include:

Proper building orientation to maximize natural light exposure.

Selection of appropriate window sizes, locations, and glazing types to allow for sufficient daylight penetration while minimizing glare and solar heat gain.

3.4 Impact of different parameters on IEQ in building .

Indoor environmental quality (IEQ) is affected by a group of building-related factors other than the factors mentioned previously, which are:

1) building characteristics 2) building envelope 3) building condition (building age) 4) room interior design 5) environmental control 6) Building design 7) Building type 8) Building location 9) Building orientation, etc. Thus, construction-related factors, if the building design is not taken into account, the visual, thermal, and hygienic aspects of the building will destroy the acoustic comfort and indoor air quality. The indoor environment of a building is not only affected by building-related factors but also depends on the occupants . Occupancy factors must be highlighted in the design to control the internal environment system of buildings, apply appropriate building materials, and design the building. Thus, the factors to be taken into consideration that influence indoor environmental quality are (Tainio et al., 2021):

1) occupant activities 2) thermoregulation 3) behavior/lifestyle 4) thermal resistance of clothing, age, and municipal origin and 5) Climatic factors are a global factor that affects IAQ. The quality of indoor air has been impacted by the effects of climate change, which include increasing use of HVAC systems, particulates in the air, chemical carbon dioxide emissions, etc. Also impacted by climate change is the health of building residents. Finally, it has been shown that people's performance, productivity, contentment, comfort, and well-being are all impacted by subpar indoor environmental quality(Li et al., 1999).

Building characteristics affect air circulation patterns and emissions. Most published studies related to the effect of home location on indoor air quality focus on the surrounding environment, direct local emissions, and seasonal or climatic influence. Sometimes contradictory conclusions can be found in the literature, such as the effects of weather and seasons and the effect of opening windows on indoor pollutant levels. These conflicting results can be caused by the location of the primary sources of contaminants and the location, use, type ,or age of the building(Guo et al., 2003).

3.5 Relationship between indoor air quality and energy consumption.

There are a range of factors that influence energy consumption in buildings, such as new designs, materials, and the use of passive design strategies. Strategies take into account building orientation, layout, finishing materials, and occupancy activities as well as air movement and ventilation in the building. Electrical loads resulting from improving indoor environmental quality consume a large amount of the building's total energy. Increasing energy consumption in ventilation and air filtration systems is necessary in parallel with the growing demand for higher air quality, a luxury that has not been widespread in this way for a long time. This has led to significant energy consumption in all building sectors. Many factors influence an occupant's perception and acceptance of indoor quality, such as air temperature, humidity, noise, odors, lighting, and stress. This falls under a different set of susceptibility and preferences among the population (SeppĘnen, 2008).

The design of the filter placed on a building's windows has a significant impact on the building's energy consumption and thus affects the indoor comfort of occupants as well as the indoor air quality. The correct selection of materials used reduces energy consumption in construction. Materials with a high capacity to absorb pollutants help reduce their passage through building windows, thus reducing the associated ventilation and filtration loads. Innovative technologies and strategies for measuring air quality are now widely available. The main problem is to determine the most effective primary raw materials for gas filtration for a particular residential building Sustainable in the long term(Awbi, 2017).

The use of air filters can have a positive impact on respiratory health and may contribute to saving money on the treatment of diseases that affect the respiratory system. Cleaner indoor air can contribute to improved sleep quality(Kolokotsa and Santamouris, 2015). Poor air quality can exacerbate respiratory conditions and disrupt sleep, leading to increased healthcare needs. Better sleep may result in improved overall health and a reduced need for medical interventions. While the upfront cost of air filters may be a consideration, the long-term health benefits can lead to savings by preventing or reducing the need for medications, doctor visits, hospitalizations, and other respiratory-related treatments (Zaatari et al., 2014).

3.6 Indoor air quality (IAQ) in Palestine.

Most developed countries take into account and follow internal quality regulations during the design and maintenance phase of built environments through appropriate measures. However, this scenario is not similar in developing countries such as Palestine, where poor indoor air quality disproportionately affects children, women and the elderly(Alatawneh et al., 2015).

The Palestine Higher Green Building Council represents the country's deliberate and well-established information source that derives its rules directly from the Leadership in Energy and Environmental Design (LEED) systems through which various buildings are evaluated. A different group of buildings in Palestine obtained this certificate to achieve the recommended safe conditions and limits(Alsamamra and Said, 2019). While the evaluation of green buildings certified by LEED is based on an annual basis to ensure safe limits for indoor air pollutants. Although green building regulations include certain steps, such as bringing more fresh air indoors and choosing safe materials, to address indoor air quality during the design phase, limited empirical data confirming improved indoor air quality during the operation phase is available. The evaluation revealed numerous air quality benefits in green buildings compared to traditional buildings in accordance with ASHRAE regulations, CO_2 levels and relative humidity measurement data were at satisfactory levels (الحضيري and 2018 ,حسن).

3.7 Strategies to maximizing indoor environmental quality (IEQ) in residential building.

The positive health effects and obvious return on investment make it imperative for building proprietors and managers to take proactive measures to enhance indoor air quality. To do this, there are several approaches and techniques. Improving ventilation systems and daylighting , creating air purification technology, and managing sources of pollution are the three basic strategies that makeup improving indoor environmental quality(Hasselaar, 2006).

3..7.1 Indoor air quality (IAQ)

Methods for improving the indoor quality of buildings have varied, whether during design and construction or by improving existing buildings (modifying them). Among them, research into new technologies for filtering and purifying air pollutants has attracted great interest because of the possibility of adding them to existing buildings without making modifications to the building(Lynes, 1979).

The basic premise of improving indoor air quality is that increasing ventilation rates (i.e. bringing more outside air indoors) dilutes indoor air pollutants. Increasing the outdoor air supply to meet ASHRAE 62.1 standards may require additional design and installation of heating, cooling, or dehumidification systems to prevent comfort or humidity-related problems. But filtration is often used to control indoor air pollutant levels, especially when the source of the polluted air is outside the building. Control strategies include installing higher-efficiency air filters in existing HVAC parts or installing activated carbon-impregnated filters on home windows to remove harmful essential gases and odors(Ng et al., 2011).

3.7.2 Visual comfort.

3.7.2.1 Double-skin façade:

A double-skin façade is a mixture of a typical single-skin façade with an external layer that doubles its surface area, creating an extra glazed façade. Because each of these layers are commonly referred to as a skin, the term "double-skin facade" came into being. Furthermore, every skin layer has a naturally ventilated, sealed, or self-regulating cavity that ranges in width from several centimeters for the narrowest to several meters for the widest cavities that are visible. The glazing could cover all of the structure or simply some of it, below Figure (3.2) show the double skin façades main types (Faggal, 2014).

The additional layer, which is often single glazed, is put in front of the primary glazing and produces the air space; the inside layer of glass, which is usually insulating, is part of a standard structural wall or a curtain wall(Regazzoli, 2013).

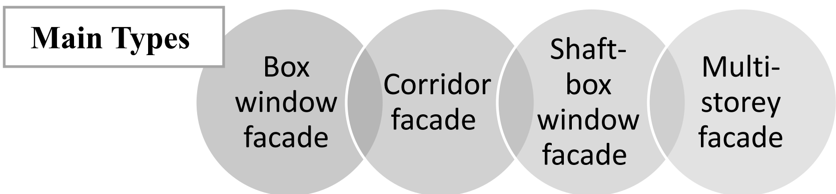


Figure (3.2) :Double Skin Façades Types.

Source:(Faggal, 2014)

Box window :

In this case, the façade is divided into smaller, independent boxes by horizontal and vertical dividing.

One of the earliest types of double-skin façade configuration is the box façade.

It is made up of modular one-story double-skin façade box modules that are split either by room-by-room or by structural bay widths.

There are openings on the outside of the single-glazed skin to let fresh air enter and stale air exit. allowing for the natural ventilation of the internal rooms as well as the middle space. Figure (3.3)   shown the typical box window type section.

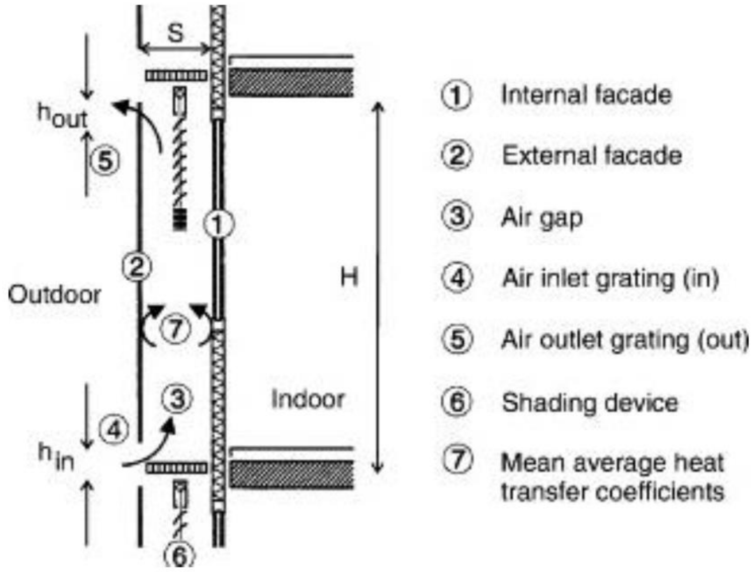


Figure (3.3) Typical Box window type section.

Source:(Faggal, 2014)

The Box Façade arrangement is frequently employed in scenarios where unique requirements for sound transmittance between adjacent rooms are present or where high levels of external noise are taken into account. Installing box windows has a big effect on how much natural light a building obtains. A box window that extends from the exterior improves the aperture's surface area, allowing more light to enter inside rooms and go deeper. By reducing the need for artificial lighting, this expansion can improve energy efficiency. Box windows can also be designed to minimize glare and direct sunlight, which will improve the uniformity and comfort of interior illumination. Box windows, when properly built, can improve the amount and quality of natural light in a building.

The historical background of the box window can be traced to the classic Mashrabiya, an architectural feature prevalent in Arab nations. Mashrabiyas, or wooden latticework screens, were installed on windows to give residents shade, ventilation, and seclusion while yet enabling them to view outside without being seen. These developed into increasingly complex constructions throughout time, retaining the core elements of their original aesthetic and functional goals while adjusting to the demands of contemporary architecture. The transition from Mashrabiya to modern box windows is an example of how technological developments in window design have been combined with cultural legacy(Shahda and Noseir, 2021).

The Mashrabiya and the box window are related because of their shared aesthetic and functional goals. A contemporary architectural modification, the box window extends from the exterior to enhance ventilation, let in more light, and create more internal space. Both show the transition from traditional to contemporary architectural design by aiming to maximize natural light and ventilation while providing privacy. Mashrabiya has five functions 1- providing shading, 2- natural ventilation, 3- controlling the passage of light, 4- reducing the temperature of the air stream and controlling its humidity, 5- providing privacy, as shown in figure (3.4)(Shahda and Noseir, 2021).

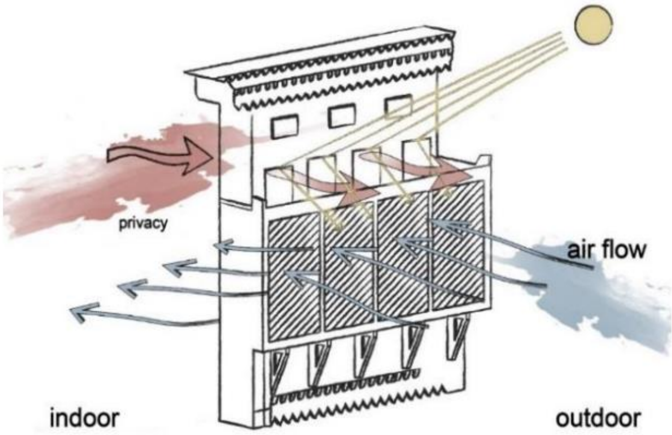


Figure (3.4): Mashrabiya functions .

Source: (Shahda and Noseir, 2021)

3.7.2.2 Light shelves :

One of the most common architectural designs for modern buildings are light shelves, which have been suggested in literature as useful devices that can enhance a room's lighting and save energy, particularly when combined with daylight controls. A horizontal or incline surface put on a window above eye level, either internally or externally, is capable of maintaining and dividing incoming daylight through reflection on its upper surface. Light shelves are probably the most basic type of daylighting device(Bellia et al., 2014).

As a result, it can serve as an externally installed shading device to prevent direct sunlight from affecting on the work surface or, if installed within, It can act as a daylighting device, bouncing off reflected sunlight onto the ceiling plane and allowing daylight to penetrate deeper into the area, or it can diminish solar gains. Many designs for light shelves have been proposed up to this point. Their performance is primarily assessed in relation to the achieved indoor lighting levels, whether they are flat or curved, static or sun-tracking, and using specular reflection or refraction.

Reviewing the characteristics of the ideal lighting shelf for the Mediterranean region was an extensive range of previous studies. For example, Soler and Oteiza (Soler and Oteiza, 1997) used two South-oriented scale models with rectangular openings to examine the efficiency of a highly reflective (91%) light shelf, in Madrid, Spain. The models represented spaces with dimensions of 6 × 6 m a ceiling height of 2.8 m and a Window-to-wall Ratio of 50%. One was equipped with a light shelf and the other was left free of obstruction as the reference case. Measurements of mean hourly illuminances were obtained during one year from both models. The objective was to show the dependence of solar elevation and solar azimuth on daylighting efficacy. This was defined as the ratio of the mean hourly illuminances obtained by the model equipped with the light shelf and the reference model respectively.

The light shelf was intended to function as a shading device with a 50° vertical shading angle. Higher similarity was offered by the light shelf compared to the reference model, as shown in Figure (3.5) below. Measurements show that the efficacy of the system increases together with the solar elevation up to a point and then decreases. Further increase in the solar elevation resulted in a decrease in the light shelf's performance(Soler and Oteiza, 1997).

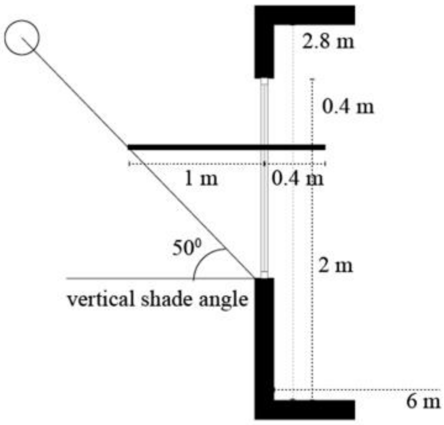


Figure (3.5):Light shelf dimensions and vertical shade angle as examined in((Soler and Oteiza, 1997)).

Source:(Soler and Oteiza, 1997).

Others looked at a control mechanism that changed an external mirror light shelf's tilt angle based on the sun's location and a predetermined target region on the ceiling, then calculated the energy savings in lighting as a result. Two case studies were simulated in a 4 × 7 × 2.8 m deep, south-facing office space: (a) with a static light shelf and (b) with an automatically controlled external light shelf(Kontadakis et al., 2017).

Using the Figure (3.6) , the tilting angle of the light shelf (θ) was defined as follows:

$$\theta = (\theta\ sun - \omega)/2$$

where θ sun is the projected sun's elevation angle, and ω a constant angle defined by the aiming point. The daylight autonomy values obtained were highly dependent on the size of the window. The increase in daylight autonomy was five times that of the reference example (without a light shelf) when the clerestory window (window-to-floor ratio: 6.2%) was the only window utilized. The previous increase was only 1.15 when the view window was used(Kontadakis et al., 2017).

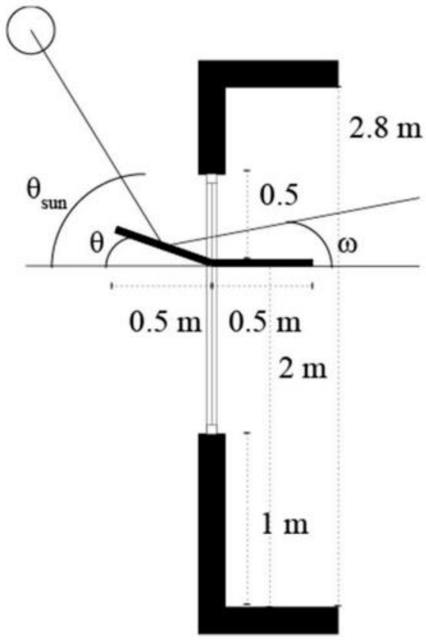


Figure (3.6): Tilted light shelf reflecting sunlight on a specified area on the ceiling examined in [(Kontadakis et al., 2017)]. Source:(Kontadakis et al., 2017)

The idea that Howard et al. (Howard, 1986)put out is an appealing one. Using direct and diffuse sunlight, VALRA (Variable Area Light Reflecting Assemblies) is a tracking light shelf system that reflects light into a structure at the south elevation or the roof. More effectiveness can be achieved with this setup at all incident sun angles. Using a direct current (DC) motor, the reflective plastic film surface can be adjusted over a spring-loaded tracking roller assembly .

3.8 Summary.

This chapter has focused on discussing the main issues related to indoor air quality in the residential building:

- ✓ The importance of maintaining indoor air quality in homes to ensure better health for individuals.
- ✓ Developing filtration and filtration technologies and integrating them into indoor spaces will ultimately lead to increased comfort and health for users.
- ✓ Impact of different parameters on IAQ in building and the air filtration.
- ✓ Study different strategies to maximizing indoor environmental quality (IEQ) in residential building.

This is in order to study all possible options and achieve the most efficient design in providing the best air quality and the acceptable daylight factor for indoor spaces.

Chapter 4

Research Methodology.

4.1 Preface.

The first stage of this study involved a thorough review and analysis of existing literature about the character of the study, identification of the most suitable model setup for testing the filter, methodologies for data collection during experimentation, comprehensive material selection criteria, and elucidation of the operational mechanisms of the active materials within the laboratory setting. Phase 1 served as the foundation for Phase 2. Relying on the information gathered in Phase 1, phase 2 focused on into delineating the execution of each step of the model and establishing the protocols for preparing the materials earmarked for laboratory testing. This thorough investigation served to validate the entire process encompassing model construction, selection of testing apparatus, material preparation, and commencement of filtration experiments. The methodology resulted in determining the specifications of the optimal filter model, which was achieved through comparative simulation, and optimization techniques as shown in figure (4.1). This verification aims to support either or refute the feasibility of applying the initial optimized design in the context of the study for future work.

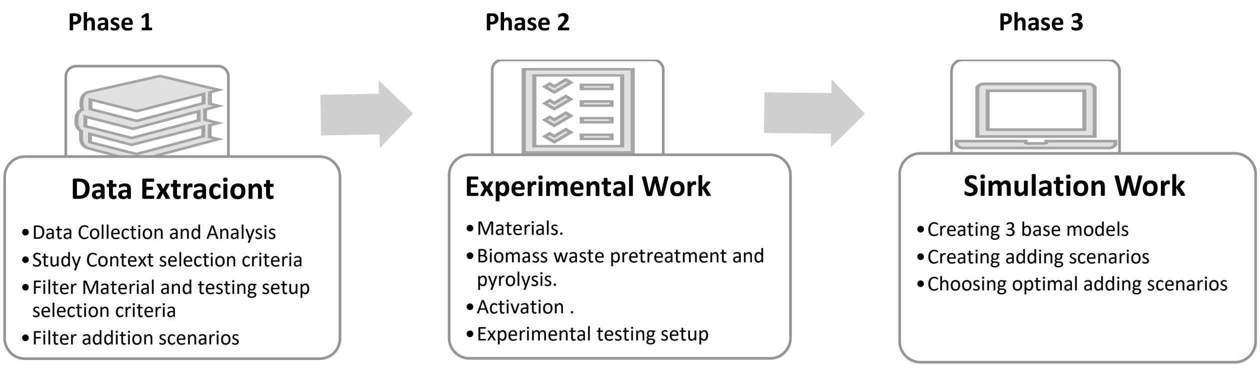
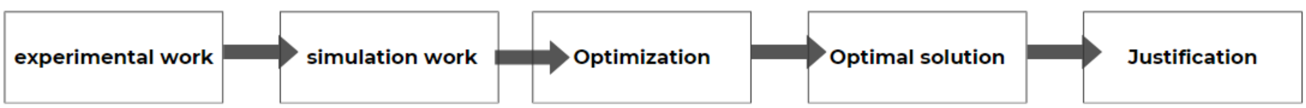


Figure (4.1): The three main phases of the research.

4.2 Research type and data collection method .

This thesis is conducted in an deductive method, in which the buildings exposed to a high percentage of carbon dioxide had been observed and make filter experiment then simulated to confirm the most appropriate solution as the following procedure presented in Figure(4.2).



Figure(4.2): The main procedure of the research.

The methodology used in this study's data collecting and analysis is a quantitative approach, found in laboratory experiments that measured carbon dioxide reduction levels both with and without activated carbon filtration. The gathering of numerical data from carbon dioxide concentration measurements taken both before and after filtration allowed for an analytical test to evaluate the adsorption of the activated carbon filter. In the end, the optimal daylighting factor for the residential building was found by quantitatively analyzing different scenarios for lighting and CFD using computer simulation modeling.

Through comparison, the study selected and justified the most suitable methods based on their availability and relevance to the local context, providing the practical work necessary to achieve results. The main aim was to answer the research questions and either prove or refute the proposed hypothesis of the research. The theoretical part of this research involved a deep literature review that has been presented in detail in chapters 2 and 3. The review was developed based on scientific journals, research papers, and books, to justify the problems associated with buildings exposed to a high percentage of carbon dioxide and then to have a strong base, knowledge, and experience about the filtration techniques and strategies for gases and materials associated with residential buildings. The practical part consists of two sections, the first includes preparing activated carbon from raw materials and the second includes the adsorption measurements taken using a carbon dioxide monitor (A37,UNI-T, Industrial North 1st Road, Guangdong Province ,China), that measures the CO2 concentration, temperature, and humidity. Following the simulation process that uses Design Builder software version 6.1 simulation software, to create artificial models for the selected cases studies. Afterward, optimal solutions are selected and justified.

4.2.1 Data Analysis Method.

The data collected through the literature was analyzed by comparing different gas filtration techniques in terms of the type of gas being filtered, filtration capabilities, availability of materials used, and the mechanism of obtaining them, in addition to their suitability for the local community in Palestine. In the same context, different filtration (adsorption) methods were analyzed. According to their suitability for research purposes and choosing the most appropriate ones. While the practical part consists of experimental work through which the data obtained through special measuring devices and simulations for different cases were carefully organized, it was designed to compare the behavior of added filters and their effect on the natural daylighting and the Computational fluid dynamics CFD test of spaces. This approach aims to provide a strong foundation for Understanding the current situation of adding filters to improve the environment in Palestinian residential buildings, Drawing valuable insights, and formulating informed recommendations for future practice.

4.2.2 Context of the study selection criteria.

The aim of creating a highly effective filter for windows in residential buildings with a purpose of purifying carbon dioxide gas was carefully considered while choosing the study area, with a focus on areas with climates similar to those of the Mediterranean region. Considering the importance of climate for determining filter performance, an example the location reflecting the main characteristics of the Mediterranean climate had to be selected. Consequently, the availability of the site's climate data profile on the design builder simulation program made the Jerusalem region an excellent candidate. Within the program, simulation trials must be performed out. The study makes sure that the simulated experiments accurately reflect the climate-related variations and challenges common of Mediterranean regions, which improves the study results' application and reliability.

4.2.3 Materials Classification and Description Criteria.

4.2.3.1 Material selection criteria.

The selection of precursor materials, which are often organic materials such as wood, coconut shells, or agricultural waste, is done based on the material's carbon content and ability to produce activated carbon with desired properties. Careful control over activation parameters, including temperature, activation time, and activating agent concentration, is essential because the pore structure and surface area of the resultant activated carbon greatly impact its adsorption capability. Laboratory-produced activated carbon can be customized to meet the unique requirements of experimental investigations by following strict material selection criteria .

4.2.3.2 Criteria for choosing the testing setup.

Several important factors were taken into account when choosing the best form for activated carbon filter performance setup testing for carbon dioxide gas. The form that is used should provide an accurate assessment of the filtration efficiency while optimizing effective gas flow and distribution across the filter. To accomplish these goals, the solid's geometry which includes the first chamber for gas collection, the filter filling region, and the second chamber for post-filtration assessment is essential (Radaideh et al., 2016, Haghighat et al., 2008) .

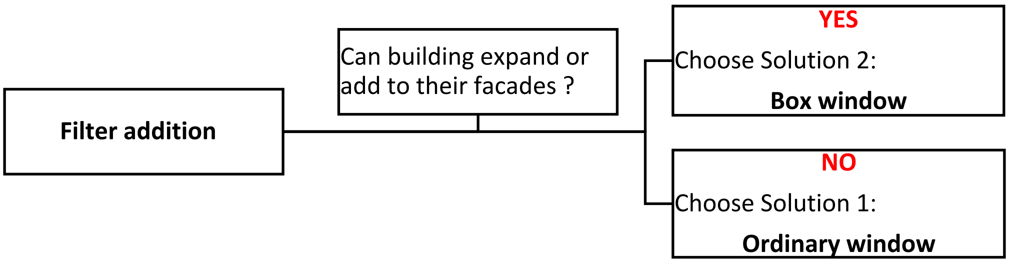
The form needs to minimize the possibility of channeling or uneven contact with the activated carbon surface, promoting uniform gas diffusion within the filter. the design should make it simple to load and replace the filter, guaranteeing uniformity in testing protocols (Haghighat et al., 2008). Furthermore, to preserve the repeatability and reliability of experiments, factors like the selection of material and structural integrity are critical. The selection of materials with a poor ability to absorb gases was finally the most crucial factor that was considered in the comparison processes to determine the most suitable form. This helped to effectively contribute to a thorough assessment of the activated carbon filter's capacity to remove carbon dioxide gas (Sahabuddin and Howieson, 2020, Bubanale and Shivashankar, 2017).

4.2.3.3 Filter addition scenarios .

The filter addition process consists of two main solation as shown in Figure (4.3).

Solution 1: This solution is for buildings on the setback or those that are unable to expand and add to their facades, this approach considers putting the filter directly to the window, this is what was called the ordinary window.

Solution 2: This solution in the case of buildings that allow facade additions and extensions, this option considers putting a filter along the window, this is what was called the box window.



Figure(4.3): The filter addition process of the research.

4.3 Experimental work .

4.3.1 Materials.

Samples of Coffee grains (COF.F) and Sunflower seed shells(SUN.F) waste was collected from a local home kitchen (Hebron, Palestine). Oak sawdust waste (OKA.S) was collected from carpentry (Hebron, Palestine) and almond shells(ALM.O)were collected from the local home garden (Hebron, Palestine). As activation agents, potassium hydroxide KOH (90%, Albemarle, Louisiana, Florida, USA)was used in this study. The CO_2 gas was obtained through the use of a Carbon Dioxide Industrial Grade (99.5%, Air Products, Heshvan St 23 10,Hebron, Palestine) Hebron, Palestine.

