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Urban Residential Building Energy Consumption by End-Use in Malawi

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Abstract: Buildings account for about 40% of the global energy consumption and this energy demand is projected to continue growing over the next few decades. Residential buildings are responsible for over 60% of this consumption pattern with commercial buildings being responsible for the remainder. While residential building energy consumption constitutes about 20% of the total consumption in the developed world, it constitutes up to more than 50% in the sub-Sahara African region. The growing consumption of energy has raised concerns over the impacts on the environment, supply difficulties, and depletion of resources. In efforts toward addressing these concerns, the need for effective management of energy resources and adequate planning for energy infrastructure cannot be overemphasized within the building industry in general and the residential building sector in particular. Toward this end, it is necessary to ensure that high quality and high-resolution information on the consumption of energy in buildings is made available. Unfortunately, in many countries within the sub-Sahara African region, building energy consumption information is hardly ever readily available. This study seeks to make a contribution toward this facet of the literature at the greater regional level in general and particularly, in Malawi, a country located in the southern part of Africa. With a grounding in the context of urban residential buildings, the study identifies the key energy end-uses, investigates the proportional mixes of the end-uses and the energy sources and, finally, establishes the periodical per capita energy consumption amounts for the end-uses and the typical residential building unit.

Keywords: building energy consumption; energy end-use; building physics; efficiency; sustainability

1. Background

Buildings account for about 40% of the global energy consumption, a thing that accords them prominence in the energy market [1]. The demand for energy in buildings is projected to continue growing over the next few decades [2,3]. The International Energy Agency (IEA) [4] suggests that by 2050, the energy consumption in buildings will have exceeded 4400 Mtoe, up from 2759 Mtoe recorded in 2007, a 37% increase. Previously, this demand has grown by about 2% annually [5]. According to the IEA [6], residential buildings are responsible for over 60% of this building consumption pattern with commercial buildings on the other hand responsible for the remainder. While residential building energy consumption constitutes about 20% of the total consumption in the developed world, it constitutes up to more than 50% in sub Saharan Africa [7].

The growing consumption of energy has raised concerns over the impacts on the environment, supply difficulties and depletion of energy resources [8].

The energy-related impacts on the environment come through the emissions of greenhouse gases (GHG), the most important of which is carbon dioxide, CO_2 [9]. This is particularly the case when power production involves the burning of fossil fuels and biomass sources of energy. It is reported that between 2000 and 2016, the global energy-related CO_2 emissions increased by about 40% [10]. In 2015, buildings were responsible for about 40% of these global energy-related CO_2 emissions about half of which originated from residential buildings [11]. In Malawi, where power production for buildings has traditionally relied on hydro-electric power plants [12], the operational energy-related CO_2 emissions from buildings have primarily originated from the burning of biomass fuels for cooking. However, the status quo is about to change with the recent commissioning of fossil fuel based power generators in all the major cities [13] and plans to establish a 300MW coal fired power plant in the southern part of the country [14]. There has also been a major proliferation of small-scale power generators for both domestic and commercial use [15]. Nonetheless, very little is known about the specifics of the building sector's contribution toward the country's total CO_2 emissions.

As the global demand for energy continues to rise, there have been concerns on the adequacy of supply. With fossil fuels accounting for about 90% of this increase in demand [16], there are fears about the growing scarcity of oil [17]. Meanwhile, the United States and the European Union constitute the world's largest energy market, and, although they produce about 23% of the global energy, they consume about 40% of the global supply [18]. This, coupled with rising energy prices and geopolitical developments [19] amidst an escalating demand for energy, has raised concerns on the long-term energy requirements.

In the Association of South East Asian Nations (ASEAN) region, massive economic growth and rapid urbanization have led to a growing demand for energy [20], and it is projected that this demand will continue to grow at about 4.2% annually into the foreseeable future. However, the energy self-sufficiency for this region with regard to oil and natural gas, which are major sources of electricity [21], has seen a decline over the years between 2007 and 2017 [22].

In the sub-Sahara African region, electricity supply is very low at about 98 MW per million people and because of this inadequacy in supply, about 75% of business establishments experience power outages resulting in major losses each year [23]. The Table 1 below provides power outage statistics in selected sub-Sahara African countries.

Table 1. Power outage statistics in selected sub-Sahara African countries [24].

