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Development of the Corncob Biomass District Water Heating System for the Rainham Government Flats in Harare, Zimbabwe

Nelson Shati
PhD in Mechanical Engineering Candidate
Industrial and Mechatronics Engineering Department
University of Zimbabwe
Harare, Zimbabwe
nshati1965@gmail.com

Tauyanashe Chikuku and Ignatious Madanhire
Senior Lecturers
Industrial and Mechatronics Engineering Department
University of Zimbabwe
Harare, Zimbabwe
tauyanashec@gmail.com, imadanhire@gmail.com

Emmanuel Mashonjowa
Department of Physics
University of Zimbabwe
Harare, Zimbabwe
emashonjowa@gmail.com

Abstract

The Zimbabwean government and corporates have intensified construction of vertical housing dwellings such as flats. This is being done to save on limited space and comfortably accommodate many residents. In some cases, these housing development schemes are followed up by installations of single dwelling solar domestic heating systems, and at times solar photovoltaic systems. These two energy systems usually compete for occupying the same space. On instances where solar thermal/photovoltaic collectors or modules are built or integrated as two-in-one assemblies, issues of efficiency and maintenance may become compromised. Previously, the Zimbabwean weather conditions were mild. This would not warrant hot water infrastructure to be included in design and installations. Nowadays, because of climate changes the winters are becoming severe, which demands designs and installations of hot water systems for household uses to be incorporated at every stage of construction. Considering these recent developments in both climate and technology, a corncob agricultural residue-fired district water heating system is being proposed, designed, and recommended for use to the Government of Zimbabwe, corporates into housing projects and other agencies. This renewable energy district water heating system which does not use wood or fossil fuels is meant to mitigate against adverse effects of climate change, especially global warming and at the same time pave way for solar photovoltaic infrastructure on buildings' rooftops. Expansion of this new energy form for use in newly developed areas will also relieve pressure being encountered in the national electricity power grid, which often sheds some load.

Keywords
Agricultural Residue, Biomass, Corncob, District Water Heating.

1. Introduction
The research was motivated by the United Nations Sustainable Development Goal (SDG) Number 7. This SDG requires countries and businesses to accelerate transition in ensuring access to affordable, reliable and sustainable renewable energy systems for all and maintain ecosystems protection (Jiang et al, 2018). This strategic transformation to save the environment from further fossil fuel damage was adopted in 2015 United Nations Sustainable Development Goals, SDG2015-2030 (Kareem et al, 2016). As a result, clean energy technologies are receiving increasing attention from governments, industry, and consumers. This interest reflects a growing awareness of the environmental, economic, and social benefits that these technologies offer (RETScreen, 2023). Therefore, the problem arose that as the government and corporate undertake constructions of flats which rise vertically, the tendency is a view that installation of stand-alone domestic water heaters is a solution. The nature of solar technology is that thermal collectors compete for space with photovoltaics modules. Ultimately, electricity being the main driver of life, solar photovoltaic electrical power systems ends up being preferred. Biomass agricultural residue district heating systems will be convenient to design and install in newly established residential areas. They will bring in economies of scale in terms of hot water delivery. At the same time, these central heating systems will leave room for solar photovoltaics roof installations. Problems of greenhouse gas emissions reduce, and then people will breathe non-toxic clean air.

1.1 Objectives
The main aim of the research is to develop a corncob agricultural residue renewable energy system for district hot water heating at Rainham Estate Flats in Harare. The objectives to achieve the aim are to:

1. Create an energy audit for a bloc of 36 flats at Rainham Estate in Harare.
2. Apply the energy audit results to design a district corncob biomass heating district water heating system.
3. Recommend for district water heating system installation to the stakeholders in the construction sector.

2. Literature Review
The Zimbabwean government and corporate housing developers are building flats in order to both optimize on available limited space, and solve the housing backlog. Figure 1 is a three-floor six-unit block of flats which is very common as adopted in Zimbabwean construction industry.

Figure 1. A Three-floor six-unit block of flats common in Zimbabwe (http://www.pinintrest.com, 2023).

Figure 2 shows a more compact back-to-back three floor structure which yields more space utilization and accommodates up to 12 families. These large-scale housing developments demand a new approach towards service provision. They could be beneficiaries of these newly developed renewable energy installations. The research focusses on introducing a biomass renewable energy-fired district water heating system for the blocks of flats being developed by the Zimbabwe Government at Rainham Estate in Harare. To establish the hot water demand for the new blocks of flats, an energy audit is conducted at initial stages of the research.

