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Air-Conditioning Control Optimization for Energy Conservation

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ABSTRACT

One of the challenges facing the world is the need to feed the ever-growing population. Agricultural engineers are working towards development of the right infrastructure that will enhance food production and processing. Smart green houses are being worked on and we look forward to the implementation of such ideas, we also have to think of what else needs to be put in place if at all we have to achieve their efficacy that we so desire. Heating, ventilation and air conditioning systems are part of the support systems that will come in demand as we purpose to actualize majority of the ideas. Whether in the green houses or in the processing firms, AC units are required to maintain the optimal space conditions for efficiency in operation. Technology is playing a key role in digitization of these systems with sensors and microcontrollers being used extensively. Energy conservation remains the main focus of scientists and engineers working on these systems. In line with working towards developing energy efficient systems for use in offices, research was carried out to optimize the control of air conditioners for energy conservation purposes. The research was geared towards having an air conditioner that is efficient in terms of energy consumption and in its operation putting into consideration the working environment of food processing firms and the long working ours. Temperature, proximity and passive infrared detectors have been used as smart sensors. The system was designed such that when room occupants' approach a room, the system is activated and rapidly cools down or warms up within a predetermined time depending on the size of the room. As long as there is an occupant in the room, the system quickly settles into the set conditions. When there is no one in the room, the system needs not be working and therefore switches off. This ensures that the system only works when needed hence helps

in energy conservation thus reducing bills paid by home owners and companies. The designed prototype is able to detect room occupancy, responds perfectly to temperature changes as well as human presence in the field of view of the PIR with an overall performance efficiency of 55.95% which is a good start towards actual implementation of an energy efficient A.C. system.

Keywords: Energy conservation, energy efficiency, performance efficiency, air conditioning system

1. INTRODUCTION

An air conditioner (AC) is a system or a device that controls the quality of air in a defined, usually enclosed area via a refrigeration cycle in which warm air is removed and replaced with cool air or cold air is removed and replaced with hot air.

The essence of having an AC is to improve the comfort of occupants by heating up a room or removing heat and moisture from the interior. A smart AC was introduced recently which utilizes Wi-Fi for its control via a smartphone.

A consideration which has been made in redesigning ACs is energy conservation to ensure that their cost of operation reduces. For energy efficiency purposes, the following modifications on an AC were adopted through this research;

i. A PIR sensor was mounted outside the building and at the entrance to monitor occupants as they approach it and thus the system is activated prior to someone entering the building.

ii. A proximity sensor was mounted inside the building detects room occupancy. This ensures that the system only works when there are occupants in the room. Therefore, system reduces the running time of the air conditioner hence energy conservation is achieved.

Peter A. *et al*., (2013) designed a smart air conditioning control by wireless sensors. Wireless sensors are not limited to wired installations and can be deployed strategically close to the fluctuating thermal sources. Wireless sensors can be used to develop intelligent monitoring systems. Their research only considered a single sensor control setting and the main recommendation to develop it was on research in interaction between multi-input and multi-control systems in a networked setting which is an area considered in this research.

Smart phones, devices that can be worn, thermal and motion sensors were interlinked as smart sensors for control of air conditioners in a study by Cheng and Lee (2014). The system obtained feedback information from these devices. Their system was effective in providing a conducive environment and achieved energy conservation goal and it utilized wireless devices.

Wireless sensors have a promising potential; however, they introduce battery lifetime challenge. They have to operate for long periods and therefore being battery powered; their battery life span has to be maximized.

The communication operation consumes a lot of energy and therefore it reduces the battery life time. Communication consistence has to be maintained for effectiveness of the system.

Control effectiveness is also another area where a big challenge was met by Cheng and Lee (2014). Considering that energy consumption is inversely proportional to efficiency (Riches, *1989*), sleeping of the device most of the time would lower energy consumption and therefore increasing battery life but would reduce the effectiveness since the system will not be running hence sensing will not be taking place. Balancing energy consumption with efficiency is key to the usefulness of these devices more so for smart applications.

A smart air conditioner system for adaptation to a smart home system was proposed by Yang *et al*., (2016). The system used sensors to control the levels of temperature and it was Wi-Fi controlled. Entirely, its control dependent on internet and it had limitations on the geographical areas to be used since not all areas have internet connections.

An energy saving controller for air conditioning in large buildings was designed and implemented by Liangh (2018). This system could also switch on and off the lights and switch on the systems when an occupant enters a room. However, it majorly controlled the level of humidity in the rooms.

