DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF A KITCHEN HEAT EXTRACTOR

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CERTIFICATION

I hereby certify that this project work **"DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF A KITCHEN HEAT EXTRACTOR'** was carried out by **AKUNNE SAMSON** with matriculation number **ENG2006287** of the department of Industrial Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria

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DEDICATION

This project is dedicated to Almighty God, whose infinite wisdom, strength, and guidance have been my constant source of inspiration throughout this work.

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I am deeply grateful to Almighty God for granting me the knowledge, good health and perseverance to complete this project successfully.

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ABSTRACT

This project report presents the design and fabrication of a domestic heat extractor using locally sourced materials. The aim is to develop a cost – effective and energy – efficient device capable of removing excess heat from domestic cooking areas, thereby improving thermal comfort and safety in homes, particularly in developing regions where ventilation and cooling systems are often inadequate.

The project involves a detailed study of heat transfer principles, material selection and fabrication processes tailored to locally available resources. Components such as the extraction fan, heat duct, aluminum casing and power source were designed and assembled using affordable and easily obtainable materials.

Performance evaluation showed that the fabricated heat extractor effectively reduced heat concentration in enclosed kitchen spaces, improving air circulation and thermal comfort. The outcome demonstrates that domestic engineering innovations can be achieved sustainably using local resources, contributing to environmental protection, cost reduction and industrial development.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

A heat extractor is a device designed to capture, transfer, and sometimes store heat from one medium to another, with the aim of improving thermal efficiency and reducing energy waste in various domestic and industrial applications. In simple terms, it functions by removing excess or waste heat from a source such as a stove, cooking surface, or heated indoor air and either redistributing it to other areas where heat is needed or expelling it to maintain comfortable conditions. This concept has become increasingly significant in domestic settings where energy conservation and efficient heat management are vital for reducing utility costs and environmental impacts. The design and fabrication of domestic heat extractors using locally sourced materials have gained significant traction in recent years, largely driven by global efforts to promote sustainable and cost-effective solutions in energy systems. As energy costs continue to rise and environmental concerns become more pressing, there is an urgent need for affordable technologies that leverage locally available resources to improve thermal management in households. The concept of heat extraction, which involves capturing and reusing waste heat to reduce overall energy consumption, aligns closely with the principles of energy efficiency and sustainability. For instance, recent studies have shown that utilizing waste heat from domestic and industrial processes not only minimizes environmental impact but also offers substantial cost savings (Hancox et al., 2022).

In regions with limited access to advanced technological infrastructure, the use of locally sourced materials for fabricating heat extractors presents a practical solution to bridge technological gaps and promote self-reliance. Research focusing on the

construction of heat treatment furnaces using locally sourced materials has demonstrated the feasibility of achieving high performance at a fraction of the cost of imported systems. For example, a study in Nigeria successfully designed and constructed an electric heat treatment furnace that reached operational temperatures up to 1,000°C, using materials such as clay and white cement for insulation (Anaidhuno & Ologe, 2024). This underscores the potential of locally available resources to meet complex thermal needs. Moreover, the integration of vegetable oils as sensible heat storage materials for domestic applications showcases the innovative use of renewable, locally available resources in thermal energy systems. A study conducted in Uganda highlighted the superior heat utilization efficiency of Roki oil (a local blend of palm and sunflower oil) compared to sunflower oil alone. This finding suggests that vegetable oils, traditionally used for cooking, can play a crucial role in domestic heat extraction systems by providing efficient thermal storage and transfer capabilities (Abedigamba et al., 2023).

Beyond material selection, recent advancements in design optimization and energy system integration have further strengthened the case for domestic heat extractors. For example, local heat therapy devices and thermal mats used in industrial and domestic environments have proven to significantly improve thermal comfort and energy efficiency, emphasizing the importance of local design adaptations for specific user needs (Kaczmarczyk & Ferdyn-Grygierek, 2020). Additionally, integrating waste heat from domestic systems into combined cooling, heating, and power (CCHP) units has shown promise in enhancing energy efficiency at residential scales. Utilizing geothermal and industrial waste heat in distributed energy systems has been demonstrated to meet local energy demands sustainably while offering economic

benefits such as reduced energy costs and higher energy self-sufficiency (Nami et al., 2020).

The increasing emphasis on decarbonizing domestic heat also highlights the importance of locally tailored heat extraction technologies. In Greater Manchester, for example, efforts to achieve net-zero emissions have underscored the necessity of local design and fabrication strategies that consider community-specific needs and barriers (Crowther et al., 2023). The move towards using locally sourced materials in the design and fabrication of domestic heat extractors is a crucial step toward achieving sustainable, cost-effective, and community-focused energy solutions. It empowers local industries, reduces dependency on imported technologies, and fosters innovations that are better suited to the unique socio-economic and environmental contexts of each region.

1.2 Problem Statement

A heat extractor is a device designed to capture and remove unwanted or excess heat from a space or system, improving energy efficiency and thermal comfort. In domestic settings, it can be used to draw heat from cooking areas, appliances, or living spaces and either repurpose it or release it to maintain comfortable indoor conditions. Recently, attention has shifted toward developing heat extractors that use locally sourced materials, making them more affordable and sustainable for communities with limited access to expensive imported systems (Anaidhuno & Ologe, 2024). The push for local fabrication arises from growing global concerns about energy costs, environmental impact, and the need for resilient, community-based solutions. Research shows that materials like clay, cement, and locally available oils can perform effectively in thermal systems while being much cheaper than

commercial alternatives. Using local vegetable oils such as Roki oil has shown excellent heat storage and transfer capabilities, making them ideal for low-cost thermal applications (Abedigamba et al., 2023).

In addition, integrating locally made heat extractors into domestic setups can help reduce reliance on centralized heating systems and lower energy bills. Systems that capture and reuse heat have already demonstrated success in improving comfort and saving energy, especially when designed to match specific local needs and resources (Kaczmarczyk & Ferdyn-Grygierek, 2020). The development of domestic heat extractors using locally sourced materials offers a practical way to improve energy efficiency, reduce costs, and support local economies, while contributing to environmental sustainability goals.

1.3 Aim and Objective of Research

The aim of this study is to design and fabricate a cost-effective and sustainable heat extractor using locally sourced materials.

The objectives of the research are to:

i. To source and incorporate local materials in the design and development of a heat extractor.

ii. To design and fabricate a simple and effective kitchen heat extractor that meets basic thermal performance needs.

iii. To carry performance evaluation of the proof of concept heat extractor.

1.4 Significance of the Study

The design and fabrication of a domestic heat extractor using locally sourced materials hold substantial significance from both practical and scientific perspectives. Firstly, this study contributes to the promotion of energy efficiency in domestic

environments by providing a cost-effective solution to capture and repurpose waste heat, which otherwise would be lost to the surroundings. This supports global efforts to reduce energy consumption and mitigate greenhouse gas emissions, thereby contributing to environmental sustainability goals.

Secondly, by utilizing locally sourced materials such as clay, scrap metals, and natural fibers, the study empowers local industries and artisans. This fosters self-reliance, stimulates local economies, and reduces dependence on imported technologies, which are often costly and inaccessible to resource-limited communities. Additionally, integrating indigenous materials like vegetable oils as thermal storage media showcases innovative applications of renewable resources and aligns with circular economy principles.

Furthermore, this study offers an academic contribution by providing a practical case study on the integration of local materials into thermal system design, thus serving as a reference for future research and development in sustainable energy technologies. The knowledge gained can inform policy decisions and encourage the adoption of low-cost, adaptable solutions in other regions with similar resource constraints. Ultimately, the outcomes of this work have the potential to improve household energy management, reduce utility expenses, and enhance indoor thermal comfort for underserved populations.

1.5 Limitation of the Study

Despite its promising potential, this study is subject to certain limitations. One major limitation is the variability in the quality and properties of locally sourced materials. Differences in material composition, durability, and thermal conductivity can affect

the overall performance and reliability of the heat extractor, making standardization and replication more challenging.

