IR Learning Remote Attachment for Occupancy Sensors to Switch Off Air Conditioners During Unoccupied Hours for Saving Energy

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Abstract

This paper reports the development of an IR learning remote which when attached to occupancy sensors can switch off air conditioners during unoccupied durations and thereby save energy. This IR learning remote acts as an interface between occupancy sensor and AC by transmitting the control signal of occupancy sensor to the AC, by sending appropriate IR command. Generally, window and split air conditioners cannot be connected to BMS and regular occupancy sensors with relays designed for smaller loads. Such ACs’ can be controlled by occupancy sensors with the help of the IR remote developed in this work. As this system does not need any wiring and uses IR signals to control AC, the system can also be used for retrofit applications. This paper describes the development of the IR learning remote and the energy savings observed during the experiment. Further, energy simulations performed using EnergyPlus show that for a typical office with two hours of unoccupied duration during 8.5 office hours in a day, savings of 20% in air conditioning and 23.5% in lighting can be achieved in composite climate by switching OFF the AC and lights when the room is unoccupied. The percentage savings in air conditioning energy consumption is less than that of lighting even when both the AC and the lights are switched off for the same duration is due to the fact that AC has to remove the heat that comes into the space during the unoccupied duration. Simple pay back of this device is about two months.

Keywords: Energy saving, Motion Sensor, Occupancy sensor, Air Conditioner, IR Learning Remote.
1. Introduction

In this urbanized world, air conditioners are being widely used. According to a study [1] by US Department of Energy, about 25% of annual energy consumption in commercial buildings goes into space-conditioning and a similar percentage goes into lighting. According to an article [2] published in Times of India, an Indian newspaper, if officers and employees of corporate and government organizations switch off their air-conditioning systems and lighting when the space is unoccupied, up to 26% of electricity can be saved. Manufacturers claim savings of 15% to 85% in lighting, although there is little published research to support the magnitude or timing of reductions. Energy savings and performance are directly related to the total wattage of the load being controlled, effectiveness of the previous control method, occupancy patterns within the space, and proper sensor commissioning. Case studies of energy savings have had varied results due largely to differences in human factors, previous control strategies and proper sensor commissioning [3]. The possible energy savings by switching OFF the lights using occupancy sensors would vary from 10%-19% in a typical small office as reported by Floyd, D. et. al [3]. Occupancy sensors have long been used in detecting occupancy and several algorithms have been developed to improve their performance [4][5]. Using the simple ON/OFF control occupancy sensors, it is easy to control small loads (such as lights and fans) but controlling the HVAC systems is difficult because they consume large amount of current which may not be handled by the occupancy sensors’ relays. There has been substantial work in controlling AC using various communication media such as RF, and direct wire connection, and with various communication protocols [6][7][8][9]. However all these require a separate communication port in the ACs. There are various prior art technologies which belong to relay base controls, Bluetooth based and PSTN based, which require these features to be existent in the AC which they control. These may also involve a tedious installation process and increase the initial investments.

As most of the stand alone AC have IR receiver, in this project, IR based system has been developed which does not require any extra wiring, any extra attachment in the AC and uses simple protocol. An IR learning remote attachment to occupancy sensor has been
developed to control AC in a similar fashion as their remote control. Whenever the occupancy sensor changes the state of its output this attachment would change the state of the AC through IR command.

The objective of the IR learning module developed is to switch ON & OFF the air-conditioner when the given space is occupied and unoccupied respectively to save energy consumed by the AC during unoccupied hours. This is achieved by connecting the IR learning remote with an occupancy sensor. This IR Learning remote acts according to the output from occupancy detector. A micro controller (ATmega8L) has been used in developing the IR learning remote. The learning algorithm and control algorithm were implemented within the same microcontroller. The system has been developed and functionally tested in this work. Details on the development of the system are given Section 2 of this paper.

The concept of energy savings through switching off AC during unoccupied period has been validated by conducting an experiment. The experiment has been performed in two identical rooms located in Hyderabad. Sensors were installed to measure temperature, electrical consumption, and weather data at the experimental site. A data logger has been used to monitor and record readings of sensors. Indoor air temperatures and power consumption of the AC have been monitored simultaneously in two rooms in a scenario where the AC in one room is switched off during unoccupied hours and in the other room the AC continues to function even during unoccupied hours. Further the collected data is analyzed to calculate energy savings. The experiment conducted has been explained in detail in Section 3 for the paper.