Country	Number of Outages in a Month	Duration of Outages	Percent of Sales Lost by Businesses due to Outages
Malawi	7.4	3.6	7.9
Zambia	5.4	2.9	9.5
Mozambique	1.8	2.7	2.1
Zimbabwe	5.3	4.5	5.7
Botswana	5.3	2.9	6.8
Lesotho	1.7	2.2	3.8
South Africa	1.2	2.3	0.9
Tanzania	7.0	5.0	7.5
Namibia	0.8	1.9	0.8
Angola	6.5	7.3	18.3

As a result of the inadequate access to electricity in the sub-Sahara African region, Brew-Hammond [25] reports that there is a heavy reliance on traditional biomass fuels for domestic cooking and heating, with about 95% of the population in many countries relying on these fuels. There are projections that this reliance will only grow as 2040 approaches [26]. However, forests which provide major sources of biomass fuels have continued to shrink overtime [27].

In recent times, the global energy market has witnessed a spate of disruptions in energy prices raising serious energy security conversations in the process. It has been suggested that such volatility in the prices, particularly for fossil fuels, may potentially be blamed on the depletion of cheap oil resources [28]. In a study by Campbell and Laherrère [29], it was reported that the world was running out of oil. Chiari and Zecca [30] report of a growing concern for fossil fuels exhaustion within the scientific community. On account of oil, natural gas and coal being finite resources, they acknowledge that overtime, fossil fuels production will reach a peak and then begin to decline. The concerns about fossil fuels depletion are made more explicit by the Hubbert model which describes how the production of a mineral resource varies as a function of progressive depletion following a symmetric bell shaped curve [31].

In efforts toward addressing the concerns that have come about because of the growing energy demand, the need for effective management of energy resources and adequate planning for energy infrastructure cannot be overemphasized, particularly within the building industry because of its prominent role in the energy market. To this end, high quality and high-resolution information on the consumption of energy in buildings is necessary.

In many countries within the sub-Sahara African region, building energy consumption information is hardly ever available. This study seeks to make a contribution toward this body of literature in Malawi especially within the context of urban residential buildings by identifying the key energy end uses, investigating the proportional mixes of the end uses and the energy sources and, finally, establishing the periodical per capita operational energy consumption. The study's findings will enable better energy management, estimation of improvements to building energy performance, and the planning of urban energy infrastructure.

2. Literature Review

Urban residential building energy consumption has been the subject of a substantial amount of research work. Some of this work has been methodological such as that of Kavgic et al. [32] who undertook a review study of the commonly used methods for estimating energy consumption in the residential sector. In their study, they focused on the methods' purposes, strengths, and shortcomings with the intention of identifying areas for improvement among others. In another study, Fumo and Biswas [33] employed regression analyses on data obtained from a residential house in order to predict its energy consumption. Through this study, they demonstrated the ease with which statistical approaches may be used to develop energy models for the residential sector, especially where measured data is available. Ma and Cheng [34] developed a model for estimating urban residential building energy consumption using GIS and big data technology. Shimoda et al. [35] developed a model to simulate the collective energy consumption of the urban residential building stock in Japan's Osaka city.

Efficiency has been another theme of residential sector energy consumption research. In a study by Balaras et al. [9], they collected energy consumption data for residential buildings in Greece including end-use detailed breakdowns to estimate these buildings' energy savings potential. Wan and Yik [36] investigated the building design and energy end-use characteristics of high rise residential buildings in Hong Kong with the intent to explore avenues for reducing consumption. They employed surveys that examined the architectural morphology of the residential units and energy consumption patterns through investigations on ownership of appliances, usage of the appliances. Farahbakhsh et al. [37] investigated the residential end-use energy consumption in Canada and developed a model to inform the development of energy saving policies.

In other studies, such as one by Hu et al. [38], the focus has been on understanding the variation of residential energy consumption as a function of the intricate interaction of different parameters. In this study, they investigated factors that influenced urban residential energy consumption in four cities in China. Another study by Perez et al. [8] noted that residential building energy consumption patterns in terms of amount and type of energy are dependent on size, location, and architectural design of the residential unit in addition to the economic level of the occupants and the climate.