4.3.2 Biomass waste pretreatment and pyrolysis.

After cleaning with tap water, the collected biomass wastes were dried for 24 hours at 105°C in an oven (Daihan LabTech Co., Ltd. in Korea). Following this, the materials were smashed and sieved for 15 minutes using an auto sieve analysis shaker (Matest, Italy) with meshes numbers (10, 18, 40, 60, and 140),. For the next analysis, particles that remained on mesh #140 were utilized. The gathered particles were placed into a porcelain crucible that was tightly packed to keep out oxygen and water vapor. The crucible was then placed inside a muffle furnace (labTech International Ltd., East Sussex, UK) and heated to 500°C for an hour see Appendix (A). The weight ratio of the produced biochar to the original biomass weight was used to determine the pyrolyzed materials' yield. Additionally, the study presents the average values along with their standard deviation values (SD. ± values).

4.3.3 Activation .

The pyrolyzed biomass was mixed with distilled water at a ratio of 10:1 (v/w) (V_{water}: $W_{biomass}$) for the purpose of impregnating the samples. The impregnation reagent , KOH, was then gradually added to the mixture at a ratio of 1:4 ($wt_{reagent}$: $wt_{biomass}$). Using a hotplate magnetic stirrer (labTech International Ltd., East

Sussex, UK), the mixture was gradually swirled at 300 rpm and heated to 80°C until the majority of the liquid evaporated. After that, the samples were dried for 24 hours at 105°C in an oven , see Appendix (A). The yield of activated carbon was determined using Equation (5):

$$Yield\ \% = W_{AC}/W_0 \times 100 \quad (5)$$

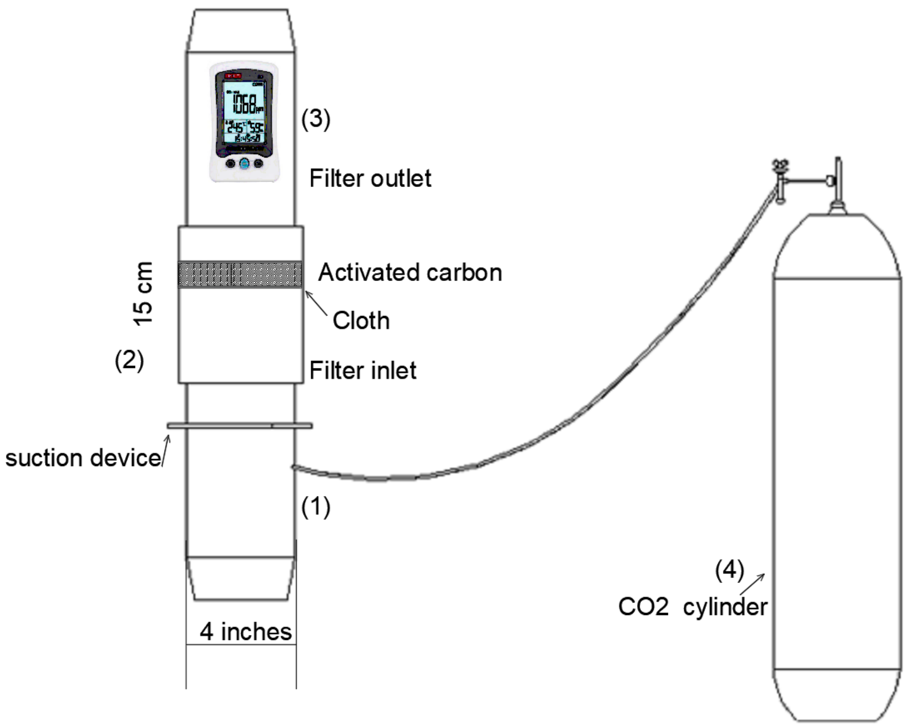
where: W_{AC}: is the dry weight of final activated carbon (g)

W_0 : is the initial weight of the biomass samples (g).

The morphologies of the activated carbon of the four samples were visualized using a Quanta FEG Scanning Electron Microscope (SEM), FEI 450 Company, Hillsboro, Oregon, USA. The magnification used for this analysis was in between 80 to 160000.The samples were mounted on aluminum stubs by double sided sticky disks of conductive carbon , then 5nm gold coated by sputter coater (Quorum Q 150R)

4.3.4 Experimental testing setup.

The adsorption tests were done using the experiments setup shown in Figure (4.4). the adsorption was carried out in packed bed plastic filter with an internal diameter of 4 inches and a height of 15 cm (Figure 4.4). To hold onto the AC particles, two thin layers of a porous fabric were placed at the filter's inlet and outlet. To study the impact of the bed material and putting the cloth on the CO_2 adsorption behavior, the bed was first run empty (without AC). Next, the AC particles were placed inside the bed at various heights of 0.5, 1, 1.5, and 2 cm, respectively.

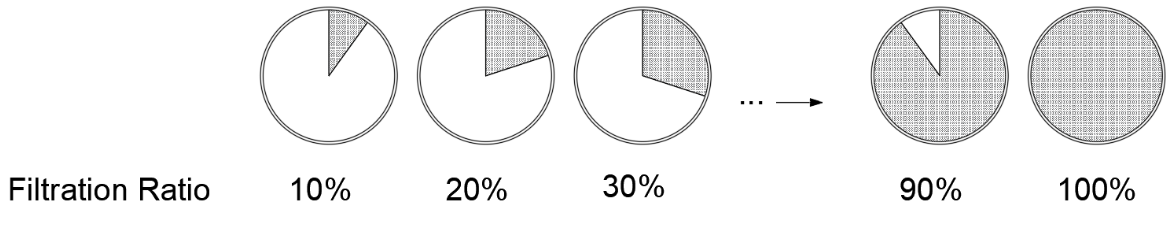


Figure(4.4): Experimental setup used for CO2 adsorption test.

(1,3 : inlet and outlet connections, 2 : packed bed, 4:CO_2 Cylinder).

The entry chamber is the first location where the carbon dioxide source gets noticed at the compound (1) is directly linked to a suction device that forces polluted air through the filter(in one direction). To provide uniform and representative airflow through the filter, the suction device's driving force selection is dependent on the average wind speed in the study area (Banyo Ve Tuvalet Aspiratörü ,Horoz Electric , Karakoy , Istanbul, Turkey). Second, a specific area has been set out for filter replacement and filling, allowing for easy maintenance and effective functioning at the compound (2). The filter's efficacy in lowering pollutant levels can be determined through measurements of the carbon dioxide concentration in the output chamber, which acts as the process's final stage at the compound (3). The goal of this detailed equipment configuration is to offer a consistent and dependable assessment of the ability of activated carbon filters to purify carbon dioxide gas.

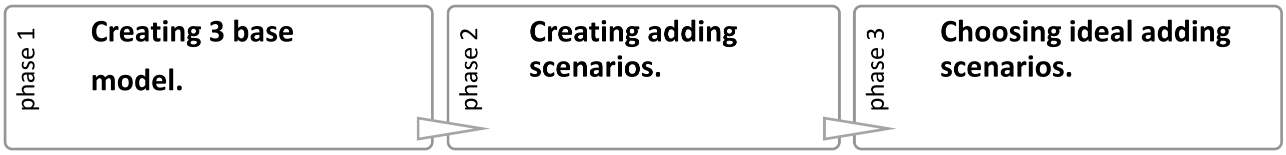
A 970 ppm average concentration of CO_2 gas stream enters into the setup from the bottom to the compound (1), passes through the AC particles at the compound (2), and then exits the top of the packed bed reactor to compound (3), where the CO_2 concentration measurement is recorded using (Uni-Trend Technology Co., Ltd. High-Tech Industrial Development Zone, Dongguan City, Guangdong Province, China). As shown in Figure (4.5), the filter filling location was modified using varying filter filling areas, ranging from 10% up to 100% of the area, in increments by 10% to investigate the impact of filter ratio on filtration performance. An airtight layer closed off the last filter area. made from compressed foam and wrapped in clear trisé paper to stop gas leaks and provide the best possible experiment results. The CO_2 concentrations at the inlet and outlet were measured at various intervals. By taking samples of the CO_2 concentrations at the inlet and outlet, the removal efficiency of CO_2 was examined in terms of period profiles. Calculating the ratio of the outlet concentration to the initial concentration ratio (C/C_o) as a function of the time of operation allowed for the development of the breakthrough curves for CO_2 adsorption inside the packed bed.



Figure(4.5): The Filtration ratio of the filter filling location at compound (2).

4.4 Simulation .

The simulation process consists of three main phases as shown in Figure (4.6)below.

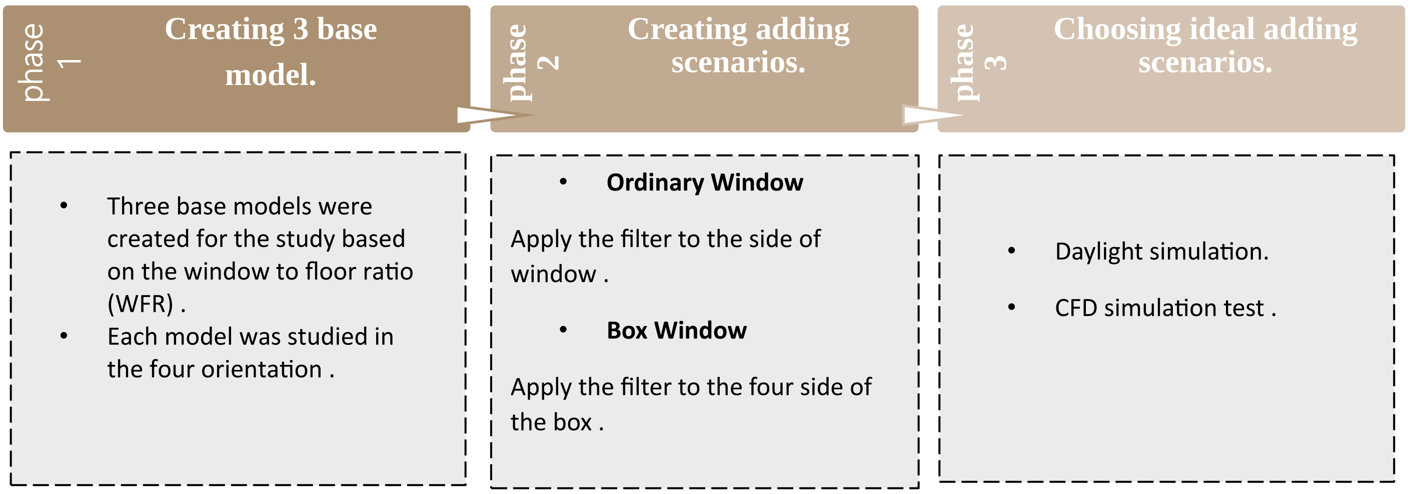


Figure(4.6): The three main phases of the simulation process.

Phase 1: Three base models were created for the study based on the window-to-floor ratio(WFR), Each model was studied in the four orientations. This stage relied strongly on data collected from the main references related to the forms of residential buildings and their measurements, such as the interior condition, dimensions, window type, and proportion, number of people in the place, and cooling and heating devices. In addition to climatic data for the study area.as shown in figure (4.7)

Phase 2: At this stage, new models were generated by modifying the basic models for each case, and then multiple simulations were performed to obtain results of applied retrofits. Adding a box window to the facade, including the study of its distance from the facade. 3 different distances were tested and chosen based on the dimensions of the human body through which he can move, work, and maintain good maintenance, and they are as follows 0.6, 0.9, and 1.2 m respectively. and their location as shown in figure (4.7)

Phase 3: choosing the optimal scenario for the filter added to the elevations. At this stage, the selection process was based on the condition of the building and the possibility of making additions to the elevations and protrusions. The optimal solution that provides the greatest amount of fresh air through air filtration, the best daylight factor of the space for each proposal, and then the best ventilation movement for the same space. as shown in figure (4.7)



Figure(4.7): The three phases of the simulation .

4.5 Conclusion, Recommendations, and Discussion Method.

The results discussion had been made in the following manner:

1. <u>Discussion of the results of the collection data(Literature Review) which include:</u>

a) The result of the materials that will be used for activated charcoal Production.

b) The result of factors affecting filtration must be taken into account when conducting experiments.

c) The result of the experimental setup by which practical experiments will be conducted.

2. <u>Discussion of the results of the experimental work which include :</u>

a) Biochar results

b) Type of biomass precursor's effect on adsorption properties result.

c) Bed height's effect on the adsorption properties result.

d) Filter ratio effect on the adsorption properties result.

e) Experimental work validity check.

3. <u>Simulation results discussion include:</u>

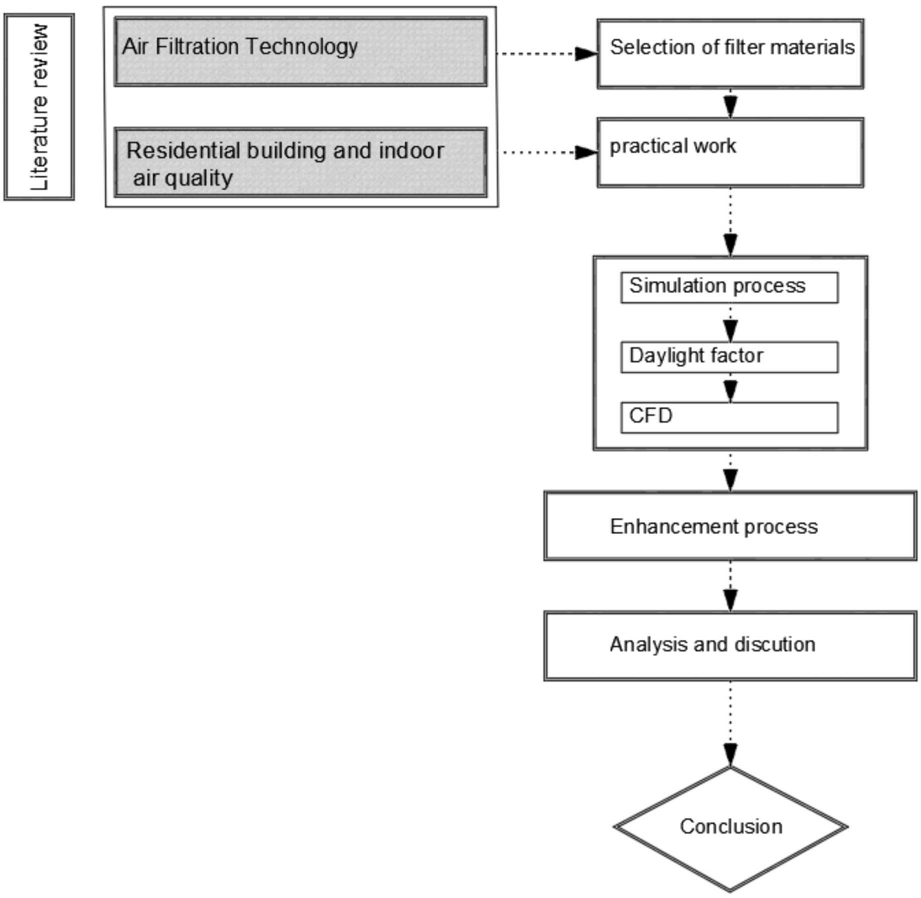
a) Description of the 3 base models, and their simulation results presented in terms of daylighting, and CFD.

b) Adding scenarios results of each case in terms of total filtration, daylighting, and CFD test.

c) The result of optimizing the adding scenarios in terms of filtration efficiency, in another mean, is the highest filtration with the good daylight factor and gives a good CFD result.

4.6 Method of Recommendations Extraction .

The recommendations and conclusions were extracted based on the research objectives and key findings. Besides, some conclusions that were inferred from the simulation process were relevant to the impacts of various variables such as box window depth, and orientation. In addition to this, recommendations had been made about the benefit of this research process in the preliminary design of highly exposed carbon dioxide residentials building as well as in filtration process. Figure(4.8) show the complete Research Methodology.



Figure(4.8): The Research Methodology.

Chapter 5

Research Results and Discussion.

5.1 Data Extraction.

From the literature review that created the guidelines for getting materials prepared for testing in a lab. windows with additional filters, the simulation parameters being used, and standards for acceptable CO2 concentration levels.

- ✓ Adsorption is a popular technique for capturing CO_2 because it uses little energy, is affordable, and works well.
- ✓ The highest lignin concentration in biomass waste facilitates the formation of biochar. The selection of various materials for biochar production is based on both their high lignin content and abundance in residential biomass waste.So selection the Coffee grains , Sunflower seed shells, Oak sawdust waste and almond shells was acceptable .
- ✓ The most important consideration for choosing the best testing configuration for the gas collection chamber, filter filling area, and post-filtration chamber is the choice of materials with low gas absorption capacity .
- ✓ Choosing the suction device used for the practical testing setup based on weather data for the selected location (that is, the worst case in which filtration is induced, which is the highest wind speed, was chosen because the relationship between Contact Time and the quality of the filter filtration is inverse).
- ✓ Residential structures can have their windows directly installed with filters, or they can have the box window type's double skin facade installed**.**

5.2 Experimental results.

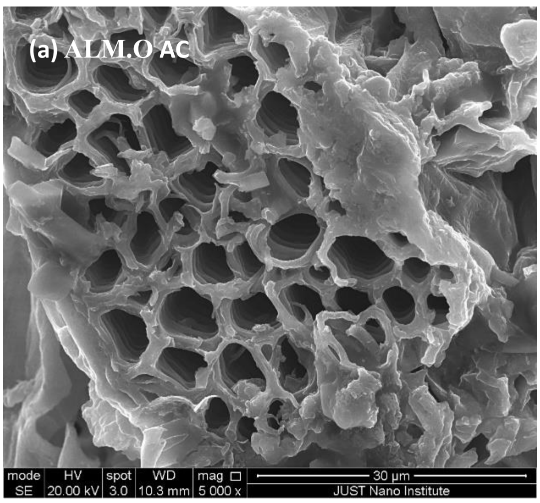
5.2.1 Biochar .

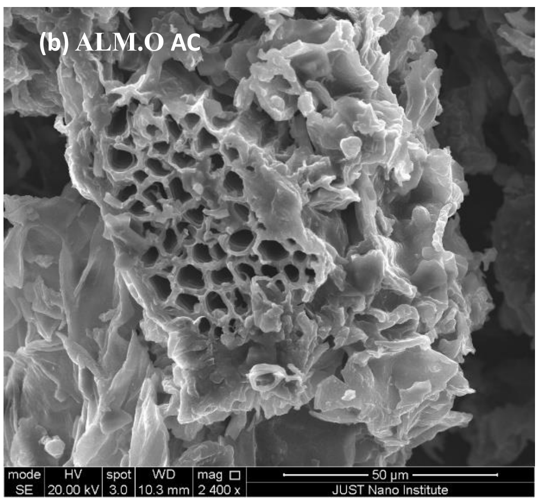
The yield of biochar produced throughout the procedure of pyrolysis based on each of the four types of biomass waste. ALM.O yielded the highest yield of(31.99%), followed by OKA.S (29.78%), SUN.F (23.6%), and COF.F (22.1%), respectively as shown in table (5.1). The cellulose and lignin content of the biomasses were obtained from literature (see table 5.1) corelate well with the measured yield.   The difference in lignin and cellulose amounts could be the cause of the variation in biochar yield; the higher the lignin content, the higher the yield (Tripathi et al., 2016, Fu et al., 2012)As a result of having the highest lignin content of all the others, the ALM.O had the highest yield.

Table (5.1). The yield, capacity for CO_2 adsorption, and lignin and cellulose amounts of different types of biomass.

Biomass	Yield (w/w %)	Adsorption Capacity (mg CO_2 /g AC)	Cellulase amounts (% W/W)	Lignin amounts (% W/W)	Reference
ALM.O	31.99 (± 3.12)	435	58	24.8	(Li et al., 2018)
OKA.S	29.78 (± 3.35)	236	55	24.3	(Le Floch et al., 2015)
SUN.F	23.6 (± 4.23)	118	53	15-25	(Antonopoulou et al., 2015)
COF.F	22.1 (± 4.52)	33	51	23.9	(Ballesteros et al., 2014)

The micromorphology of the four types of activated carbon can be clearly observed from Table (5.2). ALM.O AC contains a large number of evenly spaced macropores with no clear relationship between them. Additionally, they have a relatively uniform shape roughly round. This is because the alkali element potassium can move back and forth across carbon materials at high temperatures, causing a great number of pores to form (Huang et al., 2015).At the same time gases are produced immediately by a sequence of reactions between carbon and KOH, and the excess gases expand the pore structure.
However, because of the pore connection brought on by some pore walls breaking, uneven pore structure is visible from the surface of COF.F AC. As a result, likely pores on the surface have different sizes . The pores inside AC may also experience this change in pore structure. Furthermore, the hierarchical porous structure of AC can be seen in figure (5.1) at (d) and (h) figures, which may help to some extent with adsorption performance(Sarwar et al., 2021). The morphological analysis of the SEM analysis shows that CO_2 adsorbents with different porosities have been made and are working well.





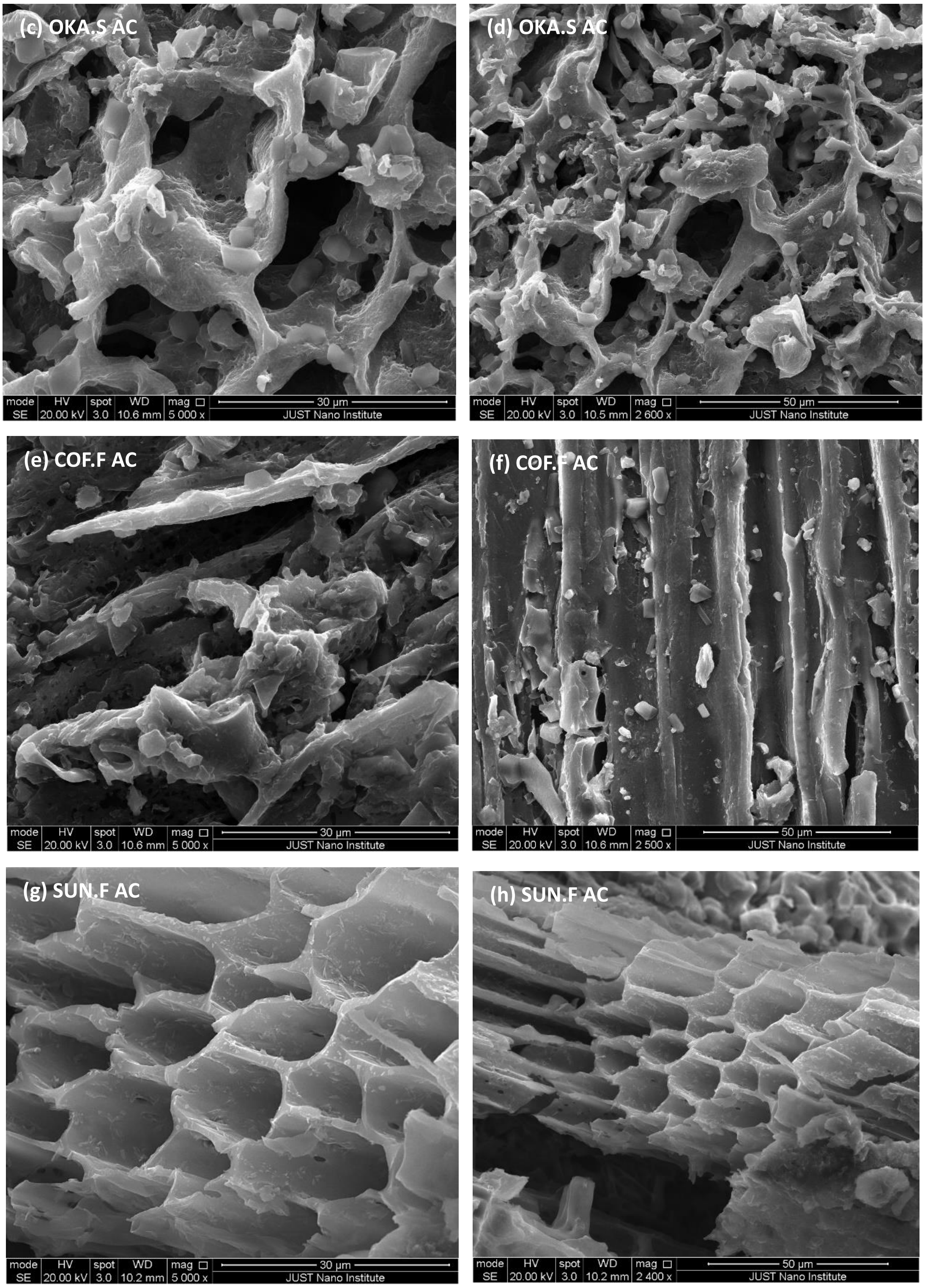


Figure (5.1). SEM micrographs of the four type of AC: (a, b) ALM.O AC, (c,d) OKA.S AC , (e , f) COF.F AC and (g , h) SUN.F AC.

5. 2.2 Type of biomass precursor's effect on adsorption properties.

The CO_2 adsorption breakthrough curves for an empty bed and one filled with one centimeter of ALM.O, OKA.S, SUN.F ,and COF.F biochar activated with KOH are displayed in Figure (5.2). The results show that while the bed was empty, the breakthrough curve was extremely steep and the exit concentration rose quickly, reaching the inlet concentration in about 35 seconds. This suggests that the amount of CO_2 that is adsorbed on to the bed material and cloth is essentially negligible. However, when the bed was filled with AC material, the breakthrough curves was significantly changed compared with empty bed and was largely dependent on the type of biomass precursors material that was used. The outlet concentration of CO_2 for each of the four samples dropped quickly to less than 500 ppm at the start of the adsorption timing, confirming excellent adsorption (CO_2 removal) efficiency. However, depending on the AC sample used in this study, the outlet CO_2 concentration rose throughout operational time at varying rates.

For example, the breakthrough curve with COF.F was steeper than other curves. After roughly 2 min remined, the CO_2 outlet concentration quickly grew to approach its inlet concentration in just 20 min. The outlet concentration stayed close to zero, indicating 100% removal efficiency. The SUN.F outperformed the COF, with the outlet concentration staying at zero for roughly 15 min before progressively increasing to reach the inlet concentration after 65 min, Furthermore, relative to the previous materials, OKA.S performed better while the concentration of the outlet remained at almost zero for around 20 min before gradually increasing to its inlet concentration after 120 min.