Figure 2. A more appealing and compact block accommodating up to 12 families (http://pininterest.com, 2023)

2.1 Energy audit

Bureau of Energy Efficiency (BEE India, 2023) explains an energy audit as the key to a systematic approach for decision-making in energy management. An energy audit attempts to balance the total energy inputs with its use and serves to identify all the energy streams in a facility. It quantifies energy usage according to its discrete functions. Industrial energy audit is an effective tool in defining and pursuing comprehensive energy management (BEE India, 2023). The need of an energy audit arises because of the fact that in any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials. If one were to relate to the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker, and thus energy management function constitutes a strategic area for cost reduction (BEE India, 2023). An energy audit provides a benchmark or reference point for managing energy in the organization and also provides the basis for planning a more effective use of energy throughout the organization. Benchmarking of energy consumption internally which is a historical or trend analysis and externally across similar industries are two powerful tools for performance assessment and logical evolution of avenues for improvement. Well documented historical data helps to bring out energy consumption and cost trends on a monthly or daily basis. Trend analysis of energy consumption, cost, relevant production features, specific energy consumption, help to understand effects of capacity utilization on energy use efficiency and costs on a broader scale (BEE India, 2023).

2.2 The biomass district heating system

Perez de la Mora et al (2017) cite that nowadays, around 9 percent of the total heating needs in Europe are supplied by community and district heating systems. Twidell and Wier (2015) cite that the material of plants and animals, including their wastes and residues, is called biomass. It is organic, carbon-based material that reacts with oxygen in combustion and natural metabolic processes to release heat. Biomass is mainly used for domestic purposes in developing countries and significant amounts industrially combusted in mature economies. Developed countries directed state policies towards utilisation of biomass feedstock for future energy requirements to meet greenhouse gas (GHG) reduction targets set by the Kyoto Protocol. This also reduces the reliance and dependence on non-renewable resources. Agricultural and Forestry residues are the remainder which is left after extracting or harvesting useful grain or timber respectively. The biomass district heating system comprises of the feedstock and the equipment. The feedstock is selected amongst agricultural residues, as it its carbon neutral and also makes use of material which would normally be sent for disposal or produce liter in the environment. Following sizing of the biomass heating system through the results of an energy audit, standard equipment for direct biomass combustion will be selected.

2.3 Selection of the biomass feedstock

Michigan State University (2017) cites that corn stover is the non-grain above ground portion of the corn plant, including the husk, cob, stalk, tassel, silk and leaves. After corn grain harvest, stover is the remainder or crop residue. In the United States and other countries that have a high practice of using agricultural residue biomass renewable energy, the corncob is given a very special attention. Anil et al (2016) cite that a corn cob is the central core of an ear of the maize (*Zea mays* ssp. *mays*). It is part of the ear on which the kernels grow. The ear is also considered a cob or pole, but it is not fully a pole until the ear is shucked or removed from the plant material around the ear. Glassner et al (1998) cite that at each collection centre, the corn cobs are readily classified or separated from the corn stover. The cobs can be shipped in loose form for further processing, generating annual revenues of $10-15 million. The cob co-product has the value of $55/ton. Baled corn stover contains 20% cobs. With 1.1 million tons of corn stover collected as a minimum, 876 000 tons of that residue remains after the cob separation (Glassner et al, 1998). Harare, the capital city of Zimbabwe, is endowed with the corn grown in urban cultivation. Corn cobs are disposed as waste and at best they are used as auxiliary heating in the absence of electricity and liquefied petroleum gas. As such distribution costs from processing place to the point of use are very low. The city is also located in Mashonaland region which is the country's main corn growing area. Alberta Local Government et al (2014) cite that agricultural residues are burned in their raw form, as pellets or briquettes. The corncob can be used directly without densification such as briquetting and palletization. This results in further cost savings in potential energy, labour, machinery and other production costs. The dried corncob at 15 percent moisture content has a high energy yield valued at an average of 16 Gigajoules per ton. Thus, the heat released in the burning process amounts to is about $16MJkg^{-1}$. Szabo (2016) cites that energy production from biomass releases carbon dioxide (CO_2) which is a major greenhouse gas (GHG) that causes global climate change. However, the same amount of CO_2 is utilised for biosynthesis during the growth of biomass. Using biomass for energy production can have a balanced CO_2 production and consumption or less CO_2 release, compared to a huge discharge of CO_2 from burning fossil fuels (Cheng, 2010). Therefore, in this particular research agricultural residue corncob biomass is selected as the energy feedstock for the Rainham Estates Flats in Harare.