Further, to support the experimental validation, energy simulation has been performed for a similar scenario as of the experiment, and for a typical office schedule. Simulations were performed using Energy Plus version-3.1 for various cases based on length of unoccupied durations such as 2hours, 1hour, 30minutes and 15minutes. The simulation results showed a saving of 20% in a typical office when the office is unoccupied for two hours. The simulations are discussed in detail in Section 4.
2. Development of the system

2.1 Introduction

The overall system is built around a PIR motion sensor and an IR learning remote as shown in Figure 1. Output from motion sensor is connected to input of IR learning remote. This IR remote switches ON/OFF the air-conditioner based on the output of occupancy sensor. This system can be used to control various appliances in a home or office which have IR remote controlling facility.

![Figure 1 Block diagram of the system](image)

2.2 Overview of IR Learning Remote

IR Learning Remote can also be referred as learning remote or universal remote. A learning remote or universal remote is a remote control that can be programmed to operate various consumer electronic devices irrespective of their make. An IR learning remote can be used to emulate the existing IR remote originally supplied by manufacturer [10]. This module can be connected to any occupancy detector available commercially to control air-conditioner or any other such devices which can be controlled through IR remote. The prototype of the IR learning remote developed is as seen in Figure 2 The schematic of the IR learning remote is shown in Figure 3
As shown in the Figure 2, the IR Learning remote module has various blocks such as Microcontroller, IR Transmitter/Receiver, Attenuator, Key Interface and Power supply. For microcontroller block a low power, high performance AVR Atmega8L microcontroller has been used in this design. The package (32 Pin TQFP) of the device has been chosen to minimize the overall module size. In the IR Transmitter/Receiver block TSOP1738 IR demodulator has been used to receive IR signals and an IR LED with a MOSFET driver is used to transmit IR signals. A capacitor and resistor voltage divider circuit is used for attenuator block. This is vital because commercially available occupancy detector output is
about 220 volts. This cannot be connected directly to a microcontroller I/O pins. Three push switches are provided on board for user interface to control various operations. A 5volts DC power supply or 2AA batteries can be used to power up the module.

2.3 The Software

Two independent routines were implemented in micro controller. One is to activate learning functionality and the second is to control air conditioner based on occupancy detector’s output.

In a typical remote controller infrared (IR) pulses (typically 950-nm wavelength) are emitted by an LED in response to the buttons pushed on its keypad. Each key triggers a unique series of pulses that distinguish a particular function. A pulse actually is a burst of IR at carrier frequency. To prevent interference from ballasts of fluorescent lights, lamps and sunlight, most IR remote controllers digitally modulate a carrier whose frequency usually ranges from 30 kHz to 56 kHz. Pulse width measurement and pulse counting has be deployed for learning the IR signals in this IR remote. This is implemented with inbuilt timer module available in ATmega8L microcontroller. Infrared demodulator is used to receive and demodulate infrared signals. Output of demodulator is connected to one of the I/O ports available on microcontroller. At each high to low and low high transition on port pin, timer is triggered and it starts incrementing value. Here value in timer registers gives width of the pulse and on every triggering register values are copied in to memory. The same procedure continues for maximum of 250 pulses and stored. Maximum limit taken here is 250 pulses because majority of manufacturers don’t use more than 100 data bits to represent a command (each pulse correspond to a data bit logic “1” or “0”). If number of pulses are less than the maximum count microcontroller stops the process of counting and measuring width of pulse.

A simple technique is used to control air conditioner. Output of occupancy detector is connected to an I/O port pin of microcontroller. When microcontroller detects change of status on I/O pin it controls device accordingly. If status on pin is at logic high microcontroller sends “on” command to air conditioner and if status on pin is logic low it sends the “off” command.
2.4 Operational Details

The IR remote can operate in four different operating modes learning/playback mode, normal operating (ON and OFF) mode, only OFF mode and bypass mode.