ALM.O demonstrated the highest removal efficiency, with a removal efficiency of around 100% for 35 minutes while the outlet concentration stayed nearly zero. But after that, it got incrementally for 200 minutes until returning to its inlet value. Equation (4), which defines the adsorption capacity of the AC to CO_2, was calculated for each of the four biomass precursors, as indicated in Table (5.1). The study's high adsorption capacity suggested improved adsorption performance, as the results make clear. At almost 435 mg CO2/g AC, the ALM.O had the highest adsorption capacity, followed by OKA.S , SUN.F and COF.F, in that order. One possible explanation for the variation in CO_2 adsorption capacities and efficiencies depending on the kind of AC is as follows: The original plant texture, or the amount of lignin and cellulose in the plant, typically has a significant impact on the porosity and microstructure of AC(Jung et al., 2015). The production of AC macropores is mostly caused by the lignin content, while the formation of micropores is mainly caused by the cellulose content(Fu et al., 2012) (Sawalha et al., 2020)It therefore appears that the porosity of the AC formed from SUN.F and COF.F (both micro- and macro-porous varieties) will be smaller than that of ALM.O and OKA.S since it contains less cellulose and lignin, respectively. This explains why the COF.F's adsorption capacity was lower than that of the other ACs examined in this investigation. However, the ALM.O has the highest amounts of lignin and cellulose as shown in Table (5.1), which would lead one to expect that it has the highest porosity among the other materials, leading to best adsorption capacity and efficiency among others (Sethupathi et al., 2017).

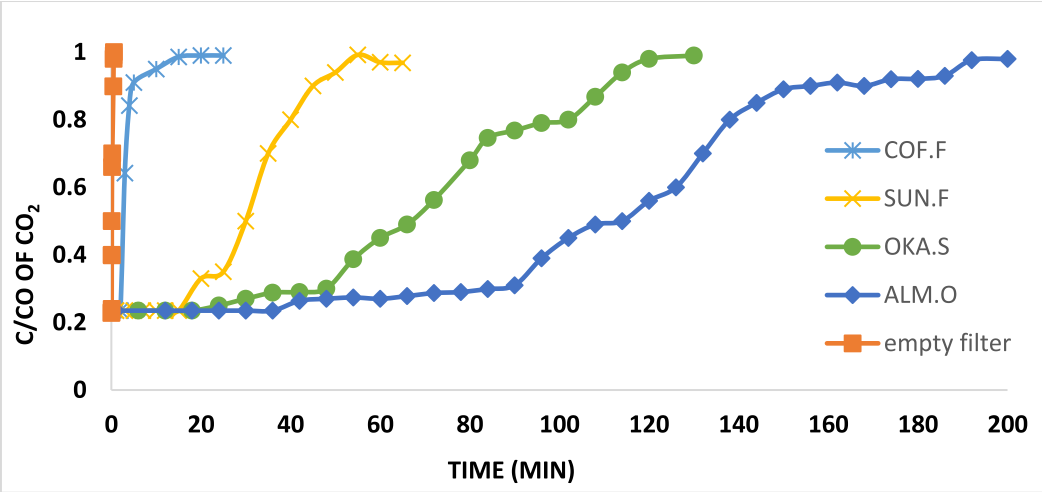


Figure. (5.2): Breakthrough curves of CO_2 adsorption in packed bed of ALM.O, OKA.S, SUN.F ,and COF.F activated with KOH and empty filter. The experiments were performed at ambient air temperature, gas flow rate of (2.5L/min), bed height of (1cm) and inlet CO_2 concentration(1700ppm).

5. 2.3 Bed height's effect on the adsorption properties .

The adsorption bed was charged with COF.F AC at heights of 0.5, 1, 1.5, and 2 cm, respectively, in order to study the impact of bed height. Figure (5.2)shows the obtained adsorption breakthrough curves. The findings showed that the adsorption effectiveness increased with bed height and that the AC required longer to reach saturation. For example, the c/c_o ratio got quickly from 0.2353 to 1 at a bed height of 0.5 cm in about 10 min, and this time increased progressively with increasing the bed height to reach around 170 min at a bed height of 2 cm. Raising the bed's height means adding more amount of AC and consequently increasing both the overall surface area and total number of active adsorption sites. Moreover, as Figure (5.4) shows, a longer AC bed extends the period of contact between the adsorbent and the adsorbate, increasing the amount of CO_2 adsorbed.

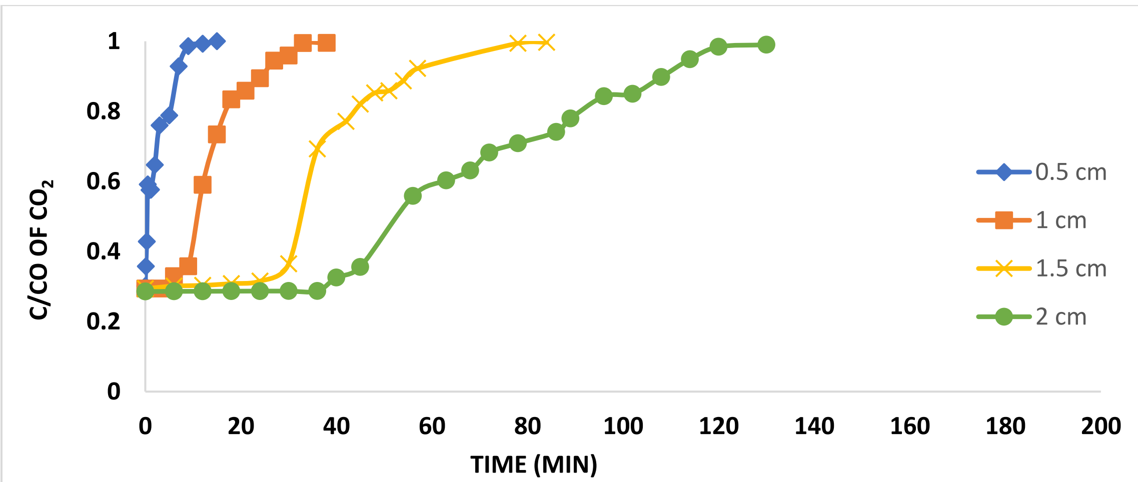


Figure (5.3). Adsorption breakthrough curves of CO_2 adsorption in packed bed of COF.F AC . The experiments were performed at ambient air temperature, gas flow rate of (2.5L/min) and inlet CO_2 concentration(1700ppm) and bed heights of 0.5, 1, 1.5 and 2 cm.

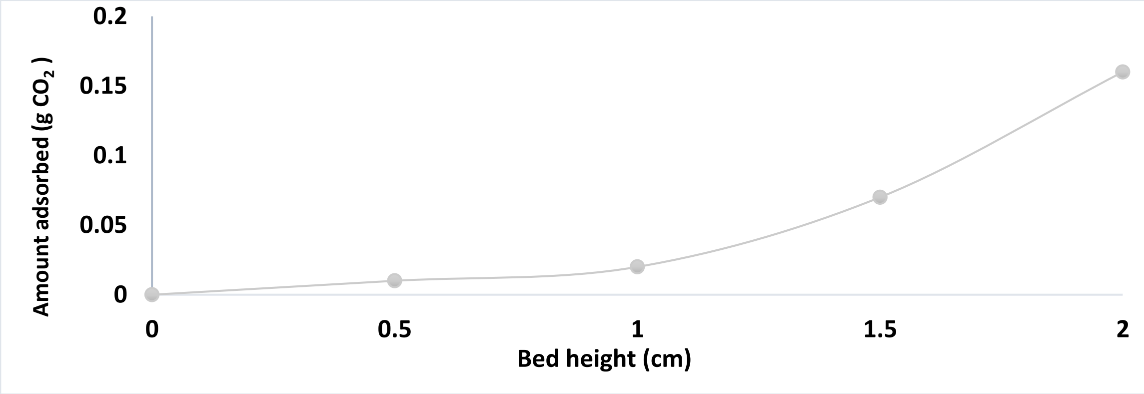


Figure. (5.4). Bed height versus the amount of CO_2 adsorbed in the packed bed.

5. 2.4 Filter ratio effect on the adsorption properties .

In order to find out the effect of filter ratio on adsorption qualities, the adsorption bed was charged with ALM.O AC at heights of 0.5 cm, with varying spaces for filling the filter, starting from 10% in increments of 10 up to 100% of the space, respectively. The resulting adsorption breakthrough curves are displayed in Figure (5.4). The results showed that the AC needed more time to reach saturation and that the adsorption efficacy increased with increasing filter ratio. For example, after roughly 15 minutes, the c/c_o ratio while growing quickly from 0.2353 to 1 at a 20% filter ratio. This duration increased slowly when the filter ratio increased, reaching approximately 130 minutes at an 80% filter ratio. Increasing the filter ratios results in an increase in amount of of AC in the filter and consequently increased the total number of active adsorption sites as well as the surface area. Furthermore, as demonstrated in Figure (5.5), a higher AC ratio increases the residence time that the adsorbent and adsorbate are in contact, which increases the quantity of CO_2 that is adsorbed.

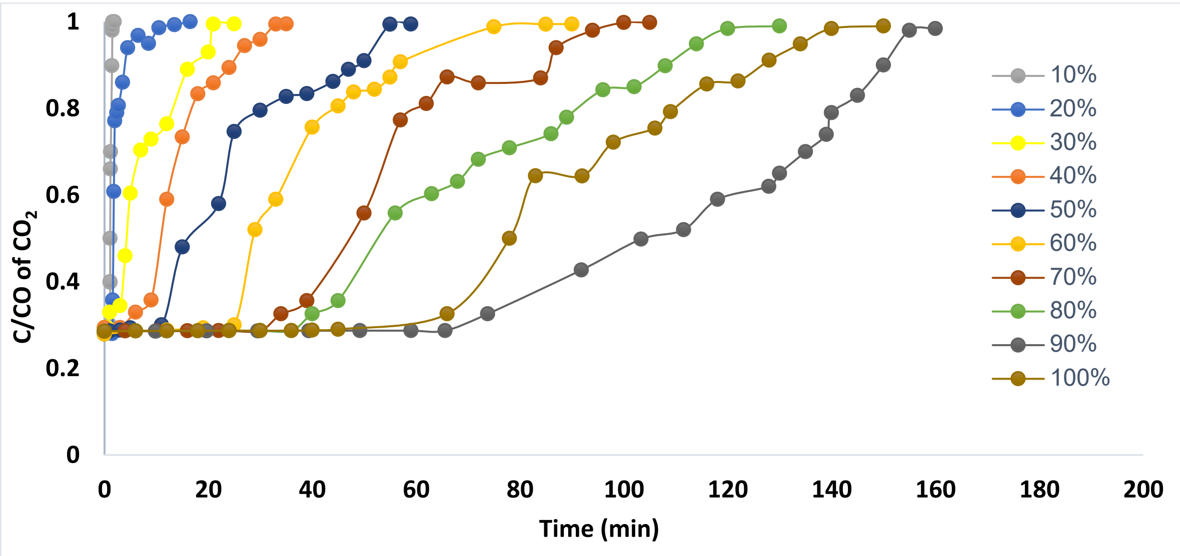


Figure. (5.5). Adsorption breakthrough curves of CO_2 adsorption in packed bed of ALM.O AC . The experiments were performed at ambient air temperature, gas flow rate of (2.5L/min) and inlet CO_2 concentration(1700ppm) and bed heights of 0.5 cm.

5.2.5 Data reproducibility.

The critical first step in verifying the reliability of the results is to repeat the practical experiments to ensure the reliability and reproducibility of the results. The adsorption bed was charged with ALM.O AC at heights of 1 cm, filling the filter for the experiments by 20% and 40% of the area, respectively. To minimize the influence of random variables and determine whether the results were consistent across many experiments. This consistent approach increases confidence in the study conclusions and also enhances the validity of the collected results. For example, the results of adsorption breakthrough curves in Figure(5.6) show that with repeated 40% filter area after approximately 33 minutes, the c/co ratio rose rapidly from 0.2353 to 1. This duration increased slowly during the first experiment in the same filter area, reaching about 35 minutes. The replication confirms the validity of the experimental methods used in this study and highlights the dedication to scientific rigor. Despite the variance in the number of repetitions, each iteration contributes to the validation of the experimental outcomes and the verification of their repeatability.

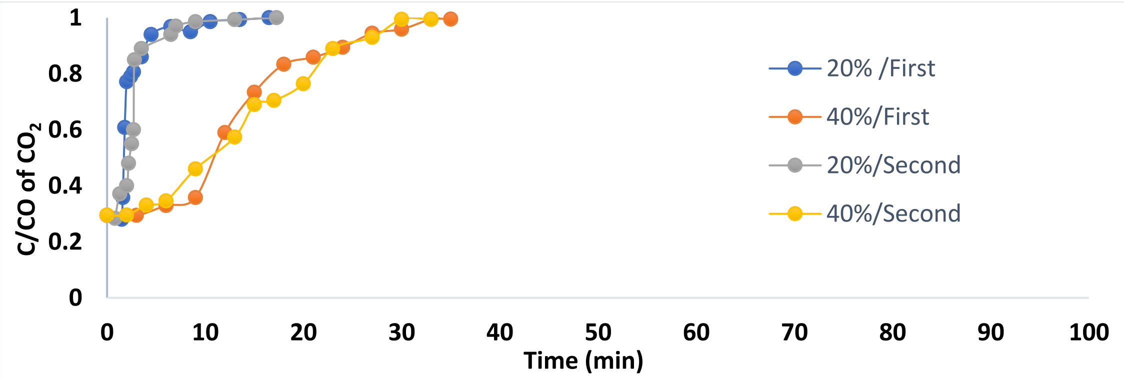


Figure . (5.6). Adsorption breakthrough curves of CO_2 adsorption in packed bed of ALM.O AC . The experiments were performed at ambient air temperature, gas flow rate of (2.5L/min) and inlet CO_2 concentration(1700ppm) and bed heights of 1 cm.

5.3 Simulation.

In order to determine the appropriate filter characteristics for each scenario, simulations were initiated of the filtration ratio associated with the number of filters used, their locations, and the filter distance in the case of a ordinary window and the case of a box window system. Daylight and computational Fluid Dynamics (CFD) simulation were done taking into account the working plan height of 75 cm and the external wind speed of 4 m/s (Latt et al., 2022) , Table (5.2) show the simulation constant parameters in this study .

Table (5.2). The simulation constant parameters .

Window Glass Type	Double glass of generic clear 3mm (for each layer) and 13 mm air between the two layers .
U-value of window	2.116 $W/m^2.K$
Natural ventilation	Active
Mechanical ventilation	Inactive

Domestic Hot Water	Active
Heating set point	22 ̊c
Cooling set point	24 ̊c
Air Infiltration	0.7 ac/h
U-value of the Wall	0.350 $W/m^2.K$
U-value of the Slab	0.250 $W/m^2.K$
Sill height	1m

5.3.1 Box window Orientation Scenarios.

Within the four different elevations orientation (north, south east, and west), the number of filters applied was examined, ranging from one filter to four filters applied in the four directions of the box as shown in figure(5.7).

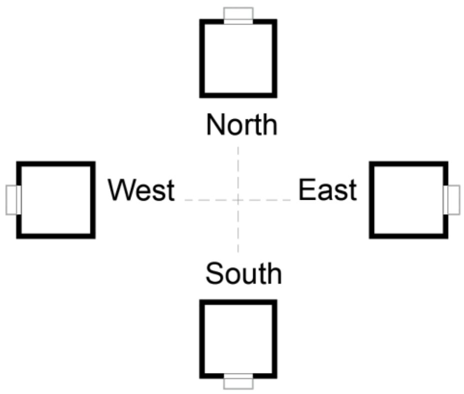


Figure. (5.7).The Box Window four orientation .

This stage of filter location optimization selection was mainly done on the basis of changing the depth of the window box starting from 60 ,90and 120 cm as shown in the figure(5.8). While other parameters were constant. For this study, the commonly used window measurement 1.2*1.5 m2 were taken and the area of a room was 36 m2 ,12 m2and 7.2 m2 to achieve the window to floor ratios (WFR)5%,15% and 25%.respectively. Those ratios that represent a bad ,good and fair WFR as shown in figure(5.9). (see appendix) (Nedhal et al., 2016) (Bournas, 2020).

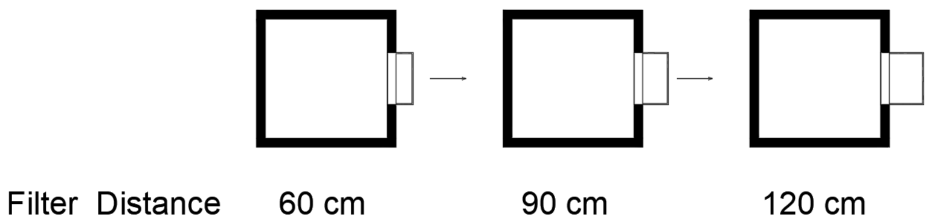


Fig. (5.8). The Box Window three distance tested.

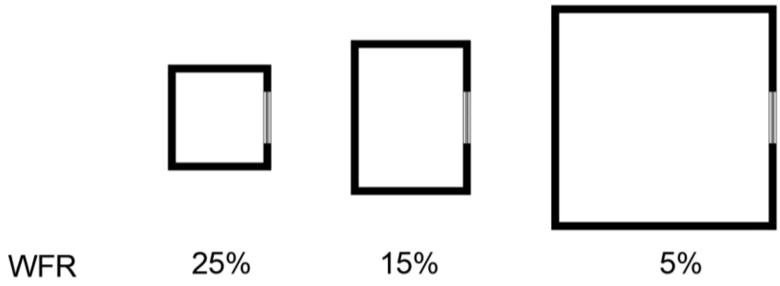


Fig. (5.9). The Box Window three Window to floor ratio tested.

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5.3.1.1 North and South Orientation.

Simulation results of the Box window on the northern and southern facades showed that the daylight factor decreases with the increase in the filtration ratio applied to the sides of the box window, as the added filters replaced the vertical and horizontal shading device elements. The effect of the daylight factor depends on the room's window-to-floor ratio. For example, on the southern façade, all cases achieved an acceptable daylight factor of 25% WFR. This is due to the amount of direct sunlight on the southern facades for a long period during the day, while the WFR of 15% and 5% achieved lower percentages of the daylight factor. One possible explanation for this difference in daylight factor for different window-to-floor ratios is as follows: Depending on the condition of the space before the filters are added, this will usually have a significant impact on acceptable daylight and glare. The lower proportions suffer mainly from a low daylight factor, that is, the proportions that are classified as poor WFR.

As for the northern façade, a good filtration ratio was achieved with the highest WFR rates in several cases with an acceptable daylight factor, but the lowest WFR ratio was not achieved in any case. Thus, experiments were prepared by adding an element to support natural lighting and reduce reliance on artificial lighting, as 12 cases achieved a daylight factor greater than 3. The reason for the difference in the daylight factor between the two facades is due to the following: reliance on direct exposure to sunlight, which may reach the point of excessive glare on the facades. The southern facades, which usually need shading devices for the spaces, have been replaced here with the presence of the filter on the sides of the box, while in the north, the lighting factor is less than the acceptable limit and an inappropriate distribution of lighting for the spaces, and these facades do not need any addition of shading elements for the internal spaces, as shown in Figure. (5.10) Which displays the filtration ratio and daylight factor for three different WFRs (See Appendices B).

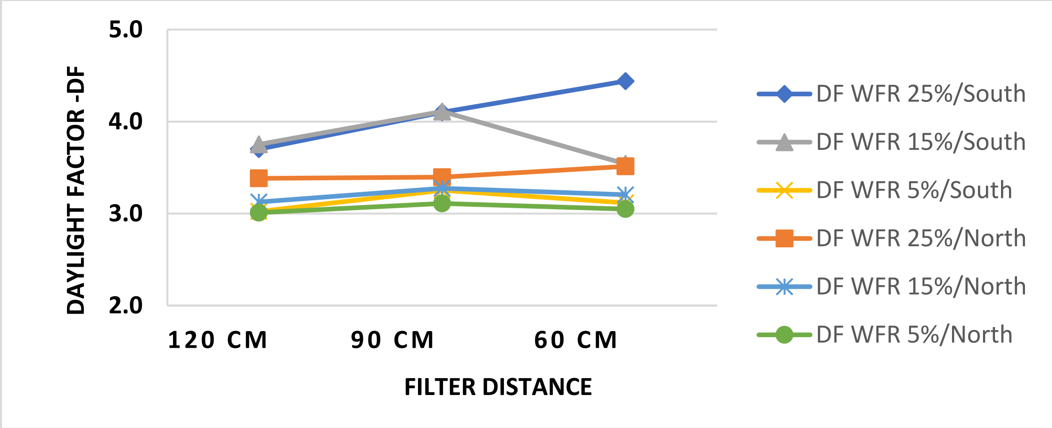


Figure. (5.10). The day light factor achieved of Box window when WFR 25%,15%and 5% /North & South .

Computational fluid dynamics (CFD) simulation testing was done to find out which scenarios would be best for each window-to-floor ratio. The CFD simulation study results showed the percentage of person dissatisfaction (PPD), predicted mean value (PMV), and average air speed. Each case was selected starting with the filter with the lowest distance, i.e. 60 cm, with the highest filtration ratio as shown in Figure (5.11). The filter with the higher distance was used in the examination if the results were less than acceptable levels as shown in Table (5.2).

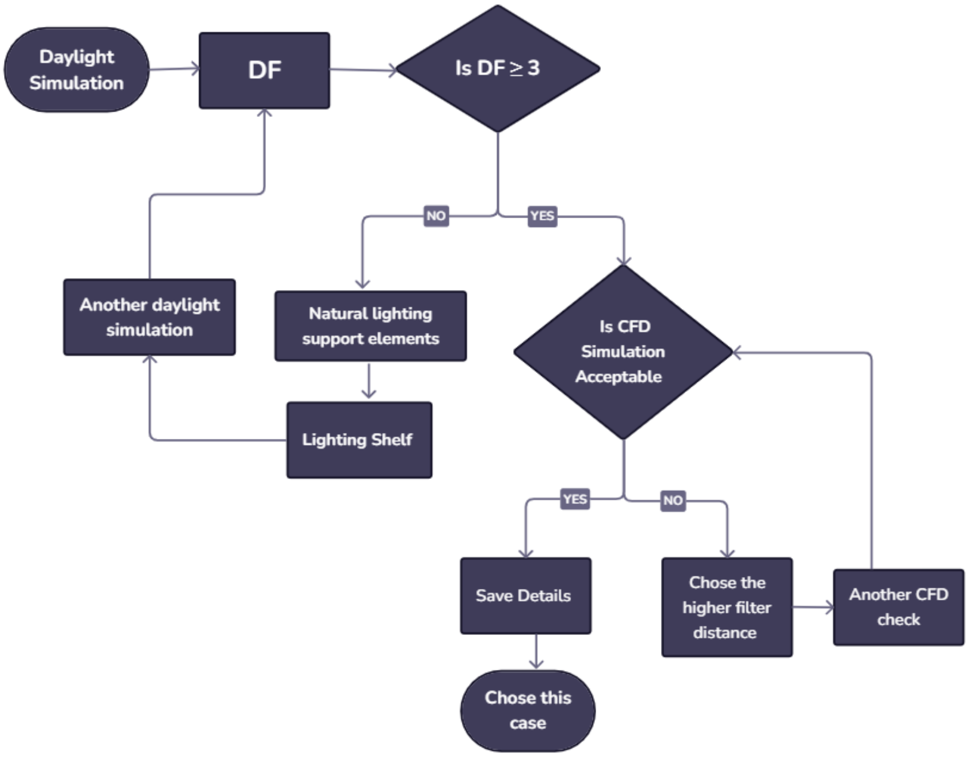


Figure. (5.11). The Workflow steps of Box window choosing .

For example, the CFD result for a 25% WFR on the north façade was 1.656 m/s average air velocity, a PMV of 0.579, and 14.141% PPD at a filter distance of 60 cm. These values fall within the unacceptable ranges of

ASHRAE, i.e. PMV (-0.5 - 0.5). However, the test was repeated at a distance of 90 cm as shown in the Table (5.3). As for the case of the facade in the southern, all cases of 60 cm depth did not achieve the appropriate values for the test. The tests were repeated for the second depth, i.e. 90 cm, and it was, for example, at WFR 5% of 1.136m/s, PMV 0.203, and PPD 15.654%. One of the most important reasons why the average wind speed on the northern facades is higher compared to the southern facades is that the northern winds are the coldest and most windy in Palestine(Kitaneh et al., 2012). As a result, Table 5 displays the results obtained and the cases selected for each scenario.

Table (5.3). The ordinary window Filtration ratio , Average air speed , PMV and PPD(North and South) box window.

Direction	WFR	Filter distance (cm)	Average air speed (m/s)	PMV	PPD (%)	
North	25%	60	1.656	0.579	14.141	✗
		90	1.854	0.497	13.059	✓
	15%	60	1.938	0.348	10.099	✓
	5%	60	1.448	0.271	15.752	✓
South	25%	60	1.143	0.511	16.943	✗
		90	1.036	0.312	15.114	✓
	15%	60	0.913	0.089	17.259	✗
		90	1.211	0.279	15.78	✓
	5%	60	0.823	0.074	18.603	✗
		90	1.136	0.203	15.654	✓

5.3.1.2 East and West Orientation .

The simulation results for the east and west facade box windows indicated that when the filter ratio applied to the window was increased, the daylight factor decreased and in certain cases resulted in an unacceptable daylight factor. At the east facade the highest window-to-floor ratio 25% however, the acceptable daylight factor (3%) was reached. At depths of 60 cm, 90 cm, and 120 cm, respectively, there were 19 cases, ordered as 9 cases, 8 cases, and 2 cases (see Appendices B). In comparison, the west facade has a higher daylight factor value due to it being exposed to a lot of sunlight, especially in the summer when the sun is higher in the sky, particularly in the afternoon and evening. In order to avoid over-illumination, excessive glare, and potential thermal discomfort due to solar heat gain, the daylight factor on the west facade must be balanced. The goal of the west facade shading techniques is to limit the amount of direct sunlight that enters the building (Razazi et al., 2022, Sghiouri et al., 2018), this decreases since the east facade is exposed to direct sunlight in the morning and early afternoon, so it is crucial to balance the amount of daylight to create interior spaces that are both comfortable and well-lit without being overly glaring. To reduce the amount of direct sunlight that enters a building while allowing diffused sunshine in. It's critical to avoid uncomfortable situations and decreased productivity due to excessive glare from direct sunshine (Boubekri, 2007). When the facade gets enough natural light, artificial lighting is not as necessary, which saves energy and increases sustainability(Sghiouri et al., 2018). The best-case for each window-to-floor ratio scenario is obtained by selecting the three options that maximize the filtration ratio from the three distinct depths while simultaneously increasing the daylight factor and lighting distribution , as seen in Figure (5.12).