2.4 Biomass heating systems equipment

Choudhry et al, (2014) cite that biomass being world's largest renewable fuel source is now considered as the best alternate for fossil fuels owing to the CO_2 saving nature as well as more economical as compared to fossil fuels. RETScreen (2023) cite that biomass heating systems burn organic matter such as wood chips, agricultural residues, or even municipal waste to generate heat for buildings, whole communities, or industrial processes. They are more sophisticated than conventional woodstoves and are highly efficient heating systems, achieving near complete combustion of the biomass fuel through control of the fuel and air supply. They often incorporate automatic fuel handling systems.

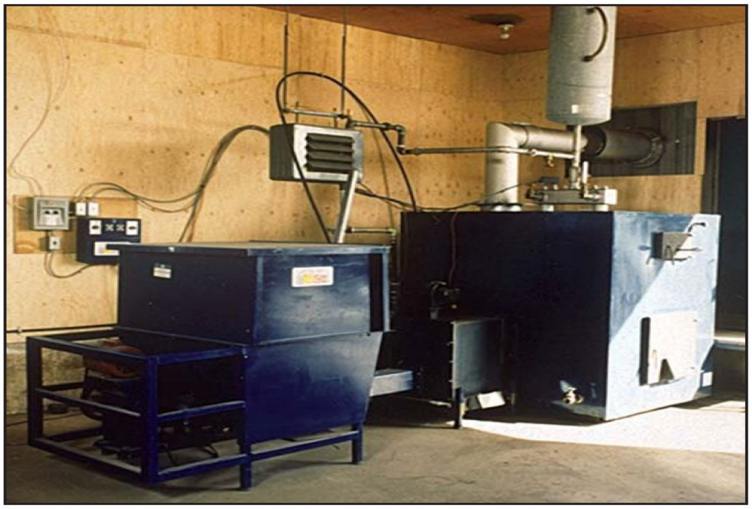

Figure 3. an Automated biomass water heating system (Alberta Local Government et al, 2014)

Figure 3 shows an automated biomass district water heating system. Biomass heating systems consist of a heating plant, a heat distribution system, and a fuel supply operation. The heating plant makes use of multiple heat sources, including a waste heat recovery system, a biomass combustion system, a peak load heating system, and a back-up heating system. The heat distribution system conveys hot water or steam from the heating plant to the loads that may be located within the same building as the heating plant the case of a single institutional or industrial building or district heating system for clusters of buildings located in the vicinity of the heating plant (RETScreen, 2023). In the biomass combustion system (BCS), the principal interest in a heating plant, the biomass fuel or feedstock moves through the BCS in several stages. Biomass fuel feedstock delivery is done to a fuel receiving area, which must be large enough to accommodate the delivery vehicles. The biomass fuel feedstock storage area must be sufficient to fire the plant over the longest interval between deliveries. The fuel can be stored in an outdoor pile, a protective shed, or inside a bin or silo. Outdoor storage, though inexpensive, permits precipitation and dirt to contaminate feedstock. Biomass fuels include a wide range of materials such as wood residues, agricultural residues, and municipal solid waste that vary in their quality and consistency far more than liquid fossil fuels. Figure 4 shows a complete operational circuit for the process of a biomass water heating system.