In learning/playback mode IR remote can learn new IR codes which are emitted from the other IR remote controller. This mode allows only to learn new codes and learned codes can be played back to test proper action. Normal operating mode puts IR remote to sense occupancy sensor output. If occupancy sensor detects motion and sends the ON command, IR remote switches ON the air conditioner by transmitting ON command and if room or place is unoccupied and the occupancy sensor send OFF command then the IR remote sends OFF command to switch off air conditioner. In the OFF mode, IR remote does not switch ON air conditioner even if place is occupied and it only switches OFF air conditioner if place is unoccupied for long duration. The bypass mode is like switching OFF the IR remote. In this mode IR remote does not respond to occupancy sensor output i.e., it cannot switch on or off the air conditioner.

3. Experimental Setup

3.1 Location of the experiment

The concept of energy savings when the AC is switch OFF during unoccupied hours has been validated through an experiment. Two rooms (Room A and Room B) of identical floor area from the Palash Bhavan (boys hostel) of IIIT Hyderabad were selected for the experiment. The experiment has been performed in parallel in both the rooms to reduce differences which may occur due to the change in climatic conditions. The experiment has been performed in April 2009.

The rooms are on the top (third) floor of the building with the roof exposed. Brick wall with cement plastering, RCC roof and single pane glass windows are the key features of rooms’ construction. Equipment such as, fans and lights, of same wattage were used in both the rooms. Two-1ton capacity air conditioners of the similar make where fitted in each room. Table 1 summaries some of the important features of the rooms and Figure 4 shows the plan of the two rooms selected.
Due to the practical availability of rooms, two identical rooms which slightly differ in their orientation were selected. For overcoming this difference measures such as window shading, permanent closure of the windows and cool roof were employed. Also the experiment has been performed during nights to reduce the effect of sun radiation over the rooms.

Table 1 Experiment room properties

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>3.46m X 3.37m</td>
</tr>
<tr>
<td>Internal loads</td>
<td>Tube light - 1</td>
</tr>
<tr>
<td></td>
<td>Ceiling fan</td>
</tr>
<tr>
<td><strong>Building envelope</strong></td>
<td></td>
</tr>
<tr>
<td>Wall</td>
<td>Mass construction with brick, cement and sand</td>
</tr>
<tr>
<td>Floor</td>
<td>Tile flooring</td>
</tr>
<tr>
<td>Roof</td>
<td>RCC roof</td>
</tr>
<tr>
<td>Window</td>
<td>Metal frame</td>
</tr>
<tr>
<td>Glazing</td>
<td>Single glazing</td>
</tr>
<tr>
<td><strong>Air conditioner</strong></td>
<td></td>
</tr>
<tr>
<td>System tonnage</td>
<td>1 ton</td>
</tr>
<tr>
<td>System COP</td>
<td>2.85</td>
</tr>
</tbody>
</table>
3.2 Equipment used in the experiment

In this experiment a data logger from Campbell Scientific [11] model CR 1000 has been used to measure and store different sensor readings such as temperature, humidity, solar radiation and electricity consumption. To monitor the internal room air temperature Campbell Scientific model 108 temperature probes were used. The 108L is a general purpose temperature sensor that can be used to accurately measure the temperature of a variety of media, most commonly air, water, and soil. The 108L consists of a thermistor encapsulated in cylindrical aluminum housing. The probe measures temperature from -5°C to +95°C and is designed for durability and ease of installation and removal [11] The photograph of the data logger and the temperature probe as installed on site is as seen in Figure 5. To measure solar radiation CM3 pyranometer from Kipp & Zonen was used. The CM3 pyranometer is designed for continuous outdoor use. For monitoring the outside air humidity and temperature HMP45C relative humidity and temperature probe was used.

To measure electricity consumption the Continental Control Systems LLC WattNode has been installed as seen in Figure 6. The Advanced Pulse WattNode is a true RMS AC watt-hour transducer with pulse output proportional to kWh consumed.

![Figure 5 Data logger and indoor air temperature sensor](image)
Using all this equipment, an experiment has been conducted to observe the saving in power with AC switched off during unoccupied hours. In Room A the AC was turned off during the unoccupied hours and in Room B the AC was continuously ON even during the unoccupied hours. Power savings in Room A with respect to Room B were measured.

