ISSN: 2449 - 0539
BAYERO JOURNAL OF ENGINEERING AND TECHNOLOGY (BJET) VOL. 18 No. 1, JAN 2023 PP 1 -7

OCCUPANCY BASED AIR CONDITIONER DIGITAL ENERGY SAVING SYSTEM

Habibu Rabiu

Department of Electrical engineering Bayer University Kano, Nigeria

ABSTRACT

Electrical energy consumption in public offices is dominantly caused by air-conditioning loads (AC). In the past, several energy reduction strategies were proposed to lower the cooling cost, which include employing alternative building materials, using variable speed compressors. One fundamental problem that results in heavy cost in term of energy consumption of AC is the poor user behaviour. It is a common practice in Government offices to have ACs left working for hours while the office occupants are not in or have even close for the day. To ensure energy supply security, this paper proposed to employ passive infrared sensor (PIR) and microcontroller to keep up scanning the offices space at a top speed to monitor the presence of staff. It shuts down the AC if it did not detect any movement after the elapse of a preset time period. To evaluate the effectiveness of the new method, we employ an ethnography approach. Obtained results show a significant energy saving, which sometimes reaches up to saving of 15hours of wasted energy per day.

Keywords: Air conditioner control, Energy consumption, Energy saving, Poor user behaviour, Passive Infrared Sensor

1. INTRODUCTION

In most sub-Saharan African countries, cooling system accounts for over 60% of the total energy consumed in both commercial and residential buildings (Rewthong et al., 2015). Since air conditioner (AC) is the chief consumer of energy in buildings, it is important to study its control with aim of improving its energy cutback. Reduced energy consumption offers several immediate advantages; to the supply authorities, it leads to the significant reduction in load especially during peak hours, since reduced load implies reduced losses in transmission, better transformer performance and fewer grid failures. To the customers; reduced energy consumption means less energy cost. Some factors that influence ACs energy consumption in African countries include; extreme weather condition, poor building insulation, lack of standards such as energy efficiency standard or energy labels, and poor user behaviour.

Several approaches for AC energy consumption reduction strategies were presented in the past. Yurtseven et al., (2014) conducted a field test experiment to evaluate the energy saving potential of constant speed (non-inverting) and variable speed (inverting) ACs in public offices. They equipped two rooms with AC units in which one is inverter AC and the other is non-inverter. They installed an energy monitoring device with two energy analysers and a digital timer switch. Temperature loggers were used to read both indoor and outdoor condition. Using this setup, they collected data for three months and analyse. The result shows that the variable speed ACs has outperformed the constant speed type in terms of energy efficiency. Thermal resistance of material used in building also has dominant influence on conserving the temperature in building. A comprehensive study on effect of green roofs with different building thermal insulation was presented by Jaffa et al., (2012). Their result shows that green roofs could reduce heat flux into the building space, which in turns translates into lower AC energy consumption. Energy efficiency standards and labels are commonly used strategies in many countries to reduce energy consumption for household appliances. An energy label is a mandatory sticker affixed on the product and their packages contain information on energy consumption of the product. This scheme convinces customers to buy and the manufacturers to produce less energy consuming products (Mahlia and Saidur, 2010). In the work of Elmoudi et al,

(2011), the authors employed web services technology to develop a smart temperature controller for AC energy consumption. Their result shows a significant reduction in the AC's energy consumption, while maintaining the user thermal comfort. Suheeman et al., (2019), Developed an extension device for attaching to the non-automatic air conditioner systems in order to reduce their energy consumption. This extension device works as a remote holder and enables existing remote controllers to perform automatic human detection to active the controlled devices. Experimental results show that the proposed device can reduce energy consumption of the standard air conditioner by 32.3% on average. Opoku et al., (2020) conducted a study on sustainable energy efficiency measures and solar energy to reduce electricity cost in public tertiary institutions. They conducted energy audits as well as actual measurements of power consumptions of some selected electrical appliances using power quality analysers. The result show that there is total electricity savings opportunity of 163,400 kWh ± 5% per month by implementing energy efficiency retrofitting for the air-conditioners, lighting systems and ventilation fans. However, the cost of implementing such retrofitting is beyond the capacity of many tertiary institutions in the developing countries. However all theseresearches did not take into account the poor user behaviour which in most cases is the main leading cause of energy wastage of air conditioners.

