A model for efficient consumption of electricity in residential buildings

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Abstract- This paper reviews various applications of Radio Frequency Identification (RFID) technology and proposes electricity-saving power switch enhancements model to control the operation of electrical appliances in residential buildings using RFID system. Estimation was made on the consumption of electricity in a private apartment in Pretoria, Gauteng Province, South Africa and compared with when the RFID card-reader system is deployed. The percentage energy saving in a year was calculated to be approximately 29 %. The possible energy savings for a period of 30years is estimated and the return on investment (ROI) determined. The authors concluded by making a case for a state policy on RFID energy efficiency technology.

Keywords- Energy saving; Electricity; ROI; RFID; Residential Buildings.

1. Introduction

Access to safe, dependable, and affordable electricity is very crucial to national development since most economic activities which drive growth substantially depend on it. Energy efficiency addresses several of the highlights of the Sustainable Development Goals (SDGs). Electricity has a tremendous potential to improve the quality of life via better health service delivery, more conducive environment, and breaking other forms of bottlenecks caused by excessive use of manual labors in manufacturing. The significance of electricity available to the socio-economic growth of any nation cannot be undermined. Indeed, electricity plays the most prominent role in security, economic growth, progress, and advancement, including poverty alleviation. Energy efficiency is at the centre of renewable and conventional energy consumption. Figure 1 shows the interrelationship between energy efficiency and energy consumption.

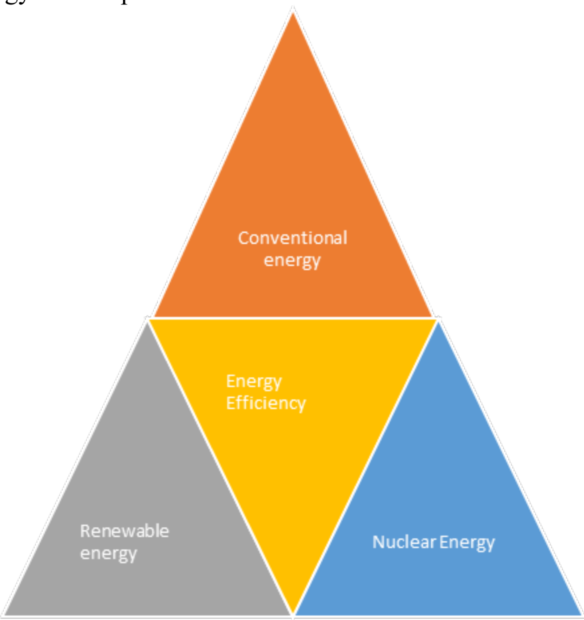

Figure 1. Centrality of Energy Efficiency.

Being at the centre, energy efficiency determines the sustainability of all energy sources. The increasing trend of global energy consumption has been shown to be associated with the world population growth and the rate of increase can be considered alarming as shown in Fig. 2.

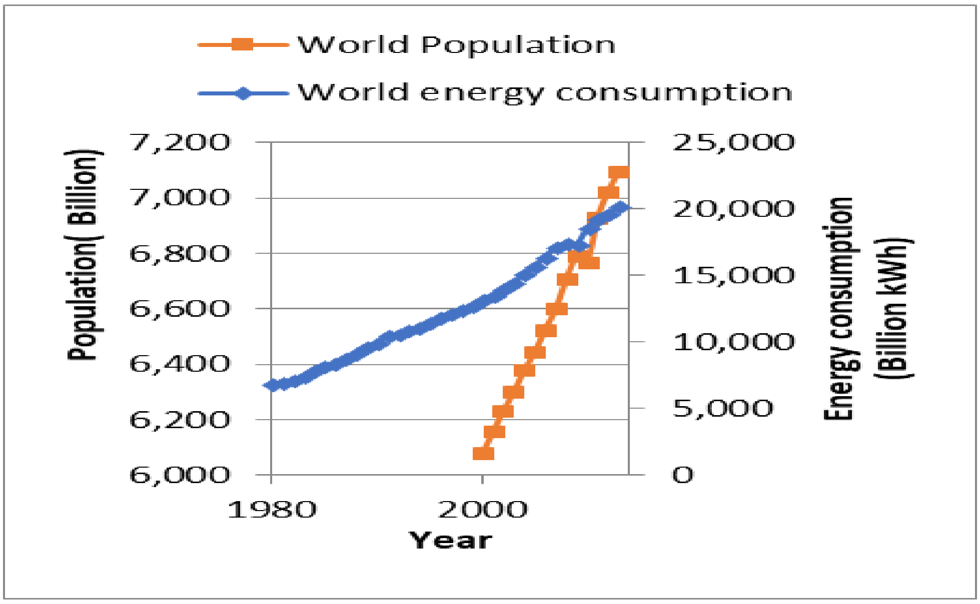

Figure 2. The global energy consumption and population growth [1]