3.3 Testing of the setup

Before the actual experiment was performed, two tests were performed to ensure that both the rooms and their respective equipment have similar thermal behavior. In Test 1 the indoor air temperatures in both the rooms were monitored over a period of two days, to observe the thermal behavior of both the rooms. Test 2 was done to check the thermal behavior of the AC equipment. Air conditioners were installed in both the rooms and were switched ON continuously for a period of 24 hours at a set point 24 deg C. Power consumption and indoor air temperatures were monitored during this period.

3.3.1 Test 1: Thermal behavior of the rooms

This test was mainly performed to check the thermal behavior of the rooms. This has been observed by plotting the indoor air temperature data of both the rooms. Indoor air
temperature was monitored over a period of 48 hours in both Room A and Room B without AC as seen in Figure 7

![Indoor Air Temperature Graph](image)

**Figure 7** Indoor Air temperature in Room A and Room B which has been monitored without switching ON the AC. The average temperature over a period of 24hr, in Room A is 31.5°C and in Room B is 30.7°C. Temperature in Room A is 0.78°C greater than that in Room B

Indoor air temperatures in both the rooms were monitored over a period of two days. Observations show that, there is a difference of 0.78°C in their average room temperatures. The major reason for this difference is possibly the difference in orientation of the rooms.

### 3.3.2 Test 2: Behavior of HVAC equipment

In Test 2, the ACs in both the rooms were switched ON for a period of 24 hours and the indoor air temperatures and the power consumption readings were monitored. Test 2 has been performed to observe the thermal behavior of the ACs installed, and the setpoint temperatures maintained by both the ACs. Power consumption and the indoor air temperatures of both the rooms where plotted over a period of 24hours as seen in Figure 8
Figure 8 Indoor Air temperatures and AC power consumption of both the rooms when the ACs’ were continuously ON, with the set point of 24°C in both the rooms. Average indoor air temperature of Room A is 0.4°C higher than that of Room B. Power consumption for cooling in Room B is 3.8% more than Room A.

The set point temperature of 24°C is closely maintained in both the rooms. Average indoor air temperature of Room A is 0.4°C higher than that of Room B. Power consumption for cooling in Room B is 3.8% more than Room A. The indoor air temperature of Room A is slightly greater than its set point temperature, which might have resulted in low power consumption when compared to Room B.

Both these tests show that the two rooms and setup are not perfectly identical however they are close enough for the purposes of this experiment and these differences would be accounted for during the experiment.

3.4 Observation and results

The experiment has been performed during nights to reduce the impact of slight difference in orientation between the two rooms. Air conditioners in both the rooms were switched
ON for a period of 12 hours (8pm-8am). In Room A, the AC is switched OFF for a period of 1 hr 45 mins (11pm-12.45am) assuming the time delay of occupancy sensor to be 15mins, where as in Room B the AC is continuously ON through out. The power and indoor air temperatures were monitored and analyzed to understand the power savings as seen in Figure 9.

![Room temperature & Power](image)

Figure 9 Indoor Air temperature and AC power in Room A and Room B over a period of 12 hrs, with AC turned OFF in Room A during the unoccupied hours. Room A temperature rises to 29°C when the AC is switched OFF. Room A average (5min interval) power ranges between 0.9 kW - 1.7 kW. As the AC is switched ON after 1 hr 45 mins, Room A reaches a peak consumption of around 2.3 kW which includes extra power consumed to reach set point. Power savings in Room A is 12.43% when compared to Room B.

A sudden dip in the power reading has been observed in Room A when the AC is switched OFF for 1hr 45mins. As the AC is switched ON, the power consumption increased. At this point of time the AC power in Room A is more than that in Room B. This extra power was put in by the AC for bringing down the temperature from 29°C (as in Figure 9) to the set point of 24°C. From 1 am till 3am in the morning, the power consumed by AC in Room A was higher than that in Room B. It has been observed that Room A is consumed 16.23% less power for air conditioning than Room B. But since Room A by default is consuming
3.8% less than Room B (as observed in Test 2), necessarily the actual saving in power in Room A when compared to that in Room B is 12.43%.

Total consumption by Room B in 12 hours: 14.6 kWh
Assuming no heat gain is there during unoccupied duration, then Room A (if identical to Room B) would have consumed: (10.25/12)*14.6 kWh = 12.5 kWh
However, as per Test 2, Room A consumes 3.8% less than Room B hence Room A should have consumed (assuming no heat gain is there during unoccupied times): 0.962 X 12.5 kWh = 12 kWh.