Erham and Samudra (2020) designed an AC system which could be controlled remotely in the convenience of their houses. Similar to what Mehmet and Hayrettin (2018) did, they could switch it on prior to arrival and if they noticed that maybe they had left it on they could switch it OFF for purposes of energy conservation providing justification for any study towards methods of increasing energy conservation. The main challenge with their system was that it was not fast in its operation. It still had to be controlled manually via a smartphone or maybe a laptop. The system was not applicable to areas without internet connectivity. Assuming that one leaves the AC running and only realizes after he/she gets home, we can think of how much energy that AC will have consumed unnecessarily.

Our research showed that indeed we can be able to modify the existing air conditioning systems for energy conservation purposes. Placement of the PIR at the entrance of the building and the proximity sensor in the building to detect room occupancy proved that indeed there is a great hope in this line of research which was demonstrated by the working of the prototype designed in this research.

2. EXPERIMENTATION

2.1 Detecting a person approaching a building

The PIR has three pins, the input, the ground and the output which are connected to a 5V, GND and GPIO pins of the microcontroller, respectively.

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2.2 Detecting the temperature inside a room

The temperature sensor gives a HIGH output when the temperature is high and this triggers the microcontroller to switch ON the fan. In case the temperature is low, the sensor will give a LOW output and this triggers the heater to be switched ON. In case of optimal temperature conditions, no action is taken, thus the system will not be set ON.

2.3 Detecting the presence of occupant inside a room

The PIR having detected an occupant coming in to the room, and the signal from the temperature sensor having been fed to the microcontroller, the system is set is either set ON or maintained OFF. The system will only go ON if the PIR has detected an occupant coming into the room and the temperature levels in the room are not within the preset range. A timer is set such that after three minutes, if the occupants will not have entered the room, then the system goes OFF.

When occupants enter into the room, the output signal from the proximity sensors installed in the room will give a HIGH output indicating room occupancy and this signal will maintain the system working until the required temperature conditions are achieved. The system continues to work as long as the signal from the proximity sensor is HIGH and the required temperature has not yet been attained.

If occupants are still in the room, the signal from the proximity sensor will remain to be HIGH. The temperature sensor signal will vary depending on the temperature changes in the room. If the conditions are conducive, the micro-controller disconnects therefore the system stops working until again the temperatures falls or raises.

When the occupants leave the room, signal from the proximity sensor goes LOW and this is interpreted by the control program to mean that the occupants have left and this triggers the microcontroller to switch OFF the system.

2.4 System operation

A passive infrared sensor measures infrared radiation emitted from objects that generate heat and therefore infrared radiation in its field of view. Basically, they detect the change in temperature in comparison with the surrounding temperature.

When a person enters in its field of view, infrared radiation from the subject is detected. Due to motion, there will be variation in the intensity of the infrared radiation. This causes a change in the output voltage generated. Having detected motion, the PIR outputs a HIGH signal on its output pin which switches ON the fan or the heater depending on the temperature state as measured by the temperature sensor in the building.

Upon room occupants entering the room, the system will be already working. For continued operation, proximity sensors are integrated in the system to detect the presence of individuals in time. The moment presence of occupants is confirmed in a room, high output signal maintains the system working. The temperature sensor will be measuring the temperature levels. When optimal temperature conditions are achieved, the microcontroller switches OFF the air conditioning system. If the temperature falls below or raises above the pre-set level the output of the temperature sensor will be LOW or HIGH respectively, then triggers the system to start working.

When occupants leave the room, the proximity sensors give a LOW output which will switch OFF the system.

3. RESULTS AND DISCUSSION

3.1 Cooling capacity

The cooling capacity for a room is defined as the heat load in a room that has to be removed in order to achieve a certain room temperature and humidity. The recommended conditions are 24℃ and 55% relative humidity (Percy *et al.*, 2020).

To calculate the cooling capacity for an AC, the volume of the room to be cooled is first determined then multiplied by six since every time the ON/OFF type of compressor starts to run, its power consumption is 6 times higher than when running steadily (Charisis and Theoklitos, 2012).

The number of occupants to occupy that room (*N)* is also considered. This will helps in knowing the amount of heat to be generated by the occupants. Each person produces approximately 147 W (Ashrae, 2017) of heat for normal office related activity. The amount of heat generated shall therefore be $147 \times N$.

Letting the volume of the room to be *V*, we multiply by 6 to get

$$6V = M \tag{1}$$

and

$$147 \times N = K \tag{2}$$

Adding M and K gives us the simplified cooling capacity (H).

$$H = M + K \tag{3}$$

Eq. 3 holds true on condition that heat from the other sources is negligible otherwise an allowance should be provided to accommodate that when designing an AC for a building.