According to the International Energy Agency, between 1984 and 2004, primary energy and CO_2 emission has grown by 49 % and 43 % respectively [2]. Based on forecast, by the year 2020, energy consumption by regions with growing economies (Southeast Asia, South America, Middle East and Africa) would have exceeded the developed countries (Western Europe, North America, Japan New Zealand and Australia). By the prediction, the average annual energy consumption rate of developing countries would be 3.2% as against 1.1% for developed countries. [2].

Energy efficiency succinctly means utilizing less energy input to deliver the same or more services. In most of the research projects on electricity efficiency, the emphasis has been on the behavioural change of the users and the equipment redesign, however, the acceptance of this approach is subjected to the willpower of the user. Again, most households do not have a detailed understanding of the contribution of standby power to their electricity consumption. Standby power is usually referred to as electricity passively consumed by appliances and equipment while they are at an inactive mode of not performing their designated functions. In the year 2007, International Energy Agency (IEA) reported that a lot of families in developed countries fail to detach plugs of electrical appliances from sockets and thus perpetually wastes standby power, which had been found to account for around 5 % to 10 % of the total electricity consumption on a daily basis [3]. As a result of standby power, a single family loses about 30 kWh in a month and this is equivalent to the emission of 16 kg carbon dioxide (CO_2) to the environment. Standby power accounts for almost 1 % of world carbon dioxide emissions [3]. In 1998 Alan Meier and co-workers discovered that standby power added up more than $3 billion to the energy cost of America per annum. America's Department of Energy report indicated that the residential electricity consumption in 2004 which was wasted due to standby power is technically equal to the output of 18 power stations in USA [16]. This among other things poses a grave danger to our environment as it serves as a notable threat to energy sustainability, facilitates greenhouse effect and affects national economic well-being.

Nowadays several methods are being used to save electricity in residential buildings such as High-efficiency lighting systems like high-intensity fluorescent lamps which saves as much as 30 to 50% of lighting costs but its main demerit is a short life cycle. Technologies, which by default ensures zero power consumption at appliance standby mode is highly encouraged for effective energy saving [1, 2]. This is effectively achievable with the use of the RFID technology. RFID technology completely removes the energy consumption due to standby mode of the household appliances. Policies which mandate the residential building to include the RFID in their design right from scratch is highly laudable if energy efficiency in residential and non-residential buildings will be a reality. This approach should be a part of the codes and standards which should be considered in approving residential building construction.

RFID technologies have recorded success in many fields and application, also, the technology has been discovered to be effective in residential energy management. This remotely controls electrical appliances and also ensures safety from potential electrical hazards. It is paramount to note that inefficient consumption of electricity and another form of energy would eventually lead to energy poverty. Energy poverty refers to a condition whereby households are negatively affected by inadequate consumption of energy resources [3, 4]. Against this background, this study proposes enhancements to control the operation of electrical appliances in homes or residences using the RFID system as an efficient energy-saving power switch in residential buildings. The technology adopted the use of pre-programmed RFID tags (cards), together with its reader to control the switching-on and off of the lightings and wall sockets of a residence equipped with home appliances like compact fluorescent light bulbs (CFL), air conditioning units, fridge, home entertainment system, fans, microwave, and laptops and so on. Although the most effective way of conserving energy is to unplug electrical appliances whenever they are not in use, adherence to this proposition is at the discretion of room occupants.

2. A Focus on South Africa Energy Efficiency in Residential Buildings

As at 2005, South Africa's energy conservation (both residential and non-residential buildings) target was to ensure that energy demand drops by 12 % by the year 2015 [5, 6]. The buildings in focus were relating to residential sector, industrial, commercial and public transport sector. It was estimated that if the energy is not efficiently used, South Africa would need well over 40,000 MW additional capacity of power generation by 2025 in order to meet her energy demands [4]. Just like most developing countries, the power crisis in South Africa is having a ripple effect on households and businesses. As of the year 2012, 23% of the energy consumed in South Africa was in the residential sector (Figure. 4).