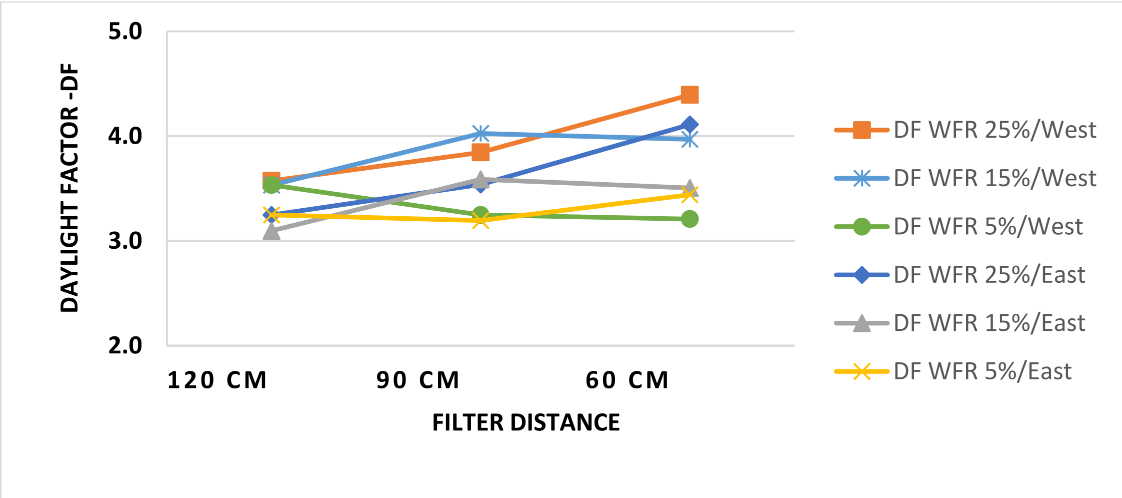


Figure. (5.12). The day light factor achieved of Box window when WFR 25%,15%and 5% /East &West .

Following (CFD) testing, the average air velocity in the eastern facade was 0.875m/s, 0.975 m/s for the 15 %and 5% WFR at the depth of 60 cm, as indicated in Table (5.3) which is an unacceptable value, the testes were repeated to reach the acceptable. According to the idea of cross ventilation, having many filters for a single window enhances and supports the filtering rate while also enhancing natural ventilation. Also, the main direction of wind can change over the winter, but it usually comes from the northeast or east. There's a possibility that these winds will bring colder temperatures (Latt et al., 2022, Taleb and Sharples, 2011, Alsamamra and Said, 2019). As for the Western facade, at the 60 cm window depth, WFR 25% the average air velocity following (CFD)simulation testing was 1.143 m/s, 1.013 m/s, and 0.723 m/s, respectively. The case of WFR 5% has average air speed value fall within the unacceptable ranges of ASHRAE, then the CFD test reparteed by choosing the higher distance as show in Figure (5.11) to have the acceptable values as shown in Table (5.4). The increasing average air speed in this case is because, in Palestine, the majority of summertime winds often arrive from the northwest or west. These winds, which flow from the Mediterranean Sea, are referred to as "westerlies" and are usually warm and dry(Tripathi et al., 2016).

Table (5.4). The ordinary window Filtration ratio , Average air speed , PMV and PPD.(East and West) box window .

Direction	WFR	Filter distance (cm)	Average air speed (m/s)	PMV	PPD (%)	
East	25%	60	1.656	0.479	14.141	✓
	15%	60	0.875	0.365	16.754	✗
		90	1.338	0.348	10.099	✓
	5%	60	0.975	0.275	13.703	✗
		90	1.448	0.271	15.752	✓
West	25%	60	1.143	0.491	16.943	✓
	15%	60	1.013	0.089	17.259	✓
	5%	60	0.723	0.074	18.603	✗
		90	0.894	0.112	17.306	✗
		120	1.136	0.203	15.654	✓

After studied all scenarios in the Box window ,this Table(5.5) summarizes the details of the ideal cases for each filter direction.

Table (5.5). The box window details :

Direction, WFR type, filter ratio , distance , number , location and adding note .

ADDDIND TYPE	DIRECTION	WFR TYPE	FILTER RATIO (%)	DISTANCE (cm)	NO.	LOCATION	NOTE
BOX WINDOW	North	25%	140%	90 cm	2	Side& Down	-
		15%	100%	60 cm	2	Up & down	-
		5%	80%	60 cm	2	Side& Side	Adding lighting shelf
	South	25%	160%	90 cm	2	Up& Down	-
		15%	140%	90 cm	2	Side & down	-
		5%	120%	90 cm	2	Side &Side	-
	East	25%	90%	60 cm	2	Side & down	-
		15%	130%	60 cm	3	Side & Side & down	-
		5%	160%	90 cm	2	Up& Down	-
	West	25%	90%	60 cm	2	Up & down	-
		15%	130%	60 cm	3	Side & Side & Up	-
		5%	160%	120 cm	2	Up& Down	-

5.3.2 Ordinary window orientation scenarios.

As in the first part of the simulation study, to achieve window-to-floor ratios (WFR) of 5%, 15%, and 25%, respectively. The same measurements for the typically used window and the room area were utilized. The effect of installing filters on the daylight factor of the different facade directions in indoor space was examined for each of the three window-to-floor ratios as shown in figure(5.13). Starting from applying a 5% filtration area at WFR 25%, 15%, and 5%, respectively (see Appendix B), up to 50% with an increase of 5% at filtration area at the window area these ratios didn't affect the WFR range as shown in Figure (5.14) , the main criteria used in this filter ratio selection step were the provision of daylighting factor and natural ventilation. While other parameters remained unchanged.

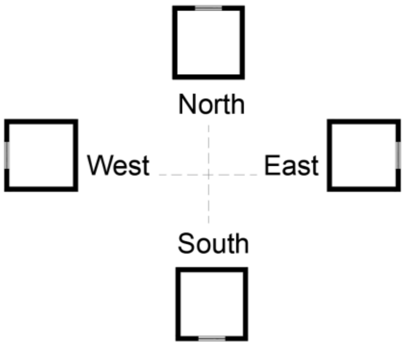


Figure. (5.13). The ordinary Window in four orientation .

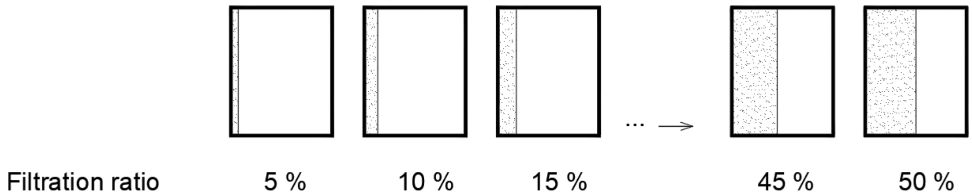


Figure. (5.14). The ordinary window filtration ratio.

5.3.2.1 North and South orientation .

The results of simulating an ordinary window on the northern and southern facades showed that the daylight factor decreases with the increase in the filtration ratio applied to the window. This is based on the effect of the addition on the window-to-floor ratio of the room. For example, on the northern facade, there were no cases that achieved the acceptable daylighting factor in the case of WFR 5 %. This is due to the limited amount of direct sunlight on the northern facades, while the 15%and 25% WFR achieved the acceptable daylighting factor. One possible explanation for this difference in the daylight factor for the different window-to-floor ratios is as follows: Depending on the condition of the space before adding the filters, usually This has a significant impact on acceptable daylight and glare. The lower ratios suffer mainly from a low daylight factor, that is, the proportions that are classified as poor.

As for the southern façade, the highest two WFRs were achieved in all cases with the acceptable daylighting factor, but the lowest WFR was achieved only in one case at a 5% filter. Thus that, the simulation was prepared with the addition of an element to support natural lighting and reduce reliance on artificial lighting, in which 5 cases achieved a factor greater than 3. The reason for the difference in the daylight factor between the two facades is as follows: depending on direct exposure to sunlight, which may reach the point of excessive glare on the southern facades, but in the north the light factor is less than the acceptable limit and inappropriate distribution of lighting for the spaces, as shown in Figure (5.15) Which Displays the filtration ratio and daylight factor of the three different WFRs (See Appendices B).

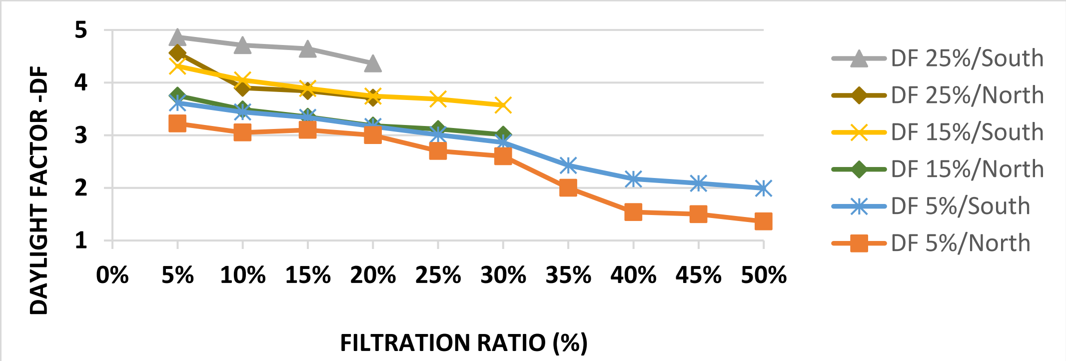


Figure. (5.15). The day light factor achieved of ordinary window when WFR 25%,15%and 5% /North & South .

To determine which scenarios would be ideal for each window-to-floor ratio scenario, computational fluid dynamics (CFD) simulation testing was conducted. The average air speed, predicted mean value (PMV), and percentage of person dissatisfaction (PPD) were displayed in the CFD simulation study results. Every case was chosen starting with the filter that had the highest filtration ratio. A lower filter ratio was used in the examination if the results fell short of the acceptable levels as shown in figure(5.16).

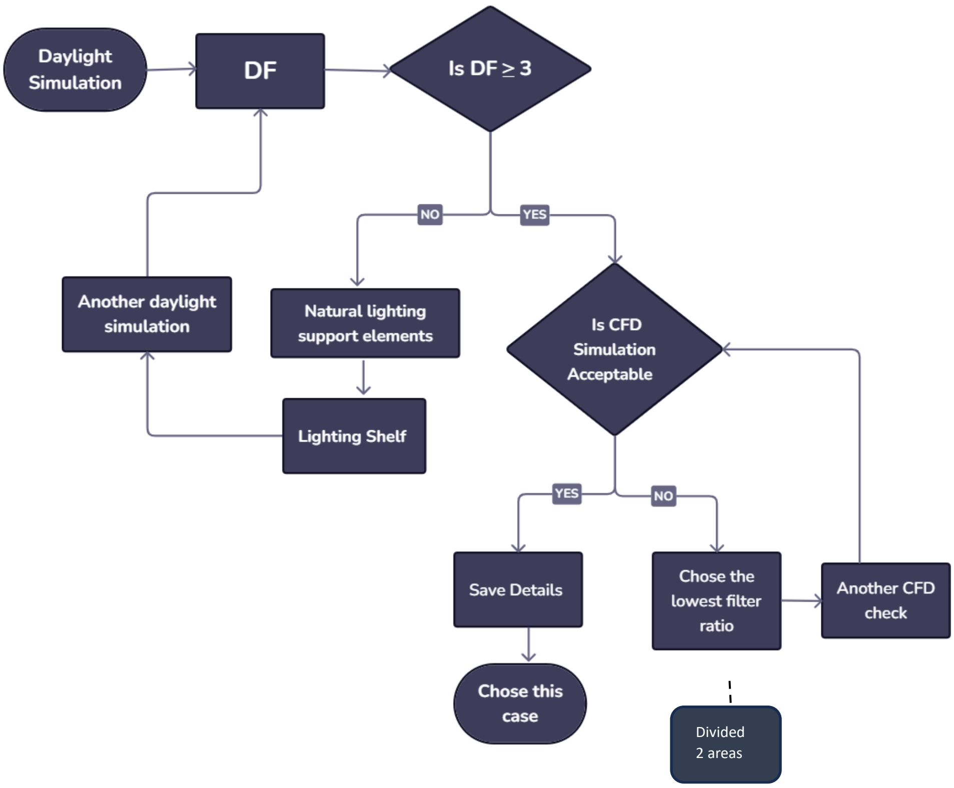


Figure. (5.16). The Workflow steps of ordinary window choosing .

For instance, the CFD result for WFR 25% at the north facade was 1.975 m/s for average air speed, 0.326 PMV, and 10.707% PPD at a filtration ratio of 20%. These values are within ASHREE's acceptable ranges. However, at 5% WFR, it was 0.768 m/s at a 20% filter ratio. This value is not acceptable. The test returned at the ratio of 15% and the filter area was divided into 2 areas to improve the air movement according to the cross ventilation idea as shown in figure (5.16) . As result. Table (5.6) displays the satisfactory outcomes that were obtained and the cases that were chosen for each orientation scenario.

Table (5.6). The ordinary window Filtration ratio , Average air speed , PMV and PPD(North and South) ordinary window.

Direction	WFR	Filtration ratio (%)	Average air speed (m/s)	PMV	PPD (%)	
North	25%	20	1.975	0.326	10.707	✓
	15%	30	1.739	0.205	14.596	✓
	5%	20	0.768	0.162	19.843	✗
		15	1.525	0.197	15.447	✓
South	25%	20	1.211	0.279	15.78	✓
	15%	30	1.136	0.203	15.654	✓
	5%	25	0.937	0.143	17.514	✗
		20	1.036	0.312	15.114	✓

5.3.2.2 East and west orientation .

The eastern and western facades achieved average daylight factor due to their exposure sun's angles which close together. The daylight factor values of the western facade were slightly higher than the eastern facade, the reason for this difference due that the eastern facade is exposed to direct sunlight in the morning, usually from sunrise until approximately midday, while the western facade is exposed to direct sunlight in the Afternoon and evening, from midday until sunset. This can result in good light and potential glare during the latter part of the day, as shown in Figure (5.17) Which Displays the filtration ratio and daylight factor of the three different WFRs (See Appendices B).

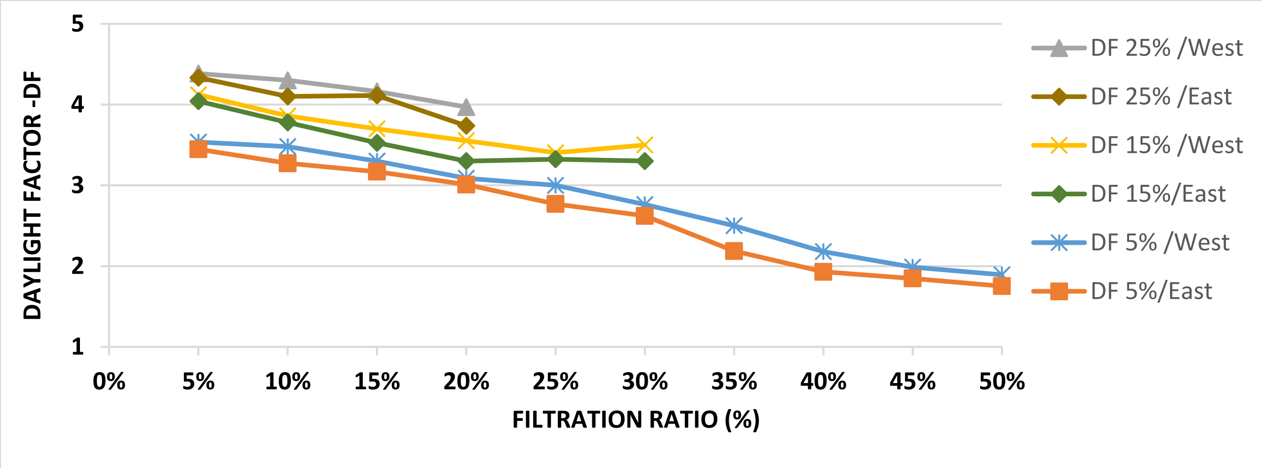


Figure. (5.17). The day light factor achieved of ordinary window when WFR 25%,15%and 5% /East &West .

Both the eastern and western facades achieved satisfactory results in CFD for each of 15% and 25% WFR. However, in the case of WFR 5%, the daylighting factor was less than the required limit for the indoor spaces, the simulation processes were repeated with the addition of a lighting shelf. Which contributed to obtaining 4, and 5 good cases for the eastern and western facades, respectively. Follow The same selection process for cases, for example, 5% WFR in the western facade achieved 2.52 m/s average airspeed, while the eastern facade achieved 0.984 m/s at 20%filtration ratio, this value is without ASHREE's acceptable ranges. The test returned at the ratio of 15% and the filter area was divided into 2 areas to improve the air movement according to the cross ventilation idea as shown in figure (5.16). Then have the value of 1.679 m/s, 0.169 PMV, and 13.959% PPD. Perhaps the reason for the difference is the winds are the most common in Palestine, especially during the winter months. Originating from the Mediterranean Sea, they bring moist air and significant rainfall, contributing to the region's wet season. The western winds are typically cool and help moderate temperatures as shown in table (5.7).

Table (5.7). The ordinary window Filtration ratio , Average air speed , PMV and PPD (East and West) ordinary window.

Direction	**WFR**	**Filtration ratio (%)**	**Average air speed (m/s)**	**PMV**	**PPD (%)**	
East	25%	20	1.918	0.495	10.677	✓
	15%	30	1.807	0.449	12.621	✓
	5%	20	0.984	0.230	11.031	✗
		15	1.679	0.169	13.959	✓
West	25%	20	2.609	0.162	12.704	✓

	15%	30	2.002	0.243	10.263	✓
	5%	25	2.52	0.457	11.759	✓

Following a thorough examination of every scenario in the ordinary window, the details of the best cases for each filter direction are compiled in Table (5.8) below.

Table (5.8). The ordinary window details :

Direction, WFR type, filter type, bed height ,filter ratio , distance , number , location and adding note.

ADDDIND TYPE	DIRECTION	WFR TYPE	FILTER RATIO %	LOCATION	NOTE
ORDINARY WINDOW	North	25%	20%	Side	-
		15%	30%	Side	-
		5%	15%	Side	Adding lighting shelf /2 location
	South	25%	20%	Side	-
		15%	30%	Side	-
		5%	20%	Side	Adding lighting shelf /2 location
	East	25%	20%	Side	-
		15%	30%	Side	-
		5%	15%	Side	Adding lighting shelf /2 location
	West	25%	20%	Side	-
		15%	30%	Side	-
		5%	25%	Side	Adding lighting shelf

Chapter 6

Conclusion and Recommendations .

6.1 Research conclusion.

Indoor air quality and daylight are essential to the health of people in residential buildings. However, housing designs, especially in areas exposed to high levels of pollution, do not take this issue into account. Therefore, many problems associated with this can be observed as a result of the high rate of carbon dioxides, such as respiratory problems, allergies, and asthma among individuals.

Lack of attention to designing residential buildings and thinking about passive ventilation solutions can cause residents to constantly breathe polluted air, or others may resort to relying on active ventilation solutions and closing windows constantly, which affects the indoor air quality and visual contact with the outside. In addition to increasing their consumption of energy loads.

This study identifies vacuum conditions inside residential buildings that can enhance outdoor air filtration of carbon dioxide and maintain a good average daylight factor while maintaining good outdoor ventilation. The resulting optimal values for the filtration rate, the type of filter used, the height of the filter, and the type of modification applied to the windows can be followed when making modifications to the windows of residential buildings. On the other hand, this would enhance the indoor environment for individuals, thus reducing cases of respiratory diseases, suffocation, and other health consequences resulting from lack of daylight and high indoor pollutants, and improving productivity.

The outcomes of this study's practical experiments demonstrate that AC can be produced from various locally accessible biomass wastes and is technically efficient at purifying CO_2. The type of biomass used determined the carbonization yield; for example, ALM.O produced the highest yield at 31.99 %, followed by OKA.S at 29.78% , SUN.F 23.6% and COF.F at 22.1%. ALM.O had the greatest adsorption capacity and removal efficiency, followed by OKA.S, SUN.F, and COF.F, in that order. The effectiveness of CO_2 removal and adsorption capacity is enhanced by raising the bed height. Based on the results, it is advised that ALM.O biochar impregnated with KOH be used in Palestine and other developing countries to achieve high CO_2 removal efficiency.

The simulation results showed a significant relationship between the studied factors and the average daylight factor as well as the ventilation rate. The optimum daylight factor, as well as the maximum ventilation limit of the space in the four directions, were recorded for the three window-to-floor ratio cases. The ideal values for the filter ratio, the filter distance from the window, the number of filters, and the location of the applied filter associated with each direction of the room with the window area of floors 25, 15, and 5% are given in Table 6.1, 6.2 and 6.3, respectively.

Table (6.1). The window details : Direction, filter type, bed height ,filter ratio , distance , number , location and adding note 25% WFR type.

WFR	DIRECTION	ADDDIND TYPE	FILTER RATIO	DISTANCE (cm)	NO.	LOCATION	NOTE
25%	North	BOX WINDOW	140%	90 cm	2	Side& Down	-
		ORDINARY WINDOW	20%	0	1	Side	-
	South	BOX WINDOW	160%	90 cm	2	Up& Down	-
		ORDINARY WINDOW	20%	0	1	Side	-
	East	BOX WINDOW	90%	60 cm	2	Side & down	-
		ORDINARY WINDOW	20%	0	1	Side	-
	West	BOX WINDOW	90%	60 cm	2	Up & down	-
		ORDINARY WINDOW	20%	0	1	Side	-

Table (6.2). The window details : Direction, filter type, bed height ,filter ratio , distance , number , location and adding note 15% WFR type.

WFR	DIRECT ION	ADDDIND TYPE	FILTER RATIO	DISTANCE cm	NO.	LOCATION	NOTE
15%	North	BOX WINDOW	100%	60 cm	2	Up & down	-
		ORDINARY WINDOW	30%	0	1	Side	-
	South	BOX WINDOW	140%	90 cm	2	Side & down	-
		ORDINARY WINDOW	30%	0	1	Side	-
	East	BOX WINDOW	130%	60 cm	3	Side & Side & down	-
		ORDINARY WINDOW	30%	0	1	Side	-
	West	BOX WINDOW	130%	60 cm	3	Side & Side & Up	-
		ORDINARY WINDOW	30%	0	1	Side	-

Table (6.3). The window details : Direction, filter type, bed height ,filter ratio , distance , number , location and adding note5% WFR type.

WFR	DIRECTION	ADDDIND TYPE	FILTER RATIO	DISTANCE cm	NO.	LOCATION	NOTE
5%	North	BOX WINDOW	80%	60 cm	2	Side& Side	Adding lighting shelf
		ORDINARY WINDOW	15%	0	2	Side	Adding lighting shelf /2 location
	South	BOX WINDOW	120%	90 cm	2	Side &Side	-
		ORDINARY WINDOW	20%	0	2	Side	Adding lighting shelf /2 location
	East	BOX WINDOW	160%	90 cm	2	Up& Down	-

		ORDINARY WINDOW	15%	0	2	Side	Adding lighting shelf /2 location
	West	BOX WINDOW	160%	60 cm	2	Up& Down	-
		ORDINARY WINDOW	25%	0	1	Side	Adding lighting shelf

Below are the details of the ordinary window and the box window contained in the study results.

- Box window:

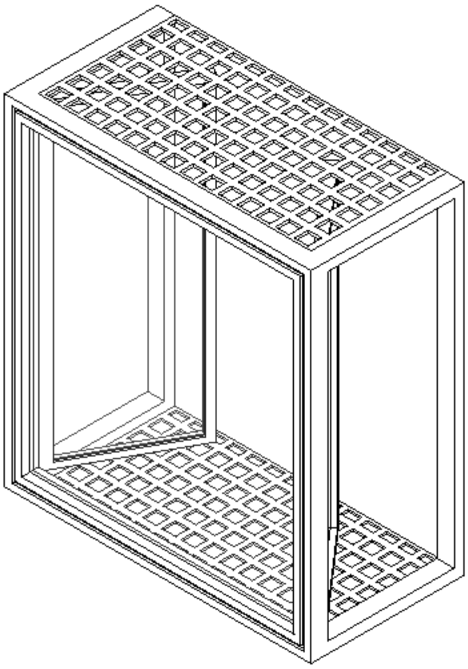


Figure. (6.1). The 3D of Box window used in the study(up ,down and 2 side area of filter) Note: the area of 2 side filter square net into which the filter is loaded is not placed in this detail to explain how to open the window.

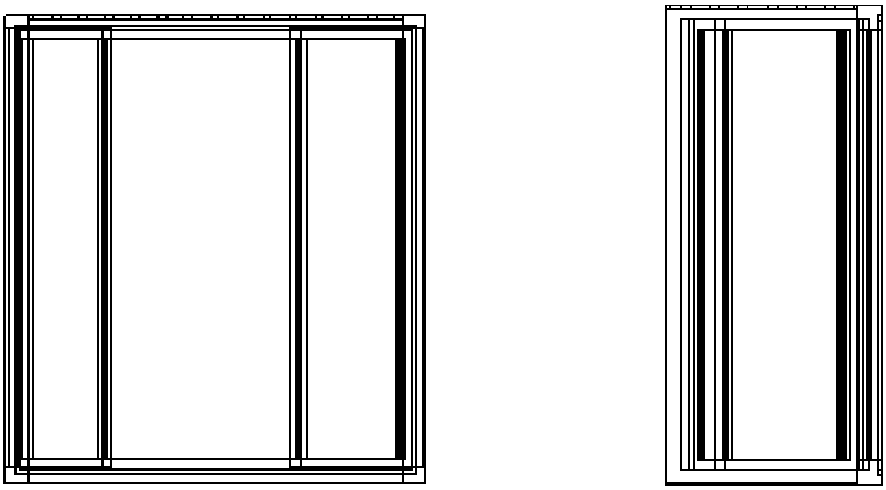


Figure. (6.2). The side and front elevations of Box window used in the study.

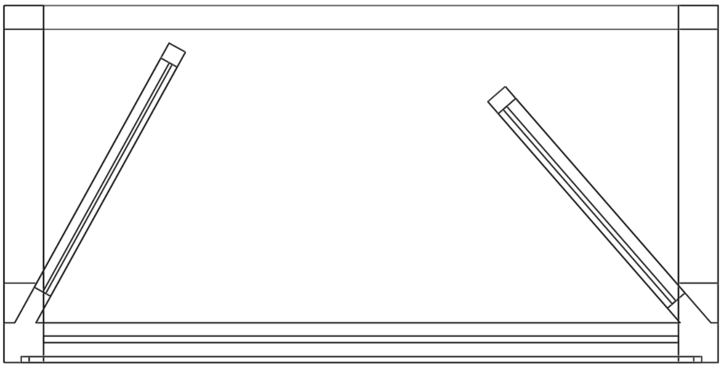


Figure. (6.3). The plan of Box window used in the study(2 side area filter).