Studies on the actual residential building energy consumption by end-use have been the subject of major statistical undertakings such as those by the International Energy Agency (IEA) [39]. These studies have identified key energy end-uses, provided the proportional mixes of the uses and their sources of energy. However, these have largely provided data covering only those countries within the Organization of Economic Cooperation and Development (OECD). Similar studies in the United States of America have been undertaken by the U.S. Energy Information Administration (EIA) [40].

At the sub-Sahara African regional level, studies on residential building energy consumption have substantially addressed issues of building energy regulations and policy. A study by Iwaro and Mwasha [41] points out that while building energy regulations are widely implemented in the developed world to facilitate efficiency, the developing world has largely lagged behind lacking consistent data on energy consumption and documentation on energy regulation. In this study, they reviewed the status of building energy regulations in 60 developing countries, a substantial proportion of which were drawn from sub Saharan Africa, within the context of development and compliance. In another study that had been predicated by a public utility's advocacy for residential energy efficient devices in South Africa, Blommestein and Daim [42] had sought to evaluate the consumers' decision in purchasing the energy efficient devices in order to determine the extent to which the incentives being offered by the public utility matched with the consumers' technological preferences.

The actual residential building energy consumption by end-use, however, remains under researched in the region. Some of the work that has sought to address this gap, albeit with limited scope, includes a study by Kazoora et al. [43] who investigated the energy consumption patterns of residential buildings in Uganda and the findings were then correlated with the buildings' physical and thermal properties with an aim to identify potential energy conservation measures (ECMs). The study showed the extent of usage of electrical appliances, sources of energy, and the overall electricity energy consumption in Ugandan residential buildings. However, it did not systematically identify the key energy end-uses, a thing which prevented the study from investigating the proportional mixes of these end-uses. Essah and Ofetotse [44] investigated the energy of residential buildings in Botswana with the intent of developing a proposal for the country's energy budget. This study provided overall electricity consumption data by economic status of households. There was no attempt to go down into the specifics of the consumption patterns by energy end-use. Other studies have only sought to address isolated building energy end-uses such as in the study undertaken by Adelekan and Jerome [45] in which they examined the sources of energy for cooking in households located in Ibadan, Nigeria.

In Malawi, energy research has largely focused on policy matters. Gamula et al. [46] undertook a review of the general energy sector in Malawi, going through the specifics of energy access and its contribution toward the national economic development to make suggestions for policy changes. An earlier study by Kaunda [47] sought to achieve a similar objective and went further to make the case for the development of small-scale hydro power systems across the country. Zalengera et al. [48] and Taulo et al. [49] also undertook similar policy-based studies.

The area of energy consumption in buildings in general and in residential buildings in particular has remained inadequately researched. While some studies have sought to investigate the sources of energy for Malawian residential buildings such as those by Bandyopadhyay [50] who quantified the availability and distribution of biomass energy sources across the country and Jumbe and Angelsen [51] who investigated factors that influenced the rural households' decisions in choosing a source for their fuel wood, detailed information on residential building energy consumption by end-use in the country is presently thin and hard to obtain. The National Statistical Office [52] provides some data on sources of household energy for isolated end-uses namely cooking and lighting with little detail on the actual consumption amounts associated with the end-uses. In a study by Openshaw [27], he estimated the supply and demand of household energy in Malawi, however, these estimates were not based on aggregated energy end-uses. A country-wide energy survey by the Malawi Energy Regulatory Authority and National Statistical Office [15] only partially addressed the issue of residential building energy consumption by end-use. It established some key energy end-uses and yielded findings on the penetration of electricity usage, mixes of biomass fuels, sources of fuel, electricity monthly expenditures, and usage of energy efficient lighting in residential buildings. The survey did not, however, provide a detailed breakdown of the typical residential buildings' energy consumption by the end-uses.

This present study seeks to make a contribution toward closing the literature gap that currently exists with regard to the specifics of urban residential building energy consumption by end-use in Malawi. It endeavors to identify the key energy end uses, investigate the proportional mixes of the end uses, and the energy sources and finally, establish the periodical operational energy consumption of the typical urban residential building unit.

3. Methodology

There are generally two approaches toward investigations into the energy consumption patterns of the existing residential building stock namely, the bottom-up and the top-down approaches [53]. The top-down approach works at an aggregated level, typically aimed at fitting a historical time series of national energy consumption within the contexts of economic and technological trends [32]. This approach does not address individual factors in buildings that may have an influence on the energy demand.