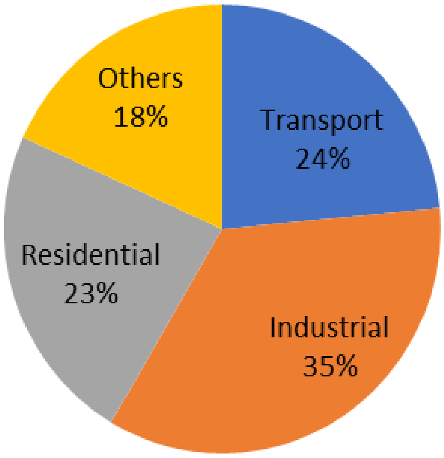

Figure 4. Energy consumption in South Africa by economic sectors [5]

The preoccupation of the government of South Africa is to alleviate poverty through strategic economic empowerment of the citizen. In pursuit of this, South Africa government has put in place several strategies which include; renewable energy policy, energy efficiency policy and so on [6]. The advantages of energy efficiency to the environment are plainly obvious. These advantages are of specific pertinence, as South Africa is one of the highest contributors to ozone depletion in the globe on per capita basis. Indeed, the Energy Policy white paper, produced in the year 2005 by the Department of Mineral and Energy (DME) of the South Africa Republic underline the commitment of the government to developing policies which would help the attainment of greater energy efficiency and raise awareness in the residential, commercial and Industrial sector of the economy [4]. In South Africa, the standby energy wastage lies between 0.05 % and 0.36 % of national electricity consumption, and notably these values translate to between 0.9 % and 6.5 % of the total residential electricity consumption [17]. The cumulative effect of this wastage would be enormous over the years; therefore, all hands must be on deck toward energy conservation.

There are different varieties of domestic appliances and equipment at residential consumption level and a review of residential electricity consumption vividly indicates that about 50 % of residential electricity is mostly used for HVAC, lighting, refrigeration, television, ironing, and radio [7]. Given the pace of advancement in technological innovations nearly all the household chores require electricity for operation. Major household electricity consumption is from the middle and high-income class, which resides in urban locations with many domestic devices and appliances with high energy rating. These include refrigerator, air conditioning systems, electric stove and oven, Geysers, and also lighting bulbs [8]. The number of these appliances increases as the number of households grows, and lifestyle changes. The typical challenge with the demands of electricity in residential buildings is the continuous nature of usage and consumption with no recourse to the need for electricity saving.

Beyond cost savings, electricity saving includes savings in terms of the resources used for its generation, preventing fire accident, and protecting the environment and lives. In the year 2013, there were 42,343 fires incidences that were reported in South Africa out of which 8.86% were attributed to electrical faults. Residential fire incidences account for more than R1-billion of the cost while industrial fire accounts for R478-million [9]. Residential fire can be attributed to inefficient consumption behaviours.