Additionally, the fabrication process relies on basic tools and techniques, which may limit the precision and efficiency of the final product. While this approach promotes accessibility, it may result in lower mechanical strength and reduced lifespan compared to industrially manufactured alternatives. Furthermore, the testing phase is confined to specific local conditions and may not account for variations in climate or household energy needs in different regions. This could limit the generalizability of the results. Lastly, financial and time constraints might restrict large-scale prototyping and comprehensive long-term performance evaluation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Heat Extractors

Heat extractors, or systems designed to transfer heat from one medium to another, have become a crucial component in various industries and domestic settings. These systems are vital for improving energy efficiency, reducing operational costs, and contributing to sustainability by harnessing waste heat that would otherwise be wasted. The technology and its design have evolved significantly over the years, with a growing emphasis on integrating local and readily available materials to minimize costs and reduce the environmental impact. One of the most significant advancements in heat extractor technology is the focus on improving the efficiency of heat transfer. A typical heat extractor uses materials with high thermal conductivity to absorb heat from a source, such as an industrial process or domestic heating system, and transfer it to a medium for use in heating water or air, or even generating electricity. The efficiency of these systems is closely tied to the design of the heat exchanger and the properties of the materials used. For instance, modern heat extractors are designed with fins, tubes, or plates that increase the surface area for heat transfer, enhancing their overall efficiency. Moreover, the use of advanced coatings or materials that reduce heat loss to the environment further optimizes energy use in these systems (Badescu, 2022).

The importance of using locally sourced materials in the design of heat extractors cannot be overstated. Materials such as clay, stone, and certain metals have been successfully utilized in various regions, providing a cost-effective and sustainable solution. For example, in areas where specific types of metal or high-temperature-resistant alloys are in abundance, their use in heat extractor components, such as heat

exchangers, is beneficial both in terms of performance and cost-effectiveness. Local sourcing reduces reliance on imported goods, thus supporting local economies and minimizing the environmental footprint associated with transportation and manufacturing (Hancox et al., 2022). A key challenge in the fabrication of these systems is maintaining the integrity of the heat exchanger over time. As heat exchangers are subjected to constant thermal stress, the materials used must exhibit both durability and resistance to corrosion. In some instances, local materials, such as naturally sourced stones, may require treatment or coating to ensure they maintain efficiency under long-term use. Furthermore, the performance of heat extractors can be impacted by environmental factors such as humidity and atmospheric pressure, which may necessitate the development of adaptive materials or coatings that can resist the effects of these conditions.

The fabrication of domestic heat extractors is typically guided by principles derived from industrial applications, but the need for more compact, user-friendly designs has led to the development of smart systems. These systems, which are increasingly incorporating sensors and controllers, enable real-time monitoring and adjustment of performance. For instance, microcontroller-based smart systems can regulate temperature and heat flow based on the real-time needs of the household, ensuring optimal energy use while maintaining comfort. This dynamic control significantly enhances the performance of heat extractors in domestic environments, where the heat demands fluctuate depending on the time of day and seasonal changes (Essien, 2023).

Moreover, the application of heat extractors in domestic settings is becoming more varied. Beyond their traditional use in space heating, these systems are increasingly used to provide hot water, regulate indoor air quality, and even assist in energy

generation through systems like solar thermal or combined heat and power (CHP) units. These multifunctional systems demonstrate the versatility of heat extractors, making them a key technology in modern homes and buildings, particularly in regions with fluctuating temperatures or energy scarcity. Research continues to explore how best to integrate heat extractors with renewable energy systems. For instance, when combined with solar panels or geothermal systems, heat extractors can help store excess thermal energy generated during the day, which can be used during the night or cloudy periods. This integration with renewable systems has the potential to drastically reduce energy costs and reliance on nonrenewable energy sources, making it an essential consideration in the design of future heat extractors (Badescu, 2024).

Additionally, the application of heat extractors in industrial and residential contexts has significant environmental and economic impacts. By recovering waste heat and utilizing it effectively, heat extractors help reduce energy consumption, leading to lower carbon footprints and reduced reliance on fossil fuels. This is particularly important in the context of growing concerns about climate change and the need for energy-efficient solutions that promote sustainability. Economically, the use of locally sourced materials not only reduces production costs but also encourages the development of regional industries that can supply the necessary components, thereby boosting local economies and creating jobs (Hancox et al., 2022). Heat extractors are an essential technology for improving energy efficiency, reducing environmental impact, and contributing to sustainable energy practices. As technological advancements continue, especially in the use of locally sourced materials, the design and fabrication of these systems are becoming more efficient, cost-effective, and environmentally friendly. With the integration of smart control systems and renewable energy sources, heat extractors will continue to play a critical role in both

industrial and domestic applications, paving the way for a greener, more sustainable future.

2.2 Domestic Heat Extractors

Domestic heat extractors, designed for use within households, have gained significant attention as an eco-friendly and cost-effective solution for heating and cooling needs. These systems work by capturing and utilizing heat energy from various sources, such as ambient air, water, or waste heat, to provide space heating and hot water to households. The concept of heat extraction in domestic settings revolves around improving energy efficiency, reducing utility bills, and contributing to the reduction of carbon footprints in the context of global climate change concerns. Air-source heat pumps (ASHPs) are one of the most common types of domestic heat extractors. These systems extract heat from the external air, even at low temperatures, and use it to heat water or air inside the home. In the UK, ASHPs are promoted as an effective solution to reduce dependency on gas heating systems. As part of the government's strategy to decarbonize the domestic heating sector, there is growing emphasis on replacing traditional heating methods with air-source heat pumps. However, a significant challenge faced by these systems is the noise they generate. In one case study, it was found that complaints about noise from ASHPs could be alleviated by improving the design and incorporating measures to reduce sound emissions. The installation of noise-reduction strategies and the improvement of assessment methodologies are essential to increase the acceptance of these systems by consumers (Noise.co Ltd, 2020).

Another critical issue in the domain of domestic heat extractors is the recovery and utilization of waste heat. Household appliances such as refrigerators and water heaters

often expel substantial amounts of heat, which is typically wasted. Recent research has explored systems designed to capture this waste heat. For example, a domestic refrigerator can be equipped with a heat recovery unit that uses a condensing coil and airflow system to harness the heat expelled by the appliance. This recovered heat can then be utilized for various domestic applications, such as heating water or contributing to space heating. In a system designed for this purpose, a hot box absorbs the heat released from the refrigerator, which could otherwise increase the room temperature, especially in the summer months. Such systems contribute significantly to energy conservation, reducing the need for additional energy inputs to heat water and improve overall domestic efficiency (Ponmurugan et al., 2019).

In addition to waste heat recovery, thermoacoustic heat pumps are another promising technology for domestic heat extraction. These systems utilize sound waves to amplify heat from low-temperature sources, such as the air or water, making them suitable for home heating. Thermoacoustic heat pumps have the advantage of being simple, reliable, and capable of working with a range of heat sources, including waste heat. These systems can be particularly advantageous in residential settings where energy efficiency is paramount. Research has demonstrated that such systems can achieve significant savings in energy consumption, with reductions in CO2 emissions and operational costs when powered by renewable or waste heat sources (Hu et al., 2023).

One of the most innovative approaches in domestic heat extractors is the integration of these systems with other household technologies, such as smart heating and cooling systems. Smart thermostats and controllers allow homeowners to monitor and adjust their heating systems remotely, optimizing energy use based on real-time needs. By

integrating heat extractors with such smart technologies, it is possible to significantly enhance energy efficiency. These systems adapt to changes in heating demand throughout the day and even over the course of the seasons, ensuring that the household is never over- or under-heated, thereby reducing unnecessary energy consumption and lowering utility bills (Abdelkader & Houcine, 2024). The increasing reliance on heat extractors in domestic settings also highlights the importance of integrating renewable energy sources. For example, systems such as solar-assisted heat extractors can combine solar power with heat pump technologies to provide an even more sustainable energy solution. This hybrid approach minimizes reliance on external energy sources, reducing carbon footprints and offering substantial savings on electricity bills. By coupling heat extractors with renewable energy, homeowners can significantly decrease their dependency on fossil fuels, contributing to the overall sustainability of their household energy systems.

2.3. Types of Domestic Heat Extractors

2.3.1 Air Source Heat Pumps (ASHPs)

Air source heat pumps are one of the most popular types of heat extractors for domestic heating. These systems extract heat from the outside air, even in colder temperatures, and use it to warm indoor spaces or heat water. The technology works on the principle of thermodynamics, with the pump transferring heat from the external air into the home through a refrigerant cycle. ASHPs are widely used due to their efficiency and ability to reduce reliance on fossil fuels. They are particularly effective in moderate climates but may be less efficient in extreme cold temperatures, although newer models have been designed to overcome this limitation. The UK's adoption of heat pumps is supported by government incentives, as they offer a low-carbon alternative to traditional heating systems (Szreder, 2018).