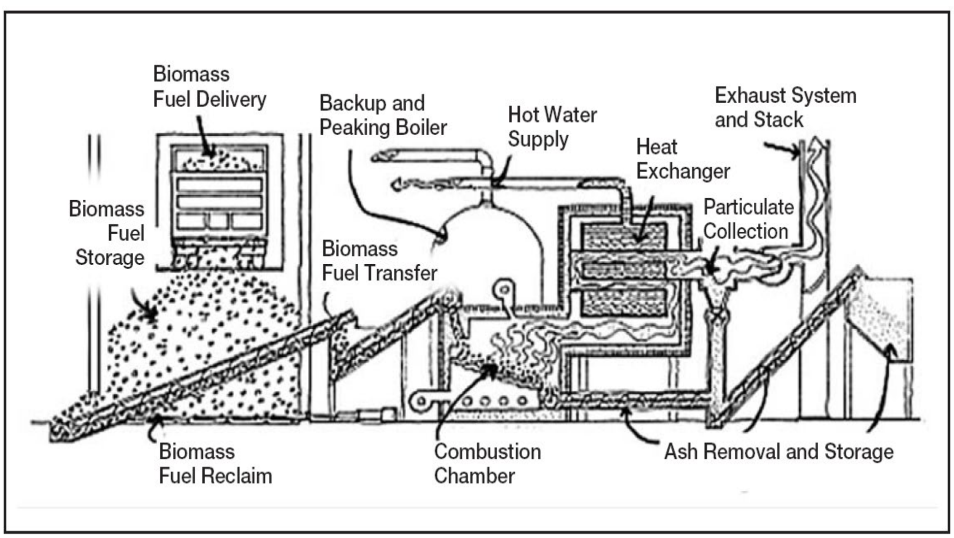

Figure 4. Biomass combustion system general layout (Retscreen, 2023)

Biomass fuel reclaim refers to the movement of the biomass fuel from storage to the combustion chamber. It can be done manually, as in the loading of outdoor furnaces with cut logs; fully automated, using augers or conveyors, or rely on both operator and machinery. Biomass heating systems have higher capital costs than conventional boilers and need diligent operators. Today, 11 percent of the world's Total Primary Energy Supply (TPES) comes from biomass combustion, accounting for over 20,000 MW of installed capacity worldwide. Corn cobs have traditionally been used for fire generation. Corn cobs have higher energy content and lower ash content resulting in a higher energy to ash ratio than any part of the stover (Lizotte et al, 2015). The only disadvantage is that of incomplete combustion because of high ash content with corn stover burnt in small furnaces producing as high as 23%. The combustion of high ash biomass leads to solid agglomerates, greater emission of fumes, and accelerated metal wastage due to gas-side corrosion. Handling large quantities may also be cumbersome and costly (Lizotte et al, 2015).

Table 1 shows the major considerations made is selection of a biomass type of use. shown in the following Table 1 (Retscreen, 2023). As explained in detail in the table, these six parameters are mainly the physical size, the type of fuel, the mode of operation, the mechanical complexity, the levels of local pollution and the impact of combustion hazards. Comparing a biomass combustion system (BCS) to conventional plants requires a careful evaluation of life-cycle costs and savings. Comparing bids from different biomass heating system suppliers calls for diligence. Table 1 shows particularities associated with biomass heating systems which should be considered:

Table 1. Technical considerations in selecting biomass combustion technology (RETScreen, 2023)

Physical size	Biomass fuel systems are much larger than conventional heating systems. They often require access for direct truck delivery of fuel, space for fuel storage, and a larger boiler room to house the mechanical fuel delivery and ash removal systems.
Fuel	Unlike gas and oil, biomass fuels are generally not standardised, homogeneous fuels backed by large national suppliers. As a result, fuel quality, consistency and supply reliability are concerns. Energy content varies significantly depending on the type of biomass used for fuel.
Operation	Biomass combustion systems typically require more frequent maintenance and greater operator attention than conventional systems. As a result, operator dedication is critical.
Mechanical complexity	Biomass combustion systems are more complex than conventional heating systems, especially when it comes to fuel storage, fuel handling and combustion. The complexity arises due to the different characteristics of biomass fuel compared to fossil fuels. The increased complexity means capital costs that are both higher and more difficult to estimate.
Local pollution	Biomass combustion generates emissions that can affect local air quality and that may be subject to regulation. These include particulates, also known as soot, gaseous pollutants such as carbon monoxide, sulphur oxides, nitrogen oxides, and hydrocarbons, and low levels of carcinogens. The emissions generated by the system will depend on the type of fuel as well as the size and nature of the combustion system. Local emission regulations may be different depending on the fuel type and combustion system. In addition, ash must be discarded according to local regulations.
Combustion hazards	Biomass combustion systems often require additional fire insurance premiums and special attention to general safety issues.

Rescreen (2023b) cite that these special considerations must be weighed against the many advantages of biomass heating systems. Table 2 shows other critical issues to be local economic benefits, the heating comfort, the flexibility of use, the environment and the price stability. Table 2 fully explain these important aspects such as reduced life-cycle costs.