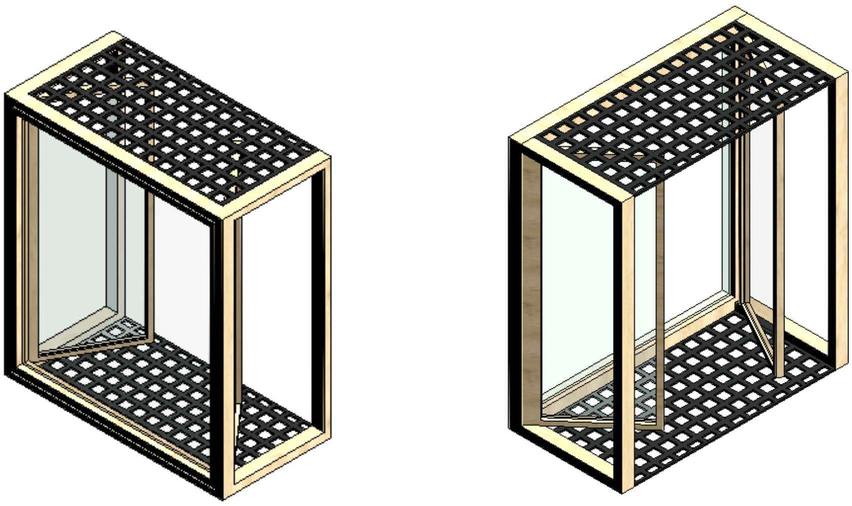
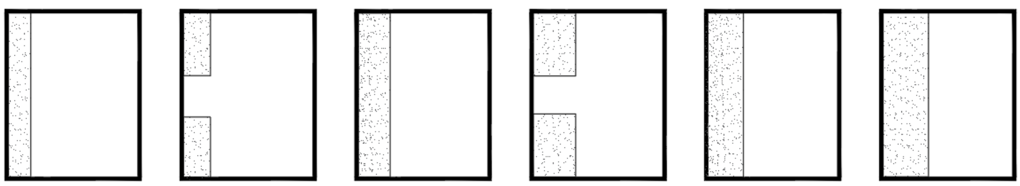


Figure. (6.4). The rendered 3D of Box window used in the study(inside and outside 3D).

- Ordinary window:



Filtration ratio	15 %	15 %	20 %	20 %	25 %	30 %
Filter Location	1	2	1	2	1	1

Figure. (6.5). The front elevations of ordinary window used in the study and filtration ration which divided to 2 areas in some cases .

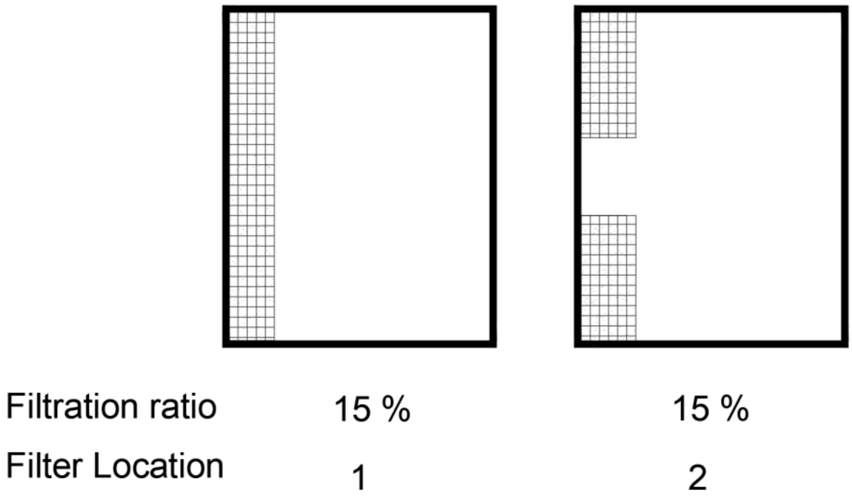


Figure. (6.6). The front elevations of ordinary window , filter square net into which the filter is loaded at filtration ratio of the case of 15% which can divided to 2 areas in some cases.

In addition to using appropriate values for the variables studied, some strategies can be used to further improve daylighting without negatively affecting the ventilation loads of the spaces. For example, it was found that using a lighting shelf at the window would increase daylighting. Moreover, a high light reflection value can be achieved by using white paint instead of other colors, which raises the daylight factor and enhances light uniformity.

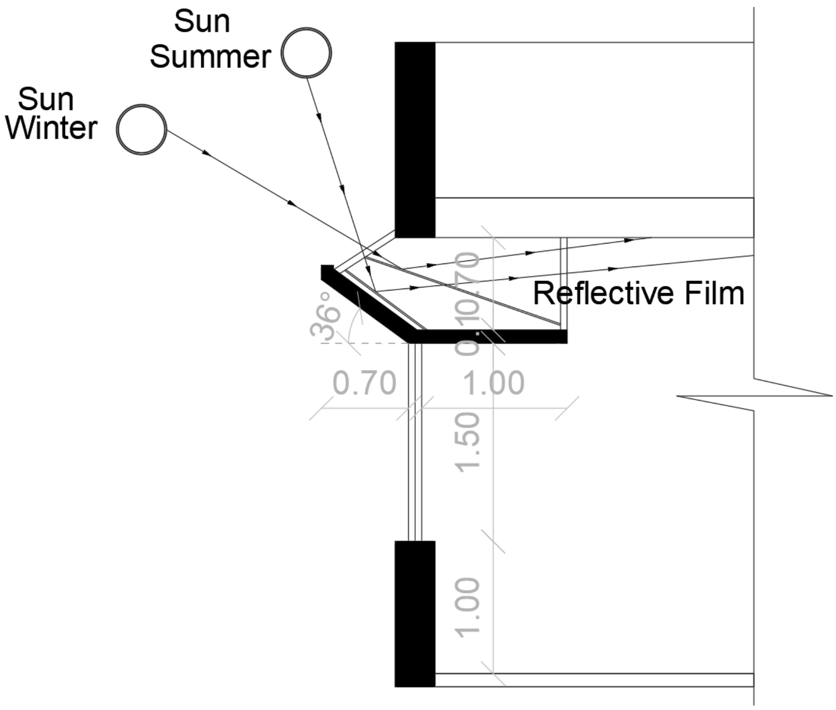


Figure. (6.7). The lighting shelf details used at the window in this study .

The previously mentioned optimal values for the variables affecting daylighting can be used to modify the windows of existing residential building spaces to comply with the standard dimensions on which the study was based. This modification can improve indoor air quality as well as daylight for most individuals. However, it has been found that a window-to-floor ratio of 25% in space planning designs is much better than 5% in terms of daylight and air entering the space. Furthermore, modifying a WFR of 25% ratio plans resulted in more individuals having adequate daylight and access to fresh air than a WFR of 5% ratio, which was found to be more difficult to modify. Therefore, spaces with a window floor area of 25% have a great possibility of modification, while spaces with an area of 5% do not have the possibility of modification. As shown in Figure (6.8).

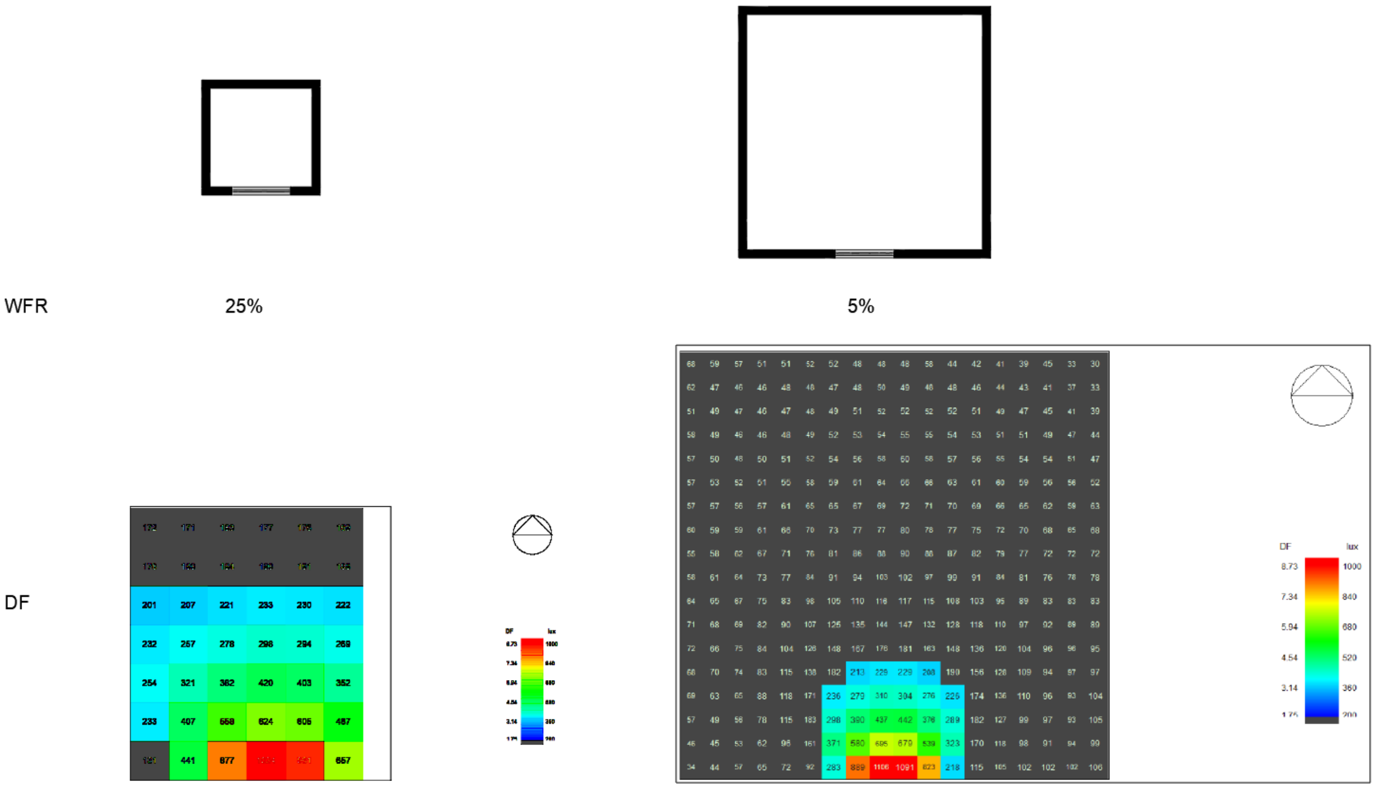


Figure. (6.8). The WFR and DF simulation for WFR 5%and 25% before modification .

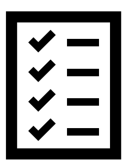
Many of factors, including stability, durability, and moisture resistance, have to be studied when designing an activated carbon filter for use in residential building windows in order to ensure the filter's useful and long-lasting performance.

In order to maximize the filter's chemical interaction with pollutants and maintain its effectiveness over time, chemicals were added to the activated carbon used in the experiments (Appendix A). Furthermore, the filter was made using removable components (in different ratios), including small activated carbon panels, so that cleaning or replacing the filter doesn't require replacing the whole system.The final product can be mixed with zinc chloride to reduce moisture absorption and increase the activated carbon filter's resistance to moisture. This will decrease moisture absorption and protect the filter from its negative effects.

Conclusions and recommendations

The main conclusions of the present study are shown in table 6.4.

Table(6.4): The main findings of the research.

Research phase	**The main findings**
1 **Phase 1:** **Data Extraction**  From the literature review study that established the guidelines for getting everything suitable for testing in a lab. Types of modification to add filters to windows, stander for acceptable values of CO_2 concentration, DF and CFD limits in residential buildings, and simulation parameters they used.	a. Adsorption is a widely used method for CO_2 capture due to its low energy consumption and cost-effectiveness and adsorption. b. The largest lignin content in biomass waste enhances the creation of biochar, The selection of different materials to be used for biochar production depends on their lignin content in addition to their high abundance in homes in the form of biomass waste. c. The selection of materials with a poor ability to absorb gases is the most crucial factor in determining the most suitable testing setup which includes the first chamber for gas collection, the filter filling region, and the second chamber for post-filtration. d. The quality of the filter filtration is affected by the physical and chemical nature of the different materials. e. For the same material, the quality of the filter filtration is affected by: Window-to-floor ratio WFR, Contact Time, Activated Carbon Bed Depth, Pre-Filtering, Flow Rate, and Filter Design. f. Filters can be added to windows in residential buildings either directly or through a double skin facade of the box window type . g. The carbon dioxide concentration allowed for residential buildings is less than 600 ppm and the daylight factor 3-5.
2 **Phase 2:** **Experimental Work** 	a. The type of biomass waste affected the CO_2 adsorption process. For example, ALM.O demonstrated the highest removal efficiency, with a removal efficiency of around 100% for 35 minutes while the COF.F was steeper than other curves. After roughly 2 min only. b. Raising the bed's height increases both the overall surface area and the total number of active adsorption sites, which increased the amount of CO_2 adsorbed. c. A higher AC Filter ratio increased the residence time that the adsorbent and adsorbate are in contact, which increases the quantity of CO_2 that is adsorbed.

Practical Work in lab (Activated Carbon Production and CO_2 adsorption tests)	d. The replication confirms the reproducibility of the experimental results.
3 **Phase 3:** **Simulation Work**  Using Design Builder version 6.1 simulation software, for daylighting and CFD simulation.	a. The simulation results showed that the highest WFR ratio gives better daylighting factor and ventilation for spaces. This helps in making better adding to them than in lower cases. b. The use of a box window is better than the ordinary one because of the view outside and higher filtration efficiency by using the filter in the four directions of the box while the ordinary lowest filtration ratio in its side. c. Increasing the depth of the box window gives a greater opportunity to increase the filtration area used. d. The southern facades have the highest daylight factor. This is due to the amount of direct sunlight on the southern facades for a long period during the day. e. The average wind speed on the northern and western facades is higher compared to the southern facades because its winds are the coldest and most windy in Palestine. f. Have 2 or more filters in the box window or divide the filter area into 2 areas in the ordinary window that improve the air movement according to the cross ventilation idea given the satisfactory outcomes then.

6.2. Research Challenges .

Several obstacles impacted the research workflow, including the following:

1. There are no similar or buildable previous research studies on window filter design in Palestine with respect to providing sufficient daylight and ventilation.
2. The absence of a database in Palestinian hospitals in Palestine for patients suffering from respiratory conditions brought on by exposure to carbon dioxide pollution.
3. The overall conditions that exist now as a result of the war, which have made it harder to finish the practical portion.

6.3 Recommendations.

Future studies should focus on the following aspects to upgrade to semi-industrial scale experiments:

- ✓ Future research should concentrate on improving experimental procedures. Determine how well adsorption columns function when exposed to a mixture of contaminants that is representative of the typical gas composition.
- ✓ Conduct extended adsorption experiments in continuous systems to determine the decline in adsorbents' adsorption capacity.
- ✓ Testing the box window at different angles from the rectangular shape, which gives a different area for the filter.

- ✓ Chosen filter models that will be feasible and scalable to be used in various architectural contexts, including commercial buildings.
- ✓ Later studies may focus on advanced filtering substances, inventive window layouts, and intelligent sensor inclusion for quick interior air quality monitoring and regulation.
- ✓ Examine the efficacy of using many layers of adsorbent materials in the filter to improve the efficiency of pollution capture.
- ✓ Provide filters that are adaptable to local pollutant profiles. For example, different filter materials or configurations may be needed in places with greater concentrations of particular pollutants (such as SO2 or NOx).
- ✓ Conduct comprehensive cost-benefit analyses of implementing these filters in various building types (residential, commercial…) to assess financial feasibility and potential energy savings over time.
- ✓ It is recommended to use a mixture of AC materials that uesed in study in future studies to explore this effect .

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APPENDICIES

A P P E N D I X A : Experimental Work .

" Experimental Work process "

1. Materials. Samples of Coffee grains, Sunflower Seeds shells, Oak sawdust and almond shells.

Figure A.1: four Samples of materials.

2. Biomass waste pretreatment and pyrolysis.

Removal of pollutants with tap water, then the collected biomass wastes were dried for 24 hours at 105°C in an oven.

Figure A.2: materials first drying in an oven .

The materials were smashed.

Figure A.3: materials smashed for suitable size.

Using an auto sieve analysis shaker with meshes numbers (10, 18, 40, 60, and 140), for 15 minutes. For the next analysis, particles that remained on mesh #140 were utilized.

Figure A.4: materials sieving.

The gathered particles were placed into a porcelain crucible that was tightly packed to keep out oxygen and water vapor. The crucible was then placed inside a muffle furnace that heated to 500°C for an hour.

Figure A.5: packing to crucible.

Figure A.6: The crucible put at muffle furnace.

The weight ratio of the produced biochar to the original biomass weight was used to determine the pyrolyzed materials' yield. Additionally, the study presents the average values along with their standard deviation values (SD. ± values).

Table A.1: Materials' yield.

Raw material	**Weight Before-** original biomass **(g)**	**Weight After -** produced biochar **(g)**	**Yield %**
Almond shells	50.006	15.996	%31.99
Sunflower Seeds shells	16.525	3.899	%23.6
Coffee grains	31.959	7.062	%22.1
Oak sawdust waste	83.402	24.837	%29.78

3. Activation .

The pyrolyzed biomass was mixed with distilled water at a ratio of 10:1 (v/w) (V water: W biomass) for the purpose of impregnating the samples.

Figure A.7: biomass, distilled water and impregnation reagent.

The impregnation reagent was then gradually added to the mixture at a ratio of 1:4 (wt reagent: wt biomass). Using a hotplate magnetic stirrer , the mixture was gradually swirled at 300 rpm and heated to 80°C until the majority of the liquid evaporated.

Figure A.8: Activation process .

After that, the samples were dried for 24 hours at 105°C in an oven**.**

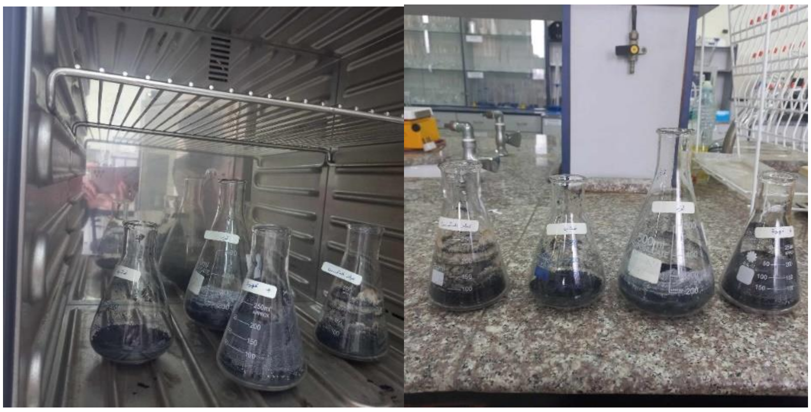


Figure A.9: samples drying in an oven .

4. Experimental testing setup.

Figure A.10: Experimental testing setup.

"DEVICES SPECIFICATION SHEETS"

1. Carbon Dioxide Industrial Grade.

Oxygen & Argon Works Ltd.	Spec.No.G-08.001	
Product Sales Control	Issue: C	Date:14.02.2008
GAS SPECIFICATION	Sheet 1 of 1	

CARBON DIOXIDE - Technical

Typical Impurity Limits:

Carbon dioxide:	≥ 99.5%
Carbon monoxide:	≤ 10 ppm
Moisture:	≤ 250 ppm
Oil:	≤ 20 mg/m^3
Others (O_2, N_2, H_2):	≤ 0.4%

Above specification applies to Carbon Dioxide for welding*, Fire fighting etc.
* Israel standard 388 recommends a purity of 99.7% for welding.

Quality Assurance - According to Suppliers' QC procedures.

Manufacture - By a fermentation process or from the burning of a fuel.

Packing & Distribution - As a liquid in high pressure gas cylinders.

Valve Outlet Thread - According to IS 637 part 3.
[21.7mm Whitworth, 14 teeth/", Male, Cylindrical, right hand, with rupture disk]

Approved Supplier - GORDON GASES or OXYGEN STORES.

(1) (2)

Figure A.11:(1) Carbon Dioxide Industrial Grade data sheet. (2) Carbon Dioxide Industrial Grade.
[Online]: https://www.shopairproducts.ie/product.php?id=14360

2. Drying oven.

Operating Manual Number : LVO-2050E(4)
Revised : May 2008
August 2008
November 2009

Vacuum Drying Oven

Covering Model LVO-2030 / LVO-2040 / LVO-2050

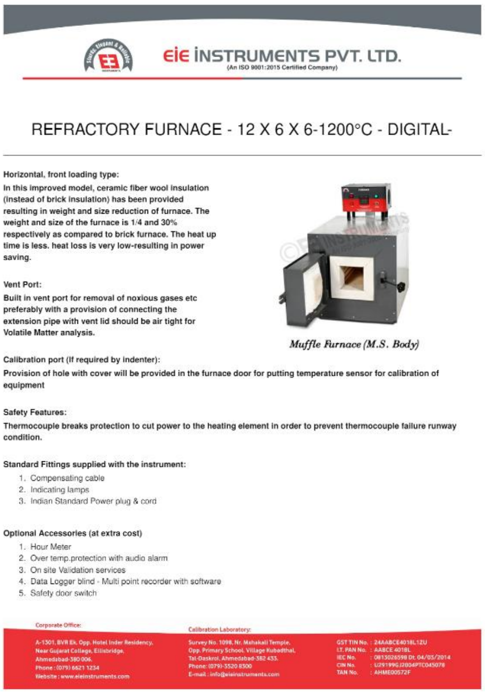
Related Products

Model #	Descriptions	Capacity	Electrical Requirements
LVO-2030	Vacuum Drying Oven	27 Liters	110 VAC, 60Hz or 220VAC, 50/60Hz
LVO-2040	Vacuum Drying Oven	64 Liters	110 VAC, 60Hz or 220VAC, 50/60Hz
LVO-2050	Vacuum Drying Oven	125 Liters	110 VAC, 60Hz or 220VAC, 50/60Hz

- 1 -

Figure A.12: Drying oven data sheet.
[Online]: https://www.scribd.com/document/445916061/LVO-Vacuum-Oven-ENG

3. Laboratory Furnace.


EIE INSTRUMENTS PVT. LTD.
(An ISO 9001:2015 Certified Company)

REFRACTORY FURNACE - 12 X 6 X 6-1200°C - DIGITAL-

Horizontal, front loading type:
In this improved model, ceramic fiber wool insulation (instead of brick insulation) has been provided resulting in weight and size reduction of furnace. The weight and size of the furnace is 1/4 and 30% respectively as compared to brick furnace. The heat up time is less. heat loss is very low-resulting in power saving.

Vent Port:
Built in vent port for removal of noxious gases etc preferably with a provision of connecting the extension pipe with vent lid should be air tight for Volatile Matter analysis.

Muffle Furnace (M.S. Body)

Calibration port (If required by indenter):
Provision of hole with cover will be provided in the furnace door for putting temperature sensor for calibration of equipment

Safety Features:
Thermocouple breaks protection to cut power to the heating element in order to prevent thermocouple failure runway condition.

Standard Fittings supplied with the instrument:
1. Compensating cable
2. Indicating lamps
3. Indian Standard Power plug & cord

Optional Accessories (at extra cost)
1. Hour Meter
2. Over temp.protection with audio alarm
3. On site Validation services
4. Data Logger blind - Multi point recorder with software
5. Safety door switch

Corporate Office:
A-1301, BVR Ek, Opp. Hotel Inder Residency,
Near Gujarat College, Ellisbridge,
Ahmedabad-380 006.
Phone : (079) 6621 1234
Website : www.eieinstruments.com

Calibration Laboratory:
Survey No. 1098, Nr. Mahakali Temple,
Opp. Primary School, Village Kubadthal,
Tal-Daskroi, Ahmedabad-382 433.
Phone: (079)-3520 8300
E-mail : info@eieinstruments.com

GST TIN No. : 24AABCE4018L1ZU
I.T. PAN No. : AABCE 4018L
IEC No. : 0813026598 Dt. 04/05/2014
CIN No. : U29199GJ2004PTC045078
TAN No. : AHME00572F

Figure A.13: Laboratory Furnace data sheet .
[Online]: https://www.indiamart.com/proddetail/laboratory-furnace-refractory-furnace-12-x-6-x-6-1200-degree-celsius-digital-model-26315195888.html

4. Hotplate Magnetic Stirrer.


LabTech
Lab Solutions

Hotplate Magnetic Stirrer

ES35A ES35A-Pro

Features of ES35A and ES35A-Pro
- Magnetic stirrer with modern design
- Stainless steel plates or porcelain enamel heating surfaces
- Precise analogical stirrer speed control
- High electronic insulation degree (IP42) and external brushless motor guarantee long service time
- Separate safety circuit automatically stop heating when temperatures exceed 350°C

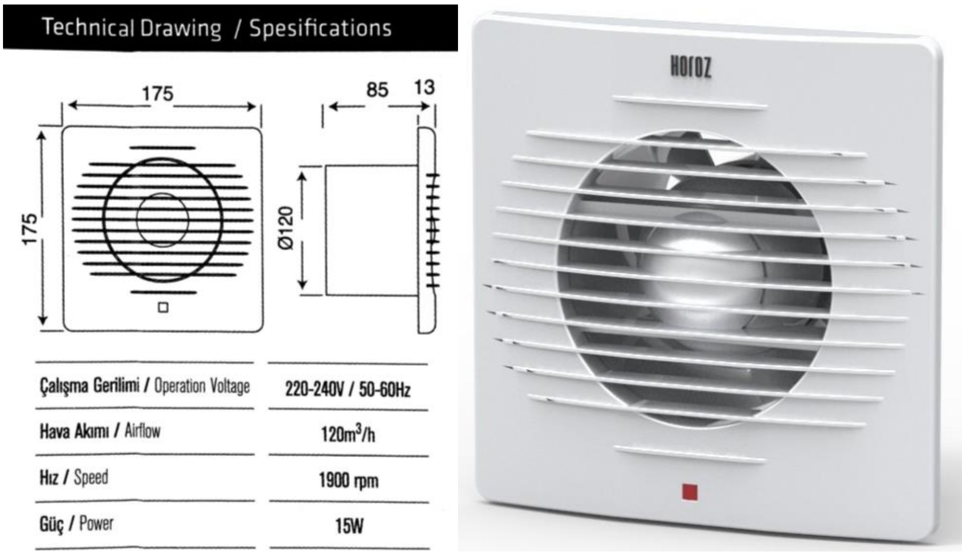
ES35B ES35B-Pro

Features of ES35B and ES35B-Pro
- New stir technology unit for unsupervised operations
- Stirrer bar breakaway function
- Easy-to-read backlit LCD display
- High accuracy heating/stirring controls
- Stainless steel plates or porcelain enamel heating surfaces for excellent chemical resistance
- Separate adjustable safety circuits
- External PT1000 temperature probe option

Figure A.14: Hotplate Magnetic Stirrer data sheet.

[Online]: https://pdf.directindustry.com/pdf/labtech-srl/hotplate-magnetic-stirrer/71284-409095.html

5.Section device .