However the actual observation for Room A is: 11.8 kWh
The difference between the observed and perceived consumption (assuming no heat gain is there during unoccupied times) is: 0.2 kWh which is due to the heat gain that happens during the unoccupied period, which has to be removed by the AC when it starts.

4. Simulations

The concept of energy savings through switch OFF of AC during unoccupied hours has also been theoretically supported with the simulation results. Energy simulation was performed using EnergyPlus Version 3.1[12], for a building block assumed in Hyderabad. Case 1 is developed assuming that the AC is switched ON throughout the occupied and unoccupied hours and Case 2 is developed assuming AC is switched OFF the AC during the unoccupied hours. The simulations are performed for two scenarios one being a typical office schedule- a daytime use building and the other is the night time use building as in case of the experiment.

4.1 Details of the simulation model

The building has been simulated for Hyderabad weather to match with the location of the experimental setup.

Building geometry:
The block model which has been considered for the simulation is of square foot print with one side dimension of 5m. A 4m x 1.6m window is placed centrally on the south wall of the
block above a sill of 0.75 m. An overhang of 0.8m depth and 4m width has been modeled to reduce the direct radiation coming inside.

The block model is of 25 sq m built up area and single floor. The floor to floor height is 3.2 m. Roof, wall and floor construction material meet the U value as per the prescriptive requirements of ASHRAE 90.1-2004 code for Indian climate. These building materials are same for both the scenarios.

**Internal load and schedules:**

An occupancy density of 10 sq m/person has been considered in the model. Internal lighting load o 10.8 W/ sq m and equipment load of 21.52 W/ sq m are considered.

**Air conditioning:**

A PTAC system has been modeled with the set point temperatures of heating and cooling as 20°C and 25°C respectively.

4.2 Simulation scenarios and results:

The model has been simulated in two major scenarios, a daytime used building- typical office schedule and second is a night time use building, as in the experiment conducted. Each scenario has been modeled for the base case and a proposed case based on the switch OFF of the AC.

4.2.1 Scenario 1: Daytime use building:

In the first scenario, the building has been modeled for a typical office schedule. The working hours of the office are considered from 9.30 am to 6.00 pm. During these office hours the building is assumed to be unoccupied for half an hour (10 am -10.30 am) during the morning, one hour during the lunch (1 pm- 2pm) and half an hour in the evening (5 pm- 5.30 pm), totaling to 2hrs of unoccupied period in the whole day. During these unoccupied hours it is assumed that the AC and lights are turned OFF completely in Case 2. AC consumption and indoor air temperatures are plotted to understand the thermal behavior of the space and the resulted savings.

Figure 10 shows the AC consumption for Case 1 and Case 2. It can be seen that there are three unoccupied durations as given above. In these durations AC power goes down to zero
for Case 2 and the room indoor temperature rises in Case 2. Further it can be observed that once the AC is started after the unoccupied duration there is an overshoot in the AC power consumption. This overshoot is because of the extra heat that has entered the room during unoccupied duration and is to be removed by the AC. Similar behavior is not seen in the Figure 11 which shows the lighting power consumption for both the cases. Because of this overshoot in AC consumption, the actual savings are less than the perceived savings. In case of lighting the actual and perceived savings are same which is equal to 23.5% however in case of air conditioning the perceived saving is 23.5% and the actual saving is 20%.

![HVAC energy consumption and indoor temperatures-AC switch OFF during unoccupied time](image)

**Figure 10** AC consumption and indoor air temperatures of Case 1 and Case 2. A clear overshoot in the energy consumption can be observed as and when the AC is switch ON with after the occupied period of time in Case 2. The resulted saving is AC consumption is 20%. Indoor air temperature during the unoccupied hour of the day reached to a maximum of 31°C during the afternoons.
Figure 11 Lighting energy consumption, assuming that lighting is switch OFF during the unoccupied hours. The total amount of unoccupied hours when lights are turned OFF is 23.5% of the office hours. The resulted saving in lighting consumption is equal to 23.5%.