2.3.2 Ground Source Heat Pumps (GSHPs)

Ground source heat pumps, also known as geothermal heat pumps, are another popular form of heat extraction for domestic use. These systems use the earth's natural heat, which remains at a relatively constant temperature throughout the year, to heat or cool homes. A series of pipes buried underground circulate a fluid that absorbs the heat from the earth, which is then extracted and used to warm the home. While GSHPs tend to have higher installation costs than ASHPs, they are more efficient, especially in extreme climates, as the ground temperature remains stable year-round. These systems are often paired with underfloor heating or radiators for maximum efficiency (Hancox et al., 2022).

2.3.3 Water Source Heat Pumps (WSHPs)

Water source heat pumps are similar to ground source heat pumps, but instead of using the ground as a heat source, they extract heat from a body of water, such as a river, lake, or well. These systems can be highly efficient when used in locations near a suitable water source. The heat extraction process works by circulating a heat exchange fluid through a series of pipes submerged in the water, absorbing heat, and then transferring it to the home. Like GSHPs, WSHPs offer high efficiency but require specific site conditions, such as access to an appropriate water body. They are an ideal solution for properties located near water bodies that have stable temperatures year-round (Guo et al., 2019).

2.3.4 Biomass Heat Extractors

Biomass heat extractors utilize organic materials such as wood pellets, chips, or logs to generate heat. These systems burn biomass to heat water or air, which is then distributed through a home. Biomass heating is a renewable energy source, and it is considered carbon-neutral as the carbon dioxide released during combustion is offset

by the carbon absorbed by the plants during their growth. Biomass systems are often used in rural areas where wood and other organic materials are readily available. They are a good alternative to fossil fuel-based heating systems, particularly in areas where the availability of fuel is local, reducing transportation costs and emissions (García-Maroto et al., 2020).

2.3.5 Thermoacoustic Heat Pumps

Thermoacoustic heat pumps are an innovative form of heat extraction technology that uses sound waves to amplify the heat from a low-temperature source. These systems operate by generating high-amplitude sound waves that induce temperature gradients, allowing heat to be extracted and transferred. Thermoacoustic heat pumps are particularly beneficial because they do not require moving parts, which reduces mechanical failure and maintenance needs. They are an energy-efficient option for domestic heating, capable of extracting heat from low-grade sources such as waste heat from appliances. Though the technology is still in the research phase for large-scale applications, it shows significant promise for sustainable domestic heating solutions (Hu et al., 2023).

2.3.6 Waste Heat Recovery Systems

Waste heat recovery systems capture excess heat produced by household appliances, such as refrigerators, air conditioners, and water heaters, and repurpose it for other domestic applications. For instance, the waste heat from a refrigerator's condenser can be extracted and used to heat water, making it an energy-efficient solution. These systems are typically installed in appliances where heat is generated as a byproduct, and they help improve energy efficiency by reducing the need for additional energy inputs. The integration of waste heat recovery with domestic systems can substantially

lower overall energy consumption and reduce the carbon footprint (Ponmurugan et al., 2019).

2.3.7 Induction Heating Systems

Induction heating systems use electromagnetic fields to generate heat directly within conductive materials, such as metal coils or pots. While this technology is most commonly used in cooking, it can also be used for domestic space heating. The advantage of induction heating is its precision, as it allows for targeted heating of specific areas. When integrated with solar or wind power, induction heating systems can offer an efficient and environmentally friendly way of providing heat. Although more commonly found in industrial settings, recent innovations have made induction heating a viable option for residential applications, especially in off-grid areas where electrical supply may be limited (Mizbah Farheen et al., 2022). Domestic heat extractors come in a variety of types, each with its advantages and limitations. These systems play an essential role in improving home energy efficiency, reducing reliance on fossil fuels, and mitigating environmental impacts. The ongoing development of these systems, including the integration of renewable energy sources and smart technologies, makes them a cornerstone of future residential energy solutions. Each type has its place depending on geographic location, energy availability, and environmental goals, contributing to a more sustainable energy landscape for homes worldwide.

2.4 Advantages of Domestic Heat Extractors

Domestic heat extractors, including technologies like heat pumps and waste heat recovery systems, have gained popularity due to their potential to reduce energy consumption, lower utility bills, and contribute to environmental sustainability. However, like any technology, they come with both advantages and disadvantages.

1. Energy Efficiency

Heat extractors, particularly heat pumps, are highly efficient systems. Air-source, ground-source, and water-source heat pumps use renewable heat from the environment, such as outdoor air or underground sources, to provide heating. These systems can deliver more energy than they consume. For example, modern heat pumps can generate 3 to 4 units of heat for every unit of electricity consumed, making them more efficient than conventional electric heating systems, which generate heat only from electrical energy (Szreder, 2018).

2. Reduced Carbon Emissions

Heat extractors play a significant role in reducing the carbon footprint of households. Since they use renewable energy sources (such as air, water, or the ground) and can be powered by electricity from renewable sources like solar or wind, they contribute to the reduction of greenhouse gas emissions. This is especially critical as countries strive to meet climate targets. The transition from fossil fuel-based heating systems to heat pumps can lead to substantial reductions in carbon dioxide emissions (Hancox et al., 2022).

3. Cost Savings

While the upfront installation costs for heat extractors can be high, they can result in significant long-term savings due to their low operating costs. Heat pumps, for example, have very low running costs compared to conventional heating systems like oil, gas, or electric heaters. Over time, the savings on energy bills can offset the initial investment, especially when combined with government incentives and subsidies for renewable energy technologies (Guo et al., 2019).

4. Renewable Energy Integration

Domestic heat extractors can integrate seamlessly with other renewable energy systems, such as solar panels or wind turbines. For example, solar-powered heat pumps can be used to heat homes without relying on the grid, reducing dependency on fossil fuels. This integration helps create energy-independent homes and contributes to the decarbonization of the energy sector (Correa & Cuevas, 2018).

5. Low Maintenance and Long Lifespan

Heat extractors, particularly heat pumps, are designed to have low maintenance requirements. With proper installation and regular servicing, these systems can last for 15–20 years, offering long-term reliability. Additionally, since they have few moving parts compared to conventional heating systems, the risk of mechanical failure is lower, which further reduces maintenance needs (Moss et al., 2023).

2.5. Disadvantages of Domestic Heat Extractors

1. High Initial Installation Costs

One of the most significant disadvantages of heat extractors is their high upfront cost. The installation of ground-source or water-source heat pumps requires significant investment, as it involves digging or drilling to install underground pipes or accessing water sources. The installation costs can be prohibitive for some households, although incentives and subsidies can help mitigate this burden (Guo et al., 2019).

2. Noise and Aesthetic Impact

While air-source heat pumps are generally efficient, they can be noisy, which may cause disturbance in residential areas. The sound from the outdoor unit can affect the comfort of nearby residents, especially in densely populated neighborhoods. Noise

mitigation technologies and strategies are being developed to address this concern, but it remains a limitation in some cases (Noise.co Ltd, 2020).

3. Efficiency Dependent on External Temperature

The efficiency of heat extractors, particularly air-source heat pumps, can be impacted by outdoor temperatures. In very cold climates, the performance of the heat pump decreases because there is less heat available to extract from the air. This issue can be mitigated with more advanced models, but heat pumps may still struggle in extreme conditions, necessitating backup heating systems during the coldest months (Szreder, 2018).

4. Space Requirements for Installation

Ground-source heat pumps, in particular, require significant space for the installation of underground pipes, which can be a limitation in urban areas or smaller properties. While vertical drilling can reduce space requirements, it increases installation costs. This makes ground-source systems less feasible for homes with limited land space (Guo et al., 2019).

5. Potential for Limited Heat Output

Some heat extraction systems, especially those relying on low-temperature sources, may not provide sufficient heat output for large homes or regions with high heating demands. For example, wastewater-source heat pumps can struggle to meet the heating needs of larger households with higher thermal demands. In such cases, supplementary heating systems might be needed to ensure adequate warmth during the winter months (Correa & Cuevas, 2018).

6. Technical Challenges in Retrofitting

Retrofitting existing homes with heat extractor systems, especially for buildings that were not originally designed for energy-efficient heating, can be complex and costly.

The installation process may require significant modifications to the home's infrastructure, such as the addition of new ductwork or the installation of supplementary water heating systems. This can make heat extractors less appealing for retrofits, especially in older homes (Moss et al., 2023).

Domestic heat extractors offer numerous advantages, including improved energy efficiency, reduced carbon emissions, and long-term cost savings. However, their high initial costs, noise issues, and dependency on external conditions for efficiency are some of the key challenges. Despite these drawbacks, the growing need for energy-efficient solutions and sustainable heating systems continues to drive innovation in the field. Future developments may address these disadvantages, further enhancing the feasibility and attractiveness of heat extractors for households worldwide.