3. Recent trends in RFID technology applications

There are many wireless non-contact systems, but RFID stands tall with a lot of promises [10]. This technology exchanges data by the methods for electromagnetically charged signals. In light of its capacity to distinguish and keep tracks on objects, RFID is being utilized in assorted applications such as; security, facility management, retailing, construction, logistics, aviation, health, library system, access control, race timing, among others. Tag detection which does not require human intervention help to lower the deployment costs and eliminate human errors in data gathering. The merits of the RFID include the following: Tag is not fixed to a location since there is no need for a line-of-sight; RFID cards can read data within a long range, unlike bar code. Tags can also have read or write memory capabilities; A RFID tag can store an enormous amount of data in addition to its function as a customized identifier. Customized object identification is much easier to achieve with RFID than with bar codes; Cards are not so reactive to harsh conditions such as high-temperature, chemicals, dust, and physical impacts. Numerous RFID tags can be perused simultaneously, and RFID tags can be used in conjunction with sensors. The main components of an RFID system are; a transceiver (usually referred to as the reader) connected to an antenna, and a set of transponders also known as tags or cards, where information is being stored [11]. Tag detection which does not require human intervention help to lower the deployment costs and eliminate human errors in data gathering. The transceiver communicates with a PC through software which manages the data stored in the cards. These readers do not only interrogate tags for information, but they can also be used to program tags. RFID tags may get their capacity in various ways. The wellspring of intensity is a basic property of a tag since it will decide a tag's coverage range, lifetime, cost, and functionalities. Considering this property, there are three fundamental classes of RFID tags - dynamic, semi-passive, and inactive [12]. Table 1 indicates the common operating frequencies [13]. RFID has been employed in other forms in smart homes as a smart plug framework and a shrewd wave system dependent on RFID innovation. In the keen fitting framework, each electrical plug in the house was furnished with a RFID reader and the attachments of electrical gadgets like lights or radios were joined with a RFID tag. At whatever point a gadget was connected to an outlet, the RFID reader in the outlet read the tag and sent information to the primary PC. The PC could straightforwardly recognize every gadget and its area, as well as control the gadget. [14]. With the notable advances in microelectronics and low-power semiconductor technologies, cheap RFID tags are now available in the market. In the nearest future, the cost of RFID will be very affordable for free usage and will be adopted for numerous functions.

Table 1. Common RFID operating frequencies [13]

Frequency Range	Frequencies	Passive Read Distance
Low	120 - 140 KHz	10 - 20 cm
High	13.56 MHz	10 - 20 cm
Ultra-High	868 - 928 MHz	3 m
Microwave	2.45 - 5.8 GHz	3 m
Ultra-Wide Band (UWB)	3.1 - 10.6 GHz	10 m

4. RFID Energy Efficiency Model

The conclusion section should emphasize the main contribution of the article to literature. Authors may also explain why the work is important, what are the novelties or possible applications and extensions. Do not replicate the abstract or sentences given in main text as the conclusion.

The study presented in this report is based on the implementation of RFID for a two-bedroom flat. The process flow for the development of RFID model for residential electricity consumption control is as shown in Figure 5. In the design and installation of the RFID energy-saving power switch for the 2-bedroom flat home considered in this study, two main parts were considered: circuitry and wiring, and programming of the microcontroller and RFID system. The energy consumption in the homes was studied both with and without RFID. In implementing the RFID system, card reader placed at a strategic location in the flat was used to verify the identity of the individuals entering the house as a genuine householder. Upon verification, the reader triggered a relay mechanism (in the normal Open state) through an Arduino unit which closes the circuit, thereby allowing power supply into the room.

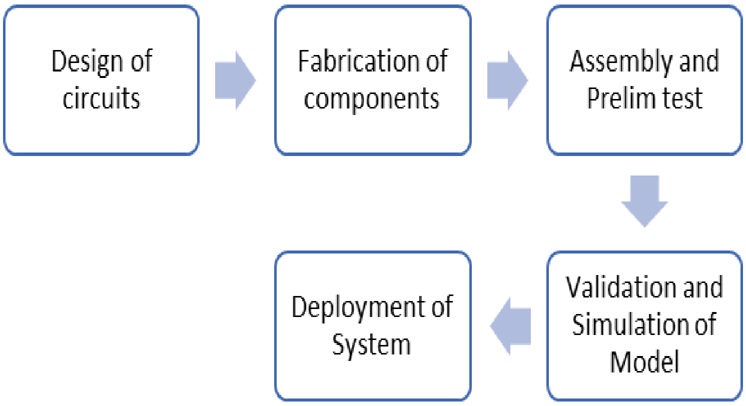

Figure 5. Development process of RFID-based Electricity efficiency model.

In order to turn off the power supply, the identification card will have to be within communication range of the reader to trigger the relay to return to its initial state. The block diagram and main components of the circuitry are as shown in Figures 6 and 7 below: The Power Supply will be from a 240V/13A AC socket. This supply will be shared between the Arduino Unit and the Relay-Load as shown in Figure 7. Although the Arduino cannot be powered by 240V AC, therefore a rectifier circuit is constructed to convert the supply to a 12V DC which is more suitable for powering the Arduino [18]. It is not advisable to power the Arduino module with DC batteries because the recommended voltage range for the module is 7-12V DC which may not be accurately achieved through a combination of batteries. A 12V DC battery may be used but the weight of the battery on the control circuit and the need to recharge the battery after a while makes the project cumbersome.