(1) (2)

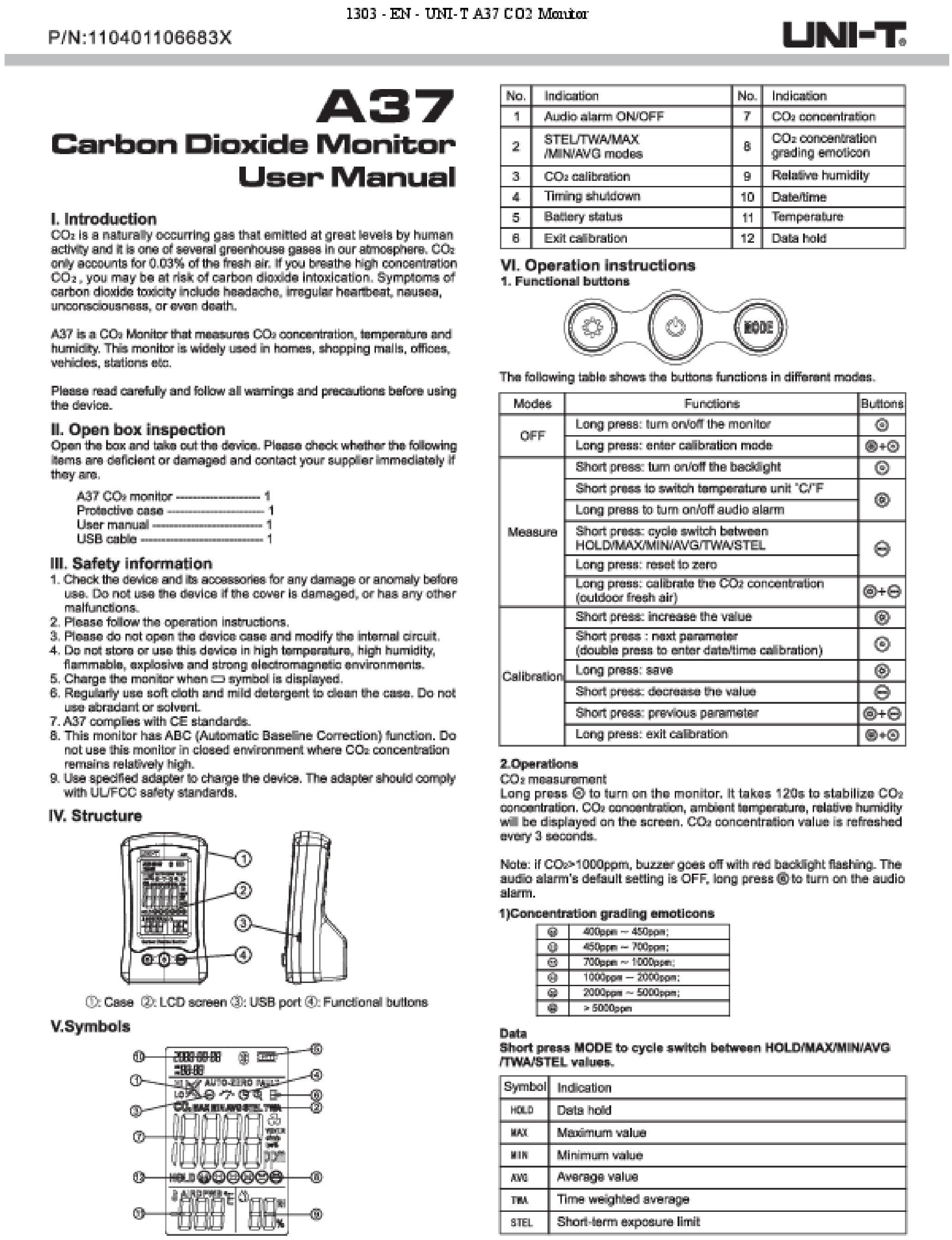
Figure A.15: (1)Section device data sheet. (2) Section device .

[Online]: https://www.buyukalpler.com.tr/urun/horoz-500-000-120-120-5-beyaz-banyo-tuvalet-aspiratoru

6.CO_2 monitor .

Figure A.16 CO_2 monitor.

[Online]: https://www.conrad.com/en/p/uni-t-a37-carbon-dioxide-detector-thermometer-2302125.html



1303 - EN - UNI-T A37 CO2 Monitor

P/N:110401106683X

UNI-T

A37
Carbon Dioxide Monitor User Manual

I. Introduction

CO_2 is a naturally occurring gas that emitted at great levels by human activity and it is one of several greenhouse gases in our atmosphere. CO_2 only accounts for 0.03% of the fresh air. If you breathe high concentration CO_2 , you may be at risk of carbon dioxide intoxication. Symptoms of carbon dioxide toxicity include headache, irregular heartbeat, nausea, unconsciousness, or even death.

A37 is a CO_2 Monitor that measures CO_2 concentration, temperature and humidity. This monitor is widely used in homes, shopping malls, offices, vehicles, stations etc.

Please read carefully and follow all warnings and precautions before using the device.

II. Open box inspection

Open the box and take out the device. Please check whether the following items are deficient or damaged and contact your supplier immediately if they are.

A37 CO_2 monitor ------------------ 1
Protective case --------------------- 1
User manual ------------------------ 1
USB cable -------------------------- 1

III. Safety information

1. Check the device and its accessories for any damage or anomaly before use. Do not use the device if the cover is damaged, or has any other malfunctions.
2. Please follow the operation instructions.
3. Please do not open the device case and modify the internal circuit.
4. Do not store or use this device in high temperature, high humidity, flammable, explosive and strong electromagnetic environments.
5. Charge the monitor when ▭ symbol is displayed.
6. Regularly use soft cloth and mild detergent to clean the case. Do not use abradant or solvent.
7. A37 complies with CE standards.
8. This monitor has ABC (Automatic Baseline Correction) function. Do not use this monitor in closed environment where CO_2 concentration remains relatively high.
9. Use specified adapter to charge the device. The adapter should comply with UL/FCC safety standards.

IV. Structure

①: Case ②: LCD screen ③: USB port ④: Functional buttons

V.Symbols

No.	Indication	No.	Indication
1	Audio alarm ON/OFF	7	CO_2 concentration
2	STEL/TWA/MAX /MIN/AVG modes	8	CO_2 concentration grading emoticon
3	CO_2 calibration	9	Relative humidity
4	Timing shutdown	10	Date/time
5	Battery status	11	Temperature
6	Exit calibration	12	Data hold

VI. Operation instructions

1. Functional buttons

The following table shows the buttons functions in different modes.

Modes	Functions	Buttons
OFF	Long press: turn on/off the monitor	⊙
	Long press: enter calibration mode	⊛+⊙
Measure	Short press: turn on/off the backlight	⊙
	Short press to switch temperature unit °C/°F	⊛
	Long press to turn on/off audio alarm	
	Short press: cycle switch between HOLD/MAX/MIN/AVG/TWA/STEL	⊖
	Long press: reset to zero	
	Long press: calibrate the CO_2 concentration (outdoor fresh air)	⊛+⊖
Calibration	Short press: increase the value	⊛
	Short press : next parameter (double press to enter date/time calibration)	⊙
	Long press: save	⊛
	Short press: decrease the value	⊖
	Short press: previous parameter	⊛+⊖
	Long press: exit calibration	⊛+⊙

2.Operations

CO_2 measurement

Long press ⊙ to turn on the monitor. It takes 120s to stabilize CO_2 concentration. CO_2 concentration, ambient temperature, relative humidity will be displayed on the screen. CO_2 concentration value is refreshed every 3 seconds.

Note: if CO_2>1000ppm, buzzer goes off with red backlight flashing. The audio alarm's default setting is OFF, long press ⊛ to turn on the audio alarm.

1)Concentration grading emoticons

☺	400ppm ~ 450ppm;
☺	450ppm ~ 700ppm;
☺	700ppm ~ 1000ppm;
☹	1000ppm ~ 2000ppm;
☹	2000ppm ~ 5000ppm;
☹	> 5000ppm

Data

Short press MODE to cycle switch between HOLD/MAX/MIN/AVG /TWA/STEL values.

Symbol	Indication
HOLD	Data hold
MAX	Maximum value
MIN	Minimum value
AVG	Average value
TWA	Time weighted average
STEL	Short-term exposure limit

Figure A.17: CO_2 monitor data sheet .
[Online]: https://www.astroshop.de/Produktdownloads/68994_Bedienungsanleitung_FR.pdf

A P P E N D I X (B) : Simulation Work.

- Three Windows to Floor Ratio was use in this research as table B.1 shows.

Table B.1: Windows To Floor Ratio measurement .

WFR	WFR	Studied WFR	Area of a room (m^2)	commonly used window measurement (m^2)
A fair Window to Floor Ratio	WFR>20 %	%25	7.5	1.2*1.5
A good Window to Floor Ratio	10%≤WFR≤20%	%15	12	1.2*1.5
A bad Window to Floor Ratio	WFR< 10%	%5	36	1.2*1.5

"BOX WINDOW SIMULATION"

- The three depths of the window box starting from 60,90and 120 cm were studied. The area of filtration is measured as the 3 tables below show.

- **60 cm depth**

Table B.2: 60 cm depth filter locations.

60 cm	One side	up	down	2 Side	Up &down	Side & up	Side &down	2 Side & up	2Side &down	4 sides
NO. of filters	1	1	1	2	2	2	2	3	3	4
Filter ratio (Filter area/window area)	40%	50%	50%	80%	100%	90%	90%	130%	130%	180%

- **90 cm depth**

Table B.3: 90 cm depth filter locations.

90 cm	One side	up	down	2 Side	Up &down	Side & up	Side &down	2 Side & up	2Side &down	4 sides
NO. of filters	1	1	1	2	2	2	2	3	3	4
Filter ratio (Filter area/window area)	60%	80%	80%	120%	160%	140%	140%	200%	200%	280%

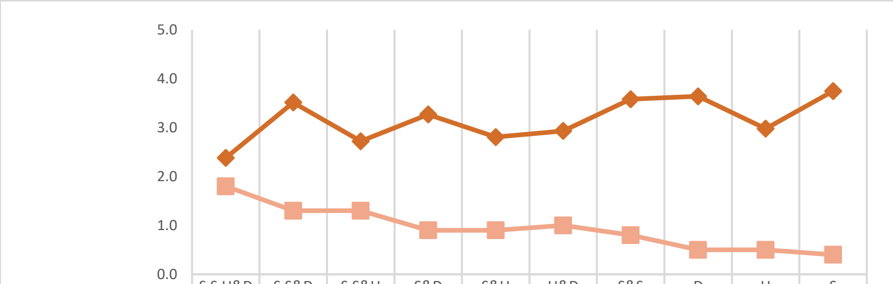
- **120 cm depth**

Table B.4: 120 cm depth filter locations.

90 cm	One side	up	down	2 Side	Up &down	Side & up	Side &down	2 Side & up	2Side &down	4 sides
NO. of filters	1	1	1	2	2	2	2	3	3	4
Filter ratio (Filter area/window area)	80%	100%	100%	160%	200%	180%	180%	260%	260%	360%

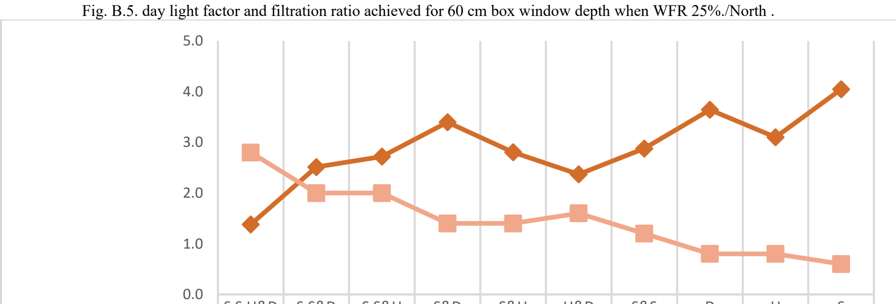
1. North:

A fair Window to Floor Ratio :



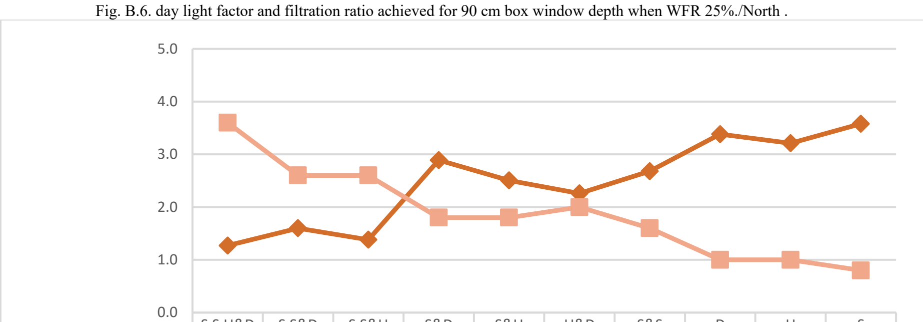
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.380	3.513	2.720	3.268	2.805	2.932	3.579	3.638	2.977	3.746
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig. B.5. day light factor and filtration ratio achieved for 60 cm box window depth when WFR 25%./North .



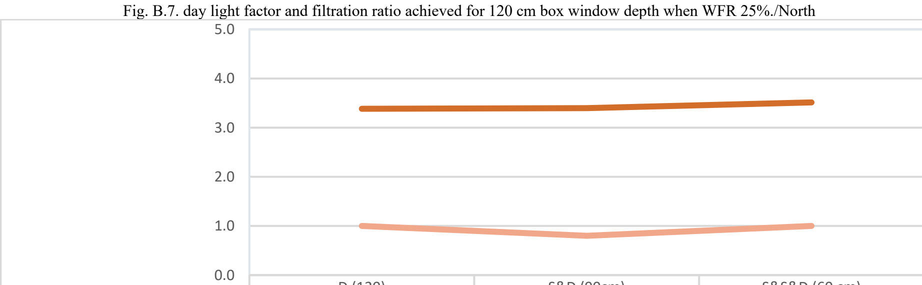
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.38	2.513	2.72	3.396	2.805	2.369	2.879	3.642	3.1	4.046
Filter Ratio	2.8	2	2	1.4	1.4	1.6	1.2	0.8	0.8	0.6

Fig. B.6. day light factor and filtration ratio achieved for 90 cm box window depth when WFR 25%./North .



	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.271	1.601	1.381	2.891	2.506	2.260	2.680	3.383	3.211	3.580
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

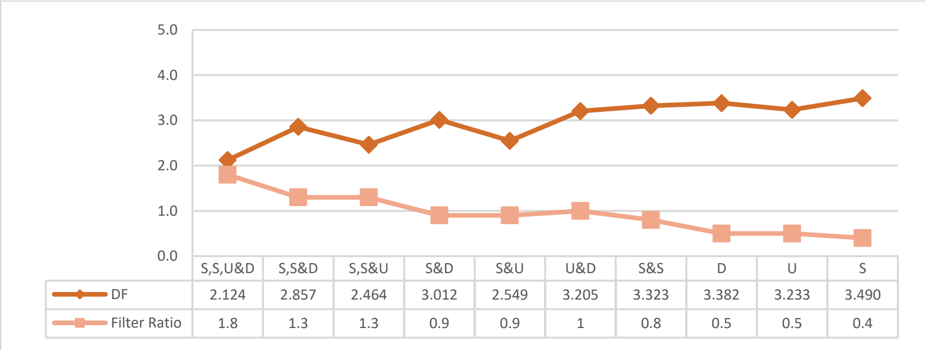
Fig. B.7. day light factor and filtration ratio achieved for 120 cm box window depth when WFR 25%./North



	D (120)	S&D (90cm)	S&S&D (60 cm)
DF	3.383	3.396	3.513
Filter Ratio	1	0.8	1

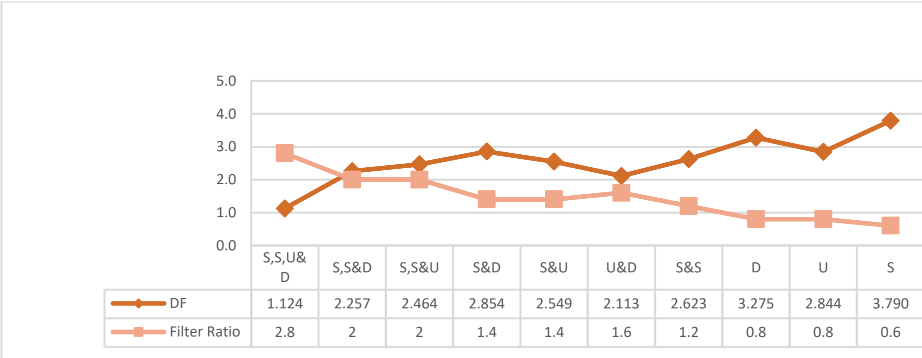
Fig. B.8. A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 25%/North .

A good Window to Floor Ratio :



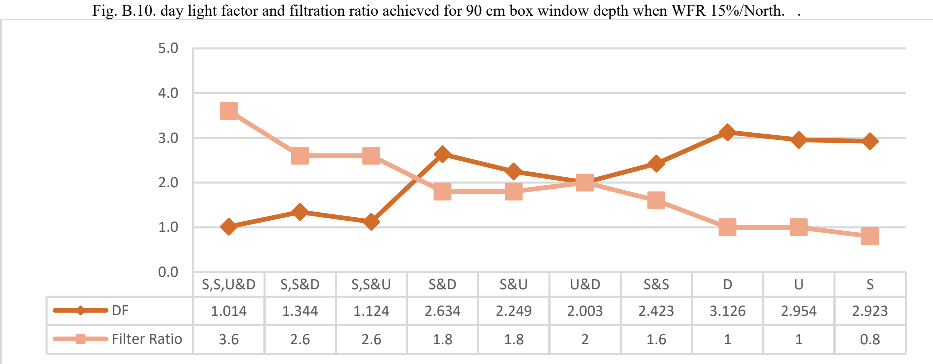
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.124	2.857	2.464	3.012	2.549	3.205	3.323	3.382	3.233	3.490
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig B.9 day light factor and filtration ratio achieved for 60 cm box window depth when WFR 15%. /North .



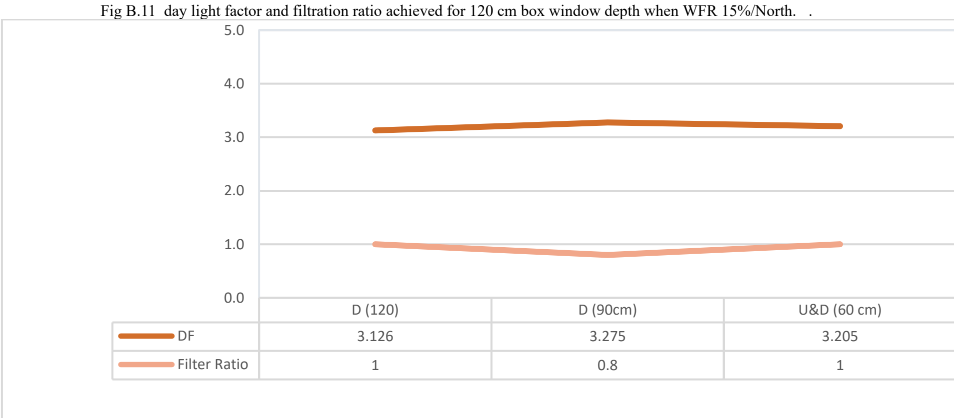
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.124	2.257	2.464	2.854	2.549	2.113	2.623	3.275	2.844	3.790
Filter Ratio	2.8	2	2	1.4	1.4	1.6	1.2	0.8	0.8	0.6

Fig. B.10. day light factor and filtration ratio achieved for 90 cm box window depth when WFR 15%/North. .



	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.014	1.344	1.124	2.634	2.249	2.003	2.423	3.126	2.954	2.923
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

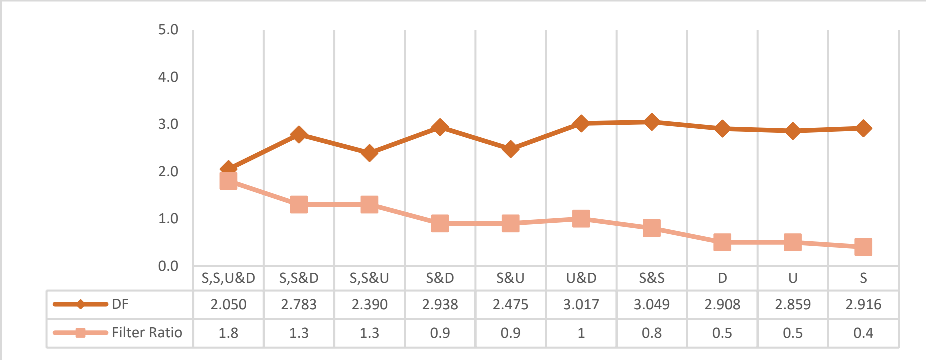
Fig B.11 day light factor and filtration ratio achieved for 120 cm box window depth when WFR 15%/North. .



	D (120)	D (90cm)	U&D (60 cm)
DF	3.126	3.275	3.205
Filter Ratio	1	0.8	1

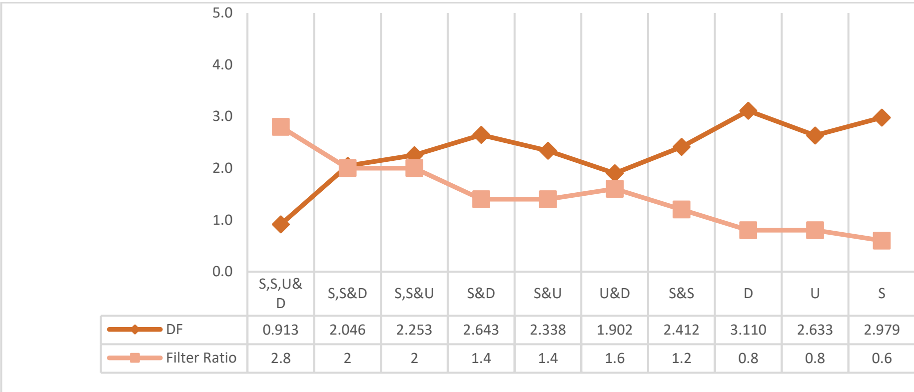
Fig B.12 A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 15%/North .

A bad Window to Floor Ratio:



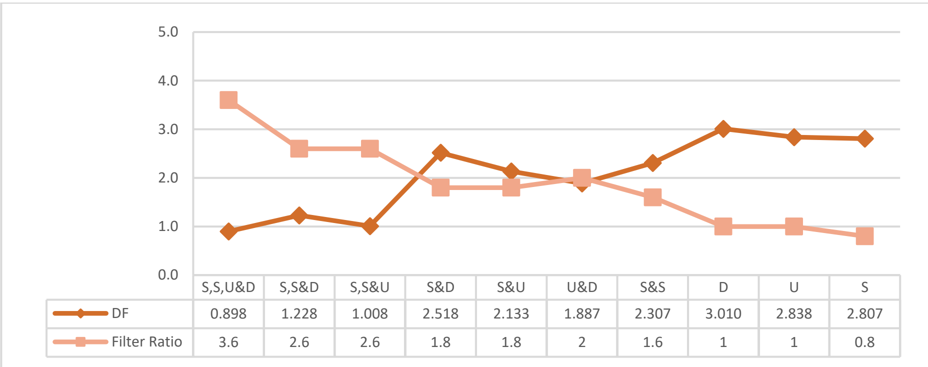
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.050	2.783	2.390	2.938	2.475	3.017	3.049	2.908	2.859	2.916
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig. B.13. day light factor and filtration ratio achieved for 60 cm box window depth when WFR 5%.with lighting shelf /North .



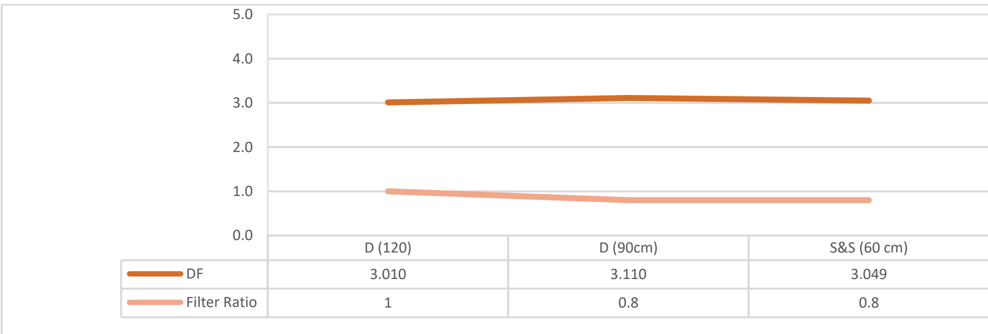
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	0.913	2.046	2.253	2.643	2.338	1.902	2.412	3.110	2.633	2.979
Filter Ratio	2.8	2	2	1.4	1.4	1.6	1.2	0.8	0.8	0.6

Fig. B.14. day light factor and filtration ratio achieved for 90 cm box window depth when WFR 5% %.with lighting shelf. /North .



	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	0.898	1.228	1.008	2.518	2.133	1.887	2.307	3.010	2.838	2.807
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

Fig B.15 day light factor and filtration ratio achieved for 120 cm box window depth when WFR 5%.%.with lighting shelf /North .

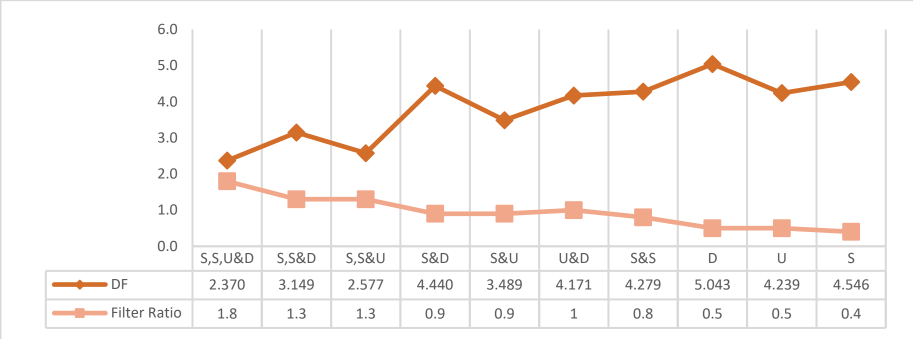


	D (120)	D (90cm)	S&S (60 cm)
DF	3.010	3.110	3.049
Filter Ratio	1	0.8	0.8

Fig. B.16. A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 5%/North .