The bottom-up approach on the other hand uses data from disaggregated components which are combined to estimate the total energy demand of the building system [32]. This provides insights into each individual component's contribution toward the energy usage and may be very helpful where certain energy consumption targets are sought [54]. The bottom-up approach can be split into two distinctive categories namely the building physics-data based and the statistical-data based approaches [55]. The building physics-data based approach uses high resolution quantifiable data on the physical characteristics of the building, appliances, and occupancy schedules among others to estimate the building's energy usage. The statistical-data bottom-up approach is largely based on regression analyses of the energy consumption as either a function of building characteristics or conditional presence of appliances [55]. According to Kavgic [32], a hybrid bottom-up approach combining the two approaches is not uncommon.

This study employed the building physics-data bottom-up approach. This approach was selected because of its ability to estimate the residential building energy usage by disaggregated individual components. This approach was found to be consistent with the study's fundamental objective in investigating the urban residential buildings' energy consumption by individual end-uses in Malawi. Previously, studies which have sought a similar objective, have employed the same approach with satisfactory results [36,38,56,57].

3.1. Study Location

As part of the present study, residential building cases were randomly drawn from locations within the four major urban areas in Malawi. The urban setting was chosen because it potentially constituted a more diverse energy source and end-use mix scenario as opposed to the rural areas, where, because of the limited access to electricity and other forms of energy [27], there is a substantially heavy reliance on biomass fuels and, largely, for cooking [58]. According to a Malawi Energy Regulatory Authority (MERA) survey [15], about 50% of the major urban centers' residential building stock in Malawi has access to electricity. There is also a higher usage of appliances in these residential buildings.

3.2. Data Collection

The data was collected through a questionnaire survey that was administered in all the four major urban areas of Malawi namely Lilongwe, Blantyre, Mzuzu, and Zomba. The urban population in the country pegged at about 2,800,000 in 2018, constitutes about 16% of the total population in the country [52]. The four aforementioned major urban areas constitute about 75% of this urban population with a combined population of about 2,100,000 [52]. The questionnaire sought to collect information on the popularity of energy end-uses, usage of appliances including the numbers of units, their power ratings and daily and yearly usage durations, household size, grid electricity supply sufficiency, and sources of energy to supplement the supply insufficiencies, and finally, monthly expenditure on energy including electricity and other alternative sources. A similar questionnaire approach had been employed in other earlier studies [36,38,44]. Occupant behavior is known to have a significant impact on the energy consumption in buildings [59]. For this reason, it can be seen that the questionnaire in the present study largely sought to obtain information that provided insights into the behavior of the urban residential building occupants. The questionnaire questions are provided in Appendix A.

3.3. Data Processing and Analysis

The study employed statistical and analytical techniques to process and analyze the data that were collected. A number of assumptions had been made to facilitate the analytical computations. First, any variations in energy consumption with respect to day of the week and time of the year had been normalized for simplicity of analysis. The study used averaged data for the typical day and year. A similar assumption had been employed by Essah and Ofetotse [44] and Ihbal et al. [60]. Second, the energy consumption of the appliances was assumed to remain constant for the duration of their usage. An earlier study by Firth et al. [61] had made a similar assumption. Finally, the energy efficiency of the appliances was not taken into consideration consistent with the assumption that was made by Essah and Ofetotse [44].

The ideal total annual appliance energy consumption, $T_{AEC(Ideal)}$, defined as the energy demand in kWh where the grid electricity supply sufficiency is at 100% without power outages, was worked out according to the expression below:

$$T_{AEC(Ideal)} = \sum_{i=1}^{n} [\Big(\frac{PR_{APP} \times N_{APP} \times DU_1 \times DU_2}{1000}\Big)(R_1)]_i \quad (1)$$

where n is the total number of end-uses, PR_{APP} is the average appliance power rating in W, N_{APP} is the average number of appliance units, DU_1 is the average daily duration of appliance use in hours, DU_2 is the average annual duration of appliance use in number of months and R_1 is the reduction factor because of the popularity of end-use. The reduction factor ensures that the ideal total annual appliance energy consumption is representative of the actual penetration of the end-uses. For the lighting end-use, for instance, the reduction factor is 0.939. It was envisaged that the reduction factor would help to minimize the error that would result from cases where some respondents out of confusion or otherwise provided appliance usage schedules even for those appliances that they had already indicated that they did not have.