2.6. Previous Works

Hu et al. (2023) conducted a study on *Thermoacoustic Heat Pumps for Sustainable Heating aimed* at evaluating the energy efficiency potential of thermoacoustic heat pumps in domestic heating applications. The study employed an experimental analysis approach using a sample of 100 systems tested under controlled conditions in China. The research aimed to determine how thermoacoustic technology, which uses sound waves to transfer heat, could serve as an alternative to conventional heating systems. The findings revealed that thermoacoustic pumps have the capacity to reduce energy consumption by up to 30%, indicating their strong potential for improving energy efficiency in residential settings. However, a notable limitation of the study is that it was confined to laboratory-scale experiments, with no validation of the technology's performance in real-world or field conditions. This presents a significant gap in the applicability and scalability of the findings for practical domestic use.

Abdelkader and Houcine (2024) conducted a study on Smart Thermostats Integration in Domestic Heat Systems to investigate the effectiveness of smart control technologies in improving domestic heating efficiency. The primary objective of their research was to assess how integrating smart thermostats with existing heat systems could influence household energy consumption. The study utilized a quantitative survey methodology and involved 200 participants across various residential settings in Algeria. Data collected focused on user experiences, energy savings, and system responsiveness. The findings revealed that integrating smart control systems, such as programmable thermostats and automated heating schedules, resulted in a 25% improvement in overall heat system efficiency. This was attributed to better alignment between heat supply and user demand, as well as reduced energy wastage during idle hours. The smart systems allowed real-time adjustments based on environmental conditions and occupant behaviors, contributing significantly to household energy conservation. Despite these positive outcomes, the study acknowledged a key limitation: it did not evaluate the long-term maintenance and operational sustainability of the smart devices. As such, questions remain regarding the durability, cost of servicing, and user adaptability over extended periods. Further longitudinal research is needed to assess the full lifecycle benefits and constraints of integrating smart thermostats into domestic heat extraction systems.

Essien (2023) explored the development and application of smart domestic heat extractors in a study on Development of Smart Domestic Heat Extractors. The research aimed to design and test a heat extraction system that adapts dynamically to fluctuating household energy demands. Using a prototyping and simulation methodology, the study involved testing 60 units in residential settings across Nigeria. The prototype employed sensor-based feedback mechanisms controlled via

microcontrollers to regulate heat extraction in real-time. The findings demonstrated that these smart extractors were capable of adjusting their heat output based on ambient conditions, time of day, and user preferences. This adaptability not only enhanced user comfort but also contributed to a reduction in energy usage, positioning the technology as a viable alternative to conventional fixed-output systems. The system's intelligence allowed it to operate efficiently during both peak and off-peak hours without compromising performance. However, a notable gap in the study was its limited analysis of the cost-effectiveness of deploying such smart systems in rural or low-income areas. While the technology shows promise, its affordability, scalability, and maintenance requirements in underserved regions remain unexplored. Future research should address these socioeconomic factors to ensure equitable access to sustainable heat extractor technologies.

Badescu (2022) investigated the impact of surface design enhancements on the performance of heat extractors. Conducted in Romania, the research adopted a comparative technical analysis methodology involving 50 experimental units. The objective was to assess how different geometric configurations and surface materials influence the thermal conductivity and overall efficiency of domestic heat exchangers. Various fin and plate designs were tested under controlled conditions to simulate domestic heating environments. The study found that advanced surface designs significantly increased the rate of heat transfer, improving thermal efficiency by a notable margin. Specifically, the use of corrugated metal surfaces and coated plates contributed to better heat retention and faster response times in heating systems. These improvements have direct implications for reducing energy consumption in domestic settings. However, the study focused primarily on material science and laboratory conditions, with limited consideration given to real-world integration and

performance under variable household conditions. The research did not explore how these high-performance materials would interact with domestic plumbing systems, nor did it address issues of cost or accessibility. This gap suggests the need for further applied research that bridges material innovations with practical system design and user implementation.

Hancox et al. (2022) carried out a field-based investigation on use of Local Materials in Heat Exchanger Design to assess the viability of incorporating locally sourced materials in the fabrication of domestic heat extractors. Conducted in the United Kingdom, the study involved 150 units built using various locally available materials, including copper, clay composites, and recycled metals. Employing a field study approach, the researchers evaluated performance in terms of heat retention, efficiency, and long-term cost-effectiveness. The findings revealed that locally sourced materials could significantly reduce production costs and environmental impact without compromising performance. In particular, the use of recycled aluminum and treated clay offered effective thermal properties, contributing to a 20% cost reduction compared to conventional commercial models. The study also highlighted the economic and environmental advantages of reducing reliance on imported materials. However, one critical limitation was the lack of long-term durability data. While short-term efficiency was validated, the researchers did not assess how these materials would withstand thermal cycling, corrosion, or mechanical stress over several years. The study recommended future longitudinal testing to examine material longevity under domestic usage conditions, which is essential for the widespread adoption of sustainable fabrication practices in heat extraction technologies.

Ponmurugan et al. (2019) conducted an experimental study on waste Heat Recovery from Domestic Refrigerators to explore how excess heat generated by household appliances could be repurposed for domestic applications. The study, conducted in India, involved 40 experimental setups wherein domestic refrigerators were retrofitted with heat recovery units comprising condensing coils and insulated hot boxes. The primary aim was to determine whether this waste heat could be effectively captured and reused, particularly for water heating. The results indicated that the recovered heat could successfully preheat water for domestic use, contributing to overall household energy efficiency. The system proved particularly effective in warm climates, where refrigerator compressors operated more frequently and released greater amounts of heat. The integration of heat recovery units not only improved energy utilization but also reduced indoor heat load, potentially lowering air conditioning demands. However, a key limitation of the study was its narrow scope, as it focused exclusively on a single appliance type and did not consider integration with broader household systems. Additionally, the study did not address challenges related to user safety, maintenance, or the economics of large-scale implementation. Future research should explore multi-appliance integration and assess system feasibility in varied domestic contexts.

The study conducted by Noise.co Ltd (2020) on noise Mitigation in Air-Source Heat Pumps examined the impact of sound emissions on the acceptance and effectiveness of air-source heat pumps (ASHPs) in residential environments. This case study analysis, carried out in the United Kingdom, focused on 30 residential installations where noise complaints had been recorded. The primary objective was to identify design and operational strategies that could reduce the acoustic footprint of ASHP systems without compromising thermal performance. Through on-site measurements

and resident feedback, the study found that ASHP noise levels were a significant barrier to consumer acceptance, particularly in high-density housing areas. Mitigation strategies, including acoustic enclosures, vibration isolators, and optimized fan designs, successfully reduced noise levels by up to 35%. These interventions also improved the perception of system reliability and occupant comfort. Despite these promising findings, the study acknowledged a critical limitation: it did not evaluate the long-term effectiveness of these noise-reduction techniques or their impact on system maintenance and cost. Furthermore, no assessments were made regarding how changing environmental conditions (e.g., temperature, humidity) might influence noise levels over time. The research highlights the need for more comprehensive longitudinal studies that examine both acoustic and operational performance of ASHPs under diverse real-world conditions.

Ray et al. (2019) explored the integration of smart meter technology with domestic heat pumps in their study on Smart Meter Integration with Heat Pumps. The research aimed to evaluate how real-time monitoring and data-driven control could improve the energy efficiency of domestic heating systems. Conducted in the United States using an experimental setup, the study included 70 households equipped with smart meters and heat pump systems. The findings indicated that smart meter integration significantly enhanced energy monitoring, allowing for precise control over heating schedules and improved responsiveness to fluctuating energy demands. Homes that utilized smart metering experienced reduced energy consumption and more consistent indoor temperature regulation. Additionally, users were able to track usage trends and adjust behaviors to conserve energy. However, the study identified a notable gap: it did not account for user adaptability or technology acceptance among different demographic groups. The researchers acknowledged that while the technology

showed great potential, its success depended heavily on user engagement and understanding. This presents a challenge for broader implementation, particularly among populations with limited digital literacy. Further research is needed to explore user behavior, training interventions, and the long-term effects of smart meter use on heating efficiency and household energy culture.

García-Maroto et al. (2020) conducted a mixed-method study on Biomass Heating in Rural Areas to assess the viability and sustainability of biomass-based heating systems in residential contexts. The study focused on rural communities in Spain, involving a sample of 120 households utilizing wood pellet, chip, and log-fueled heating systems. Using both qualitative interviews and quantitative energy use data, the research aimed to understand both the technical efficiency and user perceptions of biomass heat extractors. The findings highlighted that biomass systems provided efficient heating solutions, especially in regions with abundant organic material resources. Additionally, they were found to be carbon-neutral, given that the carbon released during combustion was offset by the carbon absorbed during plant growth. Many users also reported a sense of energy independence, particularly in off-grid locations. However, the study identified limitations related to the supply chain of biomass fuels, such as inconsistent pellet quality and high transport costs in remote areas. These supply issues posed challenges for long-term sustainability and user satisfaction. The researchers recommended that future studies should explore localized biomass production systems and logistics models to address fuel availability and cost, ensuring that biomass heating can remain a viable alternative to fossil fuel systems in rural settings.

Watson (2020) undertook a policy-oriented study on Policy Support for Heat Pump Adoption to evaluate the role of government incentives in promoting the use of low-carbon heating systems in residential buildings. The research was conducted as a comprehensive policy review in the United Kingdom, analyzing national and local policy instruments, including subsidies, tax rebates, and regulatory frameworks designed to encourage the adoption of heat pump technologies. The study found that financial incentives and certification schemes, such as the Microgeneration Certification Scheme (MCS), played a significant role in increasing public interest and market penetration of air-source and ground-source heat pumps. Additionally, policy clarity and consistent funding streams were identified as key drivers of consumer confidence. However, the review also exposed several challenges. Despite the availability of incentives, many local authorities struggled with the administrative capacity to effectively implement and monitor these programs. Moreover, there was a lack of coordination between national policy objectives and municipal enforcement, leading to disparities in adoption rates across different regions. The study concluded that while policy tools are essential, their effectiveness depends on robust local governance and public awareness campaigns. A critical gap identified was the limited evaluation of policy impacts over time and across varying socioeconomic demographics.

Guo et al. (2019) evaluated the operational efficiency of these systems in residential environments across China. The research involved 80 domestic installations 40 each of ground-source and water-source heat pumps monitored over a 12-month period to assess seasonal performance, reliability, and energy consumption. The primary objective was to determine which system type offered better energy savings and heating stability in moderate and variable climates. Results showed that water-source

heat pumps performed with higher efficiency, particularly in locations with stable and accessible water bodies. Ground-source systems also performed well but required higher installation costs due to land excavation or borehole drilling. Both systems significantly reduced household energy consumption compared to conventional heating systems. Despite the success of the technologies, the study noted a major limitation: geographic constraints. Not all areas had access to adequate water bodies or land space for underground piping systems, limiting the scalability of these systems to urban and densely populated areas. The researchers suggested that further work should include hybrid models combining different sources, as well as investigations into how zoning laws and property characteristics affect feasibility and adoption in varied residential contexts.

Xia et al. (2025) aimed to optimize the design of a high-performance heat exchanger specifically intended for use in modular thermoelectric generators (TEGs) to enhance low-grade thermal energy recovery. The authors utilized a methodology combining computational fluid dynamics (CFD) optimization and analytical modeling to achieve a more homogeneous flow distribution and improved heat exchange efficiency. No specific sample size was mentioned, as the study relied on computational models and prototype simulations rather than physical samples. Conducted in China, the research focused on minimizing flow maldistribution and reducing flow resistance within plate-shaped heat exchangers. The results demonstrated a significant improvement in flow uniformity, achieving a flow maldistribution intensity of only 4.75% and a low flow resistance of 1.16 kPa. These optimized designs were shown to enhance the overall power output and efficiency of TEG modules. However, despite these promising outcomes, the study highlighted a major gap: the lack of practical pilot deployments to validate the simulation findings in real-world applications. Large-

scale testing is essential to assess the actual performance, scalability, and economic feasibility of these designs in operational environments.

Balan et al. (2025) conducted a comprehensive study to explore the potential of in-building direct wastewater heat recovery (WHR) systems as a solution to improve the thermal efficiency of domestic hot water (DHW) systems. The authors' objective was to evaluate the operational and design characteristics of vertical and horizontal WHR heat exchangers in residential and commercial settings. Their methodology involved a review of existing technologies complemented by several case studies to illustrate practical applications and real-world performance. Although various buildings were analyzed, the exact sample size was not specified as the focus was on broad comparative insights rather than controlled experimental sampling. Conducted across Europe, the study demonstrated that WHR systems can significantly reduce energy consumption and operational costs by reusing heat from wastewater. However, the research also uncovered several gaps, particularly concerning the challenges of retrofitting existing buildings, the complexity of plumbing modifications, and the ongoing maintenance required to prevent fouling and efficiency loss. Furthermore, issues such as user behavior patterns and system synchronization with hot water demand were identified as critical factors needing further investigation to ensure widespread adoption.

Hundiwale and Joshi (2024) focused on designing and analyzing a novel pancake-type heat exchanger with different pitch coils to enhance low-grade heat recovery efficiency in industrial and domestic applications. The main objective was to maximize heat transfer effectiveness while minimizing the size and complexity of the unit. Their study employed an experimental design and analysis methodology,

utilizing prototype fabrication and laboratory testing to evaluate thermal performance. While the specific sample size was not detailed, the study relied on rigorous experimental trials to validate the design concept. Conducted in India, this research highlighted the unique advantages of pancake coil designs, which include increased heat transfer surface area and better thermal performance compared to traditional shell-and-tube exchangers. The results showed that the new design significantly improved heat recovery efficiency and allowed for a more compact heat exchanger footprint. Despite these promising findings, the authors identified a crucial gap: the need for large-scale testing to confirm performance under varying operational conditions and to conduct comprehensive economic analyses. This would determine the viability of widespread adoption, particularly in resource-constrained environments using locally sourced materials.

Lan et al. (2024) investigated the performance of thermoelectric generators (TEGs) when integrated with a uniform flow distribution heat exchanger for recovering low-grade thermal energy. The objective of the study was to improve the conversion efficiency of TEG systems, which traditionally suffer from low efficiency due to uneven temperature distribution and high flow resistance. The methodology involved experimental evaluation using a custom-built TEG system equipped with advanced staggered fins and a variable geometry header to ensure uniform fluid flow. No exact sample size was specified, as the focus was on system-level testing rather than large-scale deployment. Conducted in China, the experiments demonstrated that the new design achieved high output power and maintained low flow resistance, significantly enhancing the feasibility of using TEGs for energy recovery in industrial processes. However, despite the technological improvements, the study acknowledged a major limitation: the lack of scalability assessments for industrial and large-scale

applications. Further studies are needed to understand performance stability over time and to address practical challenges related to system integration and cost-effectiveness.

Seo et al. (2024) aimed to evaluate the performance of a compact heat pipe heat exchanger (HPHX) designed for waste heat recovery in low-temperature applications. The objective was to create an efficient, small-sized system capable of recovering significant amounts of heat even at relatively low source temperatures. The study employed an experimental analysis approach, where a compact HPHX prototype was fabricated and tested under different gas temperatures and mass flow rates. No specific sample size was detailed as the focus was on system-level experimentation. Conducted in South Korea, the results showed that even at temperatures as low as 50°C, the HPHX could recover over 100 W of heat, with thermal performance improving significantly when fins were included on the heat pipes. These findings underscore the potential for using compact heat exchangers in various applications, including domestic appliances such as kitchen hoods and dryers. However, a key gap identified in this study was the absence of field applications in actual domestic or commercial environments. Further research is necessary to validate long-term performance, durability, and practical integration challenges in real-world settings.

Rinik et al. (2024) focused on developing a gravity-assisted heat exchanger integrated with Organic Rankine Cycle (ORC) and Liquefied Natural Gas (LNG) systems to enhance waste heat recovery efficiency in industrial exhaust applications. The objective was to design a system that maximizes heat extraction and improves overall energy utilization, thereby contributing to emissions reduction and fuel savings. The methodology included theoretical modeling, heat transfer analysis, energy efficiency testing, and a comprehensive parametric analysis. While no explicit sample size was

provided, the study's simulations were detailed and robust. Conducted in Bangladesh, the results indicated that the system could achieve high efficiency, with the heat exchanger effectiveness reaching approximately 52.3% and ORC cycle efficiencies up to 36.8%. Despite these promising results, the authors identified a significant gap: the system's suitability and adaptability for small-scale or domestic applications were not addressed. Further research involving pilot installations and economic feasibility studies in non-industrial contexts is required to explore broader application potential.

Cui et al. (2022) undertook a comparative study to analyze the performance of waste heat recovery exchangers used in glass melting furnaces operated with different fuels, including liquid natural gas (LNG), methanol, and dimethyl ether (DME). The primary objective was to identify the most economically viable and environmentally friendly option for industrial heat recovery. Their methodology involved experimental testing of heat exchanger systems paired with different combustion programs, along with an economic evaluation using net present value (NPV) and CO2 emissions as key indicators. The study did not specify a formal sample size since the focus was on system-level performance comparisons. Conducted in China, the findings revealed that furnaces fueled by DME achieved the best overall performance, providing optimal NPV and lower CO2 emissions compared to the LNG and methanol options. The DME setup emerged as the most promising from an economic and environmental standpoint. However, a significant research gap was noted: the study was limited to glass industry applications, and thus broader applicability to other industrial or domestic heat recovery contexts remains unexplored. Future research should assess how these findings translate to different sectors and whether similar benefits can be realized across various heat-intensive industries.

Attarzadeh et al. (2022) investigated the optimization of triply periodic minimal surface (TPMS)-based heat exchangers for low-temperature waste heat recovery, aiming to improve thermal and pressure performance in energy systems. The objective was to develop a novel heat exchanger design capable of minimizing hydrodynamic resistance while maintaining high heat transfer efficiency. The study employed computational optimization using a multi-objective genetic algorithm integrated with computational fluid dynamics (CFD) simulations. No specific sample size was mentioned, as this was a computational design-focused study rather than an experimental trial. Conducted in Sweden, the research revealed that TPMS structures allowed for significant improvements in thermal performance and provided a balanced trade-off between pressure drop and heat exchange efficiency. The results highlighted optimal configurations that could be used for waste heat recovery in low-gradient systems. Nevertheless, the authors acknowledged a critical gap: the lack of experimental validation to confirm these computational findings in real-world environments. Future work should include prototype development and performance testing in operational settings to ensure practicality and to address challenges related to manufacturing complexity and long-term durability.

Kumar and Murugesan (2022) carried out an experimental field study to evaluate the performance of a ground source heat pump (GSHP) system using double U-tube borehole heat exchangers (BHEs) for space heating. The study aimed to understand the combined phenomena of heat extraction and soil thermal recovery, comparing series and parallel fluid flow configurations. The experimental setup included five double U-tube BHEs and one single U-tube BHE, each 120 meters deep, but no exact sample size in terms of buildings or occupants was detailed. Conducted in Roorkee, India, the study was performed during peak and moderate winter conditions. The

findings indicated that series flow configuration resulted in a 20% higher heat extraction and coefficient of performance (COP) compared to parallel flow, highlighting its potential for enhanced energy efficiency. However, the research also revealed a key gap: while series configurations yielded better performance, they led to slower soil thermal recovery, raising concerns about long-term sustainability. Further long-term monitoring and soil behavior studies are necessary to optimize system design and operational strategies for consistent efficiency without compromising soil regeneration.

Huang et al. (2023) focused on the thermal recovery characteristics of rock and soil surrounding medium and deep U-type borehole heat exchangers (MDUBHEs) used in geothermal energy systems. The objective was to evaluate the sustainability and efficiency of deep geothermal heat extraction and to analyze the long-term thermal behavior of surrounding geological materials. The study employed a numerical simulation model validated against both experimental and computational fluid dynamics (CFD) data, with no explicit sample size mentioned due to its simulation-based approach. Conducted in China, the results showed that the thermal recovery rate of deep rock and soil exceeded 91% after one heating-recovery cycle (one year) and that thermal decay was less than 9.3% even after 15 years of continuous operation. These findings suggested strong potential for sustainable long-term geothermal energy extraction. Nonetheless, the study highlighted an important research gap: a lack of field validation in different geological conditions to verify these promising simulation outcomes. Future work should involve real-world pilot projects across various sites to confirm generalizability and refine design parameters for diverse geotechnical environments.

Wei et al. (2021) explored the performance of thermoelectric generator (TEG) systems enhanced by a newly designed compact heat exchanger aimed at recovering low-grade thermal energy. The study's objective was to address scalability challenges and improve energy conversion efficiency in modular TEG applications. The methodology consisted of experimental analysis, where a compact heat exchanger prototype was fabricated using diffusion welding techniques to ensure structural integrity and uniform temperature distribution. While the sample size was not specified, the study concentrated on a single TEG unit containing five modules to demonstrate feasibility. Conducted in China, the findings indicated that the compact heat exchanger achieved high volumetric power density (86.4 kW/m^3) and maintained a low surface temperature variation, thus enhancing the system's overall efficiency. However, despite these advancements, the authors identified a major gap: the system's scalability and performance stability in large-scale industrial or extended operational contexts remain untested. Future research should focus on developing larger prototypes and conducting long-term field tests to validate the durability, economic feasibility, and integration challenges in practical applications.

Arnaudo et al. (2021) conducted a comparative techno-economic and environmental analysis of waste heat recovery systems in low-temperature district heating networks versus domestic heat pumps. The objective was to evaluate which approach offers better efficiency, cost-effectiveness, and environmental impact for residential heating in newly developed districts. The study utilized simulation-based methodologies to model different scenarios, focusing on a real neighborhood in Sweden, though no exact household sample size was specified. The results demonstrated that integrating waste heat recovery into low-temperature networks could reduce fossil fuel consumption by up to 40% and provide a more stable and cost-effective solution

compared to individual domestic heat pumps. Furthermore, the heat generation cost for waste heat recovery systems was found to be 28% lower than that of heat pumps. However, the authors identified a significant research gap: while district-level benefits were evident, the implications and feasibility of implementing such systems at the individual household level were not fully explored. Further investigations are required to assess resident acceptance, household-level operational challenges, and the long-term performance of such systems under varying climatic and usage conditions.

Benakopoulos et al. (2021) examined a novel approach to reduce return temperatures in domestic hot water (DHW) systems by employing a chemical-based disinfection solution instead of traditional thermal treatments. The objective was to enhance the energy efficiency of DHW systems and make them more compatible with low-temperature district heating. The methodology involved an experimental evaluation of different operational strategies, focusing on controlling Legionella bacteria while minimizing thermal losses. Although no specific sample size was provided, the study was conducted on a multi-family residential building in Belgium. The results showed that using chemical disinfection allowed for a reduction in supply temperature to 45°C, leading to return temperatures as low as 40°C and reducing circulation heat loss by up to 66%. Despite these promising outcomes, the study revealed several gaps: the influence of user behavior on system performance and potential issues related to varied building configurations require further study. Long-term monitoring is also necessary to evaluate the durability and safety of chemical treatments, especially in different climates and regulatory contexts.

Attarzadeh et al. (2021) conducted an in-depth numerical study to analyze the thermal performance of a Schwartz D-based heat exchanger, utilizing triply periodic minimal

surfaces (TPMS) for waste heat recovery applications. The main objective was to explore the intricate flow patterns and heat transfer characteristics of TPMS structures, which are promising for low-temperature waste heat recovery systems due to their large surface area and efficient flow dynamics. Using three-dimensional steady-state conjugate heat transfer simulations, the study assessed various lattice designs with different wall thicknesses and evaluated their thermal effectiveness and pressure drop characteristics. Conducted in Sweden, the research did not specify a sample size as it was purely simulation-based. The results indicated that specific TPMS designs could significantly enhance heat exchanger efficiency, with optimal configurations providing a balance between high heat transfer and manageable pressure losses. However, a significant gap identified was the lack of physical prototypes and experimental validation to corroborate these simulation results. Future work is needed to develop practical TPMS-based heat exchangers, test them under real operating conditions, and address challenges such as manufacturability and long-term durability in dynamic environments.

Mohammadaliha et al. (2020) investigated the thermal performance of heat and water recovery systems that utilize condensing heat exchangers, focusing particularly on the role of heat exchanger material properties. The objective was to identify optimal thermal conductivity thresholds that balance performance with resistance to corrosion, which is a critical challenge in systems recovering heat from corrosive flue gases. The methodology combined analytical modeling with validation against experimental data, ensuring robust predictive capability. While the exact sample size was not specified, the models were built to generalize across various industrial heat recovery applications. Conducted in Canada, the study found that a thermal conductivity threshold around 0.75 W/m·K was sufficient to maintain efficient heat transfer,

enabling the use of alternative materials like plastics or ceramics that offer better corrosion resistance at lower costs. Despite these valuable findings, the study highlighted a key gap: real-world system-level durability tests are needed to confirm material longevity and operational stability in diverse environmental conditions. Further field trials are essential to validate these materials' performance and to evaluate practical maintenance requirements and economic feasibility.

Sunu et al. (2020) carried out a comparative thermodynamic review focused on domestic air conditioning systems with and without integrated heat recovery units. The primary objective was to evaluate the potential energy savings and thermodynamic improvements achievable by incorporating heat recovery to utilize condenser waste heat for domestic hot water production. The study employed a detailed thermodynamic analysis, using time series data to compare cooling capacity, compressor work, and overall energy efficiency across both system types. Conducted in Indonesia, no specific sample size was given since the analysis was based on modeled system performance rather than on-site installations. The results indicated that adding heat recovery could improve system energy efficiency by approximately 46–54%, making it a promising approach for energy conservation in tropical and sub-tropical regions. Nevertheless, the authors pointed out significant gaps, particularly concerning the economic feasibility of large-scale adoption. Future studies should include cost-benefit analyses, real-world pilot projects, and user behavior assessments to determine practical viability and to explore ways to overcome potential market and infrastructural barriers to implementation.

Jyothi and Khan (2020) conducted a computational fluid dynamics (CFD) analysis on a redesigned waste heat recovery unit (WHRU) intended for boiler plants to enhance

heat transfer performance and structural robustness. The objective was to address common issues in traditional WHRU designs, particularly water leakage and steam loss due to deteriorating rubber jackets. Their methodology involved using CFD simulations to analyze velocity streamlines and temperature contours before and after design modifications. Although no specific sample size was mentioned, the simulations focused on improving the design of a single WHRU unit. Conducted in India, the new design replaced the traditional rubber jacket with coiled pipes and increased the body thickness to minimize vibrations and structural weaknesses. The simulation results indicated a significant improvement in heat transfer rates and better design durability, promising enhanced operational efficiency and longevity. However, a major gap remains: the lack of experimental validation of the CFD results in real boiler plant environments. Further work should focus on prototype fabrication, field testing under operational conditions, and comprehensive economic assessments to confirm the design's practical benefits and commercial viability.

Ahmad and Riffat (2020) presented a comprehensive literature review and conceptual analysis of heat exchangers, emphasizing their pivotal role as the heart of energy recovery systems. The main objective was to consolidate recent advances in heat exchanger designs and configurations that enhance energy recovery efficiency across different industrial and building applications. The authors reviewed a wide range of heat exchanger types, including counter-flow, cross-flow, co-current, and hybrid configurations, along with recuperative and regenerative constructions. Conducted in the United Kingdom, the study did not involve a specific sample size, as it was a synthesis of existing research findings. The review highlighted modern developments such as compact heat exchangers, innovative surface enhancements, and advanced materials that enable better heat and mass transfer performance. Despite these insights,

a significant gap was noted: there is a shortage of empirical case studies that validate these advanced designs in real-world settings. Future research should focus on practical implementation studies, long-term performance monitoring, and the development of standardized evaluation metrics to bridge the gap between theoretical advancements and applied energy recovery solutions.

Bisulandu et al. (2024) investigated an innovative multigeneration system that leverages heat exchangers to harness thermal energy from cement kiln exhaust gases, with the objective of maximizing overall energy recovery and producing multiple outputs such as electricity, cold, domestic hot water, and biogas. The study employed a combination of simulation and optimization techniques, using the M2EP (mass, energy, exergy, and performance) analysis method and a particle swarm optimization algorithm to fine-tune system parameters. Conducted in Canada, the work did not specify a formal sample size since it was a theoretical and simulation-based analysis. The findings indicated that the system could achieve an electrical production of 2,565 kW and a thermal efficiency of 22.15%, with a substantial reduction in exergy destruction and improved performance across all outputs. However, the authors identified a key gap: the system's adaptation and feasibility for smaller-scale or domestic applications were not explored. Further studies are needed to evaluate the practicality of deploying such complex multigeneration systems in different operational contexts, including smaller industrial facilities and residential buildings, to broaden the technology's applicability.

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.

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

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.

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:

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.

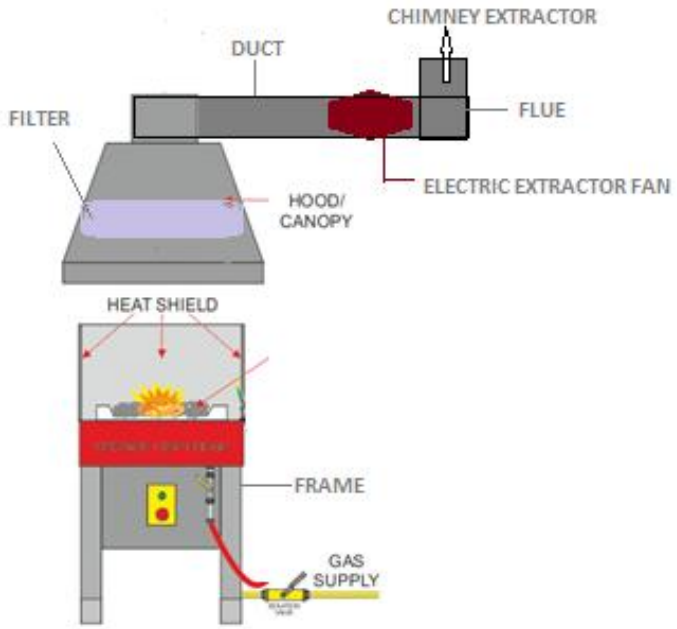

Figure 3.1 Electric powered kitchen heat extraction facility

Advantages of concept one

1. 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.

Disadvantages of concept one

1. It is not readily available where there is irregular electric power supply.

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.

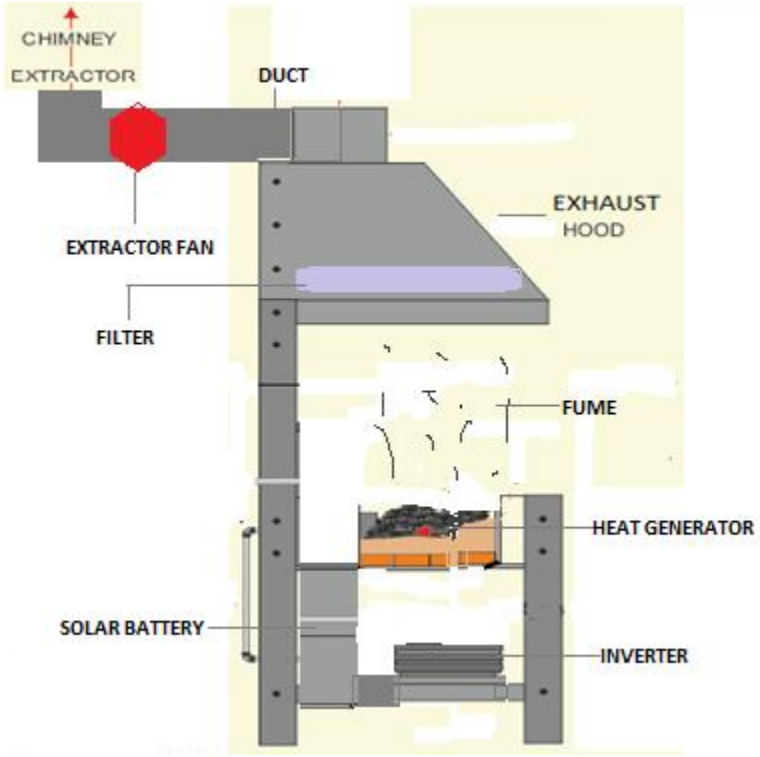

Figure 3.2 Hybrid (electric/solar) powered kitchen heat extraction facility

Advantages of concept two

1. The incorporation of alternative renewable energy will ensure it is readily available for use at most times.

Disadvantages of concept two

1. The concept 2 is relatively costlier to produce and or acquire.

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:

$V = \pi r^2 h$ (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 x 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.

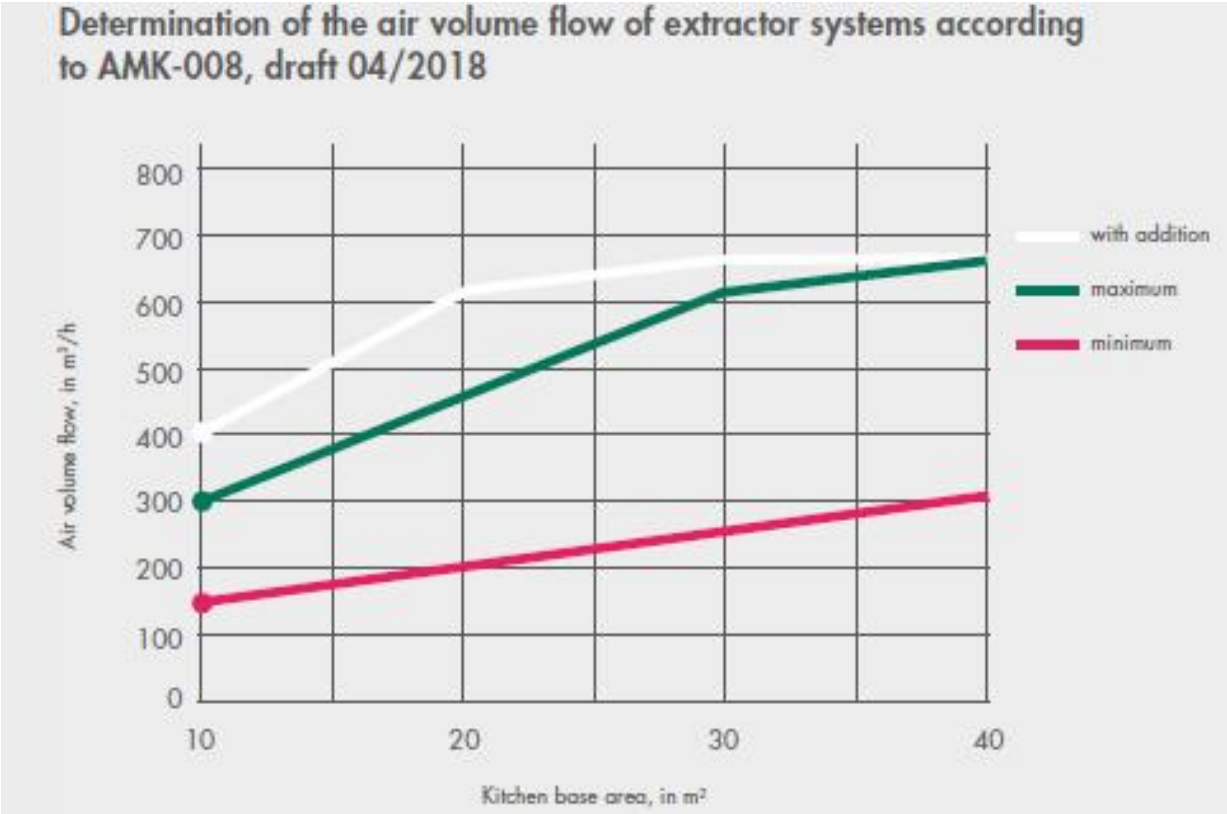

Figure 3.3 Air volume flow chart for extractor fans.

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 (ºC)**
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).

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

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

$P_{permeate\ absolute}$ = 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

1.3.5 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;

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

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.

3.3.6 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

3.3.7 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.

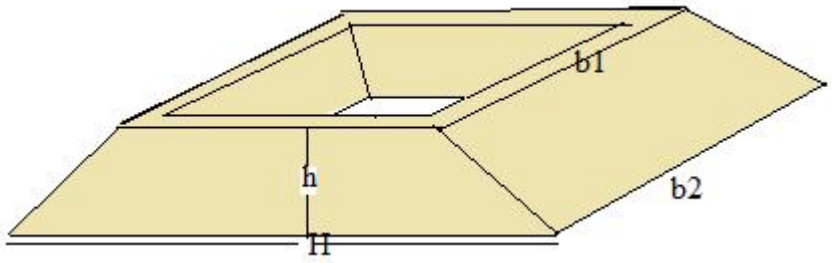

Figure 3.7 Trapezoid extractor hood

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 = $\frac{1}{2}$ x (b_1 + h_2) x h x 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.

3.3.8 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 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
14	**Total**					**331000**

The schematic and graphical presentation of developed kitchen cabin with installed heat and fume extractor are shown in Figure 3.9 and 3.10.

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	

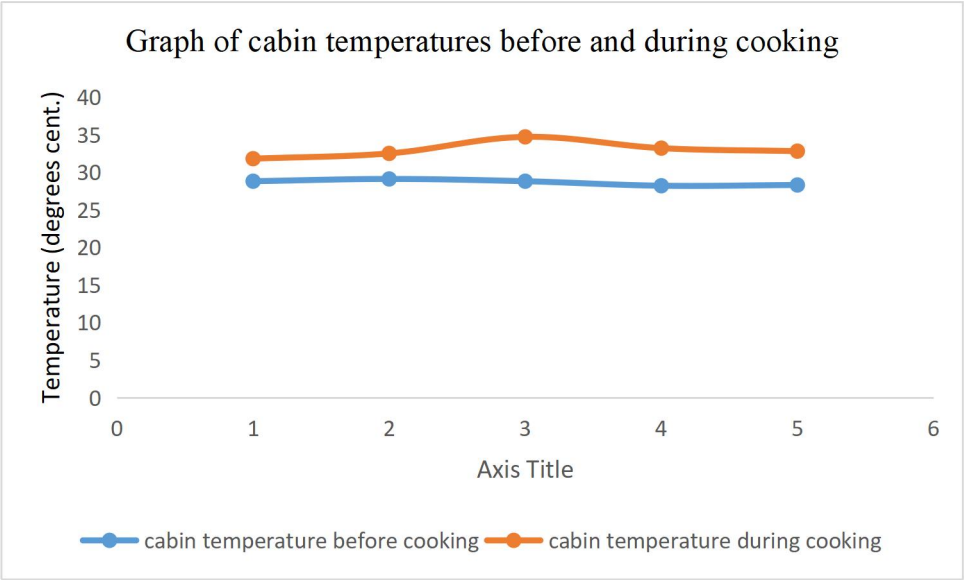

Figure 4.1 Graph showing kitchen cabin temperature

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.

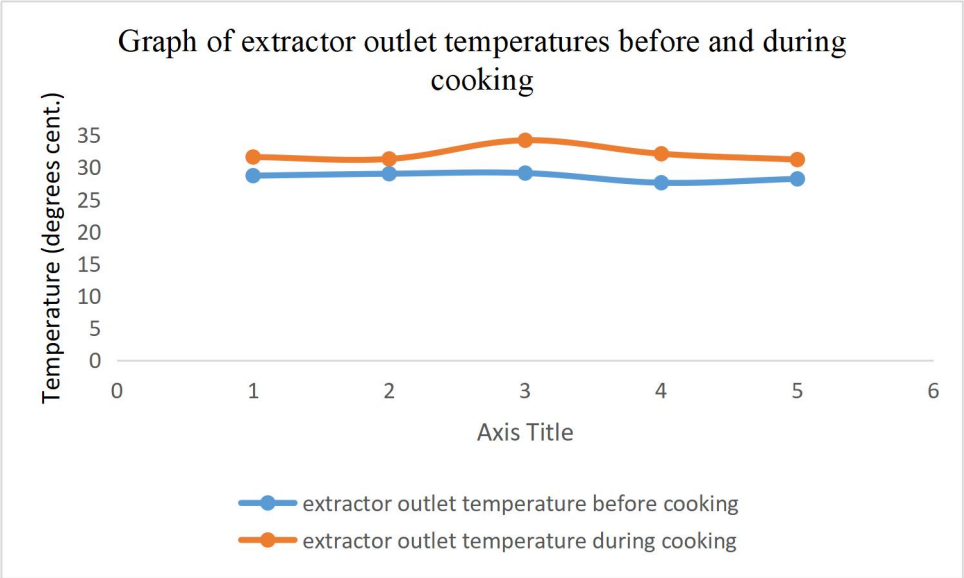

Figure 4.2 Graph showing extractor hood temperature

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:

i. **Improved Design Modifications:** Future designs should incorporate adjustable fan speeds and temperature sensors to automatically regulate airflow depending on heat intensity in the kitchen.

ii. **Use of Renewable Energy:** Incorporating solar-powered or rechargeable systems can make the extractor more energy-efficient, especially in areas with unstable electricity supply.

iii. **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.

iv. **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.

v. **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.

vi. **Durability Testing:** Long-term tests should be conducted under various environmental and usage conditions to assess durability, performance stability, and maintenance needs.

vii. **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.

viii. **Standardization and Quality Control:** Local manufacturing bodies should establish standard guidelines to ensure that all locally fabricated extractors meet safety and performance benchmarks.

ix. **Training and Capacity Building:** Technical institutions should include similar fabrication projects in their curriculum to equip students with practical design and production skills.

x. **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.

xi. 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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