3.1 Space Heat Gain

The heat coming from different sources through conduction, convection, solar radiation, lighting, human beings, heat generating equipment etc. does not go immediately to heating the room. Only some portion of it is absorbed by the air in the conditioned space instantaneously leading to a small change in its temperature. Most of the radiant heat is first absorbed by the internal surfaces, which include ceiling, floor, internal walls, furniture etc. Due to the large thermal capacity of the roof, floor and the walls, their temperature increases slowly due to absorption of this radiant heat. The radiant portion introduces a time lag between maximum insolation and the temperature on the air cycle in the conditioned space and also a decrement factor depending upon the dynamic characteristics of the surfaces. Due to the time lag, the effect of radiation will be felt even when the source of radiation is removed (Ashrae, 2017). This explains why the sensed temperature in a room my raise slightly above the required temperature and the reason cooling process has to begin instantly to stabilize the system.

3.2 Data presentation and analysis

In this research, three sensors namely PIR, ultrasonic and temperature sensors were used to actualize the system. The sensors were mounted strategically to maximize their efficiency. The PIR is mounted at the entrance of the building such that the subject cuts across its field of view so that its two sensor elements are sequentially exposed to the infrared radiation. The system responded to signals from the PIR up to a distance of 8 m (as shown in table 1) beyond which the system could not respond to any motion.

Table 1: A table showing the response of the prototype with variation in subject distance from the PIR.

Distance of subject from the PIR (m)	Did the system respond (Yes/No)
1	Yes
3	Yes
5	Yes
7	Yes
8	Yes
9	No

The ultrasonic sensor responded even when inclined at different angles. This test was necessary since in a room people can have different sitting positions. The maximum angle for its response was determined to be 15^{0}. Beyond that, room occupancy could not be detected (as shown in table 2)

Table 2: A table showing the response of the prototype with variation in subject distance from the PIR

Distance from the ultrasonic sensor (m)	System response (yes/no)	Response of the system due position Angle of the subject from the sensor (Yes/No)			
		5	10	15	20
1	Yes	Yes	Yes	Yes	No
2	Yes	Yes	Yes	Yes	No
3	Yes	Yes	Yes	Yes	No
4	Yes	Yes	Yes	Yes	No
4.5	Yes	Yes	Yes	Yes	No
4.6	Yes	Yes	Yes	Yes	No
4.7	No				

The fabricated prototype air conditioner worked well and was effective in controlling the temperature in a room. It has an android app where users can monitor the temperature inside the room as shown in figure 2. It is through the same android app where users can operate manually the designed air prototype. It displays the temperature level at any particular instant with an accuracy of 0.001°C. The Wi-Fi range of the raspberry Pi 3 microcontroller was tested and found to be 10 m in open space, distance which reduced slightly to 8 m when kept in a room. This could be as a result of obstruction of the waves by the walls of the room and the equipment in it.

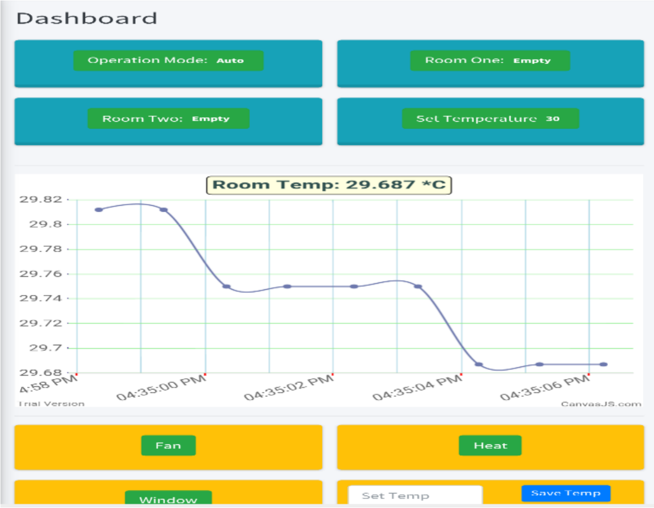

Fig. 2: A picture of the dashboard for the designed smart air conditioner android app.