The annual energy delivered, AED, defined as the electricity consumption in kWh for which the residential building is billed, was worked out according to the expression below:

$$AED = \frac{E_m \times 12}{C_u} \quad (2)$$

where E_m is the average monthly expenditure on electricity and C_u is the rounded unit cost of electricity.

The actual electricity supply sufficiency, ESS_A, defined as a ratio of the annual energy delivered, AED, to the ideal total annual energy consumption, $T_{AEC(Ideal)}$, was worked out according to the expression below:

$$ESS_A = (\frac{AED}{T_{AEC(Ideal)}})100 \quad (3)$$

The ESS_A is distinguished from the supply sufficiency perceived by the participants in the study.

The actual total annual appliance energy consumption, $T_{AEC(Actual)}$, defined as the actual energy consumption by end-use over the year, was assumed to be equal to the annual energy delivered.

The annual energy consumption deficit, $AEC_{(Deficit)}$, defined as the difference between the $T_{AEC(Ideal)}$ and the $T_{AEC(Actual)}$ was worked out according to the expression below:

$$AEC_{(Deficit)} = T_{AEC(Ideal)} - T_{AEC(Actual)} \quad (4)$$

4. Results and Discussion

A total of 33 participants, representing 33 households and residential buildings took part in the study. The study was conducted over a period of 6 months from November 2018 to May 2019.

4.1. Penetration of Energy End-Use

The participants in the study were asked to provide information on the energy end-uses that applied to their households. They were provided with a list of energy end-uses from which they were then requested to select their household's energy end-uses. The list had been developed based on reviews of the literature. The results, which are presented in Figure 1, show that refrigeration, lighting, television viewing, cooking, and water heating constitute some of the most important energy end-uses in the Malawian urban residential building. The lower penetration of space heating and cooling, and, clothes and dish washing end-uses may be linked to the country's struggling economy which would mean that these energy end-uses are unaffordable for many households. A similar trend was observed in Uganda where it was attributed to two possible reasons namely the unavailability and lack of need for these end-uses and the cost of purchasing and operating the equipment that supports them [43]. In sharp contrast, these end-uses constitute some of the most ubiquitous in developed countries such as in the United States and Europe [8,40].

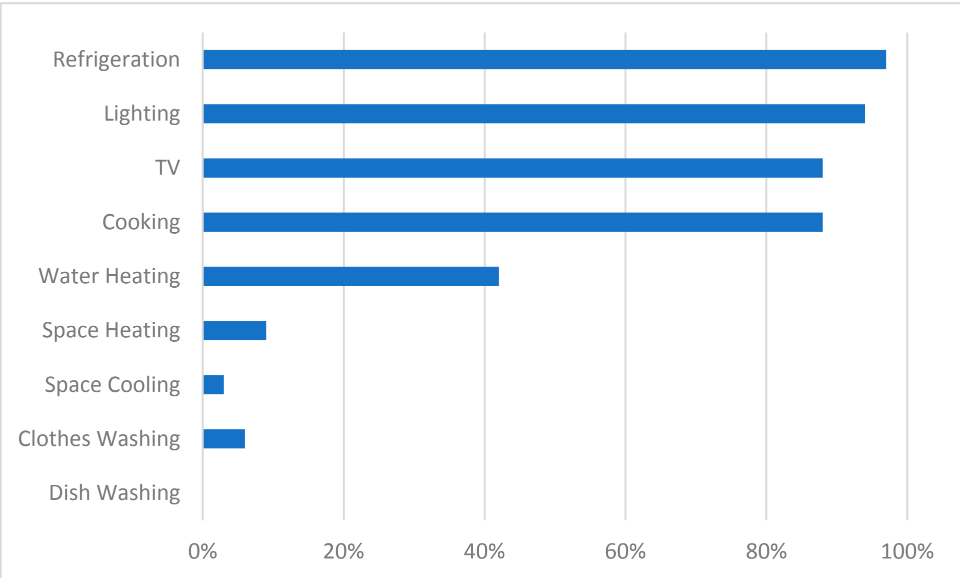

Figure 1. Penetration of energy end-uses.

4.2. Ideal Total Annual Appliance Energy Consumption

In order to work out the ideal total annual appliance energy consumption, the study participants were requested to provide information detailing their households' sizes and usage of electrical appliances. The usage information that was sought included the appliances' characteristics, quantities and usage patterns. The results, presented in Table 2, suggest that in an ideal scenario, where electricity were to be supplied without interruption, the average Malawian urban residential building would consume 7360 kWh of energy annually. The cooking end-use would be responsible for about 40% of this consumption pattern. Presently, however, electricity supply is very erratic and unreliable.

Table 2. Ideal total annual appliance energy consumption.

Appliance Name	Power Rating of Appliance (W)	Number of Appliances	Daily Duration of Use (Hours)	Yearly Duration of Use (Months)	Annual Energy Consumption (kWh)
Lights	13	10	12	12	493
Refrigerator	200	1	24	12	1564
TV	100	1	18	12	532
Cooker	2500	1	4	12	2957
Water Heater	3000	1	4	12	1693
Space Heater	2000	1	3	3	45
Space Cooling (AC)	2000	1	6	4	40
Clothes Washing Machine	1200	1	1.5	12	36
Dish Washer	0	0	0	0	0
				$T_{AEC(Ideal)}$	7360

4.3. Household Expenditure on Electricity

The study collected information on the estimated average monthly household expenditure on electricity annually. Using this information, the estimated annual energy delivered was worked out. At the time of the study, the rounded off cost of electricity was Malawi Kwacha (MWK) 57 kWh. The results presented in Table 3 show that the monthly expenditure on electricity varies widely from as low as MWK 5000 to as high as MWK 30,000. This may seem to suggest the existence of wide economic disparities among the urban households. It may also be indicative of an inconsistent electricity power sharing regime that affects households differently, leaving others with more prolonged durations of power outages. About 50% of the households were found to fall within the expenditure range of MWK 20,000 and MWK 24,999, consuming about 4736 kWh of electricity annually.

Table 3. Household expenditure on electricity. As of February 2020, $1 is equivalent to MWK 730.

Expenditure Range (MWK)	Percentage	Equivalent Monthly Electricity Energy Delivered (kWh) @ Flat C_u of MWK57/kWh	Annual Energy Delivered (kWh)
5000–9999	15%	132	1584
10,000–14,999	23%	219	2628
15,000–19,999	0%	0	0
20,000–24,999	46%	395	4740
25,000–30,000	16%	482	5784

4.4. Electricity Supply Sufficiency

The actual electricity supply sufficiency, ESS_A, a ratio of the annual energy delivered, AED, to the ideal total annual energy consumed, $T_{AEC(Ideal)}$, ranged from about 21% to about 79% for the households in the lowest and highest electricity expenditure brackets respectively. The average supply sufficiency stood at about 50%. The results suggest that the urban residential buildings only receive about half of their electricity energy needs as the supplier struggles to meet their demand. However, when asked about how they perceived of the supply sufficiency, the study's participants reported a lower supply sufficiency at about 32%.

4.5. Actual Total Annual Appliance Energy Consumption

The actual total annual appliance energy consumption stood at about 3684 kWh. Out of this amount, the cooking end-use was the most significant being responsible for about 40% of the consumption as shown in Figure 2. As suggested earlier, this consumption pattern may be a function of economic determinants. It is important to mention that this pattern may not only be unique to Malawi, but also other similarly characterized countries that are struggling in their development efforts. In the United States, by 2017, the average residential building consumed about 10,400 kWh of appliance energy annually [40]. In Botswana, by 2014, this consumption was about 6000 kWh annually [44].