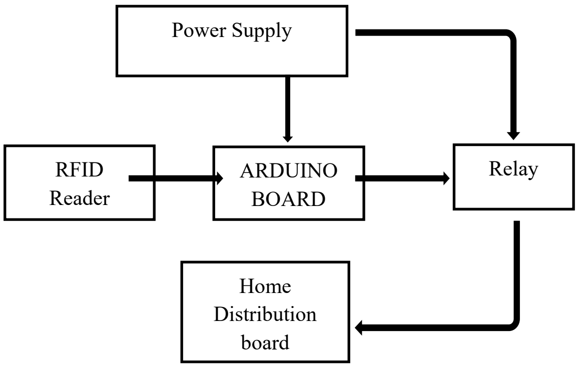

Figure 6. Power supply diagram

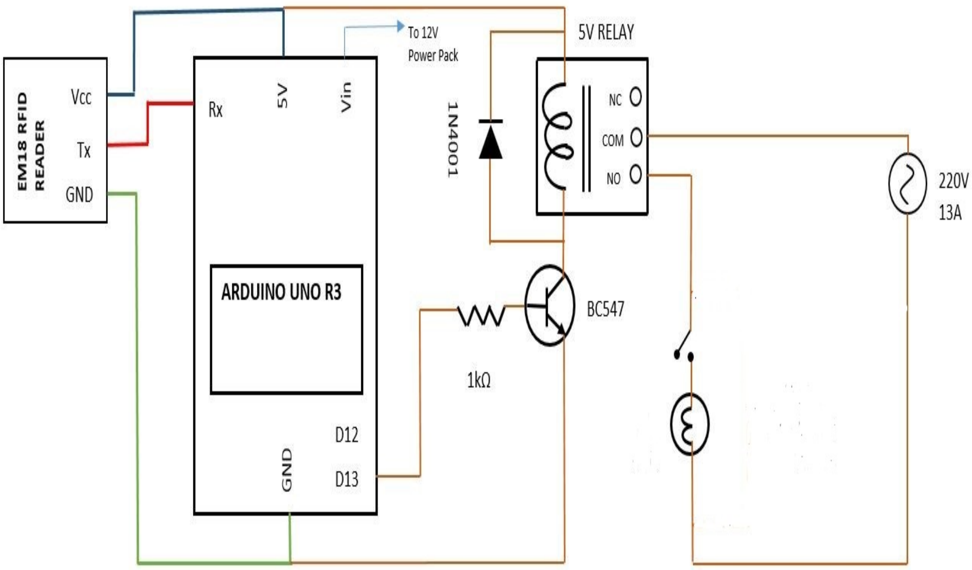

Figure 7. Circuit diagram for an RFID energy-saving power switch

5. Implementation of the model

As a case study, the household under consideration is made of a 2- bedroom flat in the residential area of Pretoria, Gauteng Province, South Africa. The total coverage of the building is 129m^2. The Living room, Main bedroom, Bedroom, and Kitchen are; 24.2m^2 , 21.4m^2 ,19.6m^2, 10.7m^2, respectively. Based on the listed appliance, the total power rating is 21.792kW. The appliance and their power rating in the household are as listed in Table 2 below:

Table 2: List of Electrical appliances in the residence

Appliances	Power rating (W)	Quantity	Total Wattage (W)
Water heater (Geyser)	4000	1	4000
LED lighting	20	20	400
Pressing Iron	1200	2	2400
Washing machine	500	1	500
Electric kettle	1200	1	1200
Electric cooker	3000	1	3000
Air-conditioning system	1750	3	5250
Laptop computers	100	6	600
Desktop computers	100	1	100
DVD Player	35	1	35
Digital TV Decoder	10	1	10
Television 25"	150	1	150
Microwave	600	1	600
Home theatre	35	1	35
Refrigerator	400	1	400
Smartphone charger	4	3	12
Toaster	800	1	800
Electric heater	2000	1	2000
Food blender	300	1	300
Total Wattage			21792

In order to evaluate the amount of electricity saved by the RFID system (in percentage), the electricity consumption of the home appliances was studied based on the availability of the households at home and based on the time during which the electrical equipment is powered on according to the households. The consumption pattern was computed by estimating the number of hours of use of the above-listed home appliances. The daily graphical representation of the energy consumption with and without the RFID for summer (September to May) and winter (June to August) are as shown in Figs 8, 9 and 10 respectively.