Table 2. Additional technical considerations in selecting biomass combustion technology (RETScreen, 2023)

Local economic benefits	Biomass fuel (feedstock) is often harvested, collected, and delivered by local operators; in contrast, fossil fuels are generally imported from outside the community. Furthermore, the preparation and delivery of biomass fuel is more labour intensive than is the case with fossil fuels. As a result, expenditures on biomass have a stronger "multiplier effect" for the local economy: money tends to stay within the community rather than leave, creating local jobs and improving the local tax base.
Heating comfort	Low-cost biomass fuels make raising thermostats a more welcome proposition than with more expensive fossil fuels, resulting in warmer, more comfortable buildings.
Flexibility	Biomass combustion systems are highly flexible. Solid-fuel systems can be easily converted to burn almost any conceivable fuel (solid, liquid or gaseous) thus providing the user with great flexibility for the future.
Environment	Plant material that is harvested in a sustainable manner is considered a renewable energy resource since it will last indefinitely. Since growing biomass removes the same amount of carbon from the atmosphere as is released during combustion, so there is no net increase in the greenhouse gases that cause climate change. Most biomass fuels have negligible sulphur content and thus do not contribute to acid rain.
Price stability	Biomass fuel prices tend to be relatively stable and locally controlled; this is in marked contrast to the price for fossil fuels, which fluctuates widely and unpredictably in response to worldwide supply and demand.

3. Methods

The adopted methodology is drawing up an energy audit, equipment sizing and design through use of the energy audit results data and recommendations to stakeholders. BEE India (2023) cites that the energy audit gives a positive orientation to the energy cost reduction, preventive maintenance and quality control programmes which are vital for utility activities. The energy audit programme helps to keep focus on variations which occur in the energy costs, availability, and reliability of supply of energy, decide on appropriate energy mix, identify energy conservation technologies and retrofit for energy conservation equipment among others. An Energy Audit is the translation of conservation ideas into realities, by lending technically feasible solutions with economic and other organizational considerations within a specified time frame. The primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs (BEE India, 2023).

3.1 Rainham Estate Flats Energy Audit

The energy audit conducted for Rainham Estate Flats in Harare has several assumptions. Foremost, it assumes that there are four people per dwelling, two parents and two children. This implies an occupation by 144 residents. The peak periods of water use are the first four hours of the morning from 3 to 7 a.m., the lunch hours from 12 to 2p.m. and the evening four hours from 6 to 10p.m. Each family member requires 7½ litres in the morning for purposes of bathing, tea and warmth. Each member again needs 5 litres at lunch for similar purposes and 7½ litres for supper. This energy need is spread evenly over the hour segments of its use. Another key assumption is that there are no additions, removals, births or deaths of people throughout the year. Winter usage adds up another 2½ litres for each individual. For design purposes, these are considered as an all-year-long requirement. Except for the specified periods of hot water use, there is no usage at any other period of the day. Saturdays and Sundays there have additional hot water demand for laundry which amounts to 40 litres per household for 36 families in the morning. For design convenience, these are considered as a daily hot water demand. Table 1 shows a complete energy audit of daily hot water demand (Table 3).

Table 3. Energy Audit for the daily hot water demand at Rainham Estate flats in Harare

Time of Day	**3 -7am**	**7-12p.m**	**12-2p.m**	**3-6p.m**	**6-10p.m.**	**10-4a.m.**	**Total**
Residents 144 at 20 liters per person per day	144 × 7½ L	0	144 × 5L	0	144 × 7½ L	0	
	= 1 080L	0	**= 720L**	0	**= 1 080L**	0	**2 880L**
Laundry at 36 families × 40 litres per household at 3-7a.m.	36 × 40L	0	0	0	0	0	
	= 1 440L	0	0	0	0	0	**1 440L**
Total Hot Water on Normal Months (Sep – Apr)	**2 520L**	0	**720L**	0	**1 080L**	0	**4 320L**
Winter Provision 144 × 2½ L × 3 times/day (May – Aug)	144 × 2½ L	0	144 × 2½ L	0	144 × 2½ L	0	
	360L	0	**360L**	0	**360L**	0	**1 080L**
Total daily demand	**2 880L**	0	**1 080L**	0	**1 440L**	0	**5 400L**