Another fundamental problem of ACs high energy consumption, especially in public offices is the poor user behaviour. Ho (2015) in his work used daily time diary of the participant activities. The diaries together with the spatio-temporal order of the household were used to study the participants' energy conservation practices. The result shows a strong correlation between the user behaviour and energy consumption. Methods use to mitigate this problem include; imposing maximum temperature setting on the AC to be use, educating users on the problem of energy mismanagement, paying incentives to users and moralising user behaviour (Zhuang and Wu, 2014). However, these approaches have their various short coming as energy saving cannot rely on human behaviours as mostly are forgetful. This article focuses on mitigating the poor user behaviour on the ACs energy consumption problem. It is a common practice in Government offices to have air conditioners left working for hours while the office occupants are not in or have even close for the day. To ensure energy supply security the proposed approach employed passive infrared sensor (PIR) to continuously scan the room at a very high speed to monitor the presence of the staff. It is design to shut down the AC if it did not detect any movement after the elapse of a present period.

2. METHODOLOGY

2.1 Passive Infrared Sensor (PIR)

The key element of this work is motion detection using PIR technology. In order to understand the problem, pose by PIR we need to study its principal components separately these are: radiation, propagation and detection.

2.1.1 Radiation Source: unlike in the visible light domain, whose reception is solely based on reflection or diffraction of light by objects. In PIR, the detection is essentially based on a phenomenon known as thermal radiation which simply means that objects themselves radiate heat due to their temperature. The thermal radiation is represented by Plank's law and mathematically express by equation (1)

$$\lambda\_peak \times T = 2898 \qquad (1)$$

Where γ_peak is wavelet in micrometres and T is the temperature in kelvins. The most suitable range for passive observation is when the λ falls in the spectral region of 5 to 20μm.

2.1.2 Propagation Medium: The heat radiated by the object reaches the detector after crossing the medium. Therefore, this radiation needs to have sufficient energy to travel through the medium, which in this case is the atmosphere. The photon energy of monochromatic radiation having a wavelength λ is given by

$$E = hc \,/\, \lambda \qquad (2)$$

Where c is the speed of light and h is Plank's constant

Even though the photons in the infrared region have lower energy as compared to those in the visible light radiation, but their energies remain sufficiently large to interact with the molecules in the gaseous layers. Generally, the conditions for atmospheric propagation mainly depend on the local metrological data and geographical characteristics of the environment.

2.1.3 Radiation Detection: Photon detectors employ the electrical properties of semiconductors. It based its principle of operation on photon-electron interaction. The

incident radiation causes the electrons on the valence band to jump the energy forbidden gap (W_G) into the conduction band, while the holes follow the inverse path. For this effect to occur, the photon energies must be greater than that of the W_G Mukhopadhyay et al., (2018). This means that the wavelength λ of the radiation must be less than or equals to a cut-off wavelength λc given by the relationship.

$$\lambda\_c = hc \,/\, W\_G \qquad (3)$$

2.2 Motion Detection

PIR modules are devices design to detect movement of objects that radiate heat such as human and animals. Radiation due to these objects though it cannot be seen but can be detected and is strongest at a wavelength of 9.4µ_m.

The sensor module comprises two slots of sensitive IR material as illustrated in Figure .1

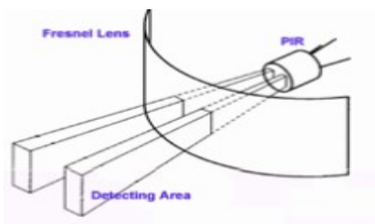

Figure 1: Internal structure of PIR sensor

When the sensor is idle, both slots detect the same amount of IR, say the ambient amount radiated from the room or walls. But, when a warm body like human or animal passes by, it first intercepts one half of the PIR

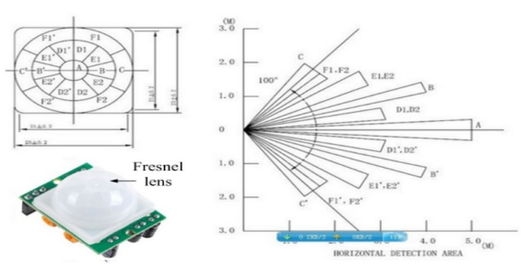

Figure 2 Illustration of PIR sensitivity enhancements using Fresnel lens

sensor, which causes a positive differential change between the two halves. When the warm body leaves the sensing area, the reverse happens, whereby the sensor generates a negative differential change. These change pulses are what is detected. The sensor generates +5v and -5v sine signal when a human or animal passes in front of the sensor or any movement is detected the sensor's output changes from low to high. Another important component of the PIR sensor is the Fresnel lens. Fresnel lens is made up of an infra-red transmitting material that has an IR transmission range of 8 to 14µ_m which is most sensitive to human body radiation. The purpose of the Fresnel lens is to break up the area under observation into optical zones so that a heat source moving from one optical zone to another will generate a heat wave on the surface of the PIR detector as shown in Figure 2. This has the tendency of increasing the device detection range and reduces the ambient noise.