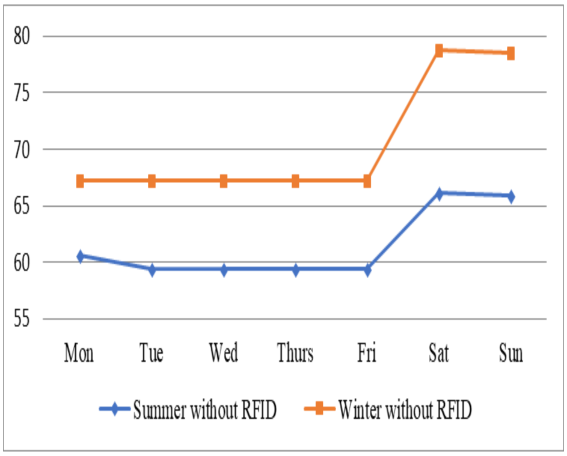

Figure 8. Average Daily electricity consumption for winter and summer without RFID

The pattern shows that more electricity is consumed during the weekends than weekdays. This is expected, considering the work-life nature of the people. Also, when comparing the overall winter energy consumption to the summer consumption, the former is higher compared with the latter. This is due to increased use of heating devices like a Water Heater, Electric heater, electric kettles which are classified as electricity-hungry devices since they account for most power consumption in the households. Following the implementation of the RFID reader system, electricity consumption is as shown in Figure 9 and 10.

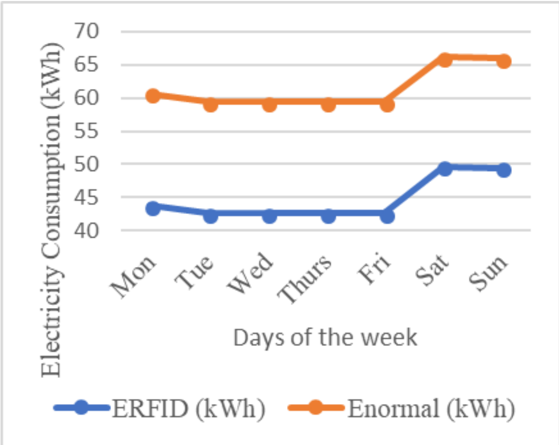

Figure 9. Average Daily consumption in summer with or without RFID

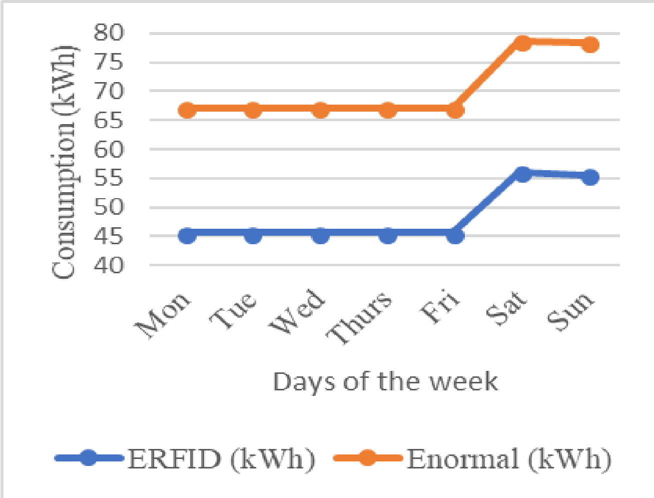

Figure 10. Average Daily consumption in Winter with or without RFID

The winter and summer electricity consumption patterns with RFID systems show a decreasing trend when compared with the seasons without RFID systems.

6. Electricity Savings Estimation

Taking the cost of electricity to be R1.82 per kWh and assuming that the cost per kWh is constant for all the weeks and the months; the followings are the estimation to portray the extent of energy savings achievable using the proposed RFID model.