The energy audit in Table 3 ensures that the daily hot water requirements for a specific entity are established. In the energy audit, care has been taken in order not to overdesign or under design the district hot water systems for the Rainham Estate Flats under construction. Designers are unanimous that renewable energy system design is a complex operation, but also provide guidance and necessary tools. Engineers and scientists themselves have to accomplish objectives based on uncertain information (Chapra, 2012). Although perfection is the main aim, it is rarely achieved if ever attained (Chapra, 2012). Mathematically speaking, processes involved even in simplest systems are nonlinear and their scaling up or down is even more complex (Sreekumar, 2007). Reliable results are obtained if a large database is at the disposal of designers (O'Hegarty et al, 2014). Designing a renewable energy thermal system involves more than just selecting a specific technology as it varies by building, location, occupancy, function and retrofitting existing systems to lower preheating costs (Retscreen.net, 2023). Inaccurate information on user requirements causes under or over dimensioned systems with main obstacles being unavailability of flow and temperature recorders in standard buildings and prediction difficulty on highly variable parameters such as human behaviour (O'Hegarty, et al, 2014).

3.2 Rainham Estate Flats District Water Heating System Generation and Distribution

However, with assistance of the above generated energy audit, an acceptable corncob biomass combustion water heating system can now be designed using tools of intuition, and experience. The system is to supply hot water to six three blocks of flats comprising of 6 units per block. Each floor has got two dwelling units. The design is specifically for the Rainham Estate Flats located near the Presidential Guard Army Unit. Figure 5 shows the layout of the corncob biomass district water heating system's generation and distribution network.

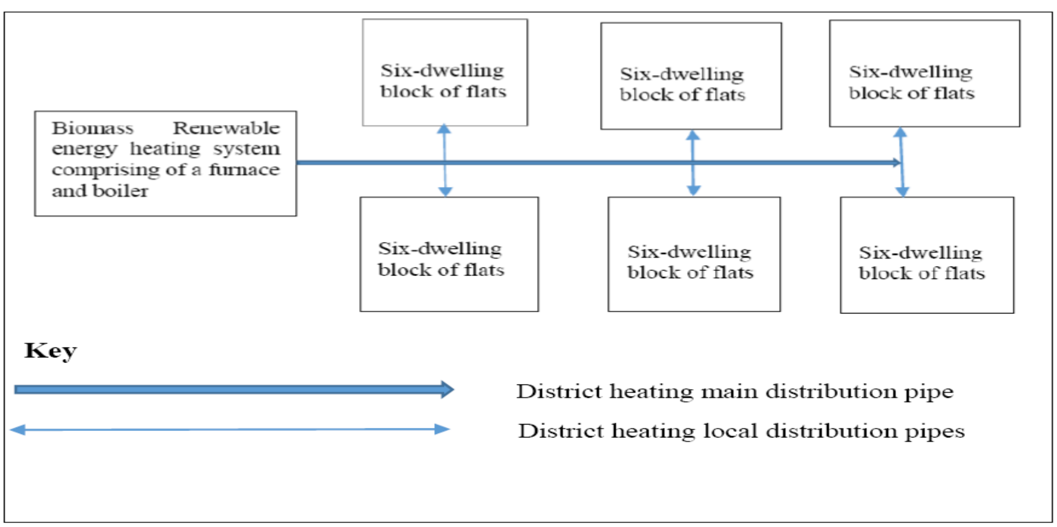

Figure 5. District water heating and distributing system layout for 36 flats at Rainham Estate

Appropriate corncob biomass loading, carriage and offloading technology was designed and constructed. It had an advantage that its working height of standing at 1 meter above the ground did not have physical strain on operators. It uses the 30o inclination from the horizontal to discharge its furl into the furnace. This technology is earmarked to promote the use of corncobs as an energy resource, thereby cutting off energy costs which used to be incurred in seeking other forms of energy such as electricity, firewood, liquefied petroleum gas, amongst others. Forests residues such as log chips and sawdust can also be used in the biomass charging and heating system. This improves the renewable energy resource availability. it is technologically versatile since it is adaptable to existing furnaces by adjusting its coupling brackets to align with those of the ovens. Figure 6 shows the model biomass charger with a fireball from corncob indicating the potential of both the energy resource and the mechanical system.