2.3 Control Unit

The brain of this device is Arduino uno board with microcontroller Atmega328 as the main chip. It contains fourteen digital input/output pins, six analogue input pins, a reset button and sixteen Mega Harz crystal oscillator. Communication between the board and the computer is established through a USB port. The main function of this unit is to provide a supervisory role between the environment and the AC. The PIR which serves as the sensing unit, is connected to pin 12 of the chip, which is configured as input. While the AC is connected to the control unit through digital pin15 configured as an out pin. As depicted in Figure 3

2.3.1 Energy Consumption Control: The AC's energy consumption can be control by switching OFF the AC when the user is not occupying his or her office. Figure 4 gives the implementation detail of the new method. The

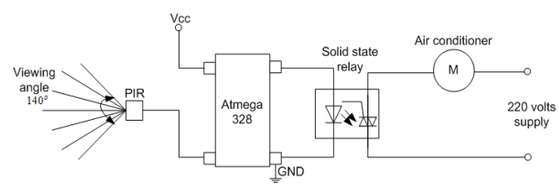

Figure 3: Schematic diagram of the control unit

circuit operation is simple, first step is for the PIR unit to scan its field of view for any motion changes. If there is any motion, the controller switch ON the AC. But if no motion is detected, the controller calls for a delay (30 minutes in this case). During this time, the controller continuously checks for motion within the field of its view. If motion is detected, it rests the timer and keeps the AC in continuous working condition with no interruption. However, if no motion is detected, the controller switches OFF the AC at the end of the delay period.

3. RESULT AND DISCUSSION

3.1 Implementation

We built the proposed controller around ATmega328 micro-controller, PIR RE200B sensor and SSR 40DA solid-state relay as the key components of the circuit. The controller is housed in 28 pins plastic package which can be power with a voltage source in a range of 1.8 to 5.5 volts. It draws a maximum of 0.2mA while in active mode and as low as 0.1µA at power down mode. Similarly, the PIR sensor can be energise with a source of 5 volt; it draws a current of 0.5mA with a spectral response of 5 to 14µm and viewing angle of 140o. Finally, the Solid-state relay has two ports; as the input and output, the input accepts 3 to 32 volts Dc to turn its output contacts resistance low. While, the output voltage ranges from 24 to 380 volts AC with a response time of <10ms.

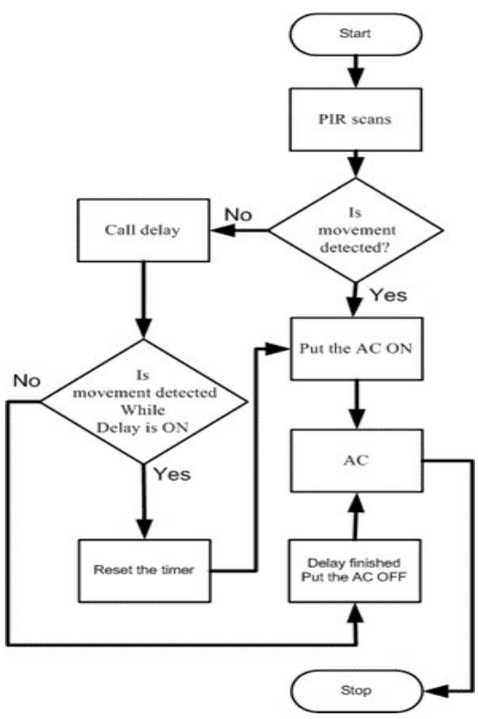

Figure 4: General frame work of the proposed method

3.2 Testing

Realising the mutuality between the proposed device and the human behaviour, we have adopted ethnography method to measure the system performance. Ethnography is a method of discerning day-to-day life of a people as they live them out. It is a tool that attempts to explore participant's setting and perspectives in as much detail as possible. Generally, this method is an unpopular because it violates the socio-cultural norms of privacy (Ho, 2015). For this reason, we selected only five university staff and request that they submit their daily time diary for their office activities for two weeks. To have a more detail understanding of individual attitude regarding their energy consciousness, we also conducted one-on-one interview to learn whether the participants turn off their ACs when leaving their offices or not. Table .1 gives the average staff air conditioner utilisation pattern.