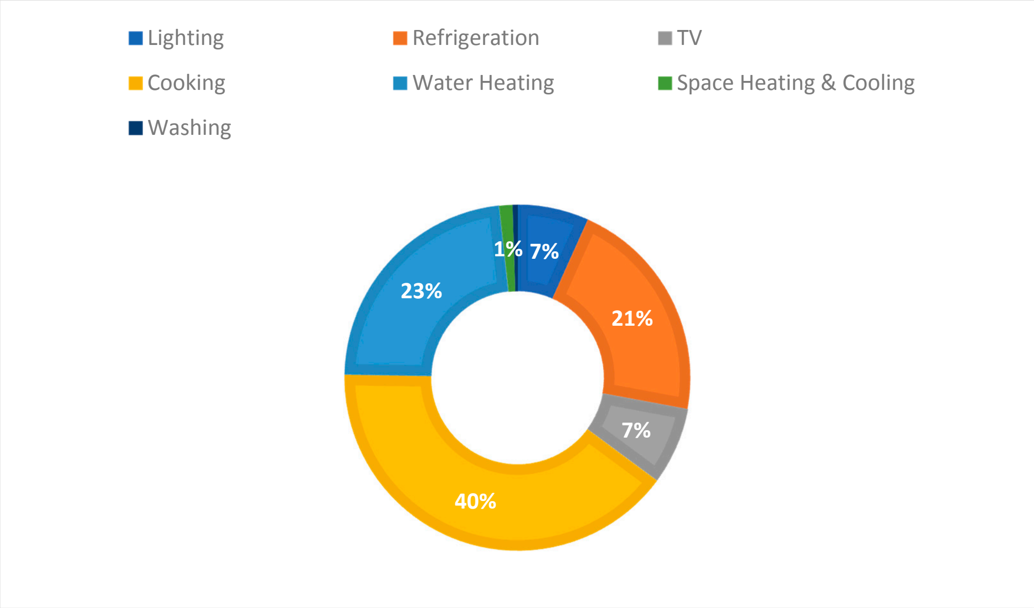

Figure 2. Actual total annual appliance energy consumption by end-use.

4.6. *Alternative Energy Sources*

In order to make up for the annual energy consumption deficit, $AEC_{(Deficit)}$, which stands at about 3677 kWh, the study findings show that a significant proportion of the urban households turn toward charcoal among other alternative energy sources as shown in the Figure 3 below.

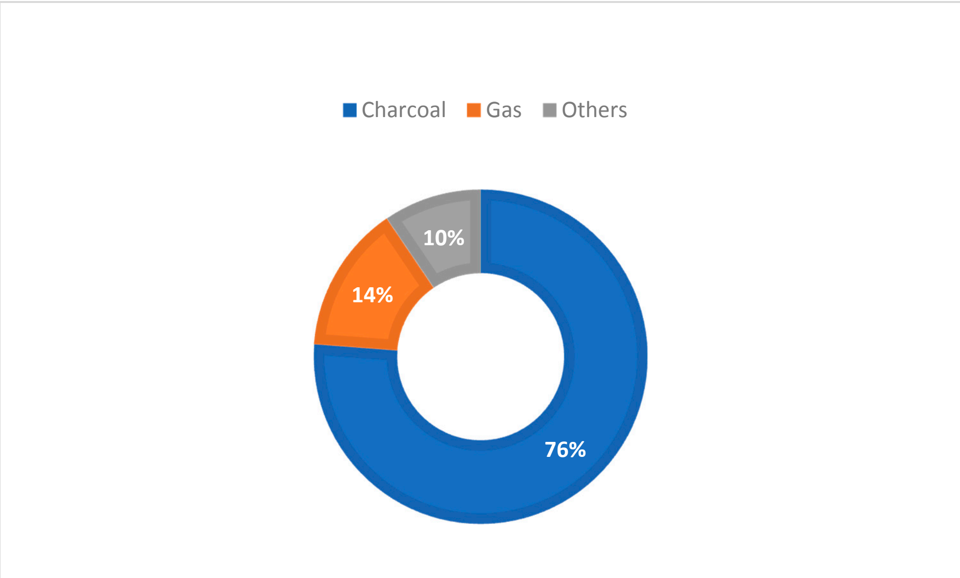

Figure 3. Alternative energy sources.

For the households that use charcoal to supplement their electricity energy needs, it was possible to estimate the electricity energy equivalent of their charcoal usage from their monthly expenditure on the biomass fuel as shown in the Table 4 below:

Table 4. Household monthly expenditure on charcoal and kWh equivalent.

Expenditure Range (MWK)	Percentage of Households	Total Mass (Kg) at a Cost of MWK 225/Kg	Electricity Energy Equivalent (kWh) at a Rate of 8.4 kWh/Kg [Before Conversion Losses]
0–4999	19%	11	92
5000–9999	38%	33	277
10,000–14,999	25%	56	470
15,000–19,999	6%	78	655
20,000–24,999	12%	100	840
25,000–30,000	0%	0	0

The results show that the average urban residential building consumes an equivalent of 5602 kWh worth of charcoal energy annually. The combined actual annual electricity and biomass energy consumption for the urban residential building adds up to an equivalent of 9286 kWh of which about 60% comes from charcoal. This amount, which is about 1000 kWh short of the annual energy consumption of an average residential building in the United States, may suggest that human energy needs are about the same regardless of the economic status. What might be different are the energy access means.

5. Conclusions

The study shows that the average urban residential building in Malawi consumes an equivalent of about 9286 kWh of energy annually. Out of this consumption, cooking constitutes the most significant end-use consuming about 40% of the available electricity energy. However, the typical urban residential building only receives about 40-50% of its electricity energy requirements, a thing that forces households to look for alternative sources of energy to make up for the shortfall. These alternatives include charcoal, gas and other forms of biomass and fossil fuels. Charcoal constitutes about 76% of the alternative sources of energy and for those that turn toward this source to supplement their electricity supply, it constitutes about 50-60% of their annual energy consumption. These findings will be helpful in enabling better energy management, estimation of improvements to building energy performance and the planning of urban energy infrastructure in a country that is struggling to meet its energy demand.

6. Limitations

The study's scope was limited because of the resource constraints. For this reason, it may be seen that the sample size of 33 households that was used for a Malawian urban population of about 2,100,000, at best, achieves a course statistical resolution representing a confidence level of 80% and a 10% margin of error. It is important, however, to point out that the sample was responsive enough to the study's objectives having been drawn from all the major urban areas of Malawi. According to Yin [62] and Flyvbjerg [63], where it is impossible to use a statistically fine sample size, researchers must instead ensure that the available sample is adequately responsive to the study's line of enquiry. In future, other studies employing the present study's methodology on bigger sample sizes may be necessary in order to obtain finer statistical resolutions.

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Appendix A

Questionnaire

A. Penetration of Energy End-Use

Which of the following appliances do you use in your household?

(a) Lights ☐
(b) Space Heater ☐
(c) Space Cooling ☐
(d) Water Heater ☐
(e) Refrigerator ☐
(f) TV ☐
(g) Cooker ☐
(h) Dish Washing Machine ☐
(i) Clothes Washing Machine ☐
(j) Other Specify _______ ☐

B. Power Rating of Appliances

What is the power rating of the appliances in A above? (Watts)

(a) Lights ☐
(b) Space Heater ☐
(c) Space Cooling ☐
(d) Water Heater ☐
(e) Refrigerator ☐
(f) TV ☐
(g) Cooker ☐
(h) Dish Washing Machine ☐
(i) Clothes Washing Machine ☐
(j) Other Specify _______ ☐

C. Number of Appliances

How many such appliances do you use in your household?

(a) Lights ☐
(b) Space Heater ☐
(c) Space Cooling ☐
(d) Water Heater ☐
(e) Refrigerator ☐
(f) TV ☐
(g) Cooker ☐
(h) Dish Washing Machine ☐
(i) Clothes Washing Machine ☐
(j) Other Specify _______ ☐

D. Daily Duration of Use of Appliances

For how many hours do you need to use your appliances each day?

(a) Lights ☐
(b) Space Heater ☐
(c) Space Cooling ☐
(d) Water Heater ☐
(e) Refrigerator ☐
(f) TV ☐
(g) Cooker ☐

(h) Dish Washing Machine ☐
(i) Clothes Washing Machine ☐
(j) Other Specify _______ ☐

E. Yearly Duration of Use of Appliances

For how many months do you need to use your appliances each year?

(a) Lights ☐
(b) Space Heater ☐
(c) Space Cooling ☐
(d) Water Heater ☐
(e) Refrigerator ☐
(f) TV ☐
(g) Cooker ☐
(h) Dish Washing Machine ☐
(i) Clothes Washing Machine ☐
(j) Other Specify _______ ☐

F. Size of Household

How many people live in your household? ☐

G. Electricity Supply Sufficiency

Does electricity supplied by ESCOM suffice your household needs?

(a) Yes ☐
(b) No ☐

If you responded No above, how does your household supplement ESCOM's electricity supply to meet their needs?

(a) Firewood ☐
(b) Charcoal ☐
(c) Gas ☐
(d) Other Specify _______ ☐

How much is your monthly electricity bill? (MK) _______________
How much is your monthly expenditure on firewood? (MK) _______________
How much is your monthly expenditure on Charcoal? (MK) _______________
How much is your monthly expenditure on Gas? (MK) _______________
Please specify any other energy source and monthly expenditure on the item (MK) _____________

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