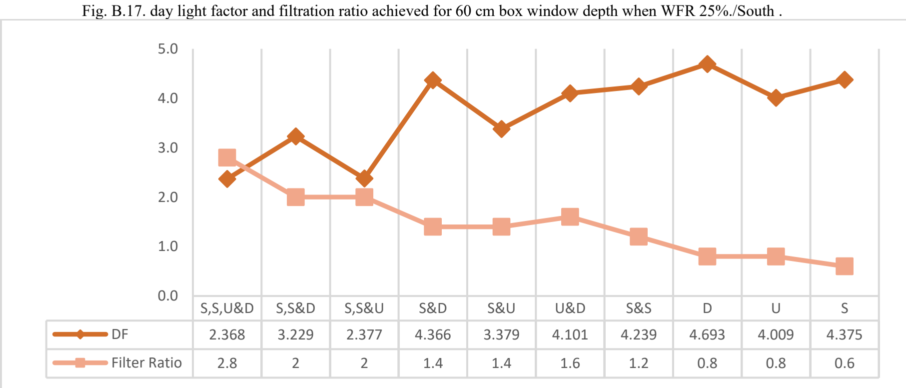
2.South:

A fair Window to Floor Ratio :



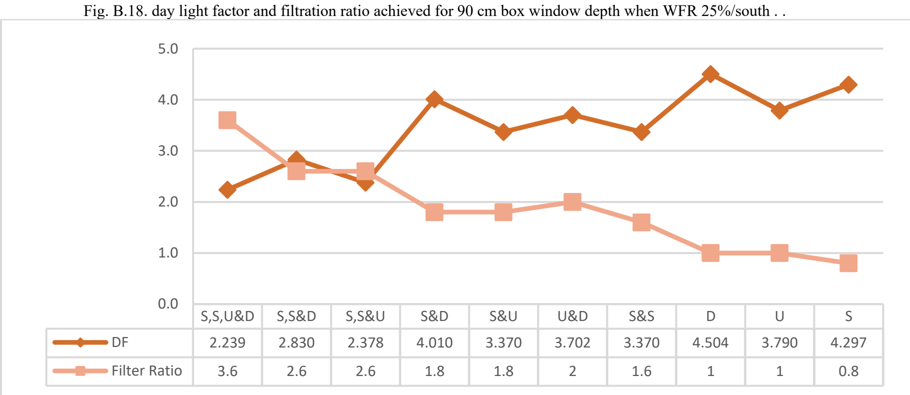
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.370	3.149	2.577	4.440	3.489	4.171	4.279	5.043	4.239	4.546
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig. B.17. day light factor and filtration ratio achieved for 60 cm box window depth when WFR 25%./South .



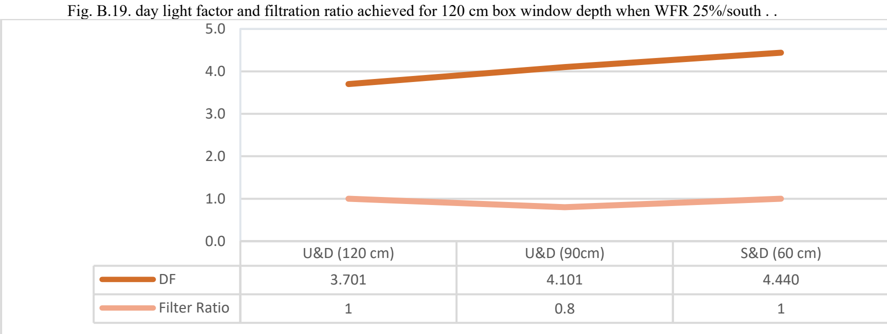
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.368	3.229	2.377	4.366	3.379	4.101	4.239	4.693	4.009	4.375
Filter Ratio	2.8	2	2	1.4	1.4	1.6	1.2	0.8	0.8	0.6

Fig. B.18. day light factor and filtration ratio achieved for 90 cm box window depth when WFR 25%/south . .



	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.239	2.830	2.378	4.010	3.370	3.702	3.370	4.504	3.790	4.297
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

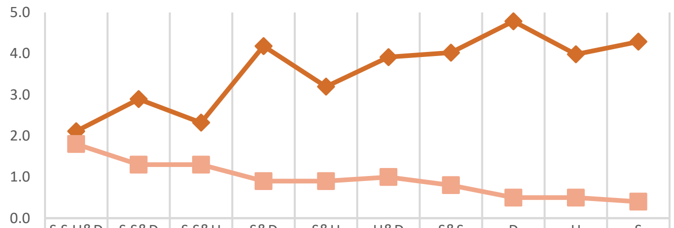
Fig. B.19. day light factor and filtration ratio achieved for 120 cm box window depth when WFR 25%/south . .



	U&D (120 cm)	U&D (90cm)	S&D (60 cm)
DF	3.701	4.101	4.440
Filter Ratio	1	0.8	1

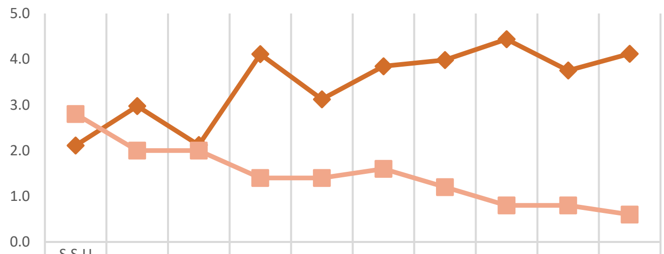
Fig B.20 A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 25%/South .

A good Window to Floor Ratio :



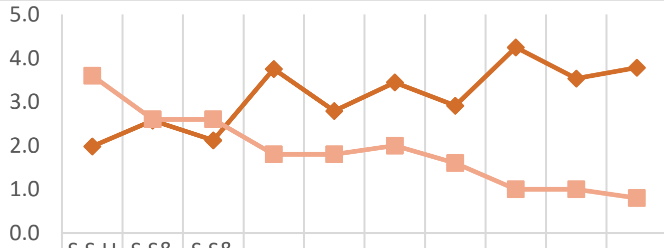
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.114	2.893	2.321	4.184	3.197	3.915	4.023	4.787	3.983	4.290
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig. B.21 :day light factor and filtration ratio achieved for 60 cm box window depth when WFR 15%./South .



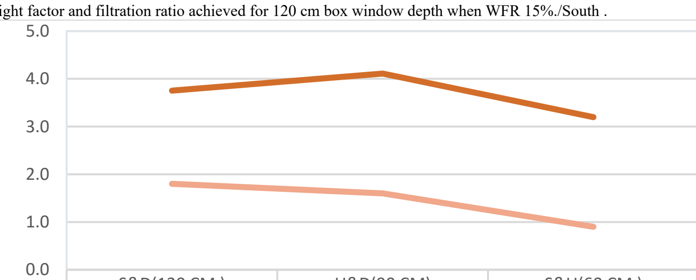
	S,S,U &D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.112	2.973	2.121	4.110	3.123	3.845	3.983	4.437	3.753	4.119
Filter Ratio	2.8	2	2	1.4	1.4	1.6	1.2	0.8	0.8	0.6

Fig. B.22. day light factor and filtration ratio achieved for 90 cm box window depth when WFR 15%./South



	S,S,U &D	S,S& D	S,S& U	S&D	S&U	U&D	S&S	D	U	S
DF	1.982	2.573	2.121	3.753	2.793	3.445	2.913	4.247	3.533	3.783
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

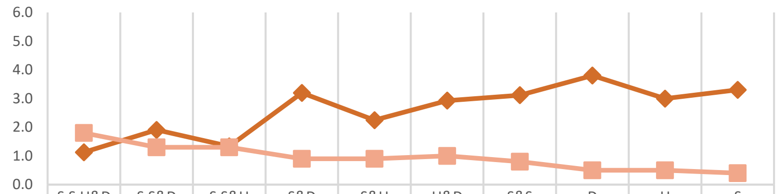
Fig. B.23. day light factor and filtration ratio achieved for 120 cm box window depth when WFR 15%./South .



	S&D(120 CM)	U&D(90 CM)	S&U(60 CM)
DF	3.753	4.110	3.197
Filter Ratio	1.8	1.6	0.9

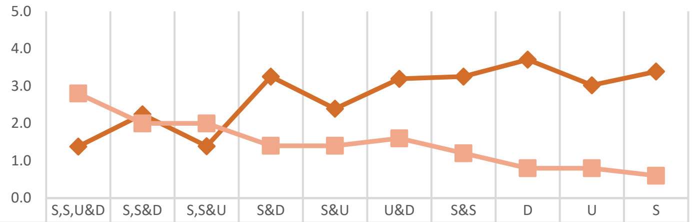
Fig. B.24 A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 15%/South .

A bad Window to Floor Ratio:



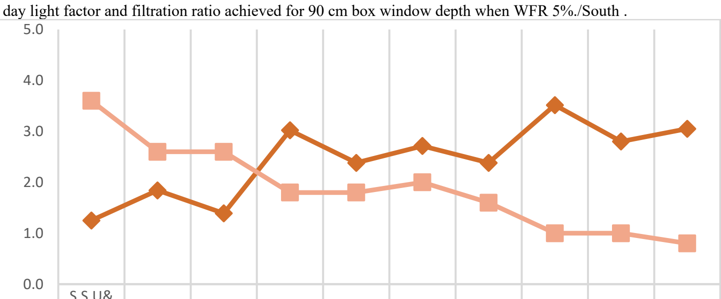
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.127	1.906	1.334	3.197	2.246	2.928	3.117	3.800	2.996	3.303
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig B.25. day light factor and filtration ratio achieved for 60 cm box window depth when WFR 5%./South .



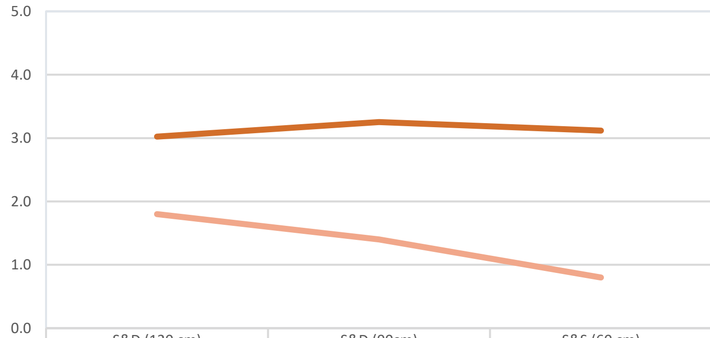
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.382	2.243	1.391	3.253	2.393	3.194	3.253	3.707	3.023	3.389
Filter Ratio	2.8	2	2	1.4	1.4	1.6	1.2	0.8	0.8	0.6

Fig.B.26. day light factor and filtration ratio achieved for 90 cm box window depth when WFR 5%./South .



	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.252	1.843	1.391	3.023	2.383	2.715	2.383	3.517	2.803	3.053
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

Fig. B.27. day light factor and filtration ratio achieved for 120 cm box window depth when WFR 5%./South

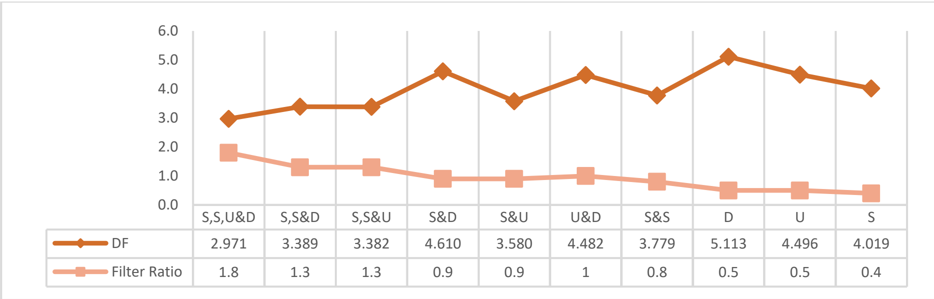


	S&D (120 cm)	S&D (90cm)	S&S (60 cm)
DF	3.023	3.253	3.117
Filter Ratio	1.8	1.4	0.8

Fig. B.28. A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 5%/South .

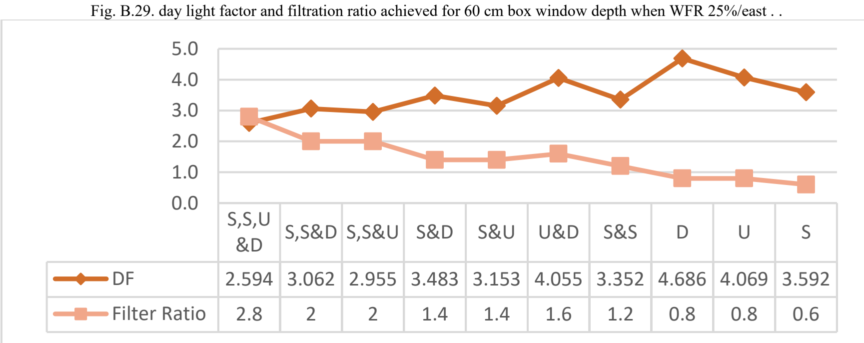
3.East:

A fair Window to Floor Ratio:



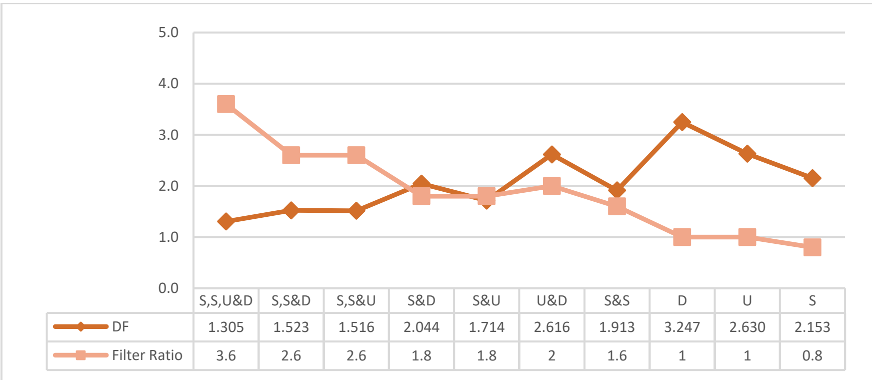
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.971	3.389	3.382	4.610	3.580	4.482	3.779	5.113	4.496	4.019
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig. B.29. day light factor and filtration ratio achieved for 60 cm box window depth when WFR 25%/east . .



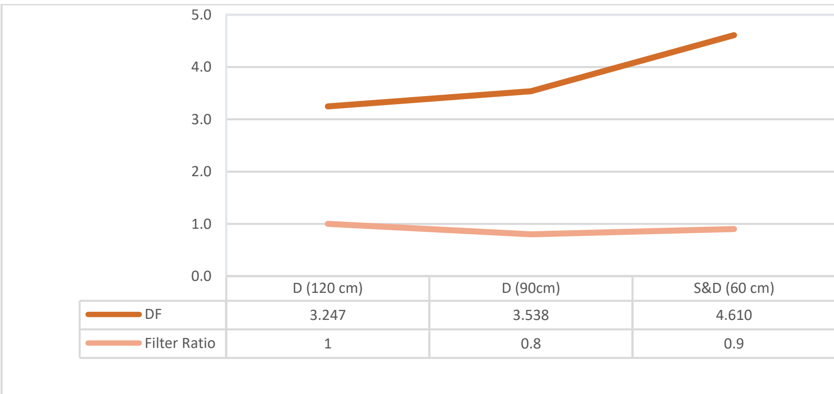
	S,S,U &D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.594	3.062	2.955	3.483	3.153	4.055	3.352	4.686	4.069	3.592
Filter Ratio	2.8	2	2	1.4	1.4	1.6	1.2	0.8	0.8	0.6

Fig. B.30 day light factor and filtration ratio achieved for 90 cm box window depth when WFR 25%/east . .



	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.305	1.523	1.516	2.044	1.714	2.616	1.913	3.247	2.630	2.153
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

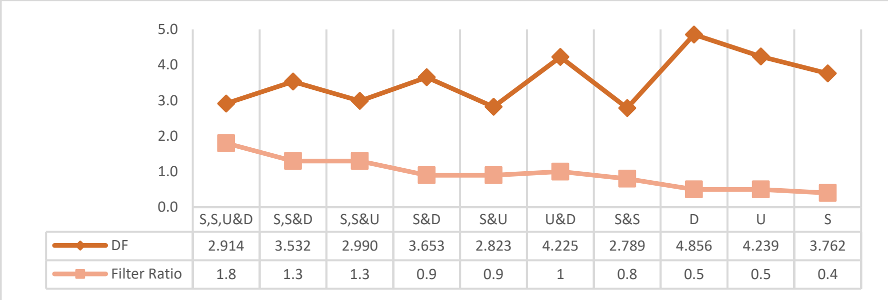
Fig. B.31. day light factor and filtration ratio achieved for 120 cm box window depth when WFR 25%/east .



	D (120 cm)	D (90cm)	S&D (60 cm)
DF	3.247	3.538	4.610
Filter Ratio	1	0.8	0.9

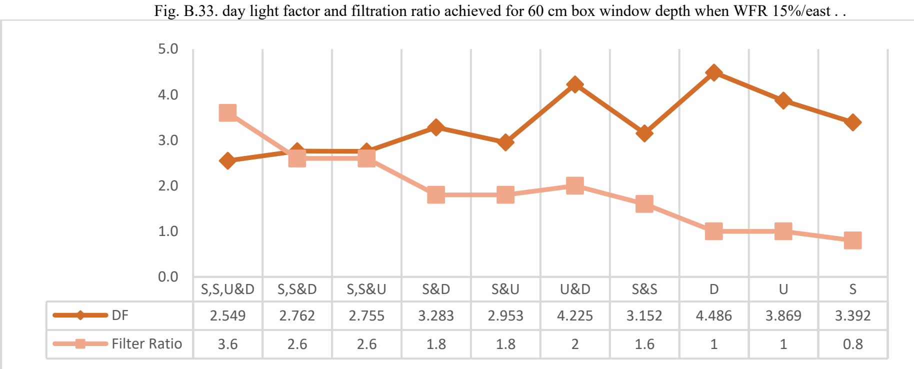
Fig. B.32. A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 25%/East .

A good Window to Floor Ratio:



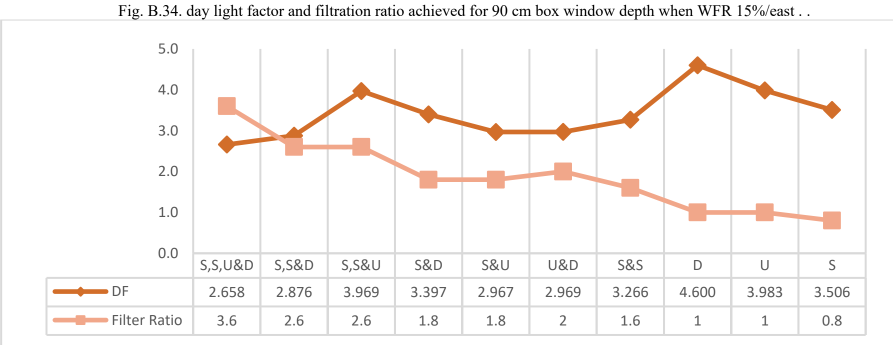
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.914	3.532	2.990	3.653	2.823	4.225	2.789	4.856	4.239	3.762
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig. B.33. day light factor and filtration ratio achieved for 60 cm box window depth when WFR 15%/east . .



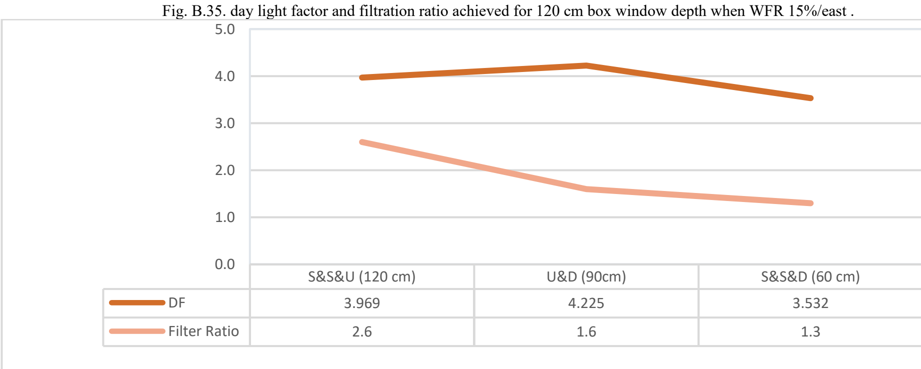
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.549	2.762	2.755	3.283	2.953	4.225	3.152	4.486	3.869	3.392
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

Fig. B.34. day light factor and filtration ratio achieved for 90 cm box window depth when WFR 15%/east . .



	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.658	2.876	3.969	3.397	2.967	2.969	3.266	4.600	3.983	3.506
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

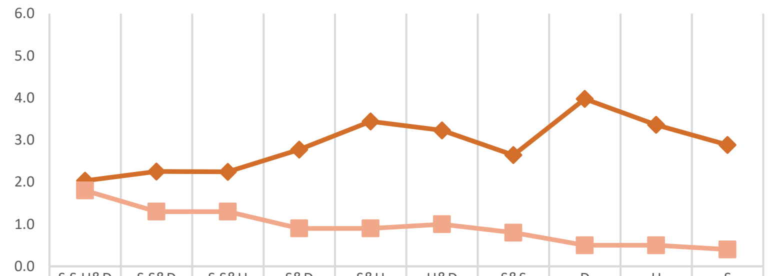
Fig. B.35. day light factor and filtration ratio achieved for 120 cm box window depth when WFR 15%/east .



	S&S&U (120 cm)	U&D (90cm)	S&S&D (60 cm)
DF	3.969	4.225	3.532
Filter Ratio	2.6	1.6	1.3

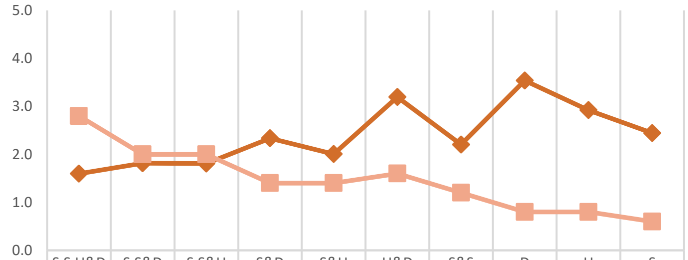
Fig. B.36. A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 15%/East .

A bad Window to Floor Ratio:



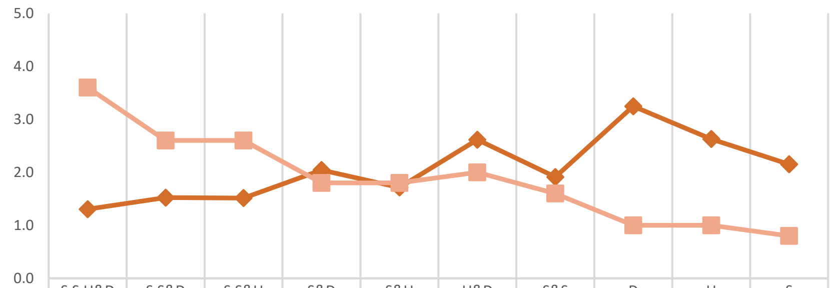
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.033	2.251	2.244	2.772	3.440	3.226	2.641	3.975	3.358	2.881
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig. B.37. day light factor and filtration ratio achieved for 60 cm box window depth when WFR 5%/east . .



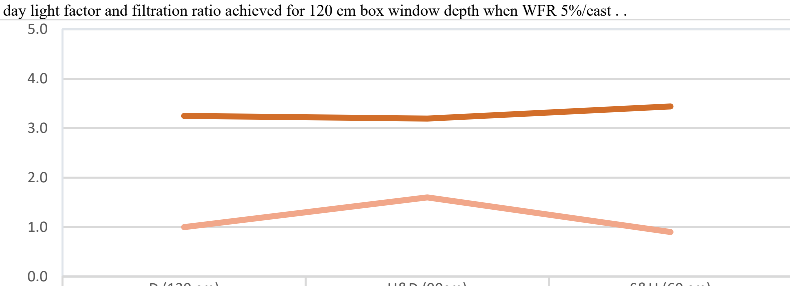
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.596	1.814	1.807	2.335	2.005	3.194	2.204	3.538	2.921	2.444
Filter Ratio	2.8	2	2	1.4	1.4	1.6	1.2	0.8	0.8	0.6

Fig. B.38. day light factor and filtration ratio achieved for 90 cm box window depth when WFR 5%/east . .



	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.305	1.523	1.516	2.044	1.714	2.616	1.913	3.247	2.630	2.153
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

Fig. B.39. day light factor and filtration ratio achieved for 120 cm box window depth when WFR 5%/east . .

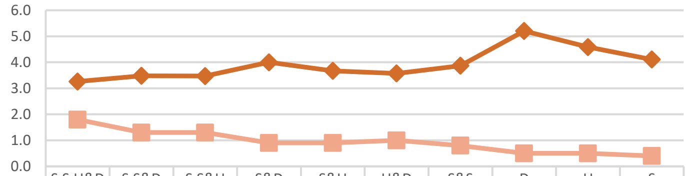


	D (120 cm)	U&D (90cm)	S&U (60 cm)
DF	3.247	3.194	3.440
Filter Ratio	1	1.6	0.9

Fig. B.40 A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 5%/East .

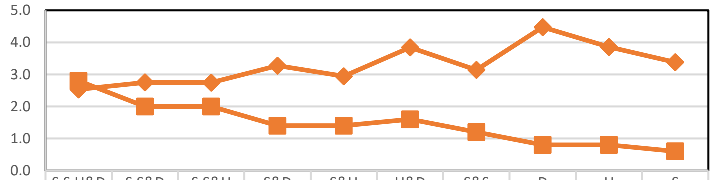
4.West:

A fair Window to Floor Ratio:



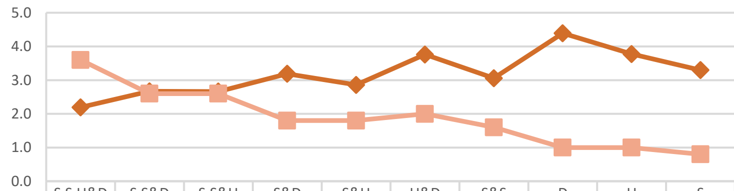
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	3.262	3.480	3.473	4.001	3.671	3.573	3.870	5.204	4.587	4.110
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig. B.41. day light factor and filtration ratio achieved for 60 cm box window depth when WFR 25%/west. .



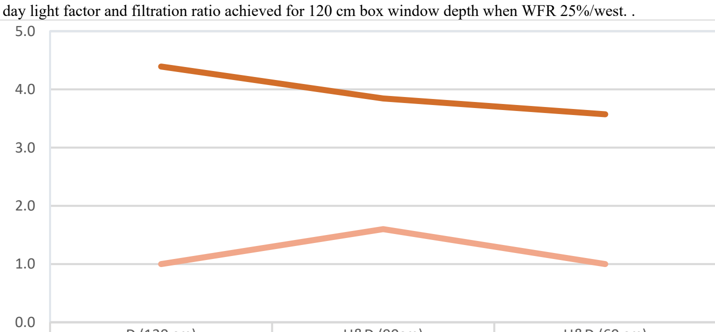
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.533	2.751	2.744	3.272	2.942	3.844	3.141	4.475	3.858	3.381
Filter Ratio	2.8	2	2	1.4	1.4	1.6	1.2	0.8	0.8	0.6

Fig. B.42. day light factor and filtration ratio achieved for 90 cm box window depth when WFR 25%/west. .