### 4.2.2 Scenario 2: Night time use building

In this scenario a night time use building has been considered and the savings are calculated for different switch OFF periods of the AC. Four different time periods of 2 hrs, 1hr, 30 mins and 15 mins are considered for unoccupied periods. In all the four conditions the AC energy consumption and the indoor air temperature are analyzed.
AC switch OFF for 2 hours

**Figure 12** AC consumption and indoor air temperatures of Case 1 and Case 2 when the AC is switched OFF for 2hrs during the night. There is a saving of 12.4% in AC consumption when compared to a perceived saving of 16.0%. The maximum temperature noted when the AC was switch OFF is 33°C.

In Case 2 the cooling consumption is zero when the AC is completely OFF for two hours. Due to the rise in the indoor temperature to around 33°C as seen in Figure 12, there is extra consumption going into cooling the room to bring down the temperature from 33°C to the set point of 25°C. Hence the proposed case is only 12.4% better than the base case when the perceived savings is around 16.03% from the base case, in terms of cooling energy consumption.
Similarly the simulations have been performed for the AC switch OFF duration of 1hr, 30min and 15mins. It has been clearly observed that as the switch OFF duration of AC is less, the percentage difference in perceived savings and actual savings is more. This is due to the fact that, when the AC is switched OFF for a lesser duration, the increase in the indoor air temperature is less; hence the extra cooling consumption which is required for bringing back the room temperature to the set point temperature is more. This can be observed from the savings shown in Table 2. From this it can be observed that when the AC is switched OFF for a lesser duration, the difference between actual savings and perceived savings is more.

<table>
<thead>
<tr>
<th>AC switch off period</th>
<th>Perceived saving in kWh (A)</th>
<th>Actual saving in kWh (B)</th>
<th>% Difference (A-B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 hours</td>
<td>1.17</td>
<td>0.91</td>
<td>22.7%</td>
</tr>
<tr>
<td>1 hour</td>
<td>0.56</td>
<td>0.41</td>
<td>27.7%</td>
</tr>
<tr>
<td>30 minutes</td>
<td>0.28</td>
<td>0.18</td>
<td>33.6%</td>
</tr>
<tr>
<td>15 minutes</td>
<td>0.13</td>
<td>0.08</td>
<td>43.4%</td>
</tr>
</tbody>
</table>

Table 2 Savings for various switch off durations of AC

This difference in the perceived and actual savings, hence, depends on the duration for which the AC is turned OFF and also on the time at which this is switched OFF (day or night).
5. Conclusion

The IR learning remote attachment has been developed to save energy by switching OFF the AC in a space during unoccupied durations. This concept of energy savings has been supported by an experiment and simulations. In the experiment conducted, power consumption in two rooms has been monitored over a period of 12 hours during the night. In Room A where the AC is switched OFF during the unoccupied time (for 2hrs) there is a savings of 15% in power consumption despite of the extra power which is consumed to decrease the indoor air temperature to the set point once the AC is switched ON. To further support this concept simulations have been performed. Two scenarios, a daytime use and a night time use building are considered. The simulation for the daytime use building has been done with a typical office schedule (9.30 am- 6pm). The resulted AC energy saving in this case was 20% where as the perceived savings was 23.5% which is equal to the savings in lighting. The night time use building has been modeled in four different conditions depending of the duration of unoccupied time. A savings of 12% was resulted in the scenario when the AC is switched OFF for 2 hrs, when the perceived saving is 16%. It has been observed that for a particular conditioned space these savings are dependent on the total duration of time for which the AC was switched ON, also the duration for which AC was switched OFF (when there is no occupancy) and time period of the day when the building is conditioned (day/ night). With the decrease in the duration for which the AC is turned OFF, the difference in the actual resulted savings and the perceived savings increase.

In the existing experimental setup, the cooling consumption in Room B where AC is switched continuously ON for 12 hours is 14.6 kWh per day and in Room A where the AC is switched OFF for two unoccupied hours is 11.8 kWh per day. Hence there is a saving of 2.75 kWh per day. An initial investment of around INR 1000 would go into the product. With the electricity cost assumed as INR 6/kWh there would be a saving of INR 16.5 per day. It is assumed that one sensor would serve an area of about 20 sq m. Since one sensor would serve the whole experimental room area, the pay back in this case would be around 60days.
References: