# A NON INVASIVE ENERGY SAVING SYSTEM BASED ON A WIRELESS SENSOR NETWORK FOR SPLIT TYPE AIR CONDITIONERS

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Degree of Master of Science

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Dissertation submitted in partial fulfillment of the requirements for the degree
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"I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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## Abstract

Energy consumption in air conditioning in supermarkets has been very high. Increase in maximum demand (kVA) has gone up as a result of heavy consumption in air conditioning. Partly, the consumption includes unnecessary cooling, which can be reduced without making inside temperature being elevated to uncomfortable levels. In this research, an energy saving solution designed to be used in the shop floor which is cooled by a number of split type air conditioner units is analyzed. A centralized sensing and control mechanism, which is fully autonomous, has been developed to maintain the comfortable temperature within the shop floor by a way of using minimum number of AC units. Temperature settings of the AC units are adjusted by the central controller every two minutes so that the system adaptively maintains the required temperature inside by consuming the least amount of energy needed to do so.

Keywords: Energy Consumption, Air Conditioning, Adaptive Control, Centralized Control, Wireless

## Acknowledgement

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# 1. INTRODUCTION

## 1. 1 Introduction

Energy required for air conditioning is one of the largest sources of energy consumption in commercial buildings. Air conditioning a large area of a building using a multiple number of individual split type air conditioners which function independently as per their individual set temperatures is a common application in many low cost air conditioning solutions where the original building design would not allow centralized air conditioning systems be installed.

The ever increasing electricity tariffs with the increased demand for electrical power make sure that electricity users are committed to save both energy and financial resources that are associated with energy. Unless closely monitored, companies can end up spending huge sums of money on electrical power used in major power consumption contributors such as air conditioning units, due to mismanagement of resources or simply due to lack of proper maintenance of related equipment.

Conventional energy saving methods such as demand control by intermittent operation might lead to unexpected temperature fluctuations causing discomfort due to the lack of feedback incorporated in to the system. Also during intermittent operation as in a bang-bang controller, air conditioner units are naturally operated in high output ranges causing low efficiency levels and in order to maintain the units in medium output ranges as much as possible temperature selection needs be altered based on the demand with reference to time such that intermittent switching OFF and ON sequences of the air conditioner units are reduced to a very low level. Intermittent control of large electrical loads could also lead to high in-rush currents to be sourced from the electrical supply frequently causing high peak power demand values as well as high rate of equipment damages.

Other similar split type air conditioner control methods such as Fuzzy Proportional-Integral-Derivative (FPID) controllers where invasive methods are used to control the room temperature and variable speed compressors used along with Proportional-Integral-Derivative (PID) controllers to control air conditioner power output based on load, as discussed in detail in chapter 2, were also evaluated during the initial exercise of identifying the best energy saving model. All above discussed methods had their own drawbacks and limitations when it comes to introducing and non invasive energy saving system to an existing split type air conditioner.

The proposed non-invasive split type air conditioner energy saving system is designed in such a way that, it can be installed on any split type air conditioner irrespective of the compressor type (conventional or variable speed) and the non-invasive characteristics and the built in demand control algorithm prevents intermittent operations as in a bang-bang controller.

## 1. 2 Problem Statement

In Sri Lankan context, air conditioning a large area of a building, for an instance a super market is often done using a multiple number of individual air conditioners which function independently as per their individual set temperatures. The major drawback in such a system is when the area becomes larger; the boundary of each area which is cooled by each air-conditioner unit cannot be exactly specified since one zone could be effectively cooled by one or several air conditioner units based on their placements. In such applications, some units will be utilized for prolonged periods of time and depending on the loading conditions and the environmental conditions the temperatures in certain areas of the concerned space will fluctuate irrespective of the set temperatures of the air conditioner units due to lack of feedback on the condition of surrounding areas making manual setting of temperature values on each air conditioner units inadequate. This observation, when the temperatures are too low than required in certain regions of the building, can be considered as a waste of energy unless an automated system is introduced to maintain an optimal temperature in all zones of the building by monitoring and controlling set temperatures of each air conditioner unit.

## 1. 3 Aims and Objectives of the Research

The aims and objectives of this research are to,

- Analyze the possibility of controlling the temperature inside a building with the minimum number of split type air conditioner units based on the demand.
- Design an energy saving system such that it provides means to centralize the control in order to operate all air conditioner units as a single system, which would have otherwise operated individually.
- Implement a demand control algorithm to the energy saving system to control the utilization of air conditioner units
- Identification of the most appropriate locations for temperature measurements and the air volume to be cooled

It is expected that the proposed temperature control system will ultimately lead to a considerable power saving due to the demand control allowing the users to benefit from its implementation.

## 1. 4 Resources Used

This research project was done by practically implementing the proposed system in a supermarket to calculate the exact energy saving capability of the system, achieved by temperature control as per demand. Required hardware was fabricated locally and coding was done using microC Pro. The software used in designing the PCBs was Orcad PCB design tool. Access to previous energy meter readings was available for comparison so that the energy saving can be identified better.

## 1. 5 Scope of the Project

This project scope is implementation of energy saving systems related to air conditioning. Within this scope it introduces temperature control to split type air conditioners based on the demand.

# 2. LITERATURE REVIEW

## 2. 1 Theory

### 2. 1. 1 Internal Structure and Operation of a Split Type Air Conditioner

The major components in a factory-assembled and ready-for-use room air conditioner include the followings: An evaporator fan to pressurize and supply the conditioned air to the space, a tube and-fin coil also called a direct expansion (DX) coil where the refrigerant evaporates and expands directly inside the tubes by absorbing the heat energy from the ambient air during the cooling an air filter to remove airborne dust particles, a compressor to compress the refrigerant from a lower evaporating pressure to a higher condensing pressure in an adiabatic compression process and a condenser to liquefy refrigerant from a hot gas to liquid which rejects heat through a coil and a condenser fan.

The complete system acts as a heat exchanger to cool the hot air inside the area being cooled. A temperature control system senses the space air temperature (sensor) and starts or stops the compressor to control its cooling and heating capacity through a thermostat. Sometimes room air conditioners are separated into two split units; an outdoor condensing unit with compressor and condenser, and an indoor air handler with an evaporator.

This architecture is mainly to have the air handler in a more advantageous location and to reduce the compressor noise indoors, hence, called a split type air conditioner [01].

Internal component of a split type air conditioner are as shown in Figure 01.

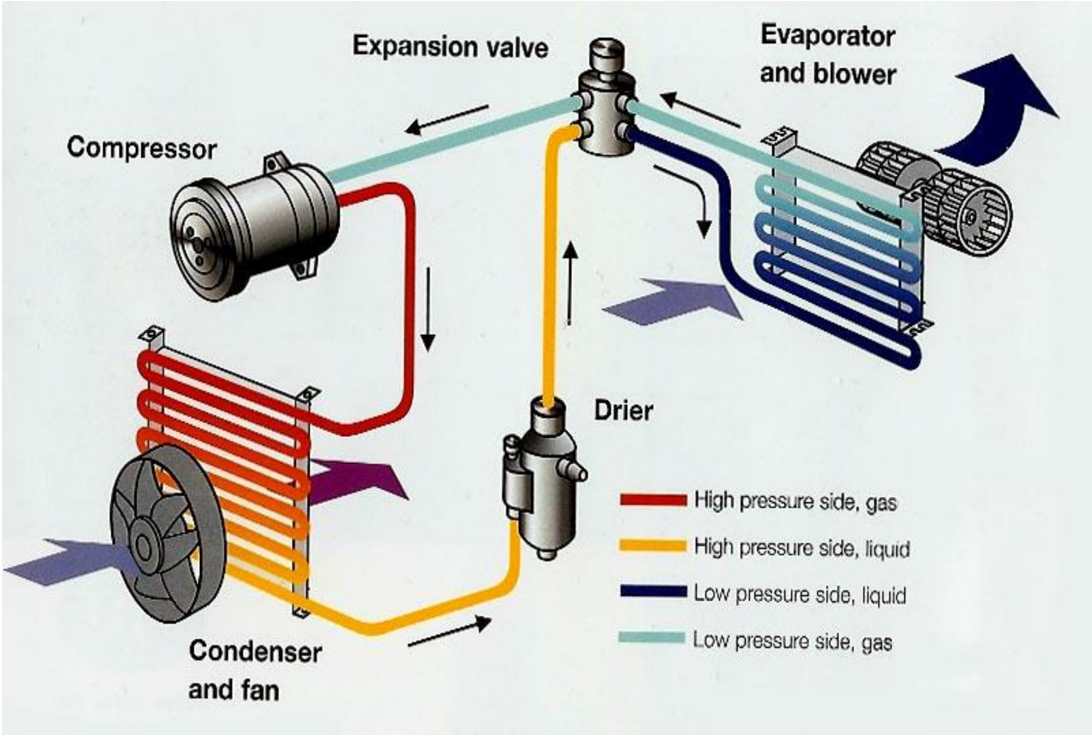


**Figure 01: Components of a Split Type Air Conditioner**

**Source: http://www.langsheatingandair.com/**

A conventional split type air conditioner without an inverter type compressor is operated in two position control mode where the final control element will be maintained at one of two positions: maximum or minimum. The two position control includes starting and stopping the compressor, where sometimes it is also called as on-off control. Unit or packaged air-conditioning units are commonly used in private residences, small buildings, and spaces that were constructed without provisions made for air conditioning [02].

### 2. 1. 2 Heat Load and Energy Consumption

The largest source of energy consumption in commercial buildings is heating, ventilating, and air conditioning (together referred to as Space Conditioning) and lighting. The heat produced by lighting, other equipment such as freezers which will be available in a shop floor which will be discussed as an example in a later chapter and heat generated by its occupants has a material effect on the energy required for space conditioning.

The largest motors in commercial buildings are the compressors used for air conditioning. If central or distributed packaged air conditioning is utilized in a building, this load may be, in aggregate, the largest demand for the building (perhaps even exceeding the lighting load during periods of maximum usage) for buildings in temperate climates [02].

The cost of operating a lighting system involves much more than energy consumed by the light fixtures. The analysis of the energy consumption should include the lighting system's interaction with all the building systems. In many buildings, the lighting system may account for one-half the load on the building's air-conditioning system [02]. Furthermore, lighting loads can vary from 5 Btu/ft2 (1.5 W/ft2) or less to 15 Btu/ft2 (4.5 W/ft2) or more. Thus, the lighting designer has a major influence on the ultimate size of the air-conditioning system. It is to be noted that when LED lighting is used these values will reduce drastically. Similar analysis needs to be done when other heat emitters such as industrial type refrigeration units are installed inside the building.

The primary source of heat for people is the heat generated within the body. The human body is a heat generating unit that is adjusted internally so as to maintain a temperature of 98.6°F (37°C) as long as the body is healthy. In a space conditioning system, the object of it is to regulate the environment so that heat is not dissipated too rapidly for human vitality, well-being, efficiency, and comfort. The rate at which heat is lost from the body is dependent on the air temperature and rate of air movement around it. Comfort is a function, among others, of the humidity of the air and temperature. The same observations can be made in regard to air conditioning, in which the temperature is controlled so as to maintain the heat flow from within. In this case, the humidity assumes greater importance.

Energy consumption may be analyzed on the basis of total energy consumed or on the basis of operating costs [02]. The main contributors for heating in a commercial building, supermarket for an instance can be summarized as follows.

- Lighting (fluorescent and incandescent type lights)
- Large freezers installed within the premises
- Direct sunlight and heating from outside environment
- Human occupants

## 2. 2 Related Previous Research

The research paper titled 'Non-invasive Zigbee wireless controller for air conditioner energy saving' [07], discusses about a similar non invasive system installed on to a single split type air conditioner unit in a seminar room environment. The method discussed in this paper operates the air conditioner by switching on & off the unit based on temperature measurements received by temperature sensors placed in various parts of the seminar room to maintain the demanded comfort conditions. The seminar room is divided into two parts namely the demand zone and non-demand zone.

The basic idea of this project is to reduce the temperature in demand zone while maintaining the temperature of the non-demand zone at a higher value which results a load reduction to the air conditioner unit. Their energy calculation is based on the on/off time of the compressor and by this method authors were able to gain a 50% energy saving.

In a similar research titled 'Simulation Research on Optimal Control of Multi-split Air Conditioning System' [05], control of a multi-split type air conditioner is discussed. The complex operation characteristics of multi-split air conditioning system are addressed by an optimal control method and a two stage Fuzzy Proportional-Integral-Derivative (FPID) controller for room air temperature control which is an invasive method. The controllability was tested in a triple evaporator multi-split air conditioning system and simulation results had shown that the proposed control method with two-stage FPID controller could achieve desired control accuracy and guaranteed good robust performance for the controlled parameters such as room air temperature. The authors do not discuss about an energy saving figure which could be achieved by the proposed optimization.

The research carried out based on 'An Innovation PID Control Method of Split Air-conditioner Based on Online Prediction' [03],uses the real-time deviation between indoor dry-bulb temperature and set temperature and PID control method of split air-conditioning is used to calculate the output power of split air-conditioning. When the temperature deviation is larger, an online prediction method of air-conditioning load is presented according to the trend change of dry-bulb temperature. In order to reduce the rise time, the output power of split air-conditioning is set to be the maximum. When the temperature deviation is changed to be small, the output power of split air-conditioning will be adjusted to be the former predicted load, and then the PID control method will be implemented to keep the stability of temperature. PID control method that is presented in this paper is suitable for the temperature control for the split air-conditioner with variable speed compressor based on the cooling / heating loads forecast. The authors have provided a simulation result for the proposed PID control method which is composed of a conventional incremental PID and load prediction algorithm, but have not analyzed the system in an energy saving perspective.

In majority of the above discussed past researches as well as other similar researches which were not discussed in this dissertation, models of different types of controllers are simulated and results are presented to explain numerous ways of temperature control abilities and energy saving capabilities. In this dissertation a similar novel system will be analyzed in a more practical context by implementing in a large floor area which will be cooled by multiple numbers of split non-inverter type air conditioner units in order to find out the true energy saving attainable using the proposed system design. The energy saving delivered by the proposed system will be calculated based on actual meter readings.

# 3. RESEARCH METHODOLOGY

In order to receive the feedback required for control model to function it was required to monitor temperature and humidity values in various zones of the building area near and away from the air conditioner units.

The proposed system consists of a network of temperature and humidity sensors positioned in various zones near each air conditioner unit throughout the building area which needs to be air conditioned and are connected to a centralized controller through a wireless medium. The positioning of sensor units in each zone near air conditioner unit was done in such a manner that sensors will capture the exact temperature and humidity levels experienced by a human user in the vicinity of that zone. The wireless medium which was used in this implementation was ZigBee [08], which provides a wireless serial link between nodes with a reasonable range with low power consumption.

The centralized controller maintains a database of reference temperature values which should be maintained near each zone during various times of the day and each air conditioner will be controlled according to these reference values and feedback from temperature and humidity values received by the sensor network. Additionally a separate temperature sensor was positioned in the central area of the building where air flows from all or most of the air conditioner units will meet to effectively cool the said area.

The temperature settings which need to be set at the air conditioner units will be calculated at the centralized controller based on the remotely measured parameters and reference database values and will be transmitted back to controllers installed near each air conditioner through the same Zigbee wireless network to get optimum output from the air conditioner units. The above mentioned set temperature calculation is done using the control algorithm which will be discussed in due course.

Effective controlling of the air conditioners is achieved by not limiting the controlling of air-conditioner units to switching on and off but, utilizing the entire range of temperature settings offered by the manufacturer by setting different temperature values based on demand control algorithm calculations. The air conditioner units will be automatically switched 'OFF' by the system only when certain conditions are met as per the control algorithm and similarly will be automatically switched 'ON' again once the 'OFF' conditions are no longer available. The control units installed near the air conditioner units will generate the exact infra red code generated by the remote controller unit of that particular air conditioner unit for each set temperature value received by the central controller. This capability of transmitting the same infra red code for temperature setting provides the non-invasive aspect of the proposed system since no changes will be done to the internal circuitry of already installed air conditioner units during the implementation of the energy saving system.

The infra red signals generated by the control units are coded to control the temperature settings of the air conditioner units only and below parameters which are available for the user to be changed in an air conditioner unit are always maintained at constant values.

- Fan Speed (to control cold air flow rate) – Always set to maximum
- Louver Setting (to control cold air flow direction) – Always set to full swing
- Air Conditioning Mode – Always set to 'COOL' mode

The reason to maintain above parameters at constant levels was, during normal operation when the air conditioner units are controlled manually; in most instances the only function manipulated by the users is the temperature and other functions are kept constant.

Refer Figure 02 for proposed system architecture.

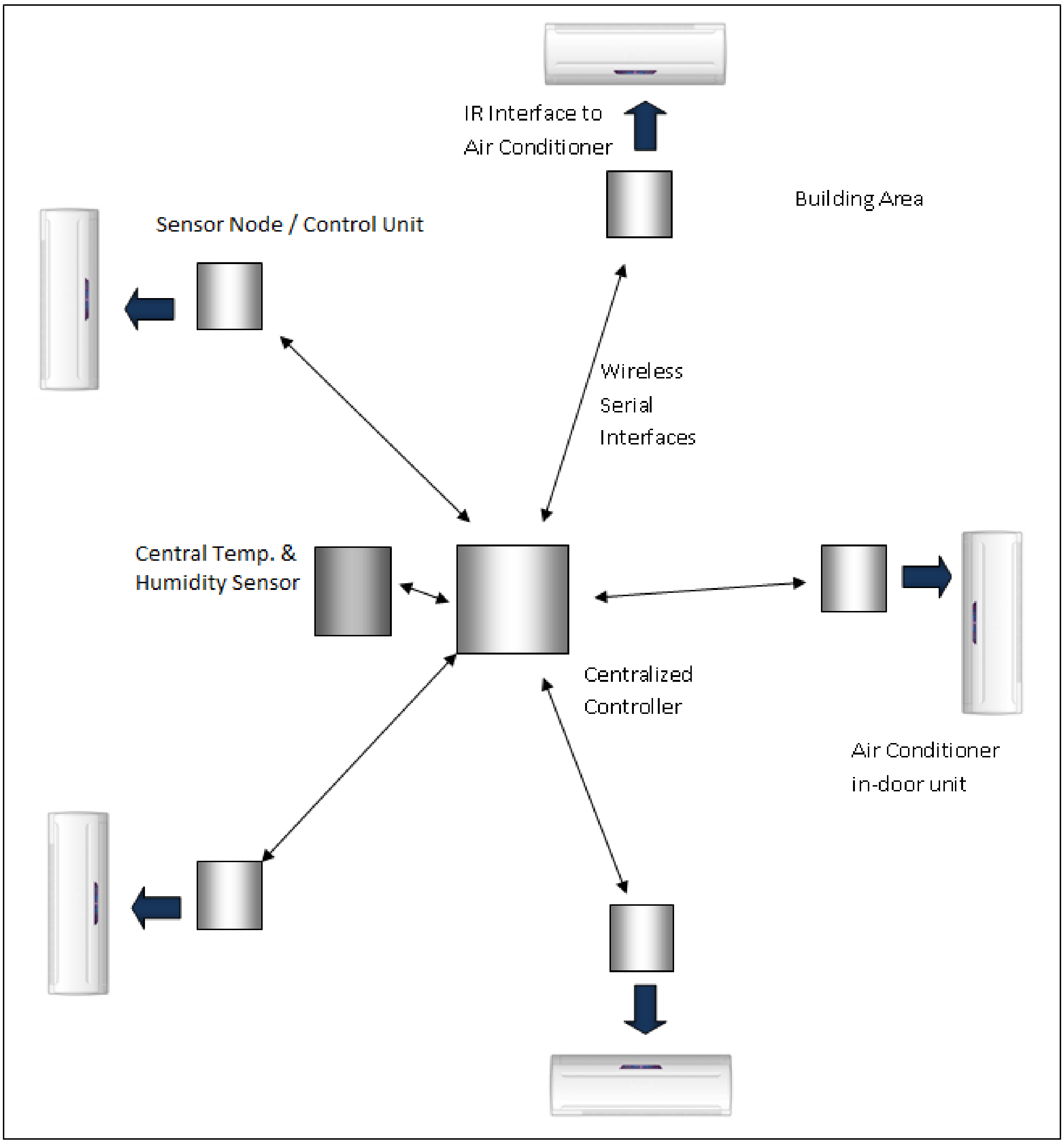


**Figure 02: System Architecture**

### 3. 1 Temperature Control Algorithm

The entire processing function of data is carried out in the centralized control unit. The centralized controller pings the sensor nodes via the wireless links in pre-defined intervals (100 seconds in this instance) and sensor nodes reply back with most recent temperature and humidity values measured in the zones which they are located through the same wireless link. Inside the centralized controller a database of constant reference temperature values defined for each reference zone near each air conditioner is maintained. These values are chosen depending on the geographical size of the zone which will be cooled by the specific air conditioner unit, load factor (human presence or presence of other heat emitters) and user preferences and are considered as the optimum temperature values which should be maintained at each zone to ensure comfort. A survey was also carried out for few days at each location including the central location where temperature sensors will be positioned to gain an idea of temperature values which needs to be maintained such that comfort levels are maintained. Based on the said survey, zones with high heat emitting loads and which had high level of human occupancy were assigned with lower reference values and rest of the zones were assigned with much higher reference values. The time of the day will be given by the real time clock (RTC) coupled to the centralized controller and based on time data, the system is capable of switching ON & OFF the energy saving system at user defined time intervals of the day.

Whenever the measured temperature nearby an A/C unit was below the reference value specified for the zone of a particular A/C unit, the system will automatically switch off that specific A/C unit until the next monitoring cycle, given that the measured temperature near the central sensor at that specific time was also below the reference value given for central temperature. This is done by sending an 'OFF' command by the Centralized Controller to individual air conditioner units via the Control Units. If the measured temperature nearby an A/C unit was above the reference value specified for the zone of that particular A/C unit, a temperature setting will be sent back to that specific air conditioner through the wireless link which will be a function of collected temperature & humidity readings at each particular zone, temperature value measured in central node, reference temperature defined for that particular zone and reference temperature defined for central area.

The temperature control system resembles a proportional control system where the set temperature proportionately increases or decreases based on the error between measured and reference values. Whenever a set temperature value is sent, an 'ON' command generated by the Centralized Controller will precede to make sure that air conditioner will be switched on before setting the temperature in case it was in a switched 'OFF' condition since the last cycle.

The equation used in calculating the temperature setting is as mentioned below.

$$S_n = k_1 R_n - k_2 T_n - k_p (T_c - R_c)$$

The above calculated set temperature value $S_n$ will be again modified based on the relative humidity factor at each zone as per below equation.

$$S_{nh} = \begin{cases} S_n - 1; & \text{if } H_n > 50 \\ S_n & ; \text{if } H_n \leqslant 50 \end{cases}$$

Where for a given air conditioner unit, the parameters are defined as in below Table 01.

**Table 01: Equation Parameter Definition**

| Parameter | Definition |
|---|---|
| $S_n$ | The calculated temperature setting which should be set |
| $R_n$ | The reference temperature value which should be maintained in the zone of a particular air conditioner is installed |
| $T_n$ | The most recently measured temperature value in the zone |
| $T_c$ | The most recent temperature measurement at a central location to all air conditioners |
| $R_c$ | The most reference temperature value which should be maintained at a central location to all air conditioners |
| $k_1$, $k_2$ and $k_p$ | Constants which decide the proportional controllability of the system |
| $S_{nh}$ | Humidity corrected set temperature |
| $S_n$ | Set temperature value before humidity correction |
| $H_n$ | Relative humidity value in each particular zone |

The reason behind humidity correction is to compensate for apparent temperature values provided in humidex index chart as shown in Figure 3. The Heat Index is a measure of how hot weather feels to the human body. This table uses relative humidity and air temperature to produce the apparent temperature or the temperature the body feels. As shown in the figure when the relative humidity increases the apparent temperature which is felt by the human body increases leading to the requirement of reducing the set temperature values further to increase comfort levels inside the building. The values shown in vertical blue column are actual temperatures in the environment in degrees Celsius and values shown in horizontal blue row are relative humidity values. The apparent temperature values are also given in degrees Celsius.

EuroWEATHER - Heat and discomfort index

**HEAT AND DISCOMFORT INDEX**

HUMIDEX INDEX OF APPARENT TEMPERATURE ( degree C )

| | 25% | 30% | 35% | 40% | 45% | 50% | 55% | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 42° | 48 | 50 | 52 | 55 | 57 | 59 | 62 | 64 | 66 | 68 | 71 | 73 | 75 | 77 | 80 | 82 |
| 41° | 46 | 48 | 51 | 53 | 55 | 57 | 59 | 61 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 79 |
| 40° | 45 | 47 | 49 | 51 | 53 | 55 | 57 | 59 | 61 | 63 | 65 | 67 | 69 | 71 | 73 | 75 |
| 39° | 43 | 45 | 47 | 49 | 51 | 53 | 55 | 57 | 59 | 61 | 63 | 65 | 66 | 68 | 70 | 72 |
| 38° | 42 | 44 | 45 | 47 | 49 | 51 | 53 | 55 | 56 | 58 | 60 | 62 | 64 | 66 | 67 | 69 |
| 37° | 40 | 42 | 44 | 45 | 47 | 49 | 51 | 52 | 54 | 56 | 58 | 59 | 61 | 63 | 65 | 66 |
| 36° | 39 | 40 | 42 | 44 | 45 | 47 | 49 | 50 | 52 | 54 | 55 | 57 | 59 | 60 | 62 | 63 |
| 35° | 37 | 39 | 40 | 42 | 44 | 45 | 47 | 48 | 50 | 51 | 53 | 54 | 56 | 58 | 59 | 61 |
| 34° | 36 | 37 | 39 | 40 | 42 | 43 | 45 | 46 | 48 | 49 | 51 | 52 | 54 | 55 | 57 | 58 |
| 33° | 34 | 36 | 37 | 39 | 40 | 41 | 43 | 44 | 46 | 47 | 48 | 50 | 51 | 53 | 54 | 55 |
| 32° | 33 | 34 | 36 | 37 | 38 | 40 | 41 | 42 | 44 | 45 | 46 | 48 | 49 | 50 | 52 | 53 |
| 31° | 32 | 33 | 34 | 35 | 37 | 38 | 39 | 40 | 42 | 43 | 44 | 45 | 47 | 48 | 49 | 50 |
| 30° | 30 | 32 | 33 | 34 | 35 | 36 | 37 | 39 | 40 | 41 | 42 | 43 | 45 | 46 | 47 | 48 |
| 29° | 29 | 30 | 31 | 32 | 33 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 45 | 46 |
| 28° | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 |
| 27° | 27 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 |
| 26° | 26 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 34 | 35 | 36 | 37 | 38 | 39 |
| 25° | 25 | 25 | 26 | 27 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 34 | 35 | 36 | 37 |
| 24° | 24 | 24 | 24 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 31 | 32 | 33 | 33 | 34 | 35 |
| 23° | 23 | 23 | 23 | 24 | 25 | 25 | 26 | 27 | 28 | 28 | 29 | 30 | 31 | 32 | 32 | 33 |
| 22° | 22 | 22 | 22 | 22 | 23 | 24 | 25 | 25 | 26 | 27 | 27 | 28 | 29 | 30 | 30 | 31 |

| | |
|---|---|
| Up to 29 C° | No discomfort |
| From 30 to 34 C° | Slight discomfort sensation |
| From 35 to 39 C° | Strong discomfort. Caution: limit the heaviest physical activities |
| From 40 to 45 C° | Strong indisposition sensation. Danger: avoid efforts |
| From 46 to 53 C° | Serious danger: stop all physical activities |
| Over 54 C° | Death danger: imminent heatstroke |

**Figure 03: Heat and Discomfort Index**

**Source: http://www.eurometeo.com/english/read/doc_heat**

The calculated temperature setting $S_{nh}$ will be sent back to control units near each air conditioner through the wireless link and control unit will generate the relevant infra red code to set the calculated $S_{nh}$ in the air conditioner unit.

Below diagrams depict the communication sequence between the centralized controller and one of the sensor / control node units and how the temperature calculation decisions are made by the centralized controller.

Below Figures 04 & 05 shows the communication sequence between the nodes and set temperature calculation algorithm respectively.

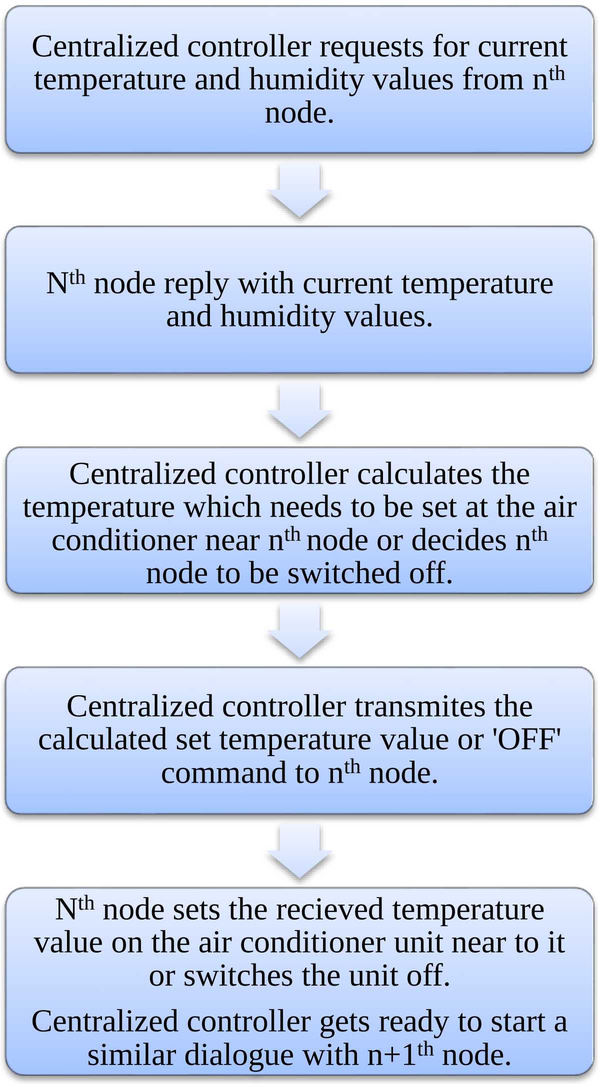

**Figure 04: Communication sequence between nodes**

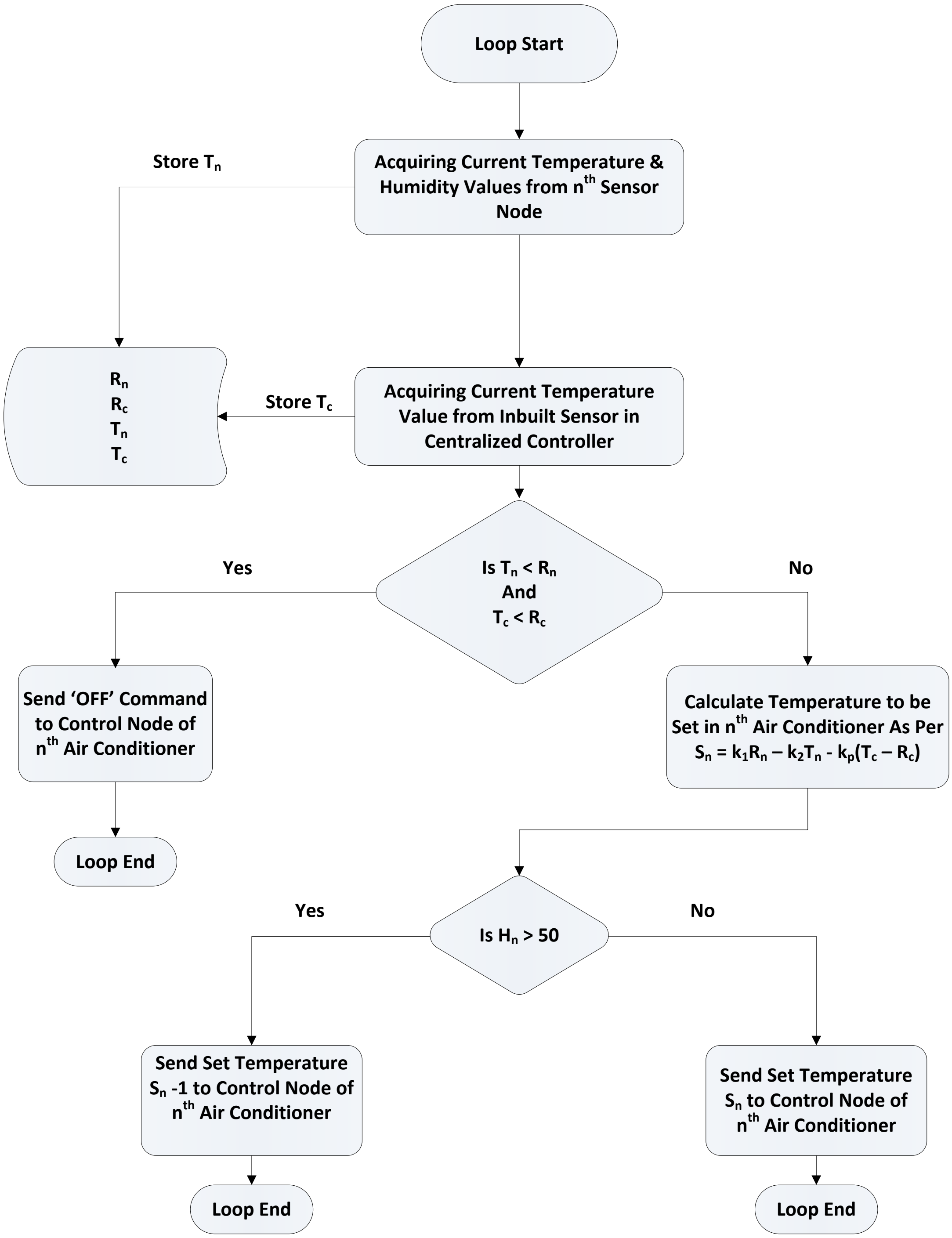


**Figure 05: Set temperature calculation algorithm**

### 3. 2 Electronic Design and Key Hardware Components

The system consists of two main types of units utilized in entire operation. Each of these units is microcontroller based and carries interfaces for sensors and Zigbee wireless modules. The units are powered by commercially available power supply packs externally fixed near each of them. The 12V DC output from the external power supplies are further power conditioned inside the units to obtain 5V DC required for microcontroller and 3.3V DC supply required for Zigbee modules.

The temperature sensing is done by LM35 precision Centigrade temperature sensor from Texas Instruments, which is a precision integrated-circuit temperature device with an output voltage linearly proportional to the Centigrade temperature [09]. LM35 sensors are rated for full −55°C to 150°C range with 0.5°C ensured accuracy (at 25°C) which makes LM35 a suitable candidate to be used in this application. In this design, the LM35 IC is supplied with 5V DC to be used in basic Centigrade temperature configuration as shown in below Figure 06 and output is connected to one of the pins of the microcontroller which supports analog to digital conversion with an operational amplifier in between.

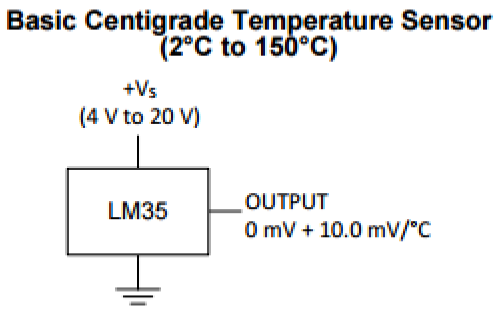


**Figure 06: LM35 IC wiring configuration**

**Source: Texas Instruments LM35 datasheet**

The relationship of the temperature and analog output voltage of the sensor can be shown as OUTPUT = 0 mV + 10.0 mV/°C. Due to the reason that output voltage from the temperature sensor is in millivolt range in the normal room temperature range, the output voltage had to be amplified using an operational amplifier before being fed to the microcontroller for analog to digital conversion.

The operational amplifier used in this design was LM324 low power quad operational amplifier [14] from Texas Instruments. LM324 was selected to be used in this application due to its design which enables it to operate using a single supply over a wide range of voltages. The amplification also increased the resolution of temperature values measured in the usable range of temperatures in this specific application which is between $10^0$C to $40^0$C. The amplified analog voltage level is used by the inbuilt analog to digital converter of the microcontroller to calculate the temperature measurement.

Humidity sensor HIH-4030 from Honeywell used in this design allows direct input to a controller or other device by its near linear voltage output [10]. The operating zone of HIH-4030 is as shown in following Figure 07, which matches with the requirements in this application.

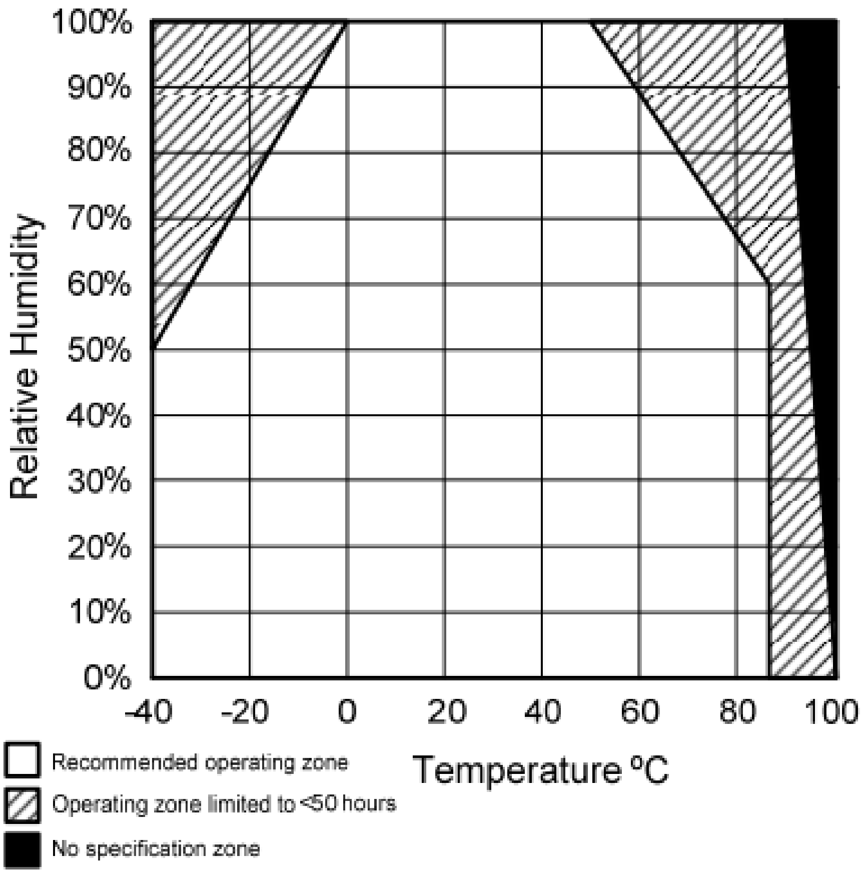


**Figure 07: Operating range of HIH-4030 humidity sensor**

**Source: Honeywell HIH-4030 datasheet**

The humidity sensor is also supplied with 5V DC and the typical output voltage variation against relative humidity is as shown in below Figure 08.

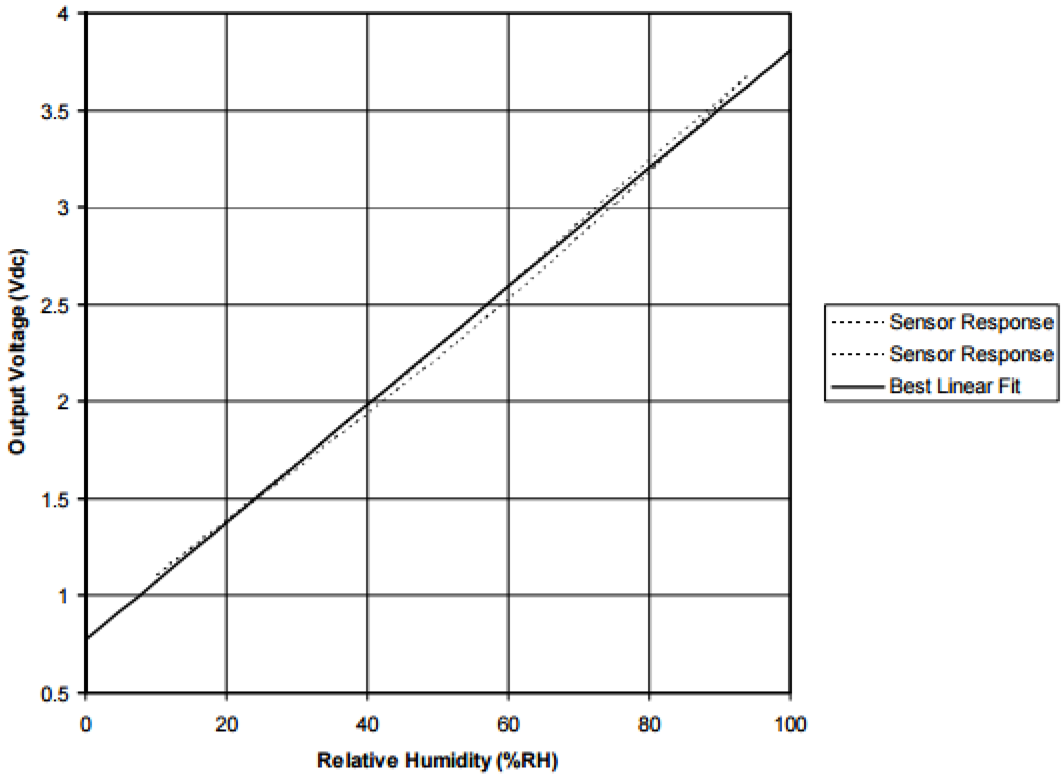


**Figure 08: Typical Output Voltage vs. Relative Humidity (At 25 ºC and 5 V.)**
**Source: Honeywell HIH-4030 datasheet**

The analog voltage output from the humidity sensor is interfaced to another analog to digital converter pin of the microcontroller and calculation is performed in accordance with above relationship to obtain the measured relative humidity level.

A real time clock (RTC) is utilized to capture time data required in switching on & off the system when required as per users' requirements. The RTC used in this application is DS1307 from Dallas Semiconductor with $I^2C$ bi-directional serial interface. The clock/calendar provides seconds, minutes, hours, day, date, month, and year information and the end of the month date is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The DS1307 has a built-in power sense circuit that detects power failures and automatically switches to the battery supply in such cases [11]. The RTC was interfaced to the microcontroller in below configuration as recommended by Dallas and 3V Li-Ion type battery was used as the backup power supply. The frequency of the crystal used in this application was 32.768 kHz. As shown in the diagram Serial Data Line (SDA) and Serial Clock Line (SCL) of the RTC were directly coupled to the SDA & SCL pins of the microcontroller in a pull up state.

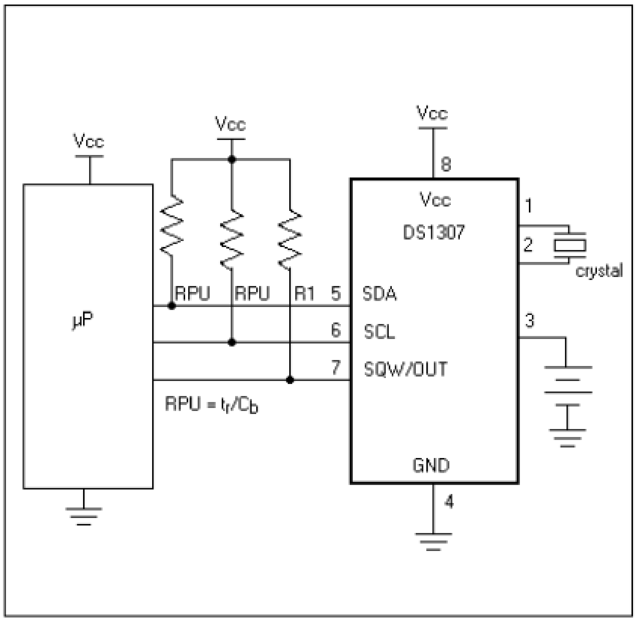


**Figure 09: Typical Operating Circuit**

**Source: Dallas Semiconductor DS1307 Datasheet**

The Zigbee 2.4 GHz wireless serial interface module was interfaced to microcontrollers of all concerned units to allow them to have wireless data transmission capability. Zigbee modules are designed to be powered by 3.3V DC and special regulating circuit using LM317 adjustable regulator IC [12] had to be used in generating the required 3.3 V DC supply. The transmission and receiving pins of microcontroller serial interface were directly linked with transmission and receiving pins of the Zigbee module with a voltage divider circuit in between for operating voltage matching.

Inside the air conditioner control units an additional 2 X 7 segment display was incorporated to display valuable information such as current ambient temperature values, set temperature values by the controller and other data required during maintenance. In order to reduce the number of output port pins utilized in displaying these data, two SN74HC595 8-bit shift registers [13] were interfaced to drive the two 7 segment displays with only 4 pins being used from the microcontroller.

The two main types of units which make the parts of the system are as discussed below.

- The Centralized Controller

The centralized controller was designed with below components interfaced to a PIC18F452 microcontroller which delivered enough processing power and I/O ports required for the application.

  - ZigBee 2.4 GHz wireless serial interface module
  - DS1307 Real Time Clock
  - Temperature sensor LM35

The real time clock provides time data to the central controller for time based controlling of the system. The microcontroller of centralized controller contains a specific firmware which contains the temperature control algorithm as well as provision for central temperature sensor, Zigbee module and real time clock interfacing. Refer Figure 10 for the Centralized Controller block diagram.

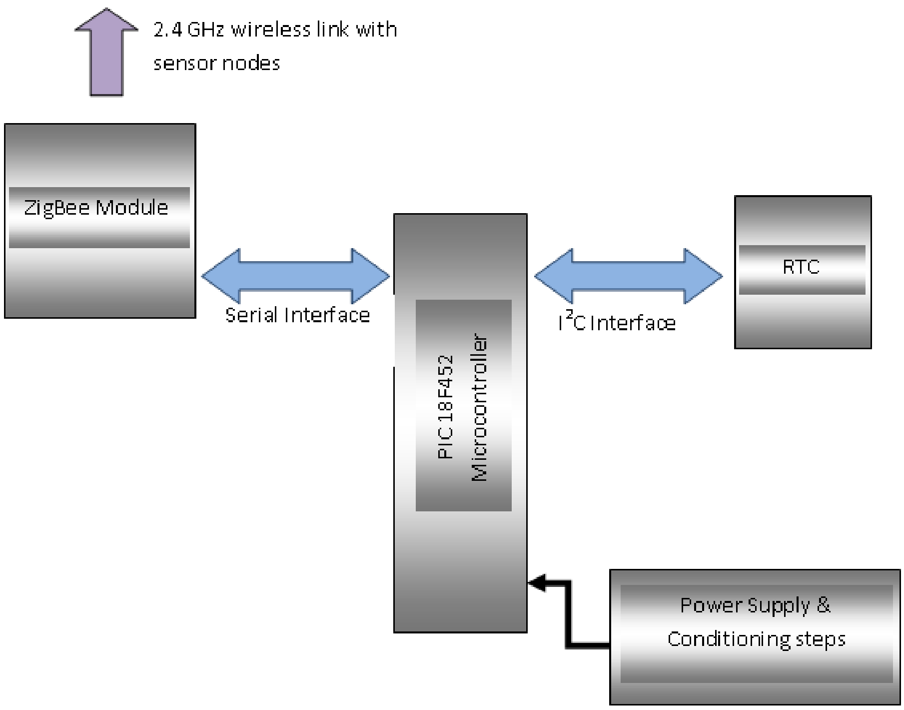


**Figure 10: Centralized Controller Block Diagram**

Centralized controller after project implementation looked as in below given Figure 11.

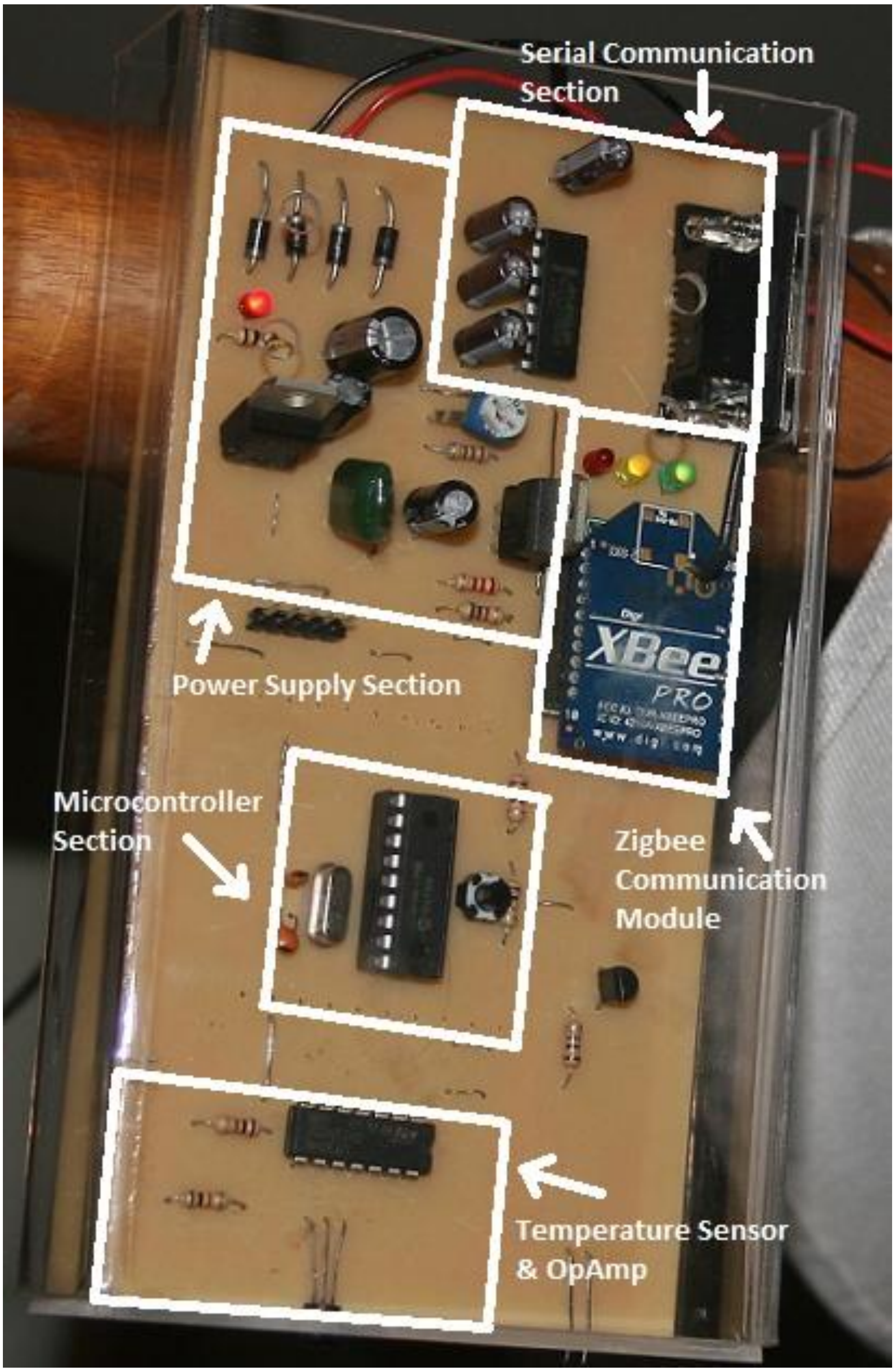


**Figure 11: A picture of the Centralized Controller**

- Sensor Nodes / Control Units

In the implementation sensor nodes and control units were designed to be installed as a single unit using a single PIC16F88 microcontroller with interfacing to below components.

  - ZigBee 2.4 GHz wireless serial interface module
  - Temperature sensor LM35
  - Humidity sensor HIH-4030
  - IR LED
  - 2 X 7 segment display

The temperature and humidity sensors were interfaced to the microcontroller via two separate A/D ports as mentioned before. PIC16F88 was programmed with a firmware to generate pulse width modulated signals to drive the Infra Red LED in controlling the air conditioner units. This firmware also provides provision for interfacing temperature & humidity sensors, Zigbee module and seven segment display units with the microcontroller as well as commands required in system interfacing with centralized controller.

Refer to Figure 12 for the Sensor Node block diagram and Figure 12 for a picture of sensor node / control unit after the implementation. The entire system requires a number of sensor node / control units equal to the number of air conditioner units installed in the building.

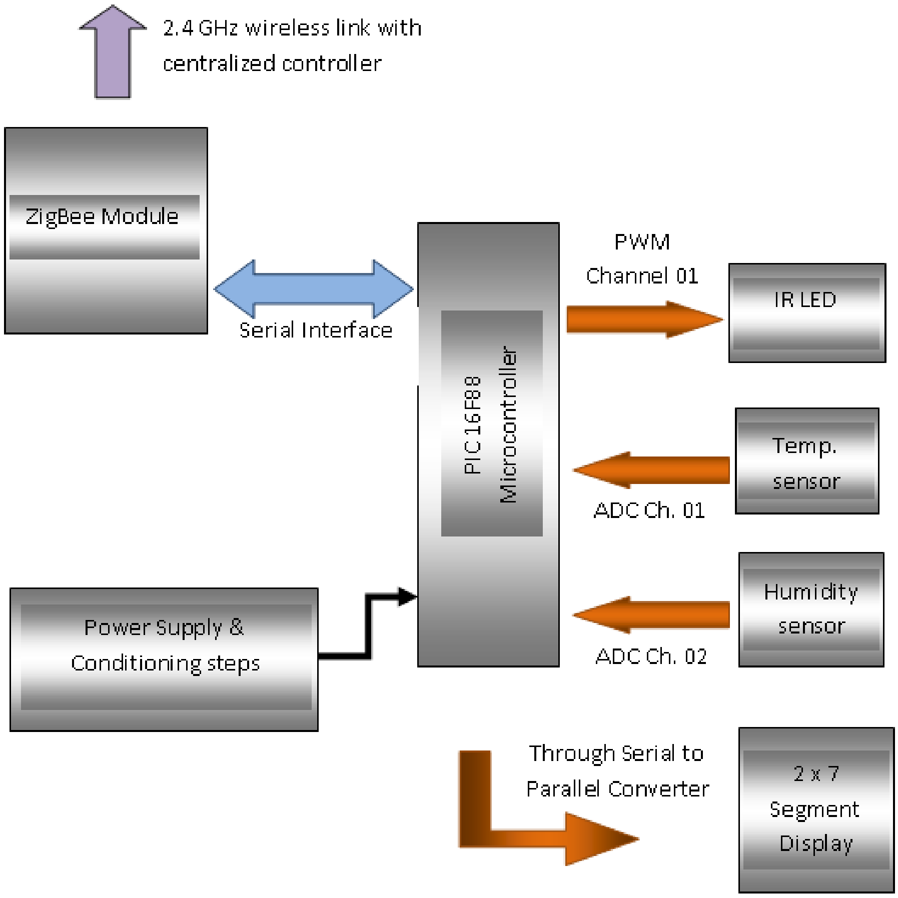


**Figure 12: Sensor Node Block Diagram**


**Figure 13: A picture of a sensor node / control unit**

The PCB layouts required for centralized unit and other sensor node / control units were realized using Orcad PCB design software. Schematic diagram drawn for above purpose is shown in below Figures 14-17.  The designed layouts were locally fabricated into PCBs and were installed in enclosures to ensure protection for the units. PCB layout and the silk screen of a sensor node / control unit PCB is shown in Appendix 2.

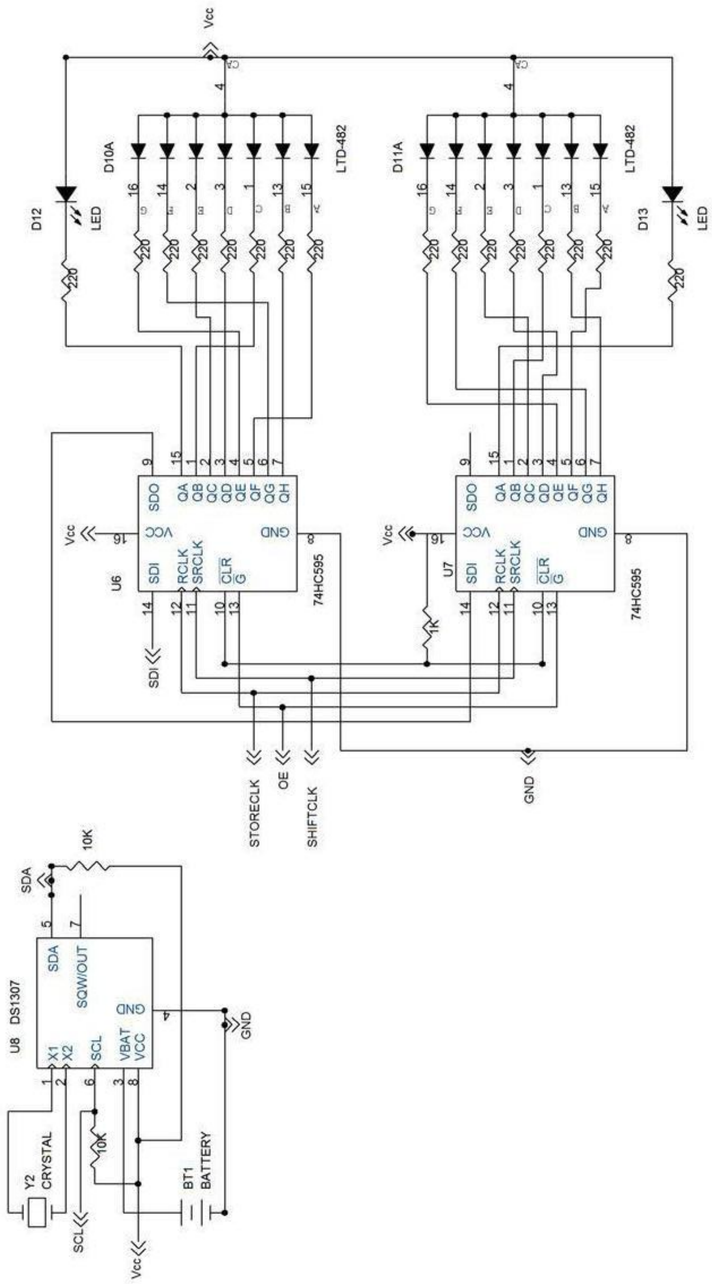

**Figure 14: Schematic Diagram Sheet 1**

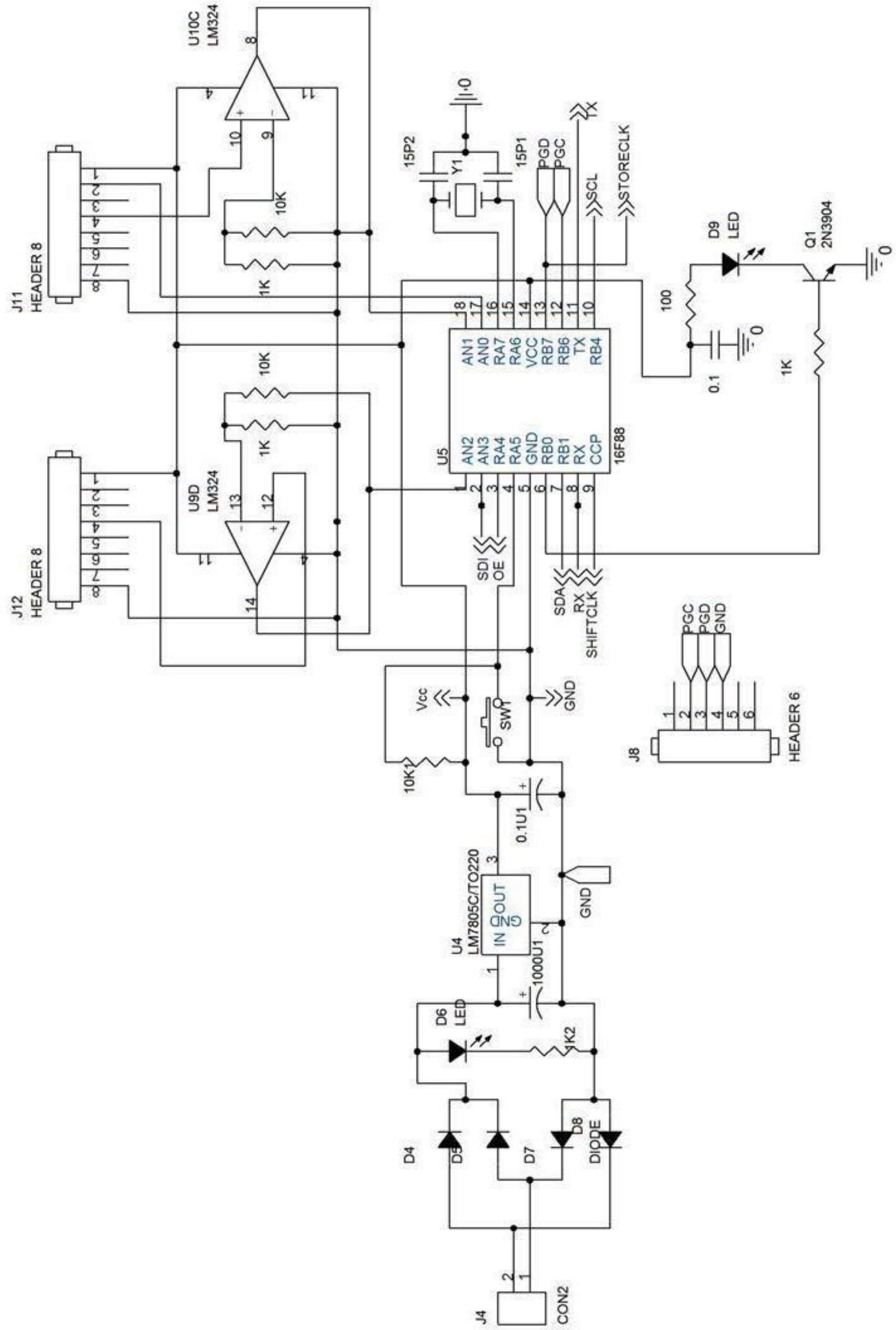


**Figure 15: Schematic Diagram Sheet 2**

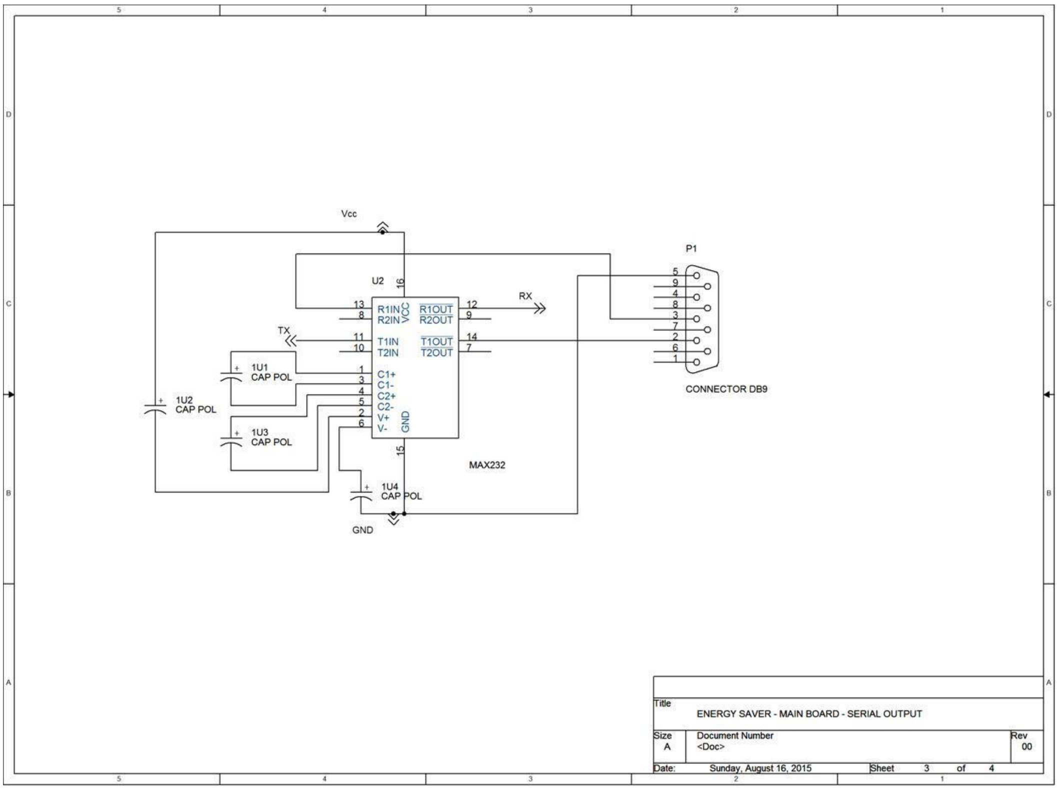


**Figure 16: Schematic Diagram Sheet 3**

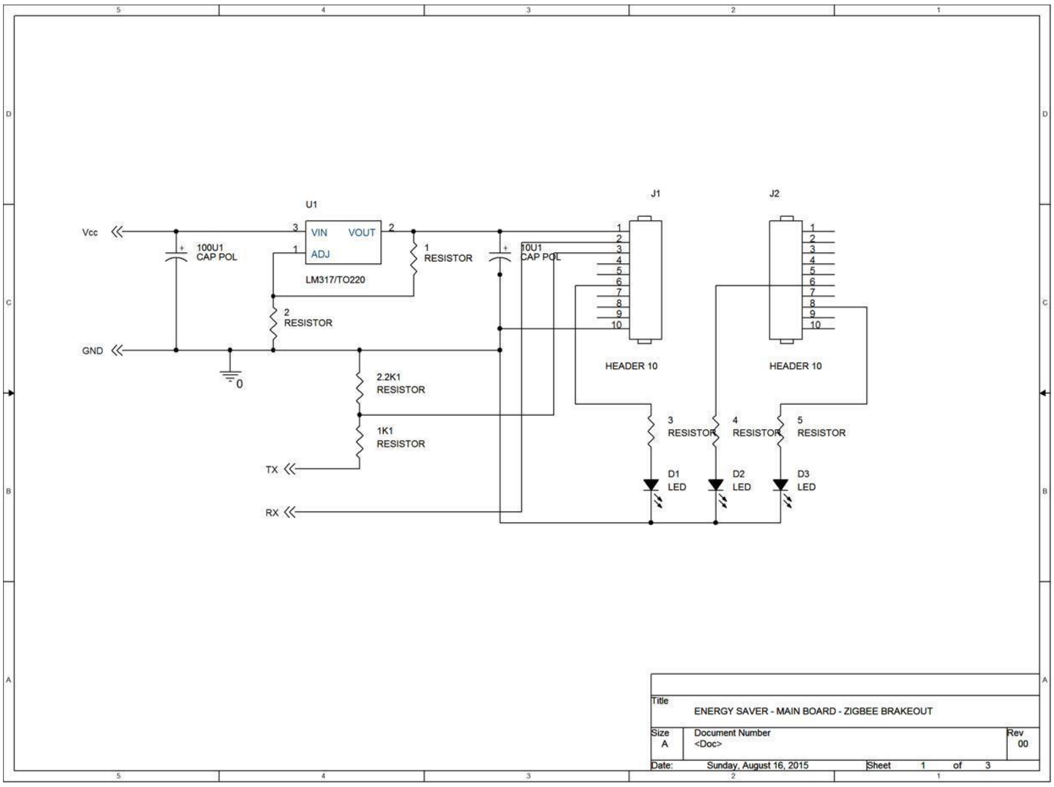


**Figure 17: Schematic Diagram Sheet 4**

# 4. RESULTS, ACHIEVEMENTS AND ANALYSIS

The proposed system was installed at Keells Supermarket outlet in Rawathawatta and all results which will be analyzed below are practical results collected from this installation. The supermarket floor area was originally designed to be cooled by eight 36,000 BTU split type air conditioner units which were installed at key locations in the market floor as shown in below Figure 18 & 19.

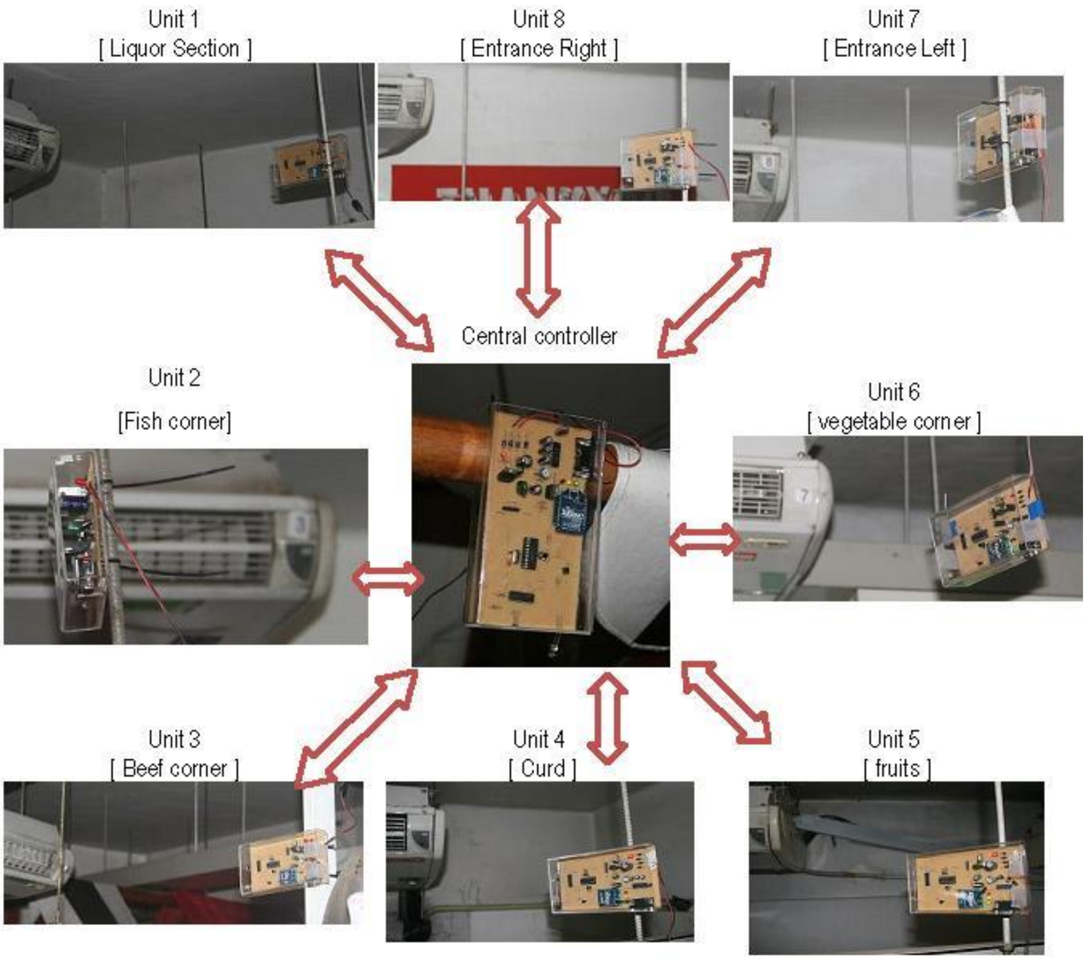


**Figure 18: Centralized Controller with Control Units**

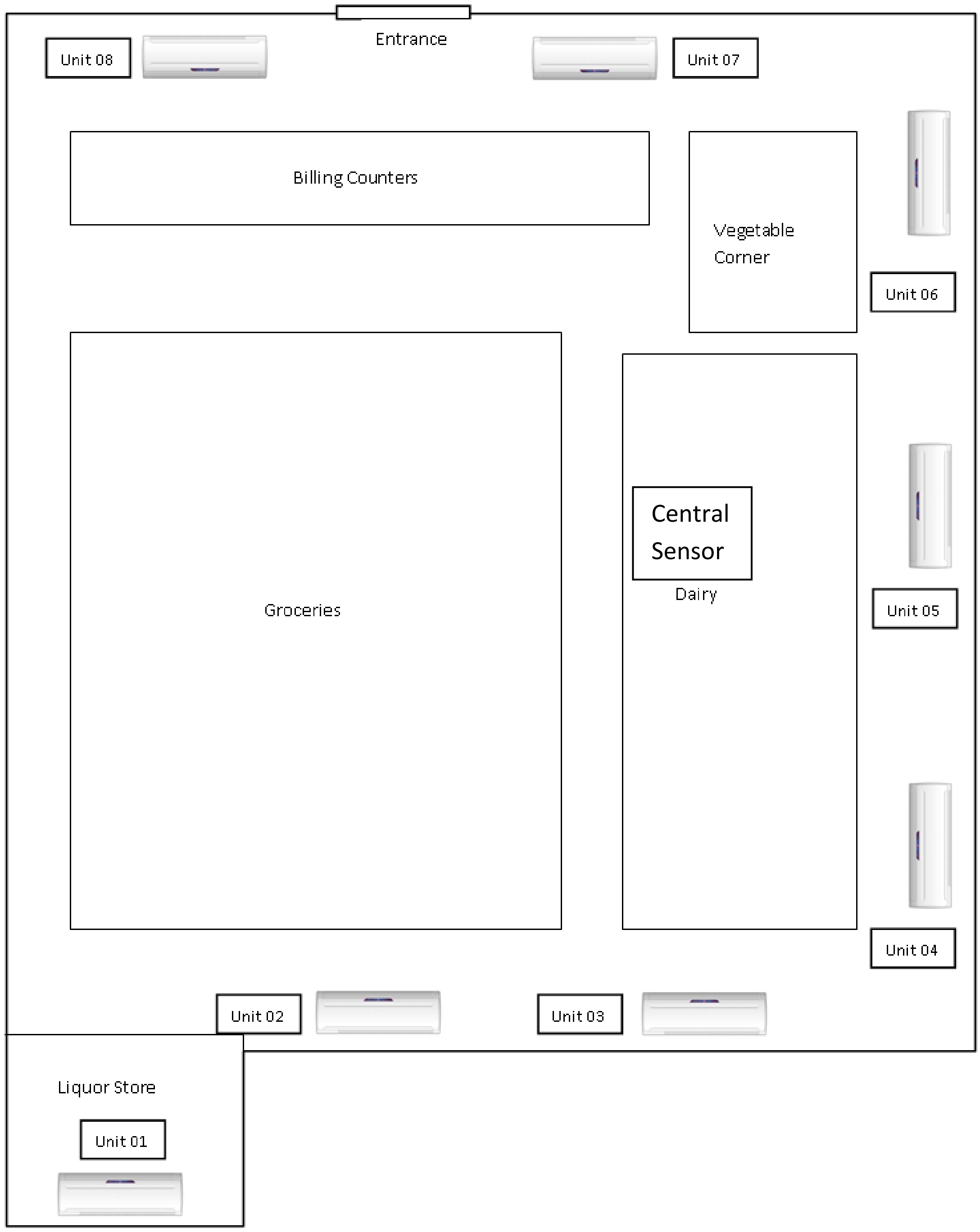


**Figure 19: Supermarket Floor Plan**

Before the system was allowed to handle the temperature inside the building, temperature measurements were collected from various locations near each air conditioner unit during normal operating conditions in various climatic conditions of the day. This exercise was carried out for few days and below temperature values were obtained as most appropriate values to be maintained near each unit by the system. Reference temperatures ($R_n$) to be maintained near each air conditioner were decided also based on occupancy by people as well as other heat emitting sources. The air conditioner units which were near main entrance, cash counters and large refrigerator units which emit lot if heat energy to outside world were given relatively low reference values while air conditioners which were installed in areas whose occupancy is low were given relatively high reference values. These set reference values were altered based on customer feedback received at each area in order to come up with the most suitable reference values for each zone shown in below Table 02.

**Table 02: Reference Temperature Values**

| Unit No. | Reference Temp. ($^0$C) |
|---|---|
| 01 | 27 |
| 02 | 25 |
| 03 | 26 |
| 04 | 25 |
| 05 | 25 |
| 06 | 24 |
| 07 | 25 |
| 08 | 26 |

Apart from above reference values to be maintained near each A/C unit, a general reference value ($R_c$) of 30 $^0$C was also obtained from the central area of the shop floor which was distant from all air conditioner units but was experiencing air flows from most of the air conditioner units. The reference value for central area was also selected after temperature measurements were monitored in that specific area.

The obtained reference temperature values were fed to the system, which utilized these values in calculating the temperature settings required for each air conditioner unit as per below equation.

The $k_1$, $k_2$ & $k_p$ values of the initial equation were assigned with various values initially and found out below values were the most suitable based on a trial and error method.

When $k_1 = 2$, $k_2 = 1$ & $k_p = 2$,

$$S_n = 2R_n - T_n - 2(T_c - R_c)$$

Resulting temperature variations due to automatic control by the system near each air conditioner unit and their on/off states which were captured in a hot and humid day are presented in Appendix 01. Figure 20 below, shows an example temperature and on/off state plot against time, near A/C unit 3.

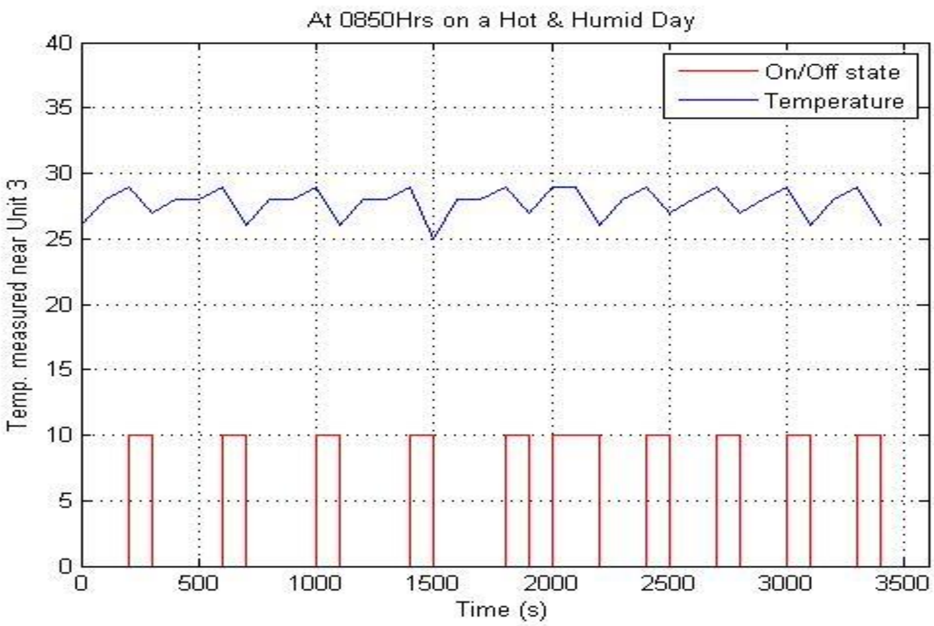


**Figure 20: Temperature Variation near A/C Unit 3 with On/Off States**

It is to be noted that A/C unit 02 was inoperative on this day and temperature variations near unit 02 were not plotted. However, under the utilization percentage which will be discussed later, OFF percentage of unit 02 has been discussed based on results which were calculated on a later day.

The observed on/off state times which were plotted as given in Appendix 01 were used to calculate below ‘OFF’ time percentages for each air conditioner unit on a hot & humid day. The ‘OFF’ percentage value for Unit 2 at 0850Hrs is kept blank due to non availability of data during that specific time slot.

**Table 03: Unit ‘OFF’ time percentages**

| **Time** | **Unit 1 OFF %** | **Unit 2 OFF %** | **Unit 3 OFF %** | **Unit 4 OFF %** | **Unit 5 OFF %** | **Unit 6 OFF %** | **Unit 7 OFF %** | **Unit 8 OFF %** |
|---|---|---|---|---|---|---|---|---|
| 0850Hrs | 9% | - | 68% | 16% | 23% | 0% | 66% | 78% |
| 1240 Hrs | 73% | 27% | 0% | 48% | 0% | 0% | 48% | 58% |
| 1315 Hrs | 76% | 82% | 6% | 48% | 0% | 0% | 36% | 55% |
| 1400 Hrs | 75% | 80% | 0% | 51% | 0% | 0% | 32% | 61% |
| 1515 Hrs | 74% | 91% | 9% | 51% | 0% | 0% | 19% | 63% |
| 1610 Hrs | 77% | 81% | 0% | 45% | 0% | 0% | 0% | 55% |

As per the values furnished in above Table 03, Unit 5 and 6 were observed to be handling more loads compared to the rest at the current reference values. The reference values for those units could not be further increased to enhance the OFF time percentage for units 5 & 6 since user comfort would be compromised with increased reference values.

The OFF time percentage shown above is the percentage of time which air conditioner units were switched ‘OFF’ by the energy saving system. It should be noted that there can be instances where air conditioner units would have shut down their outdoor units by themselves although it was recorded as an unit ON time due to the simple fact that air conditioner units operate in their normal operating mode (compressors will be switched ‘OFF’ due to actions of internal control system) after the units are switched ‘ON’ and temperature value was set by the energy saving system.

The observations show that the implementation of the energy saving system has introduced an ‘OFF’ time to air conditioner units due to centralized controlling which should result in an energy saving. Also the energy saving caused by off loading of the air conditioner units by the temperature control system based on demand to set various temperature levels in air conditioner units while they are in switched ‘ON’ mode as per the system needs to be taken in to consideration when calculating the total energy saving. During this off load function, the air conditioner units will be switched ‘OFF’ by the inbuilt control systems though they are being commanded by the energy saving system to be switched ‘ON’ and maintain a specific set temperature value.

The timer inbuilt to air conditioner units for delay start of the compressor when an air conditioner is switched ‘ON’ is another factor which could lead to an energy saving calculation done solely based on ‘OFF” time percentages to be erratic and all these factors discussed above are demanding for a more practical method of calculating the energy saving introduced by the implemented system.

The method utilized for measuring the exact energy saving was by comparing the energy meter reading values of current month’s energy consumption with a similar month of the previous year. It is to be noted that this exercise was carried out with the assurance of no other electrical loads were added to or removed from the building during this period and all air conditioner units were adequately maintained throughout the time period to make sure least amount of de-rating.

Given below in Table 04, is an example set of energy meter readings recorded during the months of November 2011 to February 2012 at Keells supermarket outlet at Rawathawatta, Moratuwa.

**Table 04: Energy Meter Readings for November 2011 - February 2012**

| Date | Time | Phase 1 (Units) | Phase 2 (Units) | Phase 3 (Units) | Total (Units) | Δ Days | Δ Phase 1 Units | Δ Phase 2 Units | Δ Phase 3 Units | KWh per Day | kVA in all three phases | Δ Days Since last bill | Total for month (Units) | Actual Mean Units |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31.10.2011 | 8.00AM | 159,003 | 52,501 | 30,181 | 241,685 | - | 463 | 154 | 94 | - | 54,54,27 | 11 | 8,164 | 742 |
| 02.11.2011 | 9.30AM | 160,050 | 52,789 | 30,352 | 243,191 | 2 | 524 | 144 | 86 | 753 | 60,54,27 | 13 | 9,670 | 744 |
| 02.11.2011 | Meter Reset | 0 | 0 | 0 | 0 | | | | | | | | | |
| 08.11.2011 | 9.30AM | 2,705 | 1,001 | 592 | 4,298 | 6 | 451 | 167 | 99 | 716 | 51,55,30 | 6 | 4,298 | 716 |
| 16.11.2011 | 9.15AM | 6,359 | 2,304 | 1,488 | 10,151 | 8 | 457 | 163 | 112 | 732 | 56,55,51 | 14 | 10,151 | 725 |
| 20.11.2011 | 9.00AM | 8,187 | 2,956 | 1,892 | 13,035 | 4 | 457 | 163 | 101 | 721 | 56,55,51 | 18 | 13,035 | 724 |
| 01.12.2011 | Bill Reading | 13,445 | 4,618 | 2,797 | **20,860** | | | | | | | 29 | **20,860** | 719 |
| 01.12.2011 | 9.50AM | 13,553 | 4,618 | 2,869 | 21,040 | 10 | 511 | 166 | 98 | 775 | - | 0 | - | - |
| 05.12.2011 | 9.15AM | 15,575 | 5,292 | 3,255 | 24,122 | 4 | 506 | 169 | 97 | 771 | 53,50,19 | 4 | 3,262 | - |
| 14.12.2011 | 9.10AM | 20,167 | 6,807 | 4,162 | 31,136 | 9 | 510 | 168 | 101 | 779 | 54,50,23 | 13 | 10,276 | 790 |
| 22.12.2011 | 9.20AM | 24,230 | 8,149 | 5,039 | 37,418 | 8 | 508 | 168 | 110 | 785 | 57,53,32 | 21 | 16,558 | 788 |
| 23.12.2011 | 9.20AM | 24,712 | 8,316 | 5,158 | 38,186 | 1 | 482 | 167 | 119 | 768 | 57,53,48 | 22 | 17,326 | 788 |
| 24.12.2011 | 9.25AM | 25,258 | 8,503 | 5,296 | 39,057 | 1 | 546 | 187 | 138 | 871 | 57,57,48 | 23 | 18,197 | 791 |
| 25.12.2011 | 9.25AM | 25,780 | 8,719 | 5,447 | 39,946 | 1 | 522 | 216 | 151 | 889 | 58,58,55 | 24 | 19,086 | 795 |
| 26.12.2011 | 9.25AM | 26,258 | 8,877 | 5,557 | 40,692 | 1 | 478 | 158 | 110 | 746 | 58,58,51 | 25 | 19,832 | 793 |
| 27.12.2011 | 9.25AM | 26,738 | 9,036 | 5,689 | 41,463 | 1 | 480 | 159 | 132 | 771 | 58,58,51 | 26 | 20,603 | 792 |
| 28.12.2011 | 9.30AM | 27,185 | 9,188 | 5,792 | 42,165 | 1 | 447 | 152 | 103 | 702 | 58,58,55 | 27 | 21,305 | 789 |
| 29.12.2011 | 9.30AM | 27,645 | 9,344 | 5,907 | 42,896 | 1 | 460 | 156 | 115 | 731 | 58,58,55 | 28 | 22,036 | 787 |
| 30.12.2011 | 9.30AM | 28,154 | 9,506 | 6,015 | 43,675 | 1 | 509 | 162 | 108 | 779 | 60,58,55 | 29 | 22,815 | 787 |

| Date | Time | Phase 1 (Units) | Phase 2 (Units) | Phase 3 (Units) | Total (Units) | Δ Days | Δ Phase 1 Units | Δ Phase 2 Units | Δ Phase 3 Units | KWh per Day | kVA in all three phases | Δ Days Since last bill | Total for month (Units) | Actual Mean Units |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **01.01.2011** | **Bill Reading** | **29,058** | **9,844** | **6,195** | **45,097** | | | | | | | **31** | **24,237** | **782** |
| 03.01.2012 | 9.25AM | 30,107 | 10,149 | 6,475 | 46,731 | 4 | 488 | 161 | 115 | 764 | 50,46,17 | 1 | 1,634 | |
| 16.01.2012 | 9.30AM | 36,800 | 12,297 | 8,030 | 57,127 | 13 | 515 | 165 | 120 | 800 | 57,55,28 | 16 | 12,030 | 752 |
| 19.01.2012 | 9.30AM | 38,289 | 12,792 | 8,332 | 59,413 | 3 | 496 | 165 | 101 | 762 | 57,55,28 | 19 | 14,316 | 753 |
| 24.01.2012 | 9.30AM | 40,975 | 13,676 | 9,017 | 63,668 | 5 | 537 | 177 | 137 | 851 | 57,55,44 | 24 | 18,571 | 774 |
| 25.01.2012 | 9.30AM | 41,472 | 13,849 | 9,153 | 64,474 | 1 | 497 | 173 | 136 | 806 | 57,55,44 | 25 | 19,377 | 775 |
| 27.01.2012 | 9.30AM | 42,530 | 14,210 | 9,446 | 66,186 | 2 | 529 | 181 | 147 | 856 | 57,55,44 | 27 | 21,089 | 781 |
| 31.01.2012 | 9.30AM | 44,710 | 14,934 | 9,844 | 69,488 | 4 | 545 | 181 | 100 | 826 | 60,55,44 | 31 | 24,391 | 787 |
| **01.02.2012** | **Bill Reading** | **45,138** | **15,102** | **9,864** | **70,104** | | | | | | | **31** | **25,007** | **807** |
| 02.02.2012 | 9.30AM | 45,756 | 15,274 | 10,025 | 71,055 | 2 | 523 | 170 | 91 | 784 | 57,49,17 | 2 | | |
| 06.02.2012 | 9.30AM | 47,980 | 15,980 | 10,440 | 74,400 | 4 | 556 | 177 | 104 | 836 | 59,55,25 | 6 | 4,296 | 716 |
| 08.02.2012 | 9.30AM | 49,008 | 16,325 | 10,665 | 75,998 | 2 | 514 | 173 | 113 | 799 | 59,55,25 | 8 | 5,894 | 737 |
| 09.02.2012 | 9.30AM | 49,587 | 16,513 | 10,770 | 76,870 | 1 | 579 | 188 | 105 | 872 | 59,55,25 | 9 | 6,766 | 752 |
| 13.02.2012 | 9.30AM | 51,843 | 17,266 | 11,201 | 80,310 | 4 | 564 | 188 | 108 | 860 | 62,58,25 | 13 | 10,206 | 785 |
| 18.02.2012 | 9.30AM | 54,330 | 18,188 | 11,720 | 84,238 | 5 | 497 | 184 | 104 | 786 | 62,59,25 | 18 | 14,134 | 785 |
| 21.02.2012 | 9.30AM | 56,009 | 18,755 | 12,074 | 86,838 | 3 | 560 | 189 | 118 | 867 | 62,59,25 | 21 | 16,734 | 797 |
| **01.03.2012** | **Bill Reading** | **61,004** | **20,460** | **12,981** | **94,445** | | **15,866** | **5,358** | **3,117** | | | **29** | **24,341** | |

Electricity bill values of each month were compared with values from the same month of previous year as shown in table. The Tables 05 & 06 show kilo Watt hour units (kWh), peak demand values (kVA) and generator usage during each month. Energy saving in kWh and kVA (Peak Demand value) are shown along with savings from the electricity bill calculated based on then valid electricity tariffs.

**Table 05: Electricity Bill Values 2010 & 2011**

| Period | 2010 Bill values | | | 2011 Bill values | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | kWh (Units) | kVA | Gen. Usage Rs. | kWh (Units) | kVA | Gen. usage Rs | Saving From kWh (Rs.) | Saving From kVA (Rs.) | Total Saving (Rs.) |
| Apr-May | 30,461 | 76 | 0 | 28,348 | 75 | 7,600 | 40,992 | 850 | 33,097 |
| May-Jun | 31,881 | 78 | 7,300 | 28,260 | 74 | 13,440 | 70,247 | 3,400 | 66,582 |
| Jun-Jul | 29,315 | 79 | 22,100 | 27,018 | 72 | 29,680 | 44,555 | 5,950 | 41,782 |
| Jul-Aug | 29,068 | 74 | 43,070 | 32,141 | 75 | 2,900 | -59,616 | -850 | -14,243 |
| Aug-Sep | 27,430 | | 14600 | 26,627 | 71 | 7,500 | 15,578 | | 23,748 |
| Sep-Oct | 26,884 | 71 | 29,200 | 25,976 | 68 | 0 | 17,615 | 2,550 | 53,765 |
| Oct-Nov | 26,580 | | 28,320 | 22,444 | 60 | 0 | 80,238 | | 112,826 |
| Nov-Dec | 25,369 | 66 | 19,315 | 24,237 | 60 | 0 | 21,961 | 5,100 | 49,286 |

**Table 06: Electricity Bill Values 2011 & 2012**

| Period | 2011 Bill values | | | 2012 Bill Values | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | kWh (Units) | kVA | Gen. Usage Rs | kWh (Units) | kVA | Gen. Usage Rs | Saving From kWh (Rs.) | Saving From kVA (Rs.) | Total Saving (Rs.) |
| Dec-Jan | 25,666 | 77 | 7,300 | 25,007 | 60 | 0 | 54,184 | 7,650 | 70,234 |
| Jan-Feb | 27,475 | 79 | 11,680 | 24,341 | 62 | 0 | 39,304 | 5,950 | 58,694 |
| Feb-Mar | 27,626 | 81 | 0 | 26,771 | 63 | 0 | 37,345 | 12,750 | 50,095 |
| Mar-Apr | 30,231 | 72 | 15,216 | 25,964 | 70 | 0 | 37,811 | 6,800 | 62,119 |

The total savings during the complete year is as shown in Table 07.

**Table 07: Total Annual Savings**

| Total Annual Saving in kWh | Total Annual kWh Saving % | Total Annual Saving in kVA | Total Annual kVA Saving % | Total Annual Saving in Rs. | Total Annual Rs. Saving % |
|---|---|---|---|---|---|
| **20,630** | **6.1** | **59** | **8.0** | **607,987** | **8.6** |

It is to be noted that all bill values reflect the total electricity consumption of the building along with its equipment such as industrial type freezers and lighting. Hence, these values do not indicate energy consumption by air conditioner units only.

# 5. CONCLUSION AND FUTURE WORK

## 5. 1 Discussion and Conclusion

With the ever increasing demand for electrical power and increasing electricity tariffs as a result of that, building air conditioning has become one of the key contributors for high costs incurred in electricity consumptions. The main objective of this project was to come up with a system designed for saving energy by control of split type air conditioner units in a non invasive method. Starting from the problem statement, the proposed system was designed and implemented for testing at a supermarket which had relatively dynamic load characteristics in nature.

As shown in the graphs provided in Appendix 01, with the implementation of the energy saving system, air conditioner units are forced to be switched 'OFF' when their desired cooling tasks are completed. The frequency and duration of an air conditioner unit been kept in 'OFF' state by the energy saving system varies with the time of the day, heat load available in the area being cooled and location of the air conditioner unit. Based on above factors it is evident that some air conditioner units are handling more loads than the others.

As shown in Table 2, with the implementation of the energy saving system, the 'OFF' time percentage of the air conditioner units has increased. Though the inbuilt control systems inside these units are designed to switch 'OFF' outdoor units whenever the set temperatures are reached, the inbuilt systems do not take into account ambient conditions of the outside environment which is cooled by several air conditioner units. Also the accuracy of the data captured by the inbuilt sensors of these units is lower than the accuracy of date collected by the sensors of energy saving system nodes which are positioned in different key locations inside the area which is being cooled. Due to these reasons, the additional 'OFF' times of the units, introduced due to the operation of the system has increased the overall 'OFF' time percentages of the air conditioner units leading to an energy saving.

When considering the temperature control function of the proposed system, the air conditioners are controlled in such a way that when they are in ‘ON’ state, the set temperature is calculated based on the demand. If the demand is too low to maintain a specific air conditioner unit in an ‘ON’ state, the system will straight away make sure that specific unit is switched ‘OFF’. Similarly when the demand is rising, the system will switch ‘ON’ the specific air conditioner units along with a set temperature which will be either be raised or lowered depending on the demand during the ‘ON’ time period of those machines. This demand control method will off