6.1. Estimated Monthly Savings

6.1.1. Summer (September – May)

The total weekly cost savings is determined as follows;

Amount of energy saved in a Month = $E_{normal} - E_{rfid}$ = 430.49 – 313.31kWh

= 117.18kWh

The total Monthly cost savings considering the price of R1.82 per kWh = 117.18 * R1.82 = R213.27

Percentage energy saved in a month = $\frac{E_{normal} - E_{rfid}}{E_{normal}} \times 100\%$

$= \frac{430.49 - 313.31}{430.49} \times 100\%$

= 2.72%

This shows the system can save energy up to an estimated value of 2.72%.

6.1.2. Winter (June-August)

Amount of energy saved in a month = $E_{normal} - E_{rfid}$ = 493.14 – 340.06kWh

= 153.08kWh

the total monthly cost savings = 153.08 * R1.82 = R278.61.

Percentage energy saved in a month = $\frac{E_{normal} - E_{rfid}}{E_{normal}} \times 100\%$

$$= \frac{493.14 - 340.06}{493.14} \times 100\%$$

$$= 3.1\%$$

This shows the system can save energy up to an estimated amount of 3.10%.

The energy saving for both summer and winter season on a monthly basis is 2.72 % and 3.1 % respectively.

6.2. Projected Average yearly Savings using the proposed RFID model

Given that the monthly energy consumption for summer (September –May) period is $430.49kWh$ and monthly energy consumption for winter (June-August) is $493.14kWh$. Total yearly consumption;

$$= (430.49x9) + (493.14x3) = 3874.4 + 1479.42kWh$$

$$= 5353.83kWh = 5.354MWh$$

Going by the earlier estimated energy saving for both summer and winter season on a monthly basis is 2.72 % and 3.1 % respectively; the monthly energy consumption for the summer period is $313.31kWh$ and monthly energy consumption for winter is $340.06kWh$. Therefore, the total yearly consumption can be deduced as;

$$= 313.31x(9months) + 340.06x(3months) = 2819.79 + 1020.18$$

$$= 3839.97kWh$$

In conclusion; Estimated yearly energy savings from implementing the RFID system

$$= 5353.83kWh - 3839.97kWh$$

$$= 1513.86kWh$$

Cost savings for a year;

$$= R1.82 \times 1513.86 = R\ 2755.22$$

This is equivalent to a yearly percentage savings of $\frac{1513.86\text{kWh}}{5353.83\text{kWh}} \times 100$

$$= 28.276\% \approx 29\%$$

This percentage on the average shows higher potentials of energy savings from household equipment when compared to research published by Manzoor *et al* where savings of 13% were discovered in the energy efficient building lightings control using RFID and PIR sensors in a University campus [19]. The higher percentage of energy saving recorded in this research is due fact that all the energy consuming appliances in the residential building was considered as against the previous author.

In 5years, total savings will be $= 5 \times 1513.86kWh = 7569kWh$

In 30years, total savings will be $= 30 \times 1513.86kWh = 45415.8kWh$

If we assume an unlikely scenario whereby the unit cost of electricity does not change over the space of 30years, the total cost savings on the consumption;

$$= 45415.8kWh * R1.82 = \mathbf{R82,656.76}$$

6.3. Deployment cost and Return for an Investment (ROI) on RFID

The cost of deployment of RFID in the building for this case study was calculated in an attempt to determine the Payback time period. The cost of installing the RFID includes the hardware/software components and also the labour cost. The overall cost of active RFID tag and reader is R17,200. From the calculation above, the cost savings in a year is R2755.22, therefore the total period for return on the investment would be;

$$\frac{R17200}{2755.22} \approx 6years$$

Obviously, the cost of deployment seems too high but the period of Returns it very encouraging. The usage of RFID technologies is increasing, so it is expected that the price will reduce with time due to expansion in RFID market which as at 2017 worth $11.2 billion and is estimated to rise up to $14.9 billion by the year 2022 [20]. Also, when RFID hardware and software procurement is done in bulk purchasing, the concession in price from the vendor would lead to a further reduction in total cost of deployment. It is very certain that the electricity tariff cannot be the same over a space of 30years, so it means the household would have to pay more for electricity consumption. This would be aside some other expenses which are most likely to increase. Therefore, the household would pay less in electricity consumption in the long run.