The energy (U_1) needed to raise the temperature of the room by 4°C is given by;

$$(U_1) = mc.\Delta T \quad (4)$$

where: *m* – Mass of air in the room (ρV) ($\rho = 1.275\ kgm^{-3}$)

c – Specific heat capacity of air (c = 1.2 kJkg^{-1}k^{-1})

ΔT – change in temperature

$$U_1 = 1.2 \times 1275 \times 4 \times 2.4 \times 4$$

$$U_1 = 58{,}752 \pm 0.18\ J$$

The energy (U_2) dissipated by the heater in the prototype AC can also be calculated

$$(U_2) = Power \times Time \quad (5)$$

$$= 500 \times 3.5$$

$$U_2 = 105{,}000 \pm 0.014\ J$$

The difference in the values can be accounted for in-terms of entropy based on the second law of thermodynamics which states that in any closed system, the entropy of the system will remain constant or increase (Boles *et al.*, 2011). This means that heat transfer cannot occur spontaneously from cold to hot or hot to cold. Entropy is not conserved but increases in all real processes. Entropy is directly related to the fact that not all heat transfer can be converted into work. Eventually, the heat energy has to spread until evenly distributed.

The efficiency (E) of the prototype is given by;

$$(E) = \frac{work\ output\ (U_1)}{work\ input\ (U_2)} \times 100\% \quad (6)$$

$$= \frac{58{,}752}{105{,}000} \times 100\%$$

$$= 55.95 \pm 0.65\ \%$$

Most of the existing systems have efficiencies ranging between 10.0 -17.0 with a few going as high as 23.45% (Yang *et al.*, 2016). The expectation is that the higher the efficiency the lower the energy consumption of the AC unit. That is to say high efficiency air conditioners drastically reduce energy costs.

The results can be used to approximate the time it would take the system when used in different rooms or even the time it would take to bring the room to a preset temperature. In-case the temperature rises above the desired value, the cooling process begins automatically as shown in figure 5.

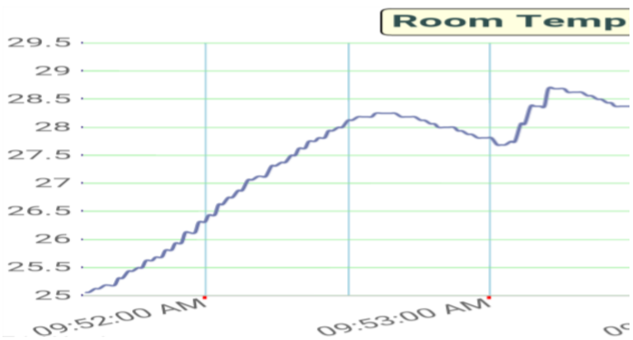

Fig. 5: A picture showing the automatic start of the cooling process after the desired temperature has been attained

4. CONCLUSION

A smart air conditioner was designed and fabricated and it proved to have high efficiency in its working. The system was able to detect a person approaching a building by use of the PIR and respond effectively. It was also able to detect room occupancy by use of a proximity sensor placed inside the room. Temperature levels inside the room were detected and optimal levels were maintained by this system as well. The working of the system can be monitored online through an android app as well as a web platform in a computer.

The expected objectives of an intelligent air conditioning control include human comfort and energy conservation and should be evaluated by;

1. Human comfort

This is determined by the response of system during the specified time to attain the required temperature in indoor which is basically a numerical value that varies with climatic conditions. The response of this system is actually fast and therefore human comfort is assured.

2. Energy consumption

Switching ON of the system only when needed then back to sleep mode when not needed is a great way of conserving energy rather than having a system that runs all through. This is taken care of in this research by having three sensors integrated in the control unit of the intelligent prototype and this aids in energy conservation.

It would therefore be in order to conclude that Implementation of this system would be a great boost in automation of air conditioners since we would have a system which is cost effective in-terms of operation. This is based on grounds that it would only run when needed. Reduced running time would mean that less energy is consumed hence energy conservation is achieved.

The efficiency of the prototype was found to be 55.95% which is higher than the 23.45% HVAC efficiency recorded so far. This shows that there is room for improvement on the existing systems to enhance energy conservation.

5. RECOMMENDATIONS

Several modifications can be made to this system to have a more advanced and more efficient system.

i. A camera can be introduced for face recognition at the entrance in place of the PIR thus enhancing security and prevent the system from being triggered by false signals like passers-by.
ii. Access to the system through its Wi-Fi is currently within the premises in which it has been installed. Any improvement to have it accessed at different places far from the area it is installed would increase its efficiency.
iii. The possibility of having other sensors on the system can still be explored to increase its utility. Example: we can have sensors to detect radiations emitted by the electronic components in buildings and hence raise alarm in case they rise above the recommended exposure.

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