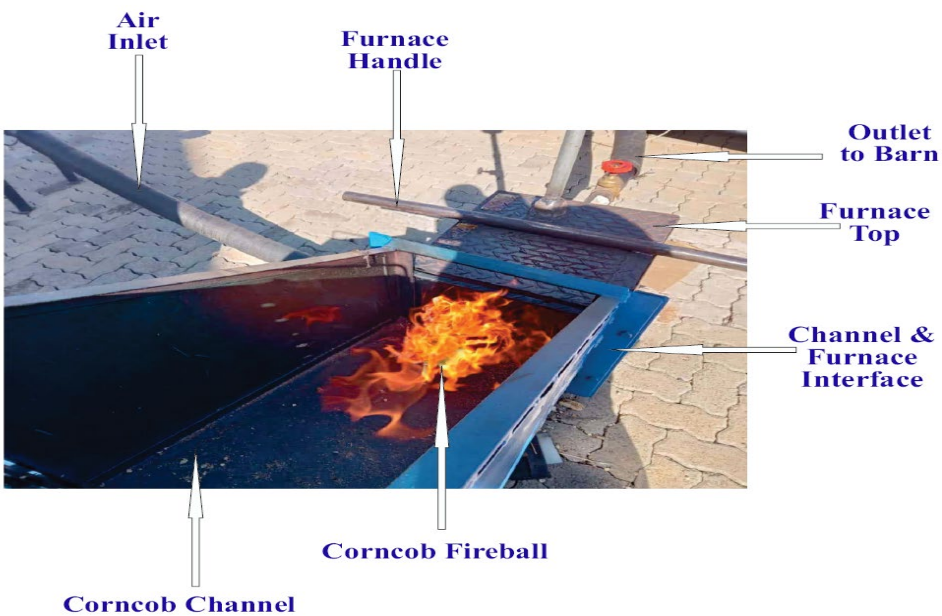

Figure 6. Testing of a corncob renewable energy charging system and energy performance.

4. Results and Discussion

The results calculated in designing the biomass district water heating network to service the Rainham Estate block of flats are mainly the hot water demand and the energy required to heat the water to required temperature. Also to be calculated is the daily biomass quantity used as well as its annual value. Amount of electricity savings realized is estimated as an equivalent of thermal energy gained from the agricultural residue energy.

4.1 Numerical Results

Table 4 results show that the morning, afternoon and evening hot water demand is different. The demand is respectively 2 880L or 2 880kg for morning use, 1 080L or 1 080kg for afternoon use and 1440L or 1 440kg for evening use. Table 4 shows calculations for the amount of energy required to raise temperatures for the water from 20^{o}C to 90^{o}C of usable hot water. Therefore, the other working gives the equivalent mass of corncob biomass to be combusted in providing the thermal energy. Table 4 also shows the loading pattern of biomass from the time of furnace ignition and throughout the heating period. A periodical feeding of the corncob energy feedstock is done in every 30 minutes after an initial loading of 10kg to ignite the furnace.

Table 4. Rainham Estate daily and annual corncob energy and resource demand

Session	Morning	Noon	Evening	Total	Comment
Hot water Required	2 880kg	1 080kg	1 440kg		
Energy required to heat the water from 20ºC to 90ºC: ($\Delta\theta$ = 90ºC - 20ºC) E = (m × c × 70ºC)	2 880 × 4.2kJ × 70 = **846 720kJ**	1 080 × 4.2kJ × 70 = **317 520kJ**	1 440 × 4.2kJ × 70 = **423 360kJ**	**1 587 600kJ**	Raising water temperature to near boiling point for multi-purpose use
Amount of corn cob to provide that energy at 16MJ/kg	846 720kJ÷16MJ/kg = **52.92kg**	317 520kJ÷16MJ/kg **= 19.845kg**	423 360kJ÷16MJ/kg **= 26.46kg**	**99.225kg**	The major assumption is of no process/energy loss.
Starting feedstock	10kg	10kg	10kg	30kg	Fire-start up
Half-hourly feed	42,92÷6 =7.153kg	9.845÷6=1.64kg	16.46÷6=2.743kg	69.225kg	Heat sustenance
Total annual corncob biomass feed =99.225 × 365 = 36217.125kg ÷ 1 000kg/Ton				**36.217 Tons**	