7. Conclusion

The design of a smart electricity environment is becoming more vital because of the cost concerns and environmental demands. There is an urgent need for the implementation of energy efficient models. This paper presented an RFID electric power saving model and the potential electricity savings from its implementation. Although it was assumed that the refrigeration system is also subjected to RFID electricity management, in actual sense, such an appliance is often left permanently on. This technology may be employed as a part of residential building codes and standard. An articulated and vigorously pursued energy efficiency policy measures in South Africa can result in enormous savings in electricity consumption over a period. This subsequently eradicates the demand for the additional power plant and its attendant cost. Energy efficiency addresses several of the highlights of the Sustainable development Goal (SDG). Since efficient consumption reduces the economic pressure and benefits the environment with respect to climate change and eventually leads to poverty eradication among the citizens.

References

1. IndexMundi (2017) http://www.indexmundi.com [accessed on 10/08/2017]
2. International Energy Agency, Key World Energy Statistics, 2006.http://www.env-edu.gr/Documents/Key%20World%20Energy%20Statistics%202006.pdf [accessed 10/08/2017]
3. Wang, Jing-Min, and Ming-Ta Yang. "Design a smart control strategy to implement an intelligent energy safety and management system." International Journal of Distributed Sensor Networks 2014 (2014).
4. Mlamo-Ngcuka, P. "Energy efficiency strategy of the Republic of South Africa." Department of Minerals and Energy, Pretoria (2004).
5. www.iea.org/statistics/topics/Electricity/ Electricity Statistics. Accessed on 10/05/2017
6. Davidson, O., Kenny, A., Prasad, G., Nkomo, J., Sparks, D., Howells, M., Alfstad, T. and Winkler, H., 2006. Energy policies for sustainable development in South Africa: Options for the future.
7. Reiss, P. C., & White, M. W. (2002). Household electricity demand, revisited. Stanford University Publication. Retrieved June 6, 2013 from http://www.stanford.edu/~preiss/demand.pdf
8. Resource Center for Energy Economics and Regulation. (RCEER) (2005). Guide to electric power in Ghana (1st ed.) Institute of Statistical, Social and Economic Research. University of Ghana, 1–57.
9. http://crown.co.za/latest-news/sparks-electrical-news-latest-news/2174-burning-issues-for-south-africa-s-electrical-industry accessed on 12/06/2017

10. Calis, G., Deora, S., Li, N., Becerik-Gerber, B. and Krishnamachari, B., 2011, June. Assessment of wsn and rfid technologies for real-time occupancy information. In Proceedings of the 28th International Symposium on Automation and Robotics in Construction (ISARC 2011), Seoul, Korea (Vol. 29).
11. Dobkin, Daniel M. The rf in RFID: UHF RFID in practice. Newness, 2012.
12. Klair, Dheeraj K., Kwan-Wu Chin, and Raad Raad. "A survey and tutorial of RFID anti-collision protocols." IEEE Communications Surveys & Tutorials 12.3 (2010): 400-421.
13. Li, Nan, and Burcin Becerik-Gerber. "Life-cycle approach for implementing RFID technology in construction: learning from academic and industry use cases." Journal of Construction Engineering and Management 137.12 (2011): 1089-1098. 2012
14. De Silva, L. C., Morikawa, C., & Petra, I. M. (2012). State of the art of smart homes. Engineering Applications of Artificial Intelligence, 25(7), 1313-1321.
15. Stephen A. Weis, “RFID (Radio Frequency Identification): Principles and Applications”, 2006. [Online]. Available: www.ingenuityworking.com. [Accessed: Oct. 25, 2015].
16. Pulling the plug on standby power, http://www.economist.com/node/5571582 accessed 14/08/2017
17. Bredekamp, A. J., Uken, E. A., & Borrill, L. (2006, April). Standby power consumption of domestic appliances in South Africa. In Domestic Use of Energy Conference.
18. Arduino Uno user manual, 2014, http://docsasia.electrocomponents.com/webdocs/0e8b/0900766b80e8ba21.pdf. [Accessed on 11/05/2017]
19. Manzoor, F., Linton, D., Loughlin, M., & Menzel, K. (2012). RFID based efficient lighting control. International Journal of RF Technologies, 4(1), 1-21.
20. Das, R. (2017). RFID Forecasts, Players and Opportunities 2017-2027.Retrieved from IDTechEx - Research, Consulting, Events: http://www.idtechex.com/research/reports/RFID-forecasts-players-and-opportunities-2017-2027-000546.asp. accessed on 11/08/2017