	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.193	2.669	2.662	3.190	2.860	3.762	3.059	4.393	3.776	3.299
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

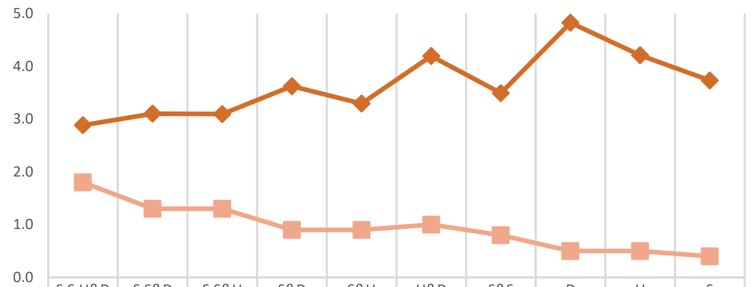
Fig. B.43. day light factor and filtration ratio achieved for 120 cm box window depth when WFR 25%/west. .



	D (120 cm)	U&D (90cm)	U&D (60 cm)
DF	4.393	3.844	3.573
Filter Ratio	1	1.6	1

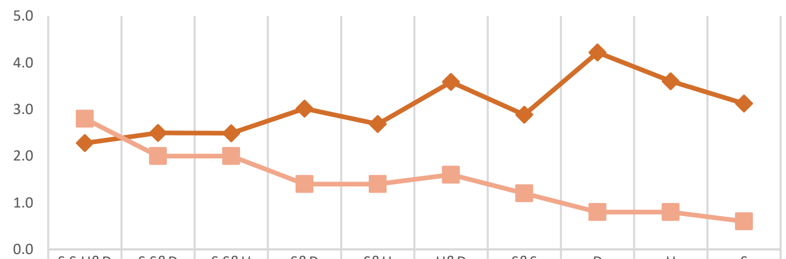
Fig. B.44. A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 25%/West .

A good Window to Floor Ratio:



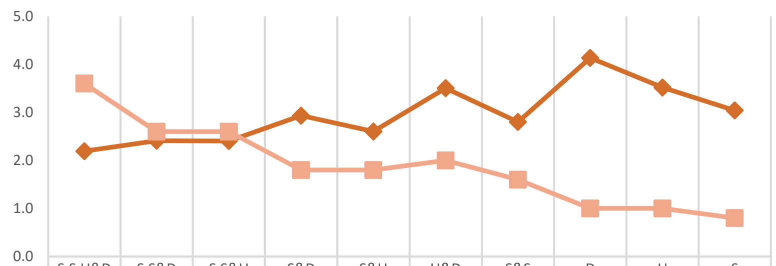
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.885	3.103	3.096	3.624	3.294	4.196	3.493	4.827	4.210	3.733
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig B.45 day light factor and filtration ratio achieved for 60 cm box window depth when WFR 15%/west. .



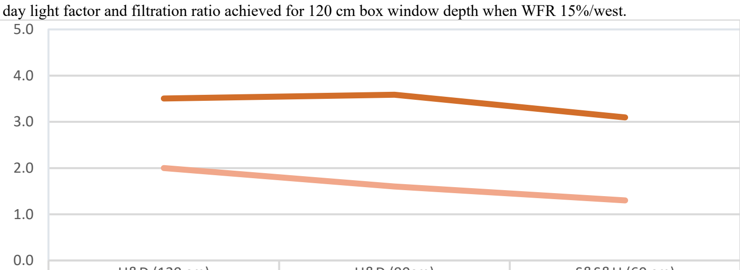
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.276	2.494	2.487	3.015	2.685	3.587	2.884	4.218	3.601	3.124
Filter Ratio	2.8	2	2	1.4	1.4	1.6	1.2	0.8	0.8	0.6

Fig. B.46. day light factor and filtration ratio achieved for 90 cm box window depth when WFR 15%/west. .



	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.193	2.411	2.404	2.932	2.602	3.504	2.801	4.135	3.518	3.041
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

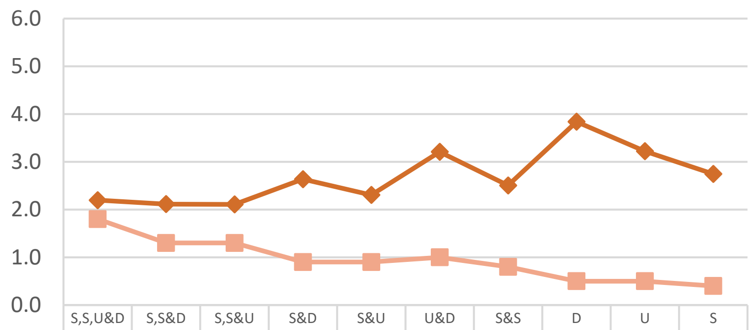
Fig. B.47. day light factor and filtration ratio achieved for 120 cm box window depth when WFR 15%/west.



	U&D (120 cm)	U&D (90cm)	S&S&U (60 cm)
DF	3.504	3.587	3.096
Filter Ratio	2	1.6	1.3

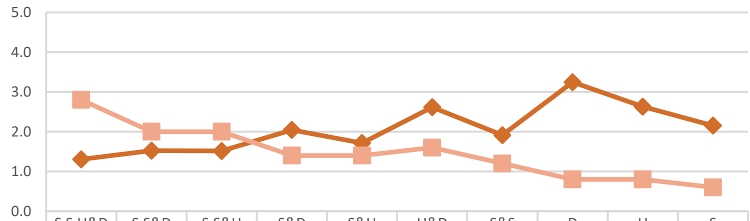
Fig. B.48. A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 15%/West .

A bad Window to Floor Ratio:



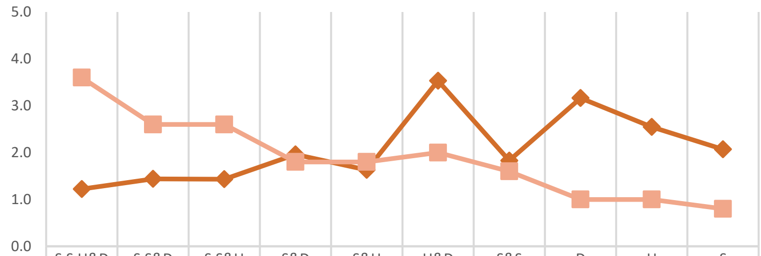
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	2.197	2.115	2.108	2.636	2.306	3.208	2.505	3.839	3.222	2.745
Filter Ratio	1.8	1.3	1.3	0.9	0.9	1	0.8	0.5	0.5	0.4

Fig. B.49. day light factor and filtration ratio achieved for 60 cm box window depth when WFR 5%/west. .



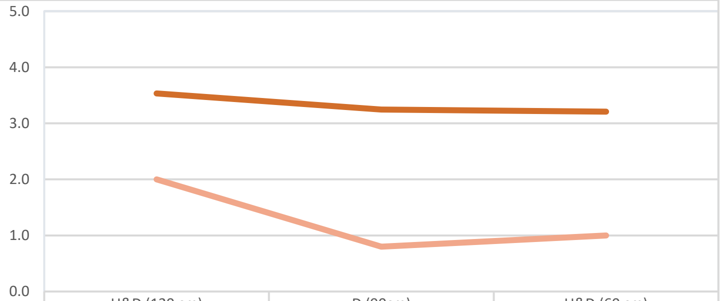
	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.305	1.523	1.516	2.044	1.714	2.616	1.913	3.247	2.630	2.153
Filter Ratio	2.8	2	2	1.4	1.4	1.6	1.2	0.8	0.8	0.6

FigB.50 day light factor and filtration ratio achieved for 90 cm box window depth when WFR 5%/west. .



	S,S,U&D	S,S&D	S,S&U	S&D	S&U	U&D	S&S	D	U	S
DF	1.222	1.440	1.433	1.961	1.631	3.533	1.830	3.164	2.547	2.070
Filter Ratio	3.6	2.6	2.6	1.8	1.8	2	1.6	1	1	0.8

Fig. B.51. day light factor and filtration ratio achieved for 120 cm box window depth when WFR 5%/west. .



	U&D (120 cm)	D (90cm)	U&D (60 cm)
DF	3.533	3.247	3.208
Filter Ratio	2	0.8	1

Fig. B.52. A best day light factor and filtration ratio achieved for 3 depths of box window depth when WFR 5%/West .

"ORDINARY WINDOW SIMULATION"

- The three WFRs 25,15and 5% were studied. The area of filtration and new WFR were measured as the 3 tables below show.

  - **A fair Window to Floor Ratio 25%:**

Table B.5: Filtration ratio in a fair Window to Floor ratio.

FILTRATION RATIO	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
WINDOW AREA	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
ROOM AREA	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2
NEW WINDOW(AREA AFTER FILTER)	1.71	1.62	1.53	1.44	1.35	1.26	1.17	1.08	0.99	0.9
NEW WFR(WINDOW/ROOM)	0.2375	0.225	0.2125	0.2	0.1875	0.175	0.1625	0.15	0.1375	0.125
	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗

  - **A good Window to Floor Ratio 15%:**

Table B.6: Filtration ratio in a good Window to Floor ratio.

FILTRATION RATIO	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
WINDOW AREA	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
ROOM AREA	12	12	12	12	12	12	12	12	12	12
NEW WINDOW (AREA AFTER FILTER)	1.71	1.62	1.53	1.44	1.35	1.26	1.17	1.08	0.99	0.9
NEW WFR (WINDOW/ROOM)	0.1425	0.135	0.1275	0.12	0.1125	0.105	0.0975	0.09	0.0825	0.075
	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗

  - **A bad Window to Floor Ratio 5%:**

Table B.7: Filtration ratio in a bad Window to Floor ratio.

FILTRATION RATIO	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
WINDOW AREA	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
ROOM AREA	36	36	36	36	36	36	36	36	36	36
NEW WINDOW (AREA AFTER FILTER)	1.71	1.62	1.53	1.44	1.35	1.26	1.17	1.08	0.99	0.9
NEW WFR (WINDOW/ROOM)	0.0475	0.045	0.0425	0.04	0.0375	0.035	0.0325	0.03	0.0275	0.025
	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

1. North :

A fair Window to Floor Ratio:

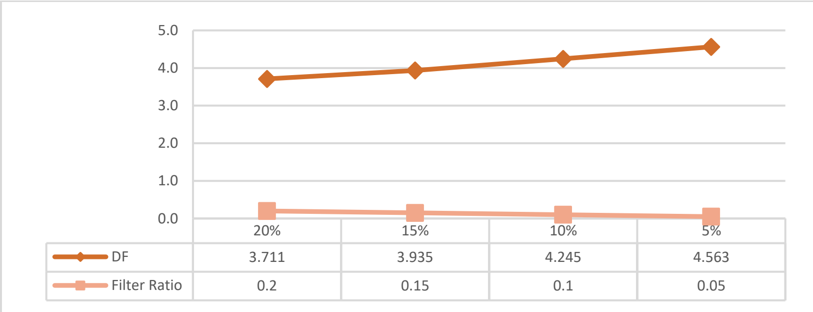


Fig. B.53. day light factor and filtration ratio achieved for ordinary window when WFR 25%/North. .

A good Window to Floor Ratio:

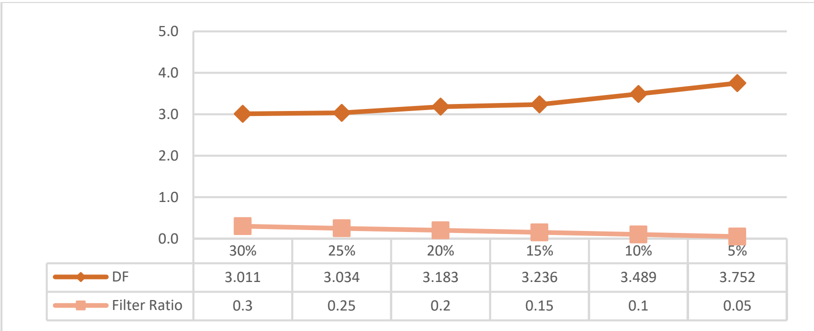


Fig. B.54. day light factor and filtration ratio achieved for ordinary window when WFR 15%/North. .

A bad Window to Floor Ratio:

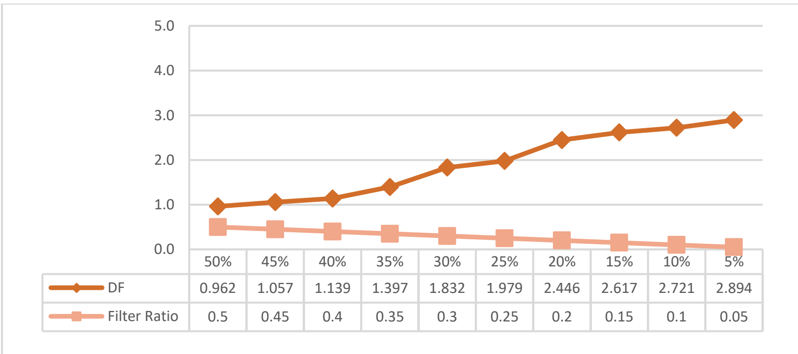


Fig. B.55. day light factor and filtration ratio achieved for ordinary window when WFR 5%/North. .
Source: The researcher.

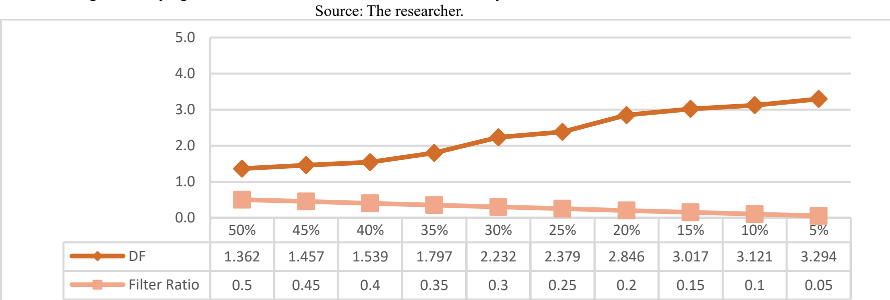
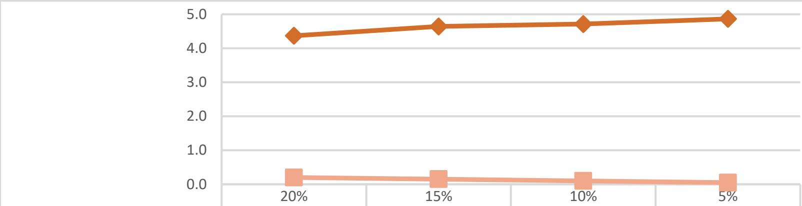


Fig. B.56. day light factor and filtration ratio achieved for ordinary window when WFR 5%/North. .
Source: The researcher.

2. South :

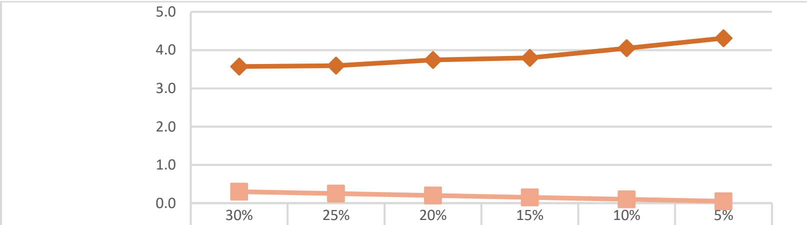
A fair Window to Floor Ratio:



	20%	15%	10%	5%
DF	4.367	4.643	4.7119	4.864
Filter Ratio	0.2	0.15	0.1	0.05

Fig. B.57. day light factor and filtration ratio achieved for ordinary window when WFR 25%/South. .

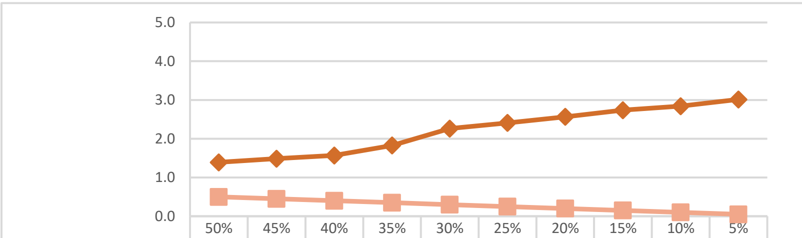
A good Window to Floor Ratio:



	30%	25%	20%	15%	10%	5%
DF	3.571	3.594	3.743	3.796	4.049	4.312
Filter Ratio	0.3	0.25	0.2	0.15	0.1	0.05

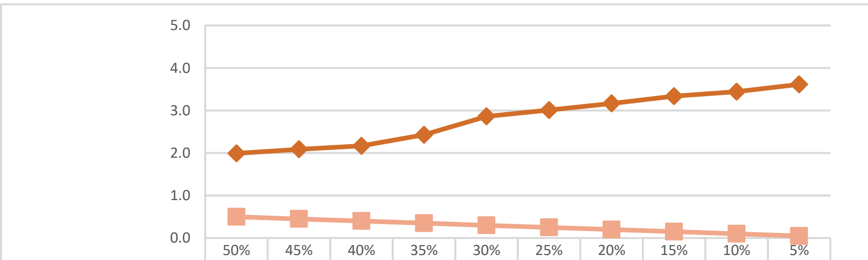
Fig. B.58. day light factor and filtration ratio achieved for ordinary window when WFR 15%/South. .
Source: The researcher.

A bad Window to Floor Ratio:



	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%
DF	1.392	1.487	1.569	1.827	2.262	2.409	2.566	2.737	2.841	3.014
Filter Ratio	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05

Fig. B.59. day light factor and filtration ratio achieved for ordinary window when WFR 5%/South. .

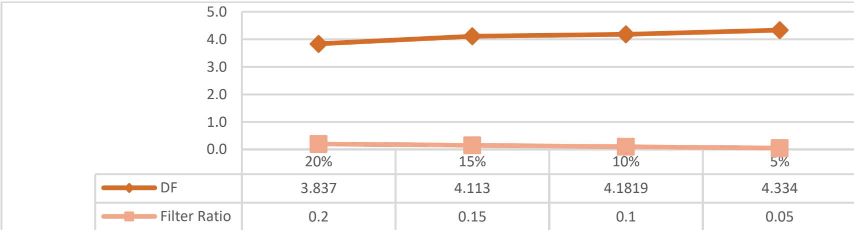


	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%
DF	1.992	2.087	2.169	2.427	2.862	3.009	3.166	3.337	3.441	3.614
Filter Ratio	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05

Fig. B.60. day light factor and filtration ratio achieved for ordinary window when WFR 5%/South. .

3. East :

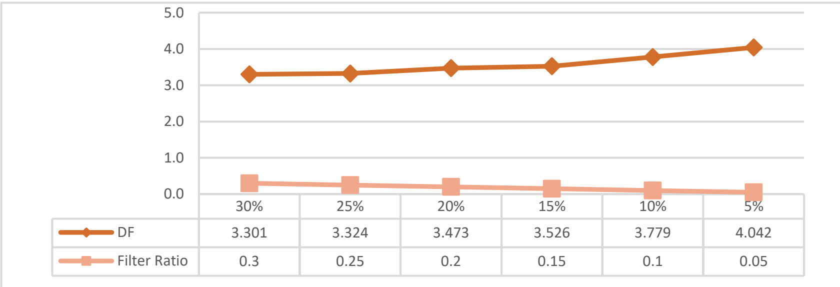
A fair Window to Floor Ratio:



	20%	15%	10%	5%
DF	3.837	4.113	4.1819	4.334
Filter Ratio	0.2	0.15	0.1	0.05

Fig. B.61. day light factor and filtration ratio achieved for ordinary window when WFR 25%/South. .

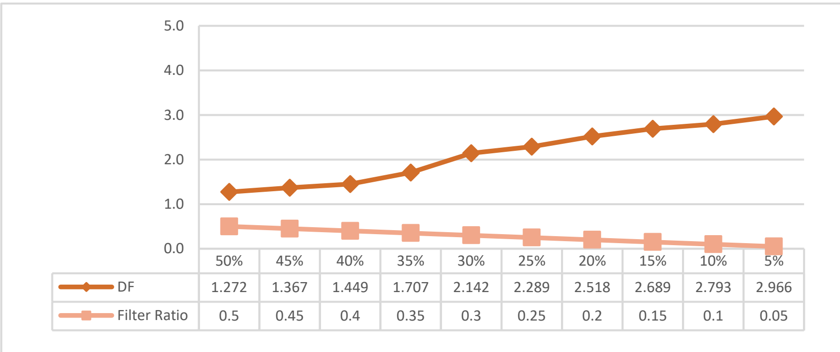
A good Window to Floor Ratio:



	30%	25%	20%	15%	10%	5%
DF	3.301	3.324	3.473	3.526	3.779	4.042
Filter Ratio	0.3	0.25	0.2	0.15	0.1	0.05

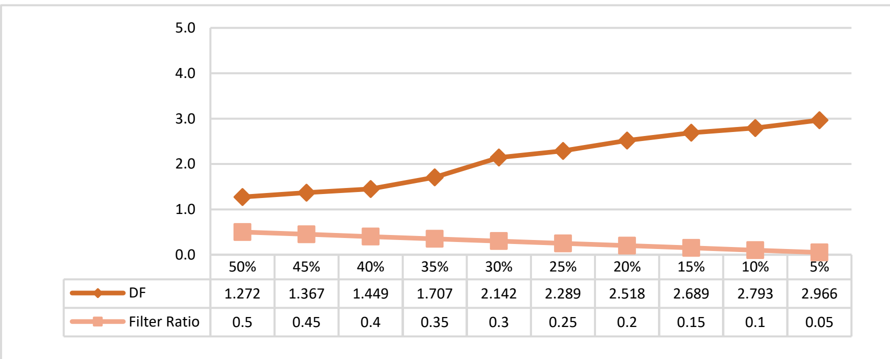
Fig. B.62. day light factor and filtration ratio achieved for ordinary window when WFR 15%/South. .

A bad Window to Floor Ratio:



	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%
DF	1.272	1.367	1.449	1.707	2.142	2.289	2.518	2.689	2.793	2.966
Filter Ratio	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05

Fig. B.63. day light factor and filtration ratio achieved for ordinary window when WFR 5%/South. .

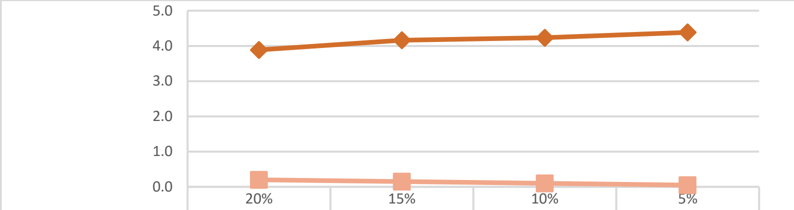


	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%
DF	1.272	1.367	1.449	1.707	2.142	2.289	2.518	2.689	2.793	2.966
Filter Ratio	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05

Fig. B.64. day light factor and filtration ratio achieved for ordinary window when WFR 5%/South. .

4. West :

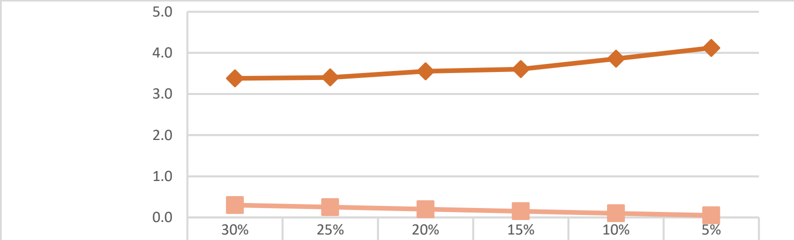
A fair Window to Floor Ratio:



	20%	15%	10%	5%
DF	3.887	4.163	4.2319	4.384
Filter Ratio	0.2	0.15	0.1	0.05

Fig. B.65. day light factor and filtration ratio achieved for ordinary window when WFR 25%/South. .

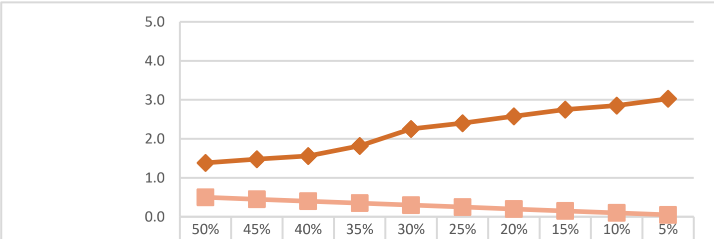
A good Window to Floor Ratio:



	30%	25%	20%	15%	10%	5%
DF	3.381	3.404	3.553	3.606	3.859	4.122
Filter Ratio	0.3	0.25	0.2	0.15	0.1	0.05

Fig. B.66. day light factor and filtration ratio achieved for ordinary window when WFR 15%/South. .

A bad Window to Floor Ratio:



	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%
DF	1.383	1.478	1.56	1.818	2.253	2.4	2.578	2.749	2.853	3.026
Filter Ratio	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05

Fig. B.67.
day light factor and filtration ratio achieved for ordinary window when WFR 5%/South. .
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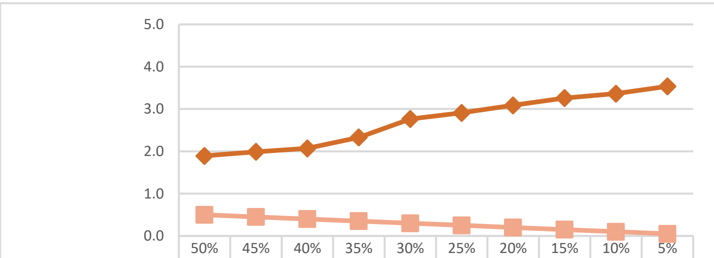

	50%	45%	40%	35%	30%	25%	20%	15%	10%	5%
DF	1.893	1.988	2.07	2.328	2.763	2.91	3.088	3.259	3.363	3.536
Filter Ratio	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05

Fig. B.68. day light factor and filtration ratio achieved for ordinary window when WFR 5%/South. .
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A P P E N D I X - C: Cost calculation

Table C.1: Price per square meter for materials .
Source: Al-Amen Building Contracting Company in the city of Hebron/Chemical lab at PPU .

Martials	Aluminum M	Double Glass M^2	Raw marital (for filter) Killo	AC Production Killo	2 layers of fabric M^2
Price/ $	80	40	10	30	2

The first model (Ordinary window):
The cost for the window(1.2*1.5 m^2) ≅ 190 $.
The cost for the filter/m^2 = 7 + 25 + (1*2) ≅ 34 $.

The second model (Box window):
The cost for the window(1.2*1.5*0.6 m^2) ≅ 230 $.
The cost for the window(1.2*1.5*0.9 m^2) ≅ 250 $.
The cost for the window(1.2*1.5*1.2 m^2) ≅ 270 $.
The cost for the filter/m^2 = 7 + 25 + (1*2) ≅ 34 $.

NOTE: In order to determine the precise cost of the filter, calculate it out using the approximate price per square meter.