3.3 Analysis of the Result.

To easy the analysis, let's first define some terminologies; (i) useful energy (UE) as the energy consumed by an air-conditioner when the utility power supply is available, the air conditioner status is ON and running and the staff is available IN his office. (ii) wasted energy (WE) as the energy consume by the air-conditioner, when the utility power supply is available, the AC unit status is ON and running and the staff is OUT of his office. (iii) Utility Power supply (UPS) as the state of the local power supply authority, whether power is available or unavailable, (iv) Air conditioner's status (AS) as the operating condition of the AC in case if it is ON or OFF.

Thus, from the result presented in Table1 we can see that utility supply was available for 15.5 hours per day. Out of this, staff A stayed in his office for only 4 hours. However, he failed to switch off his AC while leaving the office and therefore can only have valued UE for 30 minutes only while incurring 15 hours of WE. Nonetheless, with the new device installed the WE reduce to only 30 minutes, as the device automatically turn OFF the AC 30 minutes after staff A left the office and will not allow the AC to come ON again even when the UPS was restored at 19:30 hours, a significant saving of energy.

Table 1: Average staff AC utilisation pattern

Time stamp	Staff A	AS	Staff B	AS	Staff C	AS	Staff D	AS	Staff E	AS	UPS
08:00	IN	ON	IN	ON	OUT	OFF	IN	ON	IN	ON	Available
08:30	OUT	ON	IN	ON	OUT	OFF	OUT	ON	IN	ON	Available
09:00	OUT	ON	IN	ON	OUT	OFF	OUT	ON	IN	ON	Available
09:30	OUT	ON	IN	ON	OUT	OFF	OUT	ON	IN	ON	Available
10:00	OUT	ON	OUT	ON	IN	ON	OUT	ON	IN	ON	Available
10:30	OUT	ON	OUT	ON	IN	ON	OUT	ON	IN	ON	Available
11:00	IN	ON	OUT	ON	IN	ON	OUT	ON	IN	ON	Unavailable
11:30	IN	ON	OUT	ON	IN	ON	OUT	ON	IN	ON	Unavailable
12:00	IN	ON	OUT	ON	IN	ON	OUT	ON	IN	ON	Unavailable
12:30	IN	ON	OUT	ON	IN	ON	OUT	ON	OUT	ON	Unavailable
13:00	IN	ON	IN	ON	IN	ON	OUT	ON	OUT	ON	Unavailable
13:30	IN	ON	IN	ON	IN	ON	OUT	ON	OUT	ON	Unavailable
14::00	IN	ON	IN	ON	OUT	ON	OUT	ON	OUT	ON	Unavailable
14:30	OUT	ON	IN	ON	OUT	ON	IN	ON	OUT	ON	Unavailable
15:00	OUT	ON	IN	ON	OUT	ON	IN	ON	OUT	ON	Unavailable
15:30	OUT	ON	IN	ON	OUT	ON	IN	ON	OUT	ON	Unavailable
16:.00	OUT	ON	IN	ON	OUT	ON	IN	ON	OUT	ON	Unavailable
16:30	OUT	ON	OUT	OFF	Close	ON	IN	ON	OUT	ON	Unavailable
17:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Unavailable
17:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Unavailable
18:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Unavailable
18:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Unavailable
19:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Unavailable
19:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
20:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
20:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
21:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
21:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
22:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
22:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
23:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
23:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
00:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
00:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
01:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
01:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available

02:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
02:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
03:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
03:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
04:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
04:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
05:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
05:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
06:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
06:3:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
07:00	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available
07:30	Close	ON	Close	OFF	Close	ON	Close	OFF	Close	ON	Available

Similarly, staff B though stayed in his office for 5.5 hours, he only enjoyed the UE for 2hours only. Even though the staff switched off his AC at the close of the day, but still gained WE of 1 hour due to his failure to turn OFF the AC while leaving his office at 10:00 hour. The received WE could have reduced to only 30 minutes if the new device was engaged. Applying the same analysis, staff C would have 1 hour of UE and got 12.5 hours of WE. Whereas if the new method was used, the WE could have been zero. staff D and E would have 1 and 3 hours of UE respectively, while acquiring 2.5 and 12.5 hours of WE. If the new device is in place, the loss could have been 30 minutes in each case.

4. CONCLUSION

This article proposed to solve the problem of poor human behavior regarding staff turning off air conditioners when leaving offices using PIR sensor and micro controller approached. The developed system is tested and found to be working satisfactorily. To measure the effectiveness of the new approach, we employed ethnography method. Results obtained show a tremendous energy saving, which sometimes reached up to savings of 15 hours of wasted energy per day.

Acknowledgement
The Directorate of Research, Innovation and Partnership (DRIP) funded this research, Bayero University Kano.

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