Table 4 shows the expected energy consumption by the biomass heating system to provide hot water demand at Rainham Estate Flats in Harare. The daily amount of energy required is obtained as 1 587 600KJ. A total of 100 kg of corncob biomass provide the energy at 16GJ/ton or 16MJ/ton. Accordingly, the heating system operates in a discrete manner. It is operated for three hours in the morning from 2:00a.m to 5a.m., three hours towards lunch from 10: 00a.m to 1:00p.m. and three hours in the evening from 5:00p.m. to 8:00p.m. The mass of starting biomass at each production shift is higher, with constant feeding then taking place later as the furnace is heated. It was observed that the renewable corncob feedstock consumption would be 10kg at set up and subsequently topped up every 30 minutes as prescribed for the next three hours. Total energy feedstock for the whole year is 36.217 Tons, thus, saving 580GJ_{th} in potential electricity use. Discrete operation system allows for ash removal, cleaning and servicing in between heating sessions. The solar thermal collectors of 1 764m^2 in insolation area and energy value at 1 051 200 000J was found to size a 1.25Megawatt Thermal (MW_{th}) boiler. Therefore, the current research's energy content of 1 587 600kJ or 1 587 600 000J will require a boiler of size:
(1 587 600 000 ÷ 1 051 200 000) × 1.25MW_{th} = 1.51MW_{th}. A 1.5MW boiler will be the ideal heat exchanger.

5.3 Proposed Improvements

To improve on energy resource availability, consideration to use log chips, sawdust, twigs and branches are proposed. These forest residues would cover corncob deficits encountered in droughts, supply chain breaks and pre-harvest as well as harvest periods as the cobs lose moisture content to become usable. Therefore, the biomass combustion system use should be designed to accommodate the use of corncob and forest residues. This use of multiple agricultural and forest residues will ensure environmental preservation and future sustainability.

6. Conclusion

The Zimbabwean government and corporate sector initiated major construction projects of residential dwellings. One of these projects are 6 blocks of flats being constructed by the by the government at Rainham Estate in Harare. An energy audit was conducted to establish the hot water demand for the 36 dwelling units. The current engineering initiative is to design a biomass district water heating system for these flats and propose to the authorities for its implementation. This has been observed to save roof space for photovoltaics and make use of corncob renewable energy. The use of corncobs will translate the value of this agricultural residue from being an after-use disposal into a valuable asset. In the process, it will create local employment as people collect corncobs for sale to users. In using the renewable energy, the country stands to make savings of in terms of deferred electricity and fossil fuel use. The annual savings were estimated to be 580GJ_{th} in potential electricity use.

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Biographies

Nelson Shati is a PhD candidate with the Industrial and Mechatronics Engineering Department at the University of Zimbabwe. He earned B.S. in Electrical Engineering from Tianjin University, China, Master of Business Administration from University of Zimbabwe, and Master of Science in Engineering Management from Brunel University London, United Kingdom. He is a publisher of journal and conference papers with research interests in renewable energy, manufacturing and maintenance management.

Ignatio Madanhire has a DPhil in Engineering Management majoring in Cleaner Production and Waste Management from the University of Johannesburg. He is part of the lecturing team at the University of Zimbabwe in the Industrial and Mechatronics Department. He is a member of Zimbabwe Institute of Engineers (ZIE) and is a registered engineer with the Engineering Council of Zimbabwe (ECZ). He has a passion for academic research work in pursuit of insights on effective waste symbiotic solutions in industrial operations and industrial sustainability (add more).

Tauyanashe Chikuku ia an experienced lecturer with a demonstrated history of working in the higher education industry. Skilled in AutoCAD, Analytical Skills, Computer-Aided Design (CAD), PTC Creo, and Finite Element Analysis (FEA). Strong engineering professional graduated from gokomere high school. Tauyanashe Chikuku did his BS in Mechanical Engineering Honors and Masters of Science in Manufacturing Systems and Operations Management at the University of Zimbabwe, He is currently teaching Mechanical Engineering Design at the University of Zimbabwe. He is the recent Chairman of the Mechanical Engineering Department at the University of Zimbabwe.

Emmanuel Mashonjowa is a Professor and Agricultural Meteorologist at University of Zimbabwe. Emmanuel Mashonjowa holds PhD in Biosystems Engineering from Universiteit Gent. With a robust skill set that includes Weather, Curriculum Development, Weather Forecasting, Management, Lecturing and more, Emmanuel Mashonjowa contributes valuable insights to the industry. Emmanuel Mashonjowa currently works at the Department of Space Science and Applied Physics, University of Zimbabwe. Emmanuel does research in Agrophysics, Biosystems Engineering and Irrigation and Water Management.