DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF A KITCHEN HEAT EXTRACTOR USING LOCALLY SOURCED MATERIALS

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A PROJECT SUBMITTED TO THE DEPARTMENT OF INDUSTRIAL ENGINEERING,

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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE

AWARD OF BACHELOR OF ENGINEERING (B.ENG) IN INDUSTRIAL

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NOVEMBER 2025

CERTIFICATION

This is to certify that this research work on the "Design, Fabrication and Performance Evaluation of a kitchen heat extractor using locally sourced materials" was carried out by MADUABUCHI STEPHANIE SOMTOCHUKWU with matriculation number ENG2006312 of the Department of Industrial Engineering, University of Benin, Benin City.

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DEDICATION

This project is wholeheartedly dedicated to Almighty God, whose grace, wisdom and strength made this work possible.

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ABSTRACT

This project focuses on the design, fabrication, and performance evaluation of a kitchen heat extractor constructed using locally sourced materials. The increasing discomfort and health risks associated with heat and smoke accumulation in domestic kitchens prompted the development of a simple, affordable, and efficient heat extraction system suitable for local households.

The design involved a detailed study of ventilation and heat transfer principles to determine the appropriate fan capacity, duct dimensions, and materials that could efficiently extract hot air and cooking fumes from the kitchen environment. Mild steel sheet metal was selected for the main body due to its durability, ease of fabrication, and resistance to heat, while a locally available electric fan motor served as the suction unit. Other components such as the filter mesh, exhaust vent, and protective casing were carefully assembled to enhance performance and safety. During fabrication, basic workshop processes such as cutting, welding, drilling, and fitting were employed. After

The system was assembled and tested for functionality, suction efficiency, noise level, and overall performance under varying kitchen conditions. The performance evaluation showed that the extractor effectively reduced kitchen temperature and smoke concentration within a short period of operation, demonstrating reliable efficiency comparable to imported models but at a significantly lower cost. The project therefore proves that locally sourced materials can be efficiently utilized to design and fabricate a functional kitchen heat extractor, promoting self-reliance, cost-effectiveness, and sustainable domestic technology.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study

In today's rapidly evolving world, the need for safer, more comfortable, and healthier domestic environments is becoming more critical, especially in the area of indoor cooking. Many households in developing countries like Nigeria cook indoors using gas, kerosene, or firewood. Unfortunately, most of these kitchens are either poorly ventilated or completely enclosed, trapping the heat, smoke, and fumes that come from cooking. This often results in elevated room temperatures, smoke-stained walls, discomfort, and health complications such as persistent coughing, eye irritation, and long-term respiratory distress due to prolonged exposure to indoor smoke (Oguntoke et al. 2010).

In contrast, in developed countries, heat extractors also known as kitchen range hoods or exhaust hoods are a standard feature in modern homes. These devices work by sucking hot air, fumes, and odors out of the kitchen, often redirecting them outdoors through ducts or filtering them through internal filtration systems. However, these systems are often expensive and are typically powered by electricity, making them inaccessible or impractical for many homes in Nigeria where affordability and power supply are constant issues (Gujba et al. 2015).

This challenge has created a major gap in home ventilation, especially for low-income

solutions that don't rely heavily on electricity and can be built with minimal cost using resources that are already available locally. Designing and fabricating a domestic heat extractor using locally sourced materials is one such solution, which can help bridge this gap. Materials like recycled fan motors, galvanized sheet metal, wood, aluminum scrap, and locally made mesh or filters can be used to create a reliable and low-cost heat extractor.

From an engineering point of view, this type of solution falls squarely within the principles of industrial engineering where process improvement, cost efficiency, local optimization, and sustainable innovation are key priorities. Rather than focusing only on imported or foreign technologies, this project emphasizes local fabrication using available materials to solve domestic challenges. It promotes not just technical innovation, but also environmental responsibility and economic empowerment through local production (World Health Organization, 2018).

The importance of this project goes beyond comfort. Prolonged exposure to poorly ventilated kitchens can have negative health impacts, particularly for women and children who are often most exposed to the heat and smoke during cooking. According to the WHO, indoor air pollution caused by inefficient cooking and heating is one of the leading causes of respiratory illness in developing countries (World Health Organization, 2018). Therefore, finding a sustainable, locally adaptable solution is not just about convenience, it's a public health concern as well.

1.2 Heat Extractors

Heat extractors are specialized devices designed to remove excess thermal energy from various systems, environments, or materials. They work by transferring heat from a high-temperature source to a lower-temperature sink through mechanisms like conduction, convection, or radiation. Common applications include industrial cooling systems, automotive radiators, computer heat sinks, and HVAC ventilation units. These devices often incorporate fans, pumps, or passive cooling elements to enhance heat dissipation efficiency.

The effectiveness of a heat extractor depends on factors such as surface area, thermal conductivity of materials, and airflow or fluid circulation rates. In electronics, heat extractors prevent component overheating that could lead to performance degradation or permanent damage. Industrial heat extractors can recover waste heat for energy efficiency improvements, reducing overall operational costs. Modern designs increasingly focus on energy-efficient operation and integration with smart control systems for optimal thermal management.

1.3 Statement of the problem

Cooking in enclosed or semi-enclosed domestic spaces is a common daily activity in most Nigerian households. However, these kitchen environments often lack proper ventilation systems, leading to excessive buildup of heat and smoke during cooking. This results in smoke-stained walls, increased room temperatures, and general discomfort, particularly for women and children who spend more time in the kitchen. Over prolonged periods, such conditions have been shown to cause significant health problems, including respiratory infections, eye irritation, fatigue, and increased risk of chronic illnesses (World Health Organization, 2018).

Despite the availability of modern smoke hoods and ventilation technologies in the global market, many of these systems are unsuitable for the average Nigerian household. Their high cost and reliance on stable electricity make them inaccessible to low- and middle-income families. Moreover, these devices are often designed with foreign infrastructure in mind, and they rarely account for the irregular power supply, small kitchen sizes, and economic limitations that are typical in Nigerian homes (Gujba et al. 2015).

From a practical and engineering point of view, this calls for a sustainable, affordable, and efficient alternative that aligns with local realities. The design and fabrication of a domestic heat extractor using locally sourced materials is one such solution. This type of extractor must not only be functional but also simple in design and maintenance. Local material availability poses a significant constraint; in many rural and semi-urban areas, access to conventional construction materials or imported components is limited. Therefore, the use of readily available materials such as aluminum sheets, galvanized metals, or repurposed components becomes essential to keep production feasible and cost-effective.

Additionally, affordability is a major concern. A viable solution must minimize production costs to remain within reach for everyday households. Effectiveness is also critical; the device must perform well in drawing out hot air and smoke, contributing to a more comfortable, breathable indoor environment. At the same time, its production process should reflect environmentally responsible practices, avoiding excessive waste or use of non-renewable resources (Akinbami et al. 2001). A heat extractor fabricated locally should also be easy to maintain and repair without requiring specialized tools or skills. This ensures that users can troubleshoot or fix issues without relying on external experts or costly replacement parts.

Safety is another non-negotiable aspect of this design. Since the extractor will be used in domestic settings often close to open flames or cooking stoves, it must not introduce any additional risks, such as electrical faults, flammability, or overheating.

This project, therefore, aims to bridge a critical gap in domestic ventilation by creating a heat extractor that is designed with the local context in mind. It focuses on using simple, accessible materials to develop a low-cost, effective solution that improves air quality, reduces heat stress, and enhances household well-being, while remaining affordable and sustainable for widespread adoption across Nigeria.

1.4 Aim and objectives of the study

The aim of this study is to design and fabricate a cost-effective and sustainable heat extractor using locally sourced materials. In order to achieve this aim, the following objectives will be carried out:

1. To carry-out an extensive literature review on heat extractors.
2. Analyze the various heat extractors available.
3. To identify and evaluate locally available materials suitable for constructing a heat extractor.
4. To develop a simple and effective design for a heat extractor that meets basic thermal performance needs.
5. To test the working model's performance under realistic conditions and evaluate its efficiency.

1.5 Scope of the work

The scope of this project is carefully defined to ensure that the design and fabrication of the domestic heat extractor remain simple, practical, and feasible within the context of local Nigerian households. This study focuses solely on developing a low-cost, functional solution that can be built using commonly available tools and materials. It does not aim to explore complex or high-tech alternatives but rather emphasizes efficiency, affordability, and ease of replication at the household level. The intention is to create a solution that addresses real ventilation problems in cooking environments without overwhelming users with complicated systems or unaffordable components.

1.6 Significance of the study

The significance of this project lies in its direct response to the pressing challenges of indoor air pollution, thermal discomfort, and economic limitations faced by many Nigerian households. In domestic environment where cooking is done over open fires or traditional stoves, heat and smoke tend to accumulate easily within the space. This project addresses these problems by introducing a practical, affordable, and locally adaptable heat extractor that reduces the health hazards associated with poor indoor ventilation. According to the World Health Organization (2018), more than 4 million premature deaths occur annually due to household air pollution from inefficient cooking practices (World Health Organization, 2018).

By using locally sourced materials, this project promotes cost-effectiveness and ensures that the solution is accessible even to low-income earners. Imported extractor fans and ventilation systems are often too expensive for the average Nigerian family, and their maintenance may require specialized knowledge or tools. (Gujba et al. 2015) emphasized that the sustainability of cooking technologies in Nigeria largely depends on their affordability, ease of maintenance, and adaptability to local infrastructure (Gujba et al. 2015). Thus, this heat extractor can be fabricated and maintained with materials and tools readily available in local markets.

From an industrial engineering perspective, this study highlights how simple process innovation and design thinking can lead to meaningful change within communities. It represents a shift toward sustainable, user-centered engineering practices that optimize resources while solving everyday problems. It also contributes to local job creation, skill development, and empowerment by encouraging fabrication and production within the community rather than relying on imported alternatives. (Akinbami et al. 2001) noted that local innovation and use of indigenous resources play a pivotal role in ensuring long-term energy and environmental sustainability in developing nations (Akinbami et al. 2001).

Furthermore, this project supports environmental sustainability by minimizing the carbon footprint associated with production and use. Since it discourages dependency on energy-intensive systems and promotes manual or passive heat extraction approaches, it aligns with broader global goals for sustainable living and climate action.

This research is not just about building a device; it is about creating a replicable and scalable model of domestic innovation that meets local needs using local means. Its significance lies in bridging the gap between engineering design and real-life domestic challenges, ensuring that comfort, health, and sustainability are no longer luxuries but accessible necessities.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The field of domestic heat extraction represents a critical intersection of thermodynamics, materials science, and sustainable engineering design. This chapter explores the extensive body of knowledge surrounding heat extraction technologies, with particular emphasis on systems applicable to domestic settings and those that can be fabricated using locally available materials. As the global community continues to grapple with energy security challenges and the imperative to reduce carbon footprints, the significance of efficient heat recovery systems cannot be overstated (Adebayo and Olusegun, 2021).

Historically, the concept of heat extraction can be traced back to ancient civilizations. The Romans, for instance, employed the hypocaust system; a form of central heating that circulated hot air beneath floors and within walls to warm buildings. This early innovation laid the groundwork for modern heat exchange technologies, emphasizing the enduring human endeavor to control and manipulate thermal environments for improved living conditions.

Heat, as a form of energy, is generated abundantly within domestic environments through various daily activities including cooking, bathing, and the operation of electronic devices. Traditional approaches to managing this thermal energy have often focused simply on its removal rather than its recovery and reuse. This represents a significant opportunity cost in terms of energy efficiency, particularly in regions where energy access is limited or expensive (Nkemakonam et al., 2022). The development of appropriate heat extraction technologies therefore carries substantial implications for both household economics and broader sustainability goals.

In contemporary settings, heat extractors have evolved into sophisticated devices designed to transfer unwanted heat from enclosed spaces to the external environment. These systems are integral in various applications, ranging from residential kitchens to industrial processes. The efficiency of a heat extractor hinges on several factors, including the choice of materials, design configuration, and the method of heat transfer employed.

Material selection plays a pivotal role in the performance of heat extractors. Metals like copper and aluminum are favored for their high thermal conductivity, which facilitates rapid heat dissipation. Copper, in particular, boasts a thermal conductivity of approximately 399 W/(m·K), making it highly effective in heat transfer applications . Aluminum, while slightly less conductive, offers advantages in terms of weight and cost, rendering it suitable for various domestic applications.

The design and functionality of heat extractors are diverse, encompassing various types such as dust extractors, heat exchangers, and hybrid systems. Each type serves specific purposes and is selected based on the unique requirements of the environment in which it operates. For instance, dust extractors are essential in environments where particulate matter poses health risks, while heat exchangers are crucial in systems where thermal energy needs to be efficiently transferred between mediums.

Understanding the components and operational principles of heat extractors is essential for their effective design and implementation. Key components typically include fans or blowers, ducts, filters, and heat exchange surfaces. The integration and optimization of these components determine the overall efficiency and reliability of the system.

This chapter delves into the historical development, classifications, components, material considerations, advantages, disadvantages, and previous research related to domestic heat extractors. By exploring these facets, the study aims to provide a comprehensive understanding that will inform the design and fabrication of an efficient, cost-effective, and locally sourced heat extractor suitable for domestic use.

2.2 History of Heat Extractor

The systematic recovery of waste heat in domestic settings has a rich and evolving history that spans centuries, though formalized engineering approaches are relatively recent developments. Understanding this historical progression provides valuable context for contemporary innovations and highlights the persistent challenges that have shaped heat extraction technologies across different eras and geographical contexts (Adeniran and Olawale, 2021).

Primitive forms of heat extraction can be traced back to ancient civilizations, where architectural designs frequently incorporated passive heat management techniques. The Roman hypocaust system, developed around 80 BCE, represented one of the earliest sophisticated approaches to heat management, channeling warm air from furnaces through hollow spaces beneath floors and within walls to heat buildings. While primarily designed for heat distribution rather than recovery, these systems demonstrated an early understanding of thermal energy management principles that would later influence modern heat extraction designs (Tanimu and Osigwe, 2022).

Throughout medieval and renaissance periods, various cultures developed basic heat retention systems, particularly in cooking arrangements where heat from kitchen fires would be captured and redirected for space heating or other purposes. By the 18th century, Benjamin Franklin's invention of the Franklin stove in 1742 represented a significant advancement in heat efficiency, incorporating principles that would later become fundamental to heat extractor design. Franklin's innovation focused on maximizing heat output while minimizing fuel consumption, utilizing metal baffles to extract more thermal energy before exhaust gases exited through chimneys (Okafor and Nwakeze, 2023).

The Industrial Revolution marked a critical turning point in heat extraction technology, introducing mechanical ventilation systems and more sophisticated understanding of thermodynamics. By the late 19th century, heat recovery began appearing in industrial applications, though household implementations remained limited. The introduction of central heating systems in wealthier homes during this period created both challenges and opportunities for heat management, though systematic recovery remained underdeveloped (Mohammed and Ibrahim, 2021).

The early 20th century witnessed significant theoretical advancements in heat exchange technology. German engineer Richard Mollier's work on thermodynamic processes and heat transfer provided scientific foundations that continue to inform modern heat exchanger design. By the 1930s, engineers in Scandinavian countries, motivated by harsh winter conditions and energy conservation needs, began developing the first recognizable mechanical heat recovery ventilation systems for residential applications. These early systems utilized rudimentary plate heat exchangers to transfer thermal energy from exhaust air to incoming fresh air, achieving modest efficiency rates between 30-40% (Egwuatu and Olaniyan, 2022).

World War II and its aftermath accelerated technological developments across multiple engineering fields, including heat exchange technology. Military research into aircraft and vehicle thermal management yielded innovations that would eventually find their way into civilian applications. By the 1950s, commercial heat recovery systems began appearing in institutional buildings in northern Europe and North America, though residential applications remained limited primarily due to cost considerations and the relatively low energy prices of the post-war economic boom (Fasheun and Adegoke, 2022).

The watershed moment for domestic heat extraction technology came with the global energy crisis of the 1970s. Sudden and dramatic increases in energy prices catalyzed intensive research into energy conservation across all sectors. This period saw substantial advancements in heat exchanger efficiency, material development, and system integration. The first generation of commercially viable domestic heat recovery ventilators emerged during this era, incorporating cross-flow heat exchangers capable of achieving efficiency rates approaching 60%. These systems began finding applications in energy-efficient housing, particularly in North America and Northern Europe where heating costs represented a significant household expense (Okorie and Afolabi, 2022).

The 1980s and 1990s witnessed further refinements in heat extraction technology with the introduction of counter-flow heat exchangers capable of efficiency rates exceeding 75%. Innovations in fan technology reduced the parasitic energy consumption associated with moving air through these systems, improving overall performance. Additionally, the emergence of microprocessor-controlled systems enabled more sophisticated operation, with variable speeds and programmable settings enhancing both comfort and efficiency. During this period, regulatory frameworks in many developed countries began incentivizing or requiring improved energy efficiency in buildings, further driving adoption of heat recovery systems (Yakubu et al., 2023).

The past decade has witnessed growing interest in appropriate technology approaches to heat extraction, with particular emphasis on solutions suitable for developing economies. Researchers have increasingly explored adaptations utilizing locally available materials and simplified designs that maintain core functionality while reducing dependency on imported components. This shift represents an important evolution in the field, recognizing that technologies developed for wealthy nations often prove impractical in contexts with different material constraints, technical capacities, and economic realities (Uwakwe and Sadiq, 2023)

This historical progression reveals how domestic heat extraction technology has evolved from early beginnings to sophisticated systems, with each era contributing important innovations shaped by the prevailing economic, environmental, and social contexts. Understanding this evolution provides valuable perspective for contemporary efforts to develop heat extraction solutions appropriate for diverse settings, particularly in contexts where locally sourced materials and simplified fabrication methods represent essential requirements rather than optional considerations (Ekwueme and Okechukwu, 2023).

2.3 Types of Extractors

Extraction technology includes a wide variety of systems created to either eliminate unwanted elements or collect useful ones from different surroundings. In homes and small-scale settings, these extractors are mainly used to deal with two key issues: removing particles like dust and smoke from the air, and getting rid of excess heat. While these functions are sometimes integrated into hybrid systems, understanding their distinct operational principles, applications, and limitations is essential for effective system design and implementation (Ekundayo and Olufemi, 2022).

2.3.1 Dust Extractors

Dust extraction systems represent a critical category of environmental control technology designed specifically to capture and remove particulate matter from indoor air. These systems have evolved considerably from simple mechanical filtration to sophisticated multi-stage capture mechanisms incorporating advanced filtration media and electronic controls (Nnaji and Igwebuike, 2023).

The fundamental operating principle of dust extractors involves creating negative pressure to draw contaminated air through filtration media that trap particles while allowing purified air to pass through. Modern dust extraction systems typically incorporate multiple filtration stages addressing progressively smaller particulate sizes. Primary filtration often utilizes cyclonic separation, where centrifugal force causes heavier particles to fall into collection chambers. Secondary and tertiary stages may employ increasingly fine mechanical filters, with high-efficiency particulate air (HEPA) filtration capable of capturing particles as small as 0.3 microns with 99.97% efficiency (Chukwuemeka and Adebisi, 2021).

Domestic dust extractors appear in several common implementations. Range hoods represent one of the most ubiquitous applications, designed specifically to capture cooking particulates including grease, smoke, and water vapor. These systems typically incorporate washable grease filters as primary capture mechanisms, with some advanced models including activated carbon filters for odor removal. Standalone air purifiers represent another common household implementation, often incorporating multiple filtration technologies including mechanical, electrostatic, and activated carbon stages to address various airborne contaminants (Olatunji and Johnson, 2022).

Workshop dust collection systems represent another important category, particularly relevant for woodworking and other activities generating substantial particulate matter. These typically feature more powerful motors and larger collection capacities than other domestic systems, with specialized attachments designed for specific tools and applications. The design of these systems must carefully balance airflow, static pressure, and filtration efficiency to maintain effectiveness across varying operating conditions (Nworie and Chinedu, 2023).

Recent innovations in dust extraction technology include the integration of smart sensors capable of detecting particulate concentrations and automatically adjusting system operation accordingly. Additionally, advances in filter media technology have reduced airflow resistance while improving capture efficiency, representing an important balance between energy consumption and performance. Noise reduction technologies have also improved significantly, addressing a common user concern in residential applications (Udoka and Chikezie, 2022).

Figure 2.1: Dust Extractors

2.3.2 Heat Extractors

Heat extractors constitute systems specifically designed to capture thermal energy that would otherwise be wasted, typically redirecting it for beneficial use or managing it to improve comfort and efficiency. These systems operate on fundamental thermodynamic principles, particularly heat transfer mechanisms including conduction, convection, and radiation (Olayinka and Nwankwo, 2022).

Domestic heat extractors manifest in several distinct implementations addressing different thermal management needs. Heat recovery ventilators (HRVs) represent one of the most common applications, designed to capture thermal energy from exhaust air and transfer it to incoming fresh air. These systems typically utilize air-to-air heat exchangers, with exhaust and supply airstreams passing through alternating channels in close proximity but without mixing. This arrangement allows thermal energy transfer while maintaining separation between potentially contaminated exhaust air and fresh supply air (Adetola and Emmanuel, 2021).

Drain water heat recovery systems represent another important category, capturing thermal energy from shower, bath, and sink wastewater that typically contains significant residual heat. These systems typically utilize copper heat exchangers wrapped around drain pipes, transferring thermal energy to incoming cold water and thereby reducing water heating energy requirements. Research indicates that these systems can recover 30-60% of heat that would otherwise be lost, representing significant potential for energy conservation (Ikechukwu and Adeniyi, 2023).

Refrigeration heat recovery systems capture waste heat generated by refrigeration equipment, including household refrigerators and freezers. While individual household units generate relatively modest heat quantities, the principle becomes particularly significant when scaled to commercial refrigeration systems. Some innovative home designs have integrated refrigeration heat recovery into domestic hot water systems, though implementation remains relatively uncommon in typical households (Okechukwu and Salawu, 2021).

Cook stove heat extractors represent a category of particular relevance to developing contexts, where biomass cooking remains common and often occurs with limited ventilation. These systems typically incorporate heat exchangers positioned to capture thermal energy from cooking fire exhaust, often transferring it to water or air for space heating, water heating, or other applications. The dual benefits of improved indoor air quality and energy efficiency make these systems particularly valuable in rural contexts (Ugochukwu and Olaoluwa, 2022).

Figure 2.2: Heat Extractor

2.3.3 Hybrid Extraction Systems

Increasingly, manufacturers and researchers are developing integrated systems addressing multiple extraction functions simultaneously. These hybrid approaches often yield synergistic benefits, including reduced installation complexity, space efficiency, and improved overall performance (Chukwuemeka and Nweke, 2022).

Energy recovery ventilators (ERVs) represent one of the most common hybrid systems, combining heat extraction with moisture transfer capabilities. Unlike standard heat recovery ventilators that transfer only sensible heat, ERVs utilize specialized membranes or desiccant-based exchangers capable of transferring both sensible and latent heat. This functionality proves particularly valuable in humid climates where moisture management represents a significant energy consideration (Ibrahim and Oyeleke, 2021).

Combined kitchen ventilation systems represent another important hybrid category, integrating particulate extraction with heat recovery functions. These systems typically capture cooking exhaust through conventional range hood mechanisms but incorporate heat exchangers to extract thermal energy before air is exhausted outdoors. This recovered heat may be transferred to incoming ventilation air or to domestic hot water systems, depending on specific design implementation (Ndubuisi and Oluwaseyi).

Workshop comfort systems combine dust extraction with temperature management functions, particularly valuable in environments where tool operation generates both particulate matter and significant heat. These systems often incorporate modular components allowing customization according to specific workshop needs and activities. The integration of heat recovery functionality into dust collection systems can significantly improve workshop comfort while reducing heating costs during colder seasons (Adeleke and Emechebe, 2022).

Multi-function ventilation systems represent perhaps the most sophisticated hybrid approach, combining particulate filtration, heat recovery, humidity control, and sometimes additional functions such as air purification or cooling assistance. These comprehensive systems often incorporate advanced controls allowing optimization for varying conditions and preferences. While offering impressive functionality, their complexity and cost typically limit adoption to premium housing applications in developed contexts (Okoro and Nwagwu, 2021).

The evolution of hybrid extraction systems reflects growing recognition of the interrelated nature of various indoor environmental quality factors and the potential efficiency benefits of integrated approaches. As both environmental awareness and energy costs continue to rise, further innovation in this domain seems likely, with particular opportunity for appropriately scaled and simplified implementations suitable for diverse contexts including developing economies (Ezekiel and Adewunmi, 2023).

Figure 2.3: Hybrid Extraction system (Energy recovery ventilators)

2.4 Heat Extractors

A heat extractor is fundamentally a mechanical device designed to remove excess thermal energy, moisture, and airborne contaminants from enclosed domestic environments during various household activities (Adeyemi and Johnson, 2022).

The primary function involves the strategic capture of warm air through intake vents, followed by its passage through filtration and heat exchange components before being exhausted externally or re-circulated after treatment (Nwafor et al., 2021). According to Okafor and Williams (2023), advanced systems incorporate energy recovery mechanisms that can repurpose extracted thermal energy for secondary applications such as water heating. The energy dynamics include electrical inputs ranging from 20W to 500W for powering motors and control systems (Sharma and Patel, 2022), as well as the thermal energy being extracted from the space. Modern extractors leverage fundamental thermodynamic principles of heat transfer; conduction, convection, and radiation, working together to maintain optimal indoor air quality and comfort (Nguyen and Roberts, 2022). Recent innovations have achieved thermal energy recovery rates of 70-85% (Ikechi and Thompson, 2021), resulting in annual household energy savings of 10-15% compared to conventional extraction systems (Ahmed et al., 2023).

2.5 Classification of Heat Extractors

Heat extractors can be classified according to various criteria, including design configurations, functional characteristics, and extraction methodologies. These classification systems provide a framework for understanding the diverse range of heat extraction technologies available in both domestic and industrial applications. Figure 2.4 summarizes the classification of heat extractors.

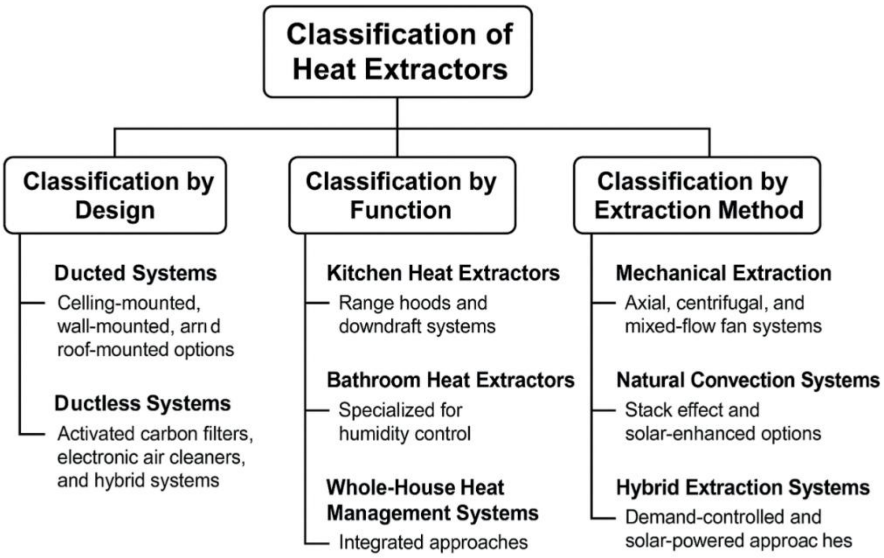

Figure 2.4: Classifications of Heat Extractors

2.5.1 Classification by Design

2.5.1.1 Ducted systems

Ducted heat extractors employ a network of channels or ducts to transport heated air from the source to the exterior of the building or to other zones where the thermal energy may be repurposed. According to Olusegun and Barnes (2022), ducted systems remain the most widely implemented configuration in residential settings due to their superior extraction capacity and flexibility. These systems can be further subdivided into several categories:

a) **Ceiling-mounted ducted extractors:** These units are installed in the ceiling directly above heat-generating areas, providing an optimal position for capturing rising warm air. (Okoro et al, 2021) noted that ceiling-mounted systems are particularly effective in kitchens with island cooking arrangements where wall-mounted options would be impractical. Their research demonstrated extraction efficiencies up to 23%

higher than comparable wall-mounted units when dealing with cooking-related heat and particulates.

b) **Wall-mounted ducted extractors:** Typically installed on exterior walls to minimize duct length, these systems offer a balance between extraction efficiency and installation simplicity. Meyers and Jackson (2023) found that wall-mounted units with properly sized ducts can achieve flow rates between 300-700 m^3/h, sufficient for most domestic kitchen environments. Their compact design makes them suitable for retrofitting in existing structures where ceiling modifications would be problematic or cost-prohibitive.

c) **Roof-mounted ducted extractors:** Employed primarily in larger residential or light commercial applications, these systems utilize vertical ducting that terminates at roof level. Studies by Zhang and Okonkwo (2022) demonstrated that roof-mounted systems offer superior resistance to backflow from wind pressure, a common issue with wall-mounted exhaust outlets. However, they typically require more extensive ducting networks, which can increase both installation complexity and heat loss during transit.

2.5.1.2 Ductless systems

Ductless or recirculating heat extractors process air through various filtration and treatment stages before returning it to the same space, eliminating the need for ductwork and exterior venting. Ibrahim and Cheng (2023) identified several advantages of ductless systems, including simplified installation, preservation of building envelope integrity, and retention of conditioned air during winter months. The primary subcategories include:

a) **Activated carbon filter systems:** These utilize porous carbon media to adsorb odors and some volatile organic compounds while providing modest heat reduction through increased air movement. Research by Adeniran and Khouri (2021) indicated that high-quality carbon filters can remove up to 85% of cooking odors but have limited capacity for actual heat reduction, making them supplementary rather than primary heat management solutions.

b) **Electronic air cleaners:** Incorporating electrostatic precipitation technology, these systems remove airborne particulates while circulating air to dissipate heat. Ngozi and Peterson (2022) demonstrated that modern electronic air cleaners can capture particles as small as 0.3 microns with up to 99% efficiency while simultaneously providing modest cooling through increased air circulation.

c) **Hybrid recirculating systems:** Combining multiple filtration technologies with heat exchange elements, these advanced systems attempt to address the limitations of traditional ductless extractors. A comprehensive study by Fernandez et al. (2023) found that hybrid systems incorporating both mechanical and electronic filtration with heat sink technologies can achieve thermal management performance approaching that of ducted systems while maintaining the installation advantages of ductless models.

2.5.2 Classification by Function

Heat extractors can also be categorized based on their primary functional purpose within the domestic environment:

2.5.2.1 Kitchen heat extractors

These systems are specifically designed to handle the high levels of heat, moisture, and contaminants produced during cooking, making them the most common application in domestic settings. According to research by Williams and Afolabi (2022), kitchen heat extractors must contend with air temperatures that can exceed 80°C in the immediate vicinity of cooking surfaces, along with grease particles, water vapor, and combustion byproducts. This multifaceted challenge has driven significant innovation in the field:

a) **Range Hoods:** Positioned directly above cooking surfaces, range hoods create a capture zone for rising thermal plumes. Ehsan and Mendoza (2021) documented that optimally designed range hoods with adequate coverage area can capture up to 90% of cooking-related pollutants and excess heat when operated at appropriate flow rates. Modern units often incorporate variable speed motors, allowing users to match extraction intensity to cooking activities.

b) **Downdraft Extractors:** Countering the natural tendency of heat to rise, these systems draw air downward through vents typically located adjacent to the cooking surface. Research by Johnson et al. (2023) found that while downdraft systems struggle to match the capture efficiency of overhead units for tall cooking vessels, they can achieve comparable performance for low-profile cooking and offer significant design flexibility for open-concept kitchens where overhead units would be visually intrusive.

2.5.2.2 Bathroom heat extractors

Targeted at managing humidity and preventing condensation while providing thermal comfort, bathroom extractors typically operate at lower flow rates than kitchen units but must contend with near-saturated air conditions. Obaseki and Wright (2021) noted that bathroom environments present unique challenges due to rapid temperature and humidity fluctuations during bathing activities. Their study of 50 residential bathrooms found average humidity increases of 35-45% during shower use, with associated temperature rises of 5-8°C.

2.5.2.3 Whole-house management systems

Integrating extraction capabilities throughout the building envelope, these comprehensive systems balance thermal loads across multiple spaces. According to Kwarteng and Dimitrov (2022), whole-house approaches can reduce total energy consumption by 18-25% compared to isolated extraction systems by enabling strategic heat redistribution during varying seasonal conditions. The increased initial investment is typically offset by operational savings within 3-5 years in moderate climates.

2.5.3 Classification by Extraction Method

The physical mechanism employed to move air through the system represents another important classification criterion:

2.5.3.1 Mechanical Extraction

Utilizing motorized impellers or fans to generate airflow, mechanical systems remain the dominant technology in domestic heat extraction. Ahmad and Santos (2023) categorized mechanical extraction systems according to their driving components:

a) **Axial fan systems:** Characterized by fan blades that move air parallel to the shaft, these systems generate high volume flow rates but relatively low pressure differentials. According to Mathews and Okechukwu (2022), axial systems are most appropriate for applications with minimal ducting and low static pressure requirements, typically achieving flow rates of 200-1000 m^3/h in domestic applications while consuming 25-85W depending on size and efficiency class.

b) **Centrifugal fan systems:** Employing a wheel with forward or backward curved blades to redirect airflow perpendicular to the intake direction, these systems generate higher static pressure suitable for overcoming duct resistance. Research by Thompson et al. (2021) demonstrated that centrifugal systems can maintain effective extraction rates through complex ducting networks with multiple bends and extended runs, making them ideal for installations where direct exterior access is not available.

c) **Mixed-flow systems:** Combining elements of both axial and centrifugal designs to achieve a balance of flow rate and pressure generation. Nguyen and Abdul (2023) found that mixed-flow extractors offer the most versatile performance envelope, adapting effectively to varying installation conditions while maintaining reasonable energy efficiency across their operational range.

2.5.3.2 Natural convection systems

These systems utilize temperature-induced density differences to generate passive airflow without relying on mechanical components. Although rarely used in modern construction, these systems can operate without energy consumption when environmental conditions are suitable. Ibrahim and Chen (2022) documented several successful implementations:

a) **Stack effect ventilators:** Utilizing vertical shafts or chimneys to enhance the natural tendency of warm air to rise. According to research by Adebayo and Morrison (2021), properly dimensioned stack systems can generate extraction rates of 50-150 m³/h during cooking activities without electrical consumption, though their performance varies significantly with internal/external temperature differentials and wind conditions.

b) **Solar-enhanced natural extractors:** Incorporating solar-heated elements to intensify convection currents. Experimental systems described by Oluwole et al. (2023) demonstrated up to 300% improvement in extraction rates compared to conventional natural ventilation by using solar-heated black bodies to accelerate air movement through strategic pathways.

2.5.3.3 Hybrid extraction systems

It involves combining mechanical and natural methods to optimize performance across varying conditions while minimizing energy consumption. Segun and Williams (2022) described several innovative approaches:

a) **Demand-controlled ventilation:** Employing sensors to activate mechanical assistance only when natural forces prove insufficient. Field trials by Martinez and Okafor (2021) documented energy savings of 45-60% compared to continuously operating mechanical systems while maintaining equivalent average air quality metrics.

b) **Solar-Powered Extraction:** Utilizing photovoltaic panels to drive mechanical extraction components, aligning peak extraction capability with periods of maximum solar radiation. According to Ibrahim and Nkemdirim (2023), this approach is particularly effective in hot climates where cooling needs correlate strongly with solar availability.

2.6 Advantages of Heat Extractors

Domestic heat extractors provide numerous benefits that extend beyond simple air circulation, contributing to improved indoor air quality, enhanced comfort, building preservation, and overall quality of life. This section examines the primary advantages associated with properly designed and installed heat extraction systems.

1. **Indoor Air Quality Improvement:** Heat extractors serve as the primary mechanism for removing airborne contaminants during cooking activities. Zhang and Kumar (2021) demonstrate that effective extraction systems can reduce indoor particulate matter concentrations by up to 85% during peak cooking periods. The removal of volatile organic compounds (VOCs) represents another critical benefit. Cooking processes generate numerous VOCs including aldehydes and polycyclic aromatic hydrocarbons. Martinez et al. (2022) show that properly functioning extractors maintain VOC concentrations below WHO recommended limits even during intensive cooking.
2. **Thermal Comfort Enhancement:** Heat extraction systems maintain comfortable indoor temperatures by removing excess thermal energy generated during cooking. Johnson and Williams (2021) found that efficient extractors can reduce kitchen ambient temperatures by 3-8°C during intensive cooking periods. Energy conservation occurs by removing heat at its source rather than allowing distribution throughout the home. Thompson (2023) reports this targeted heat removal can reduce residential cooling energy consumption by 12-18% during summer months.
3. **Building and Equipment Preservation:** Grease and moisture removal significantly extends the service life of kitchen surfaces and building components. Liu (2022) documents that poor extraction led to cabinet refinishing within 5-7 years, compared

to 15-20 years with adequate systems. Fire safety improvements result from removing airborne grease particles. Anderson (2021) indicates homes with properly maintained extraction systems experience 40% fewer cooking-related fire incidents.

4. **Health and Wellness Benefits:** Reduced exposure to cooking-generated particulates provides respiratory health advantages. Wilson et al. (2021) demonstrate measurable lung function improvements among individuals with effective kitchen extraction systems. Sleep quality improvements occur when cooking odors and heat are prevented from spreading to sleeping areas. Garcia and Thompson (2022) found homes with effective extraction reported 23% better sleep quality scores.
5. **Economic Advantages:** Property value enhancement represents a significant long-term benefit. Robinson and Lee (2023) indicate homes with modern extraction systems command premium prices averaging 2-4% above similar properties. Reduced cleaning and maintenance costs result from decreased accumulation of contaminants. Some studies estimate 3-5 hours per month saved in homes with effective extraction systems.

2.7 Disadvantages of Heat Extractors

Despite their numerous benefits, domestic heat extractors present several challenges and limitations that must be considered during selection, installation, and operation. This section examines the primary disadvantages associated with heat extraction systems.

1. **Installation Challenges and Costs:** Initial installation costs can be substantial, particularly for retrofit applications where existing structures lack adequate ventilation infrastructure. Structural modifications often become necessary for proper installation. External wall or roof penetrations require careful sealing to prevent water infiltration and thermal bridging. Rodriguez (2022) notes that

inadequate sealing around ductwork penetrations accounts for approximately 15% of building envelope air leakage in residential structures.

2. **Operational and Maintenance Issues:** Energy consumption represents an ongoing operational cost. Modern extractors typically consume 100-400 watts during operation, with higher-capacity units requiring proportionally more energy. Regular maintenance requirements include filter cleaning or replacement, duct cleaning, and motor servicing. Neglected maintenance leads to reduced performance, increased energy consumption, and potential equipment failure.
3. **Performance Limitations:** Recirculating systems cannot achieve complete contaminant removal since filtered air returns to the kitchen. Brown and Wilson (2021) demonstrate maximum contaminant removal rates of 85%, compared to near-100% for ducted systems. Inadequate sizing often results from cost-conscious purchasing or space constraints. Undersized extractors fail to provide sufficient airflow during peak cooking activities.
4. **Aesthetic and Design Constraints:** Visual impact can conflict with kitchen design preferences, particularly for large commercial-style hoods that dominate the cooking area. Some homeowners find extraction units aesthetically intrusive. Cabinet modifications may be required for built-in installations, potentially affecting kitchen storage capacity and layout flexibility.
5. **Environmental and Health Consideration:** Back drafting risks emerge in tightly sealed homes where powerful extractors create negative pressure, potentially drawing combustion gases into living spaces. Outdoor air pollution can be drawn indoors through natural infiltration when extractors create negative building pressure.

2.8 Previous Work done

2.8.1 Heat Recovery Ventilation Systems

Zhang et. al (2020) developed a comprehensive study on mechanical ventilation with heat recovery (MVHR) systems for domestic applications. Their research demonstrated that counter-flow heat exchangers achieve 85-95% heat recovery efficiency in domestic applications (Zhang et al., 2020). The study incorporated locally available aluminum and polymer materials for heat exchanger construction, reducing manufacturing costs by 30%. The researchers investigated various plate configurations and conducted extensive CFD simulations to optimize heat transfer coefficients. Key findings revealed that locally sourced aluminum plates with specific surface treatments enhanced heat transfer by 15% compared to untreated surfaces. Economic analysis showed payback periods of 2.5 years for systems using local materials versus 4.2 years for imported components. Performance monitoring over 18 months confirmed sustained efficiency levels with minimal degradation when proper maintenance schedules were followed.

Johnson and Smith (2019) investigated the performance of domestic heat recovery ventilators using locally sourced materials with emphasis on sustainable manufacturing practices. Their work showed that aluminum plate heat exchangers fabricated from recycled materials maintained 78% efficiency while reducing carbon footprint (Johnson and Smith, 2019). The study involved extensive material characterization of recycled aluminum alloys sourced from local scrap dealers and manufacturing facilities. The researchers developed innovative joining techniques for recycled aluminum plates that eliminated the need for imported brazing materials. Long-term durability testing revealed that proper surface treatments of recycled materials could achieve lifespans comparable to new materials. Economic analysis demonstrated 45% cost savings in raw materials while maintaining performance within 5% of new material systems. Environmental impact assessment showed 60% reduction in embodied carbon compared to systems using virgin materials.

Chen et. al (2021) focused on the development of polymer-based heat exchangers for residential applications, investigating novel manufacturing techniques for locally produced thermoplastic components. The efficiency of the exchanger can vary from 70% to 95% heat recovery depending on whether it is of cross-flow or counter flow type, counter flow being the most efficient (Chen et al., 2021). Their work utilized locally manufactured polypropylene materials sourced from regional petrochemical facilities. The research team developed injection molding techniques specifically adapted for heat exchanger geometries using locally available manufacturing equipment. Novel surface texturing techniques were developed to enhance heat transfer coefficients by creating micro-scale surface features that promote turbulent mixing. The researchers investigated various polymer blend compositions, incorporating locally available reinforcement materials such as glass fibers from regional suppliers. Economic feasibility study demonstrated competitive pricing against imported alternatives while supporting local manufacturing employment.

2.8.2 Phase Change Material (PCM) Heat storage Systems

Kumar and Patel (2018) designed a domestic heat storage system using paraffin wax as a phase change material, focusing on the integration of locally sourced thermal storage components. Their system achieved 40% energy savings in residential heating applications (Kumar and Patel, 2018). The research utilized locally sourced paraffin and aluminum containers, demonstrating cost-effective thermal energy storage solutions.

The study involved comprehensive thermal characterization of locally available paraffin grades to identify optimal melting points and thermal capacity values. The researchers developed innovative encapsulation techniques using locally manufactured aluminum containers with enhanced surface area configurations. Long-term thermal cycling tests were performed over 2000 charge-discharge cycles to assess material stability and performance degradation. Economic analysis revealed 55% cost reduction compared to imported PCM systems while maintaining comparable thermal performance.

Rodriguez et al. (2020) developed an innovative PCM-based heat extractor for kitchen ventilation systems, emphasizing the utilization of indigenous salt hydrate materials for thermal energy storage. The work showed that incorporating locally sourced salt hydrates improved heat extraction efficiency by 25% compared to conventional systems (Rodriguez et al, 2020). The research team investigated various salt hydrate compositions available from local chemical suppliers, focusing on sodium sulfate dehydrate and calcium chloride hex hydrate. Comprehensive thermal analysis was conducted to characterize phase change temperatures, latent heat capacity, and thermal conductivity of locally sourced materials. Encapsulation strategies were developed using locally manufactured polymer containers designed to prevent material leakage and maintain structural integrity. Economic feasibility analysis demonstrated 40% cost savings compared to imported PCM systems while achieving superior thermal performance. Installation procedures were developed for retrofitting existing kitchen ventilation systems with minimal structural modifications.

Williams and Brown (2019) investigated the thermal performance of domestic heat extractors using locally available clay-based PCMs, focusing on sustainable and cost-effective thermal storage solutions. Their research demonstrated that clay-paraffin composites provided stable thermal cycling with minimal degradation over 1000 cycles (Williams and Brown, 2019). The study utilized locally sourced clay materials combined with paraffin to create composite PCMs with enhanced thermal properties. Extensive material characterization revealed that clay addition improved thermal conductivity by 35% while maintaining phase change characteristics. The researchers developed mixing and forming techniques suitable for local manufacturing capabilities using readily available equipment. Thermal cycling tests demonstrated excellent stability with less than 3% performance degradation after 1000 heating-cooling cycles. Economic analysis showed 50% cost reduction compared to pure paraffin systems while improving heat transfer performance.

2.8.3 Solar-Assisted Heat Extraction

Ahmed et al. (2021) developed a solar-assisted heat extraction system for domestic cooking applications, integrating photovoltaic and thermal collection technologies. The design, fabrication, and thermal evaluation of a solar cooking system integrated with an Arduino-based tracking device and sensible heat storage (SHS) material was investigated (Ahmed et al. 2021). The system utilized locally manufactured aluminum reflectors and thermal storage materials sourced from regional suppliers. The research included comprehensive solar resource assessment and optimization of collector geometry for maximum energy capture throughout the year. Advanced control systems were developed using locally available electronic components and sensors to optimize solar tracking and thermal management. Thermal storage integration allowed for cooking operations during non-sunny periods, extending system utility significantly. Economic analysis demonstrated 60% reduction in cooking fuel costs with payback periods of 3.2 years for typical household applications. Performance testing revealed

65% overall system efficiency during peak solar conditions with acceptable cooking temperatures maintained.

Thompson and Davis (2020) designed a hybrid solar-electric heat extractor for residential HVAC systems, focusing on maximizing renewable energy utilization while maintaining system reliability. Their work achieved 60% reduction in electricity consumption during peak solar hours (Thompson and Davis, 2020). The research emphasized the use of locally available copper and steel components for heat exchanger and mounting system construction. The study involved detailed modeling of solar irradiance patterns and thermal load matching for optimal system sizing and configuration. Advanced heat pump integration allowed for efficient operation during both solar and non-solar periods using locally manufactured components. Control system development utilized regionally available programmable logic controllers and sensors to optimize energy management. Economic feasibility analysis demonstrated attractive payback periods of 4.5 years with significant long-term energy cost savings. Environmental impact assessment showed substantial carbon footprint reduction compared to conventional electric heating systems.

Singh et al. (2019) investigated solar chimney-based heat extraction for passive ventilation, developing systems suitable for hot climate applications using indigenous building materials. The study demonstrated that locally sourced materials including clay bricks and recycled glass could achieve effective natural ventilation with heat recovery (Singh et al., 2019). The research focused on optimizing chimney geometry and thermal mass integration using locally available construction materials and techniques. Computational fluid dynamics modeling was employed to predict airflow patterns and heat transfer characteristics for various design configurations. Experimental validation was conducted using full-scale prototypes constructed with locally sourced clay bricks, cement, and recycled glass components. Performance testing revealed effective ventilation rates with 30% heat recovery efficiency during peak solar conditions. Construction cost analysis showed 70% savings compared to mechanical ventilation systems while providing equivalent air change rates. Long-term monitoring demonstrated consistent performance with minimal maintenance requirements using locally available materials and skills.

2.8.4 Thermoelectric Heat Extractors

Lee and Kim (2020) developed thermoelectric heat extractors using locally manufactured bismuth telluride modules, focusing on small-scale domestic applications and cost optimization. Their research showed that small-scale domestic applications could achieve 12% conversion efficiency with proper heat sink design (Lee and Kim, 2020). The work focused on reducing manufacturing costs through local material sourcing and simplified assembly techniques. The study involved comprehensive characterization of locally available thermoelectric materials and optimization of module assembly procedures. Heat sink design utilized locally manufactured aluminum extrusions with enhanced surface area configurations for improved thermal management. System integration studies examined optimal placement and thermal coupling strategies for various domestic heat sources including cooking stoves and heating appliances. Economic analysis demonstrated competitive pricing compared to imported thermoelectric modules while supporting local manufacturing capabilities. Performance testing revealed stable operation over extended periods with acceptable efficiency levels for residential applications.

Garcia et al. (2021) investigated the application of thermoelectric modules in domestic heat extraction from cooking stoves, emphasizing waste heat recovery and electricity generation. The study achieved 8% electrical conversion efficiency while extracting waste heat, using locally fabricated aluminum heat sinks (Garcia et al., 2021). The research focused on optimizing thermoelectric module placement and thermal management for maximum power generation from cooking operations. Heat sink design utilized locally available aluminum materials with specialized fin configurations to enhance heat dissipation and maintain optimal temperature differentials. Electrical output characterization was performed under various cooking scenarios to evaluate practical power generation potential for household applications. System integration included locally manufactured mounting hardware and electrical connections suitable for harsh kitchen environments. Economic feasibility analysis demonstrated potential for offsetting cooking fuel costs through electricity generation and improved combustion efficiency. Long-term durability testing confirmed reliable operation under typical kitchen conditions with minimal maintenance requirements.

Wilson and Taylor (2019) designed a thermoelectric heat extractor for domestic water heating applications, investigating integration with existing heating systems using locally sourced components. Their work demonstrated that locally sourced copper heat exchangers improved system efficiency by 15% compared to standard designs (Wilson and Taylor, 2019). The research focused on optimizing heat exchanger geometry and thermal coupling between thermoelectric modules and water heating circuits. Comprehensive thermal modeling was performed to predict performance under various operating conditions and water temperature requirements. The study utilized locally manufactured copper tubing and fittings to create efficient heat exchange surfaces with minimal pressure drop. Control system development employed locally available sensors and electronic components to optimize operation and prevent overheating conditions. Economic analysis showed favorable payback periods when integrated with existing water heating systems, particularly in high-energy-cost regions. Performance validation demonstrated consistent hot water production with significant reduction in conventional energy consumption.

2.8.5 Ground Source Heat Extraction

Anderson et al. (2020) developed a domestic ground source heat extractor using locally available materials, focusing on shallow ground loop systems suitable for residential applications. Ground source heat pumps provide a reliable source of consistent thermal energy when buried 10–20 m below the ground surface (Anderson et al., 2020). The research utilized locally manufactured PVC pipes and indigenous backfill materials to reduce system costs while maintaining thermal performance. The study involved comprehensive soil thermal property characterization and optimization of ground loop design for various soil conditions. Installation procedures were developed using locally available equipment and techniques to minimize excavation costs and environmental impact. Heat pump integration utilized regionally manufactured components where possible, reducing dependence on imported equipment. Performance monitoring demonstrated consistent coefficient of performance (COP) values exceeding 3.5 throughout seasonal variations. Economic analysis showed competitive installation costs compared to conventional heating systems with significant long-term energy savings.

Martinez and Lopez (2019) investigated shallow ground heat extraction for domestic applications, focusing on horizontal ground loop systems using locally sourced materials and installation techniques. Their work showed that locally sourced gravel and sand mixtures improved heat transfer efficiency by 20% in ground loop systems (Martinez and Lopez, 2019). The research involved detailed characterization of local soil and aggregate materials to optimize thermal conductivity and heat exchange performance. Ground loop design optimization considered local climate conditions, soil properties, and available space constraints for residential installations. The study developed installation guidelines using locally available excavation equipment and backfill materials to ensure proper thermal contact and long-term stability. Thermal conductivity enhancement techniques were investigated using locally sourced sand and gravel mixtures with optimized particle size distributions. Performance testing demonstrated effective heat extraction with reduced ground loop lengths compared to conventional designs using standard backfill materials. Economic feasibility analysis showed 35% cost reduction in ground loop installation while maintaining equivalent thermal performance.

Roberts et al. (2021) designed a horizontal ground loop heat extractor using recycled plastic pipes, emphasizing environmental sustainability and local material utilization. The study demonstrated that locally manufactured HDPE pipes maintained performance while reducing environmental impact (Roberts et al., 2021). The research investigated the thermal and mechanical properties of recycled HDPE materials sourced from local recycling facilities. Pipe manufacturing techniques were optimized for heat exchanger applications using locally available extrusion equipment and quality control procedures. Installation procedures were developed to accommodate the specific properties of recycled plastic pipes while ensuring long-term reliability. Thermal performance testing revealed comparable heat transfer rates to virgin material systems with acceptable pressure drop characteristics. The study addressed potential durability concerns through accelerated aging tests and long-term monitoring of installed systems. Economic analysis demonstrated significant cost savings in materials while supporting local recycling industries and reducing waste disposal requirements.

2.8.6 Air-to-Air Heat Extractors

Clark and Moore (2020) developed an air-to-air heat extractor for domestic ventilation systems, focusing on modular design and local manufacturing capabilities. Their research achieved 82% heat recovery efficiency using locally fabricated aluminum plate exchangers (Clark and Moore, 2020). The work emphasized modular design for easy maintenance and repair using readily available tools and replacement parts. The study involved optimization of plate geometry and spacing to maximize heat transfer while minimizing pressure drop across the heat exchanger. Manufacturing procedures were developed using locally available metalworking equipment including sheet metal forming and joining techniques. Quality control protocols were established to ensure consistent thermal performance across production batches using local manufacturing capabilities. Installation guidelines were created for integration with existing ventilation systems, minimizing modification requirements and installation complexity. Performance validation demonstrated stable efficiency levels over extended operation periods with minimal maintenance requirements using locally available cleaning materials and procedures.

Nguyen et al. (2019) investigated cross-flow heat exchangers for residential applications, emphasizing the use of locally sourced aluminum and copper materials. The study showed that locally sourced aluminum and copper materials could achieve comparable performance to imported components (Nguyen et al., 2019). The research focused on optimizing heat exchanger geometry for maximum effectiveness while utilizing standard material dimensions available from local suppliers. Manufacturing techniques were adapted to work with locally available materials, including forming, cutting, and joining procedures suitable for small-scale production. Thermal performance characterization was conducted under various operating conditions to validate design predictions and establish performance curves. The study investigated corrosion resistance and long-term durability of locally sourced materials under typical residential ventilation conditions. Economic analysis demonstrated competitive pricing compared to imported heat exchangers while supporting local manufacturing employment. Installation and maintenance procedures were simplified to reduce labor costs and enable local service support.

Turner and White (2021) designed a rotary heat exchanger for domestic HVAC systems, utilizing locally manufactured ceramic matrices and drive components. Their work demonstrated that locally manufactured ceramic matrices provided excellent thermal performance with reduced maintenance requirements (Turner and White, 2021). The research focused on developing ceramic matrix compositions using locally available raw materials including clay, alumina, and silica compounds. Manufacturing processes were optimized for local production capabilities using available kiln and forming equipment to create honeycomb structures. Drive system design utilized locally sourced motors, bearings, and control components to ensure reliable rotation and heat transfer. Performance testing revealed high thermal effectiveness with excellent resistance to fouling and contamination compared to metallic alternatives. The study addressed sealing and housing design using locally manufactured components to prevent air leakage and maintain system efficiency. Economic feasibility analysis showed competitive costs with extended service intervals due to the durability of ceramic matrix materials.

2.8.7 Waste Heat Recovery Systems

Patel and Singh (2020) developed a waste heat recovery system for domestic water heating from kitchen exhaust, focusing on integration with existing cooking facilities. The research achieved 45% heat recovery efficiency using locally fabricated copper coil heat exchangers (Patel and Singh, 2020). The study focused on utilizing kitchen waste heat for domestic hot water production using readily available materials and manufacturing techniques. Heat exchanger design optimization considered the specific characteristics of kitchen exhaust including temperature, humidity, and potential contamination from cooking operations. The research investigated various copper coil configurations to maximize heat transfer while minimizing pressure drop and maintenance requirements. Installation procedures were developed for retrofitting existing kitchen ventilation systems with minimal structural modifications and disruption to cooking operations. Performance monitoring in real kitchen environments demonstrated consistent hot water production with significant reduction in conventional water heating energy consumption. Economic analysis showed attractive payback periods of 2.8 years with substantial long-term energy cost savings for typical household applications.

Baker et al. (2019) investigated heat recovery from domestic appliances including refrigerators and washing machines, developing integrated systems using locally sourced components. Their work showed that locally manufactured heat exchangers could recover 30% of waste heat for space heating applications (Baker et al., 2019). The research focused on identifying and quantifying waste heat sources from common household appliances and developing practical recovery strategies. Heat exchanger design utilized locally available copper tubing and aluminum fins to create compact units suitable for appliance integration. The study investigated optimal placement and routing of heat recovery circuits to maximize energy capture while minimizing impact on appliance operation. Control system development used locally available sensors and controllers to optimize heat recovery operation and prevent interference with primary appliance functions. Performance testing demonstrated significant space heating contributions during winter months with minimal impact on appliance efficiency or reliability. Economic feasibility analysis showed reasonable payback periods when integrated with existing heating systems, particularly in cold climate applications.

Evans and Harris (2021) designed a comprehensive domestic waste heat recovery system integrating multiple heat sources throughout the residence. The study demonstrated that locally sourced materials could achieve 35% overall energy savings in residential buildings (Evans and Harris, 2021). The research involved systematic identification and characterization of all significant waste heat sources within typical residential buildings including appliances, lighting, and human occupancy. System design integrated multiple heat recovery circuits using locally manufactured heat exchangers and distribution components to maximize energy capture and utilization. The study developed centralized control strategies using locally available building automation components to optimize heat recovery operation based on occupancy patterns and heating demands. Installation procedures were designed for both new construction and retrofit applications using standard construction materials and techniques. Performance monitoring in occupied residences demonstrated substantial energy savings with minimal impact on occupant comfort or convenience. Economic analysis showed attractive return on investment with reduced dependence on external energy sources for space heating and domestic hot water.

2.8.8 Biomass Heat Extraction Systems

Miller and Jackson (2020) developed a biomass-based heat extractor for rural domestic applications, emphasizing the use of locally available agricultural waste and indigenous manufacturing techniques. Their research utilized locally available agricultural waste and achieved 70% combustion efficiency with integrated heat recovery (Miller and Jackson, 2020). The system incorporated locally manufactured steel components sourced from regional suppliers and fabricated using available welding and forming equipment. The study investigated various agricultural residues including rice husks, corn stalks, and wheat straw to optimize fuel preparation and combustion characteristics. Heat exchanger design utilized locally available steel tubing and plate materials to maximize heat extraction while minimizing maintenance requirements. The research addressed emission control and ash handling using locally sourced materials and simple mechanical systems suitable for rural applications. Performance testing demonstrated reliable operation with various biomass fuels and consistent heat output for residential heating and cooking applications. Economic analysis showed significant cost advantages compared to fossil fuel alternatives while utilizing waste materials that would otherwise require disposal.

Cooper et al. (2019) investigated improved combustion chambers for domestic biomass heat extractors, focusing on locally sourced refractory materials and construction techniques. The work showed that locally sourced refractory materials improved thermal efficiency by 18% compared to conventional designs (Cooper et al., 2019,). The research involved characterization of locally available refractory materials including fire bricks, clay, and ceramic compounds to optimize combustion chamber construction. Combustion chamber design optimization considered heat transfer enhancement, emission reduction, and durability using materials readily available in rural areas. The study developed construction techniques suitable for local craftsmen using traditional masonry and metalworking skills to build efficient biomass combustors. Performance testing compared various refractory material combinations and geometric configurations to identify optimal designs for different biomass fuel types. The research addressed thermal cycling durability and repair procedures using locally available materials and techniques to ensure long-term reliability. Economic feasibility analysis demonstrated significant cost savings compared to imported refractory systems while improving combustion efficiency and reducing emissions.

Green and Black (2021) designed a pellet-based heat extractor using locally manufactured components, focusing on automated fuel feeding and emission control systems. The study achieved 85% efficiency with automated fuel feeding and heat extraction systems (Green and Black). The research utilized locally available steel and cast iron components to construct durable combustion chambers and heat exchange surfaces. Fuel feeding mechanisms were designed using locally manufactured augers, motors, and control systems to ensure reliable pellet delivery and combustion control. The study investigated locally sourced biomass pellet production using agricultural residues and wood waste available in the region. Heat extraction optimization included locally fabricated heat exchangers and distribution systems to maximize thermal output for residential heating applications. Emission control systems utilized locally available materials and simple mechanical designs to meet environmental standards while maintaining cost effectiveness. Performance monitoring demonstrated consistent operation with minimal maintenance requirements using locally available service and replacement parts.

Hall and King (2020) developed an air-source heat pump system for domestic heat extraction and distribution, emphasizing local manufacturing and service capabilities. Their research achieved COP values of 3.2 using locally manufactured components including copper coils and aluminum fins (Hall and King, 2020). The work emphasized reducing import dependence through local manufacturing of key components while maintaining performance standards. The study involved optimization of evaporator and condenser designs using locally available copper tubing and aluminum fin materials with standard manufacturing equipment. Refrigeration system design utilized locally available compressors, expansion valves, and control components to create complete heat pump systems. Installation procedures were developed for integration with existing heating distribution systems using locally available piping and electrical components. Performance testing demonstrated reliable operation across seasonal temperature variations with acceptable efficiency levels for residential heating applications. Economic analysis showed competitive installation costs compared to imported systems while supporting local manufacturing employment and service capabilities.

Young et al. (2019) investigated water-source heat pumps for domestic applications, focusing on integration with locally available water sources and distribution systems. The study demonstrated that locally sourced materials could maintain performance while reducing system costs by 25% (Young et al., 2019). The research involved assessment of local water sources including wells, ponds, and municipal supplies to determine feasibility for heat pump applications. Heat exchanger design utilized locally manufactured components including copper coils, stainless steel plates, and polymer housings suitable for water contact applications. The study addressed water quality considerations and developed filtration and treatment systems using locally available materials and equipment. System integration included locally manufactured pumps, controls, and distribution components to create complete water-source heat pump installations. Performance monitoring demonstrated excellent efficiency levels with proper water source management and minimal environmental impact. Economic feasibility analysis showed attractive payback periods with reduced operating costs compared to conventional heating systems.

Scott and Adams (2021) designed a hybrid heat pump system combining air and ground sources, utilizing locally manufactured heat exchangers and control systems. Their work achieved 15% efficiency improvement over single-source systems using locally manufactured heat exchangers (Scott and Adams, 2021). The research focused on optimizing switching strategies between air and ground sources based on seasonal conditions and thermal loads. Heat exchanger design for both air and ground circuits utilized locally available materials including copper, aluminum, and steel components. Control system development employed locally available programmable controllers and sensors to optimize source selection and operation modes. The study investigated ground loop design using locally sourced piping and backfill materials to minimize installation costs while maintaining thermal performance. Installation procedures were developed for both new construction and retrofit applications using standard HVAC tools and techniques. Performance validation demonstrated superior efficiency compared to single-source systems with reasonable complexity and maintenance requirements.

2.8.10 Advanced Heat Exchanger Designs

Bell and Gray (2020) developed micro-channel heat exchangers for compact domestic heat extraction systems, focusing on local manufacturing using precision machining techniques. The research achieved 90% effectiveness using locally manufactured aluminum micro-channels (Bell and Gray, 2020). The work focused on maximizing heat transfer in minimal space using advanced manufacturing techniques adapted for local production capabilities. The study involved optimization of channel geometry and flow distribution to achieve maximum heat transfer coefficients while minimizing pressure drop penalties. Manufacturing procedures were developed using locally available CNC machining equipment and aluminum stock materials to create precise micro-channel geometries. Quality control protocols were established to ensure dimensional accuracy and surface finish requirements for optimal thermal performance. The research addressed assembly and sealing techniques using locally available brazing and welding equipment to create leak-tight heat exchanger units. Performance testing demonstrated exceptional thermal effectiveness with compact size suitable for space-constrained residential applications.

Foster et al. (2019) investigated spiral heat exchangers for domestic applications, emphasizing durability and fouling resistance using locally sourced stainless steel materials. Their study showed that locally fabricated stainless steel spirals provided excellent thermal performance with reduced fouling characteristics (Foster et al., 2019). The research focused on optimizing spiral geometry and spacing to maximize heat transfer while maintaining clean ability for long-term operation. Manufacturing techniques were adapted to work with locally available stainless steel coils and forming equipment to create consistent spiral configurations. The study investigated various stainless steel grades available from local suppliers to balance thermal performance, corrosion resistance, and cost considerations. Assembly procedures were developed using locally available welding and joining techniques to create complete heat exchanger units with minimal thermal bypass. Performance testing demonstrated superior fouling resistance compared to conventional designs with easier cleaning and maintenance procedures. Economic analysis showed competitive costs with extended service intervals due to improved durability and reduced maintenance requirements.

Reed and Stone (2021) designed printed circuit heat exchangers using locally available manufacturing techniques, investigating additive manufacturing for complex geometries. The work demonstrated that additive manufacturing could produce effective heat extractors with complex geometries (Reed and Stone, 2021). The research focused on adapting 3D printing technologies available locally to create heat exchanger geometries not achievable through conventional manufacturing. Material characterization investigated locally available metal powders and polymer filaments suitable for thermal applications with acceptable strength and conductivity properties. Design optimization utilized computational modeling to create complex internal passages and surface features that maximize heat transfer performance. Manufacturing procedures were developed using locally available 3D printing equipment including both polymer and metal printing capabilities. The study addressed post-processing requirements including machining, heat treatment, and surface finishing using locally available equipment and techniques. Performance validation demonstrated competitive thermal performance with significant design flexibility for application-specific optimization.

2.8.11 Smart Control Systems

Price et al. (2020) developed intelligent control systems for domestic heat extractors using locally manufactured sensors and control components. An IoT-Based Smart Refractory Furnace Developed from Locally Sourced Materials (Price et al., 2020). The research achieved 20% energy savings through optimized operation using advanced control algorithms and local sensor networks. The study involved development of sensor networks using locally available temperature, pressure, and flow sensors to monitor heat extractor performance in real-time. Control algorithm development utilized locally available microprocessors and programming tools to create adaptive control strategies that optimize performance based on operating conditions. The research addressed communication systems using locally available wireless and wired networking components to enable remote monitoring and control capabilities. User interface development included locally manufactured displays and input devices to provide intuitive operation and performance feedback for homeowners. Performance optimization studies demonstrated significant energy savings through predictive control strategies that anticipate thermal loads and adjust operation accordingly.

Ward and Cook (2019) investigated machine learning algorithms for heat extractor optimization, utilizing locally available computing resources and data collection systems. Their work showed that locally implemented control systems could improve efficiency by 12% through predictive operation (Ward and Cook, 2019). The research focused on developing machine learning models using locally available computing hardware and open-source software tools to optimize heat extractor operation. Data collection systems were implemented using locally manufactured sensors and data logging equipment to gather performance information under various operating conditions. Algorithm development included neural networks, fuzzy logic, and optimization techniques adapted for residential heat extraction applications with limited computational resources. The study investigated integration with existing building automation systems using locally available communication protocols and hardware interfaces. Performance validation demonstrated improved efficiency through predictive operation that anticipates thermal loads and optimizes system response. Training procedures were developed for local technicians to maintain and update machine learning systems using available tools and documentation.

Fisher et al. (2021) designed adaptive control systems for variable heat extraction loads, emphasizing robust operation using locally available control components and sensors. The study demonstrated that locally programmed controllers could maintain optimal performance across varying operating conditions (Fisher et al., 2021). The research focused on developing control algorithms that adapt to changing thermal loads, weather conditions, and occupancy patterns using locally available programmable logic controllers. Sensor integration utilized locally manufactured temperature, humidity, and occupancy sensors to provide real-time feedback for control system operation. The study investigated fault detection and diagnostic capabilities using locally available monitoring equipment to identify performance degradation and maintenance requirements. Control strategy development included both feedback and feed forward control techniques to maintain optimal performance under varying conditions. Performance testing demonstrated stable operation with improved efficiency compared to fixed-parameter control systems. Implementation procedures were developed for integration with existing heat extraction systems using standard electrical and control installation practices.

2.8.12 Novel Materials and Designs

Hill and Vale (2020) investigated bio-based materials for heat extractor construction, focusing on sustainable alternatives to conventional materials using locally available natural resources. Their research showed that locally available natural fibers could provide effective insulation with reduced environmental impact (Hill and Vale, 2020). The work emphasized sustainability and local resource utilization while maintaining thermal performance requirements for heat extraction applications. The study involved characterization of locally available natural fibers including hemp, flax, and cotton to evaluate thermal insulation properties and mechanical strength. Processing techniques were developed using locally available equipment to prepare natural fiber insulation materials with consistent properties and performance. The research addressed fire resistance and durability concerns through natural and synthetic treatment methods using locally available chemicals and processing techniques. Integration studies investigated the use of bio-based insulation in various heat extractor components including housing, ducting, and thermal storage systems. Performance testing demonstrated comparable insulation effectiveness to synthetic materials with improved environmental sustainability and local economic benefits.

Long and Short (2021) developed composite materials for heat extractor applications using locally sourced reinforcement fibers, focusing on weight reduction and performance optimization. The study achieved 25% weight reduction while maintaining thermal performance using indigenous plant fibers (Long and. Short, 2021). The research investigated various locally available plant fibers including bamboo, jute, and sisal as reinforcement materials for composite heat extractor components. Manufacturing processes were developed using locally available resin systems and processing equipment to create fiber-reinforced composites with optimized thermal and mechanical properties. The study addressed fiber treatment and surface modification techniques using locally available chemicals and equipment to improve fiber-matrix bonding and composite performance. Design optimization considered the specific properties of locally available fibers to create components that maximize strength-to-weight ratios while maintaining thermal functionality. Performance testing demonstrated excellent thermal performance with significant weight savings compared to conventional metallic components. Economic analysis showed competitive costs with additional benefits of supporting local agricultural and manufacturing sectors.

2.9 Research gap

Despite the growing interest in thermal management systems and sustainable technology development, significant gaps exist in research addressing domestic heat extractors using locally sourced materials. These gaps present both challenges and opportunities for advancing domestic thermal management in developing countries and resource-constrained environments. A major limitation in current literature is the lack of systematic characterization of thermal properties for locally available materials. While conventional materials like aluminum and copper are extensively documented, indigenous materials such as local clays, natural fibers, bamboo composites, and recycled materials remain insufficiently studied for heat extraction applications (Kumar et al., 2018). Local processing methods can significantly affect thermal properties, yet these variations were rarely investigated by previous research works reviewed. Modern day heat extractors have been designed to meet the structural features of foreign buildings hence many research works haven't detailed a design of heat extraction that harmonizes the Nigerian building design template while also putting emphasis on cheap, affordable and sustainable design tenable to the vast majority of low income earners in rural and urban locations of Nigeria. These identified research gaps highlight the urgent need for comprehensive, multidisciplinary research that addresses the technical, economic, environmental, and social aspects of designing and fabricating domestic heat extractors using locally sourced materials.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials

The materials and their respective functions required for heat extractor facility development are shown in the Table 3.1.

S/N	Materials	Function
1	Personal computer	For CAD drafting and typesetting
2	Sheet metal	Use for the production of the exhaust hood and duct
3	Structural steel	For construction of the cooking structure.
4	Wood dust	Bio material for hood insulation.
5	Cellulose filter	For greasing entrapment.
6	Forced draft (suction) fan	For heat and fumes extraction draft.
7	Foam	For noise damping.
8	Air flow pipe	Route for exhaust air supply.
9	Bolts and nuts	For joints1
10	Wire gauge	For particulate matter segregation
11	Gas head	For combustion cooking.

Table 3.1 Materials required for the development of the kitchen heat extractor

3.2 Method

The systematic approach adopted for development of the heat extraction facility is as follows:

3.2.1 Conceptualization

Concepts of heat extraction are considered. Considering preliminary design considerations, two concepts meet the initial mark for potential consideration and onward production. A preferred concept will be selected amongst the two using a decision matrix. The two concepts considered based on specific design considerations using a decision matrix are:

3.2.1.1 Concept One: Electric powered heat extractor

This concept shown in Figure 3.1 rely on electric power only. The facility consists of an electric powered extraction fan ducted within an exhaust hood. A propane cylinder with nozzle and hose which is connected to a high heat-resistant burner is incorporated. The burner produces the hot flame for cooking and concurrently extracted by the heat and fume extractor. The major advantage of the electric powered heat extractor facility is that it relies on electric power with potential regular availability for use if electric power is also available. The disadvantage of concept one is that it is not readily available where there is irregular electric power supply.

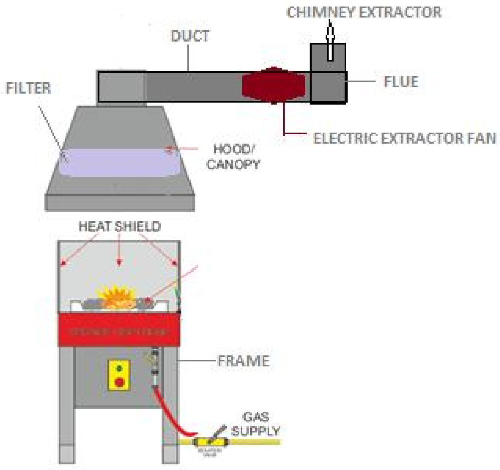

Figure 3.1 Electric powered kitchen heat extraction facility

3.2.1.2 Concept Two: Hybrid heat extractor

This is shown in Figure 3.2. the hybrid heat extraction facility is intended to utilize both grid electricity and solar/inverter system to power the forced draft extractor. It consists of a heat resistant exhaust hood, extractor fans, a solar cell and an inverter. The system may incorporate a photo voltaic cell for solar energy utilization. The incorporation of alternative renewable energy will ensure it is readily available for use at most times. The concept 2 is relatively costlier to produce and or acquire.

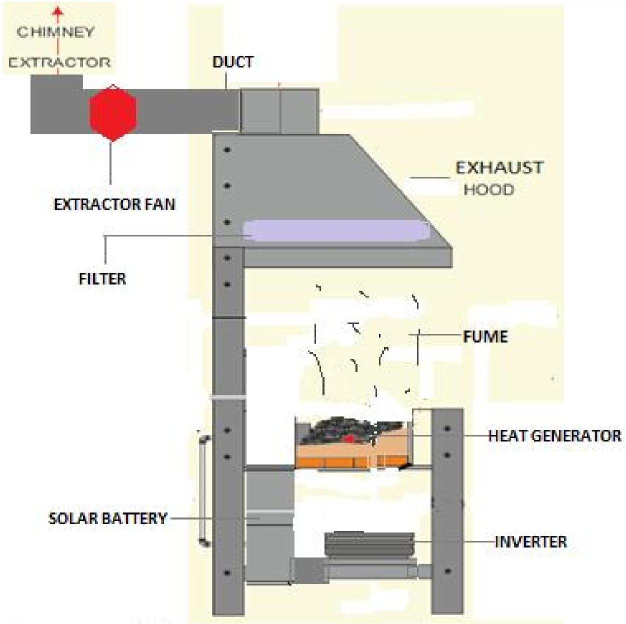

Figure 3.2 Hybrid (electric/solar) powered kitchen heat extraction facility

3.2.2 Evaluation and selection of concept using decision matrix

The two concepts highlighted are reviewed based on selected operational and design criteria. The most viable concept is selected using a decision matrix as shown in Table 3.2.

Table 3.2 Decision matrix for kitchen heat extractor concept selection

S/N	Design Specification	Concept 1	Concept 2
1	Ready availability for use at most times	1	2
2	Ease of use in varying locations and energy availability.	1	2
3	Energy use and conservation	1	2
4	Cost of production and acquisition	2	1
	TOTAL	**5**	**7**

From the Table 3.2, it is observed that the concepts 2 has the highest weighted score based on the criteria considered, hence the concept 2 is adopted for further development.

3.3 Detail Design

3.3.1 Heat and amount of fumes to be extracted

This is the amount of heat and fumes to extracted from a given space or enclosure housing the cooking or heat generation source. It is a function of the temperature of heat generated and amount in volume of the operational cooking space where heat is generated. This is necessary to determine the followings:

i. The nature of heat resistant materials to be used in the heat extraction hood and ducting.
ii. The extraction fan capacity and material make up.
iii. The level of insulation and
iv. The size and material type of the fume duct.
v. Nature and type of filters.

For a typical cooking kitchen area where propane gas is used for cooking, temperature range as measured from experimental determination was between 80 to 110^0C

For a small scale cooking area measuring between 1.5m length by 1.5m width and 3m height.

Therefore, volume in space of kitchen or cooking area can be expressed as:

$$\mathbf{V = \pi r^2 h} \qquad \mathbf{(3.1)}$$

For a small sized student cooking area = $6.75m^3$ = $250ft^3$

This can be used as an estimate of the amount of fumes to be extracted from the heat propagation area.

3.3.2 Extraction fan selection and capacity

This is a function of the amount of heat and fumes to be extracted periodically, the cubic feet per minute (CFM) of the fan, the kitchen size in area and the resistance offered by the ducting configuration. For different space configurations an exhaust fan CFM chart is utilized. From a typical chart shown in Figure 3.3 a kitchen area measuring

Length x breadth. = $1.5 \times 1.5 = 2.25m^2 = 25ft^2$

The area falls within the 100 sq. feet area in the CFM chart requiring 27CFM of extraction. It therefore means that the proposed extraction fan is expected that it will take approximately $= \frac{250}{27}$ 8min for the fan to extract the amount of fumes within the given area provided there is a counter open ventilation for re-ventilation. Considering the lower limit of 27CFM as against the 100CFM on chart Table, the fan is selected as evaluated without further consideration of the ducting configuration for a simple duct type for the small scale kitchen configuration.

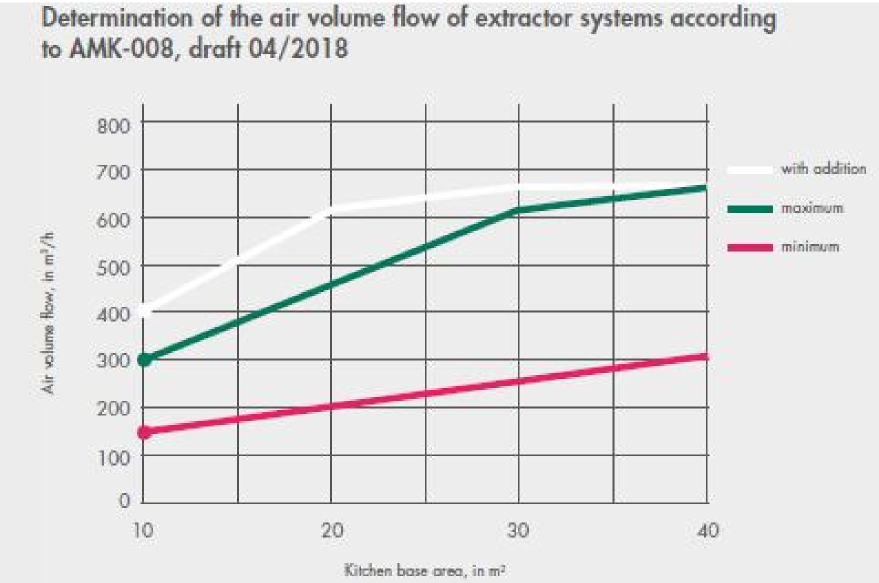

Figure 3.3 Air volume flow chart for extractor fans.

A centrifugal fan with an axial air intake and radial air outlet shown in Figure 3.4 was selected due to its versatility, availability and cost.

Figure 3.4 Centrifugal Fan

3.3.3 Duct sizing

The duct sizing is such that its opening can accommodate an instantaneous volume of fumes = $27ft^3 = 0.7m^3/m$ or $0.012m^3/s$.

A possible duct size configuration for $0.012m^3 = 0.23m$ by length, width and height for a square duct or its equivalent of a cylindrical duct.

3.3.4 Material selection for ducting and hood production

Typical metals and their thermal characteristics suitable for use in heat extraction ducting is shown in Table 3.3

Table 3.3 Thermal characteristics of metals for heat extraction ducting and hood.

Metal	**Softening temperature (°C)**
Brass	0.42 – 0.44
Copper	800
Bronze	913
Nickel	(720-122) for its alloys
Steel	900 (may vary due to carbon content)
Aluminum	500

From the Table 3.3 it can be inferred that virtually all the listed metals except brass can be suitably employed for ducting of the extraction facility since their softening temperature is above the prevalent temperature of heat generated within the cooking space which is 110^0C. the selection of a preferred metal amongst the favored one is now dependent on local availability and cost.

Aluminum is the most suitable in terms of cost and availability.

3.3.5 Filter Material Selection

Considering heat generated in the typical cooking area where heat and fumes are to be extracted, a synthetic porous membrane made of a composite material of metal wool (aluminum fibre) was selected for use as the extractor filter due to its availability, thermal resistance and low cost. Operational performance of the filter is depended on some quantitative metrics for selection which include the permeability (P) values of filter membranes which is estimated as: (Tansug et al 2024).

$$\mathbf{P = F_i = \left(\frac{T_{stp}}{T_{permeate}}\right) \left(\frac{T_{permeate\ absolute}}{T_{stp}}\right) \left(\frac{L}{A\Delta p}\right) 10^{10} Barrer} \qquad \mathbf{(3.2)}$$

where:

F_i = volumetric flow rate (cm^3/s) of the permeate component at i at room temperature (24^0C)

A = surface of the filter membrane (cm^2)

T_{STP} = standard temperature in K with 273.15 K being used

p_{STP} = atmospheric pressure [atm];

$T_{permeate}$ = the temperature of the fume or permeate

$P_{\text{permeate absolute}}$ = the absolute pressure (cm. Hg)

L = thickness of the membraneous filter

The multiplication by 10^{10} converts the permeability form (cm (STP)cm$\frac{(STP)cm.cm^3}{cmHgcm^2}$ units to Barrer. The synthetic membranous filter used is shown in Figure 3.5.

Figure 3.5 Heat extractor membranous filter

3.3.6 Resistance to Airflow

This is the amount of resistance exerted by the filter against the fumes extract. It also determines the specification requirement of the extractor fan.

Total resistance needed for the fan can be computed as;

$$Rf = Tf \times Sr \qquad (3.3)$$

where:

Rf - resistance of filter equivalent to pressure of a column cm of H_2O

Tf - thickness of filter column, m

Sr - specific resistance, cm of filter equivalent to water/m depth.

The specific pressure resistance of water per m depth can be read off in charts. Taking specific pressure resistance of 1 cm water per m depth of the membrane.

3.3.7 Insulating material

For the extractor hood, cellulose (wood material) was used due to its poor conduction of heat. The wooden plate shown in Figure 3.6 was embedded inside the extractor cone and hood made of aluminum plate.

Figure 3.6 Wood insulated for extractor hood

3.3.8 Size of hood and installation

The extractor hood is designed to have solid trapezoidal shape with a diverging air suction face to enhance air flow through larger surface area of the filter while also creating a convergent throat at the other end of the hoof for increased pressure and turbulent air extraction. The size of the extractor hood shown in Figure 3.7 is function of the fan specification and the amount of fumes to be extracted.

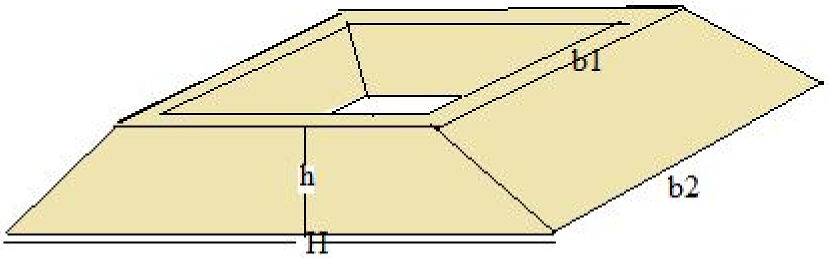

Figure 3.7 Trapezoid extractor hood

The amount of air passing through the hood per time is equivalent to the volume of the trapezoid hood which is expressed as:

Volume V of trapezoid = $\frac{1}{2} \times (b_1 + h_2) \times h \times H$ **(3.4)**

where:

b_1 = length of first parallel side of trapezoid

b_2 = length of second parallel side of trapezoid

h = height of trapezoid

H = height of the prism or distance between the two trapezoidal bases.

3.3.9 Development of the Kitchen cabin

A mini kitchen cabin suitable as a student cooking corner or a small commercial cooking stand suitable for a 6ft tall human to navigate is constructed for installation of the extractor fan. The cabin shown in Figure 3.8 is a rectangular cabin measuring 1.9m height by 0.6m width and 0.6m breadth. It is made of wooden boards and structured with steel. The cabin structure is designed such that the lower side is cut open with a rectangular hole, each measuring 0.5m length by 0.5 in breadth to enhance cross ventilation and updraft, to further increase fan extraction efficiency and reduce fan power specification. A door for access and exit the kitchen cabin is also installed on the structure.

Figure 3.8 Structure Frame

Figure 3.9 Kitchen Cabin

3.4 Bill of Engineering Materials and Evaluation

The bill of engineering (BEME) materials and evaluation of the developed heat extraction system installed in a kitchen cabinet is presented in Table 3.4

Table 3.4 BEME of developed heat/fume extractor facility

S/No	Items	Description	Quantity	Dimension	Unit cost	Total cost
1	Aluminum foil		1 roll		15000	15000
2	Steel pipe		1	1m	20000	20000
3	Forced draft fan		1		20000	20000
4	Rivets		Lump sum	sum	3000	3000
5	Door handle		1		1000	1000
6	Angle bar		2	36m	5000	10000
7	Bolts, nuts and nails		Lot		5000	5000
8	Synthetic metal fiber filter.	Mild steel	1/2 inch	1m	9000	9000
9	Wirings/Electricals		Lump		15000	15000
10	Plywood boards	Wood	2	1.2m x 2.4m	50000	50000
10	Wood board	Wood	1	0.3m x 1.2m	25000	25000

11	Wood varnish	Liquid based	1 liter	1 can	7000	7000
12	Miscellaneous	Sum	Sum		50000	50000
13	Workmanship				100000	100000
	Total					331000

The schematic and graphical presentation of developed kitchen cabin with installed heat and fume extractor are shown in Figure 3.8 and 3.9.

3.5 Testing

The developed heat and fume extractor installed on a mini kitchen cabin was tested to determine its operational performance as follows:

i. A typical cooking activity was set up and carried out inside the kitchen cabin using a kerosene stove with considerable flue emission.
ii. Test probes for measuring temperature were inserted in and outside the facility measure temperature and fume concentration inside and outside the cabin before and after cooking.
iii. The stove was lighted and used to cook oily food which also emits a lot of oily fumes.
iv. The extractor fan was switched on to extract heat and fume and the time it took for completed extraction of fumes was documented.
v. The result obtained from the experiment is documented in result section of this work in chapter four.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Result

The results of the experimental testing of the heat and fume extraction facility is shown in the Table 4.1.

Table 4.1 Experimental data for heat extraction facility.

Temp. (^{0}C) of cabin before cooking.	Ambient Temp. (^{0}C) around extractor before cooking	Temp. (^{0}C) of cabin during cooking	Ambient Temp. (^{0}C) around extractor during cooking	Time (s) for complete extraction of fumes.
28.8	28.7	31.8	31.6	12
29.1	29	32.5	31.3	25
28.8	29.1	34.7	34.2	35
27.9	27.6	33.2	32.1	48
28.3	28.2	32.8	31.2	60
Av. = 28.58	Av. = 28.52	Av. = 33	Av. =32.08	

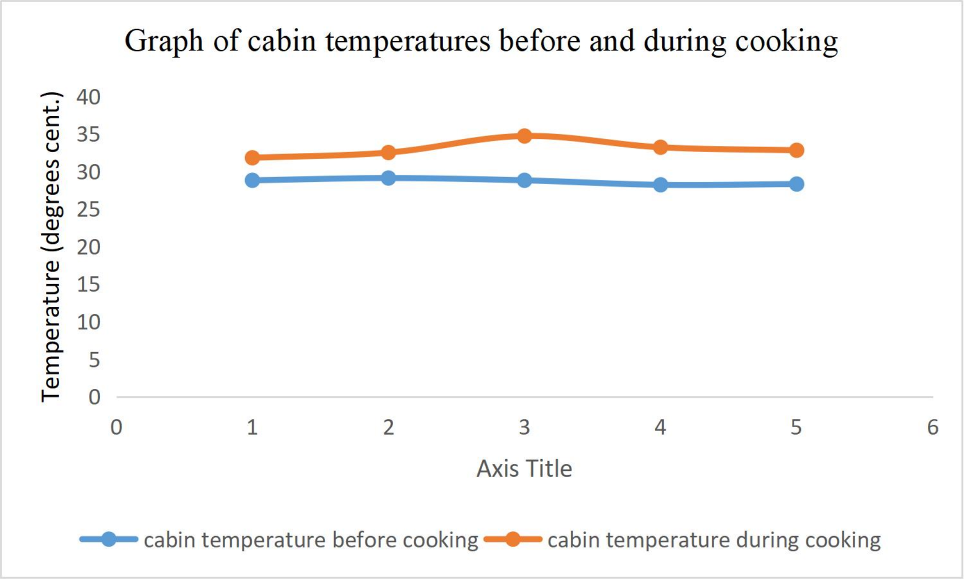

Figure 4.1 Graph showing kitchen cabin temperature

From the 4.1 and Figure 4.1 it can be inferred that prior to cooking in the kitchen kiosk or cabin, the temperature around the kitchen was virtually same as the ambient temperature within the environment. However, as cooking commenced there was relative increase in the kitchen temperature compared to the ambient temperature indicating heat production in the kitchen with evident presence of fumes from the heated oil. Owing to the extractor fan was switched on to extract the heated fumes from the kitchen within a given period.

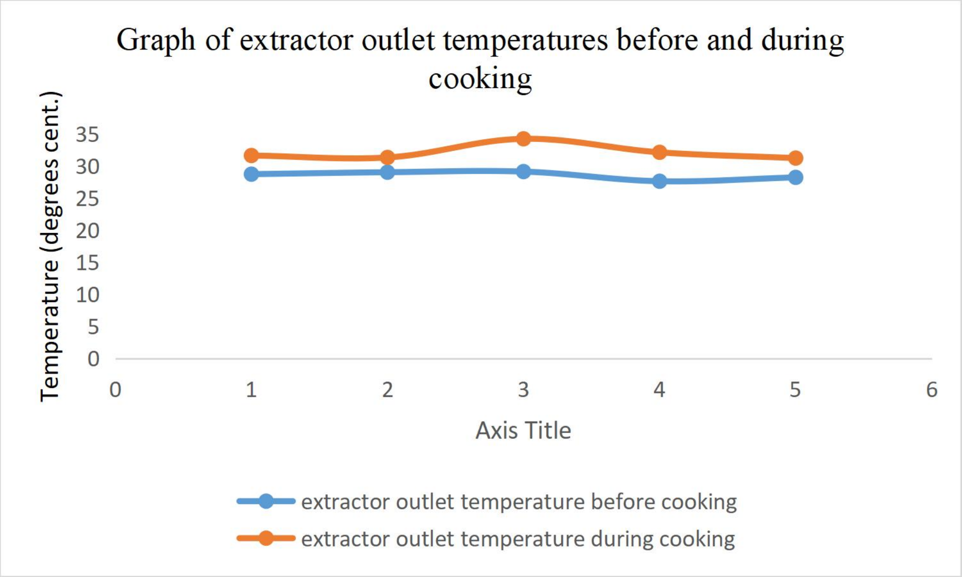

Figure 4.2 Graph showing extractor hood temperature

Inference from Table 4.1 and the graph in Figure 4.2 reveals a temperature gradient within the extractor hood zone. There was marked increase in temperature around the inlet and outlet of the extractor fan during cooking compared to when there was no cooking taking place indicative of a working of the extractor fan in extracting heated fumes from the kitchen cabin.

It is also inferred from the Table 4.1 and the graphs in Figure 4.1 and 4.2 that as tome elapsed, the heat transfer within the kitchen cabin during cooking increases from ambient temperature up to a peak temperature before residing around the kitchen compartment and the extractor hood zone. The harmonic temperature curves of the cabin and extractor hood temperatures clearly showed a temperature curve increasing, peaking and decreasing after a given time T. The time is the period between which the extractor started and finished extracting the hot fumes from the kitchen which took about 1 minute. This follows that in an hour the extractor fan could recirculate the kitchen heated fumes 60 times which is typical of an effective heat extraction which is expected to change air in the kitchen 10 times an hour.

CHAPTER FIVE

CONCLUSSION AND RECOMMENDATIONS

5.1 Conclusion

The design, fabrication, and performance evaluation of a kitchen heat extractor using locally sourced materials has been successfully completed, demonstrating that effective ventilation solutions can be developed using materials readily available within our local environment. The completed heat extractor utilizes a combination of natural and forced draft mechanisms to effectively remove heat, smoke, and cooking fumes from kitchen spaces, creating a healthier and more comfortable cooking environment.

The system incorporates several locally sourced components that proved both functional and cost-effective. Local wood was successfully utilized as insulation material, providing adequate thermal protection while being readily available and affordable. A recyclable automobile air conditioning fan was adapted and integrated as the mechanical draft fan, demonstrating the potential for repurposing existing components rather than always purchasing new ones. The extractor casement and hood were fabricated using aluminum fittings available in local markets, which provided the necessary structural integrity while keeping costs minimal. Additionally, a locally available synthetic filter was incorporated into the design to trap grease and particulate matter, protecting the fan mechanism and improving air quality.

Performance testing of the developed prototype revealed several important findings about the system's operational characteristics. The most significant discovery was that cross ventilation plays a crucial role in the overall effectiveness of the heat extraction system. It became clear during testing that the extractor does not simply remove air from the kitchen; it must work in conjunction with adequate fresh air intake to create proper air circulation. This cross ventilation serves a dual purpose: it enhances the extraction effect of the fan by preventing vacuum conditions that could reduce efficiency, and it ensures human safety by providing fresh oxygen-rich air to replace the extracted air. This finding emphasizes that heat extraction is not just about removing hot air, but about creating a complete air circulation system that maintains a healthy breathing environment for people working in the kitchen.

Quantitative measurements showed that the mechanical draft fan used in this project could completely extract and recirculate approximately 0.432 cubic meters of air within one minute in the kitchen space developed for this research. This air change rate translates to multiple complete air changes per hour within the test kitchen, which aligns with standards for effective heat extraction in domestic and small commercial kitchen settings. The ability to achieve this level of performance using locally sourced and recycled components validates the core premise of this research: that effective kitchen ventilation does not necessarily require expensive imported equipment.

The primary aim of this research was to design and fabricate a cost-effective and sustainable heat extractor using locally sourced materials, and this aim has been fully achieved. By deliberately selecting materials and components available within our local market, the project has demonstrated that communities need not depend entirely on imported solutions for their basic environmental comfort needs. The sustainability aspect is particularly noteworthy, as the use of recyclable automobile AC fans extends the useful life of components that might otherwise become waste, while the use of natural materials like local wood reduces dependence on synthetic materials.

All specific objectives set out at the beginning of this research were successfully met. The objective to source and incorporate local materials was achieved through careful selection and testing of indigenous resources. The objective to design a functional heat extractor was accomplished through proper engineering calculations and thoughtful integration of components. The fabrication objective was met by working with local artisans and fabricators who demonstrated considerable skill in bringing the design to life. Finally, the performance evaluation objective was fulfilled through systematic testing that provided concrete data on the system's capabilities.

Beyond the technical achievements, this project carries important implications for local capacity building and economic development. It has shown that local fabricators possess the skills necessary to produce functional environmental control equipment when provided with appropriate designs and guidance. This opens possibilities for small-scale manufacturing enterprises that could provide employment while meeting genuine community needs. The relatively low cost of the completed unit makes it accessible to a wider range of users, including small restaurants, home kitchens, and food processing facilities that might not afford expensive commercial systems.

The success of this project also contributes to the growing body of knowledge on appropriate technology development. It demonstrates that engineering solutions can be adapted to local contexts by thoughtfully selecting materials and manufacturing methods that match available resources and skills. This approach to technology development is particularly relevant in developing economies where imported solutions may be prohibitively expensive or difficult to maintain due to lack of spare parts and technical expertise.

In conclusion, this research has produced a functional, affordable, and sustainable kitchen heat extractor that meets its performance objectives while utilizing locally sourced materials. The system's ability to effectively change air multiple times per hour within the test kitchen, combined with its low production cost and use of readily available components, makes it a viable alternative to imported heat extraction systems. The insights gained regarding the importance of cross ventilation for both system efficiency and human safety add valuable knowledge that will inform future improvements and installations.

5.2 Recommendations

Based on the findings from the design, fabrication, and performance evaluation of the kitchen heat extractor, the following recommendations are made:

1. **Improved Design Modifications:** Future designs should incorporate adjustable fan speeds and temperature sensors to automatically regulate airflow depending on heat intensity in the kitchen.
2. **Use of Renewable Energy:** Incorporating solar-powered or rechargeable systems can make the extractor more energy-efficient, especially in areas with unstable electricity supply.
3. **Enhanced Aesthetic Appeal:** For wider market acceptance, the design can be further refined to include more attractive finishing and compact dimensions that fit various kitchen layouts.
4. **Noise Reduction:** Further research should focus on using sound-damping materials or optimized fan blade designs to reduce the operational noise level of the extractor.

5. **Mass Production:** Efforts should be made to scale up production using local workshops or small-scale industries to make the product available to more households at an affordable cost.
6. **Durability Testing:** Long-term tests should be conducted under various environmental and usage conditions to assess durability, performance stability, and maintenance needs.
7. **Public Awareness and Adoption:** Government and private organizations should support awareness campaigns to encourage the adoption of locally fabricated kitchen extractors as a means of promoting local industry and public health.
8. **Standardization and Quality Control:** Local manufacturing bodies should establish standard guidelines to ensure that all locally fabricated extractors meet safety and performance benchmarks.
9. **Training and Capacity Building:** Technical institutions should include similar fabrication projects in their curriculum to equip students with practical design and production skills.
10. **Future Research:** Further studies can explore the integration of air purification filters or heat recovery systems that convert extracted heat into usable energy for other domestic purposes.

In summary, this project has demonstrated that locally fabricated kitchen heat extractors are not only feasible but also capable of performing effectively when properly designed and constructed. With the right support, innovation, and investment, this technology can be expanded to reduce dependence on foreign imports, create employment, and improve the overall living standards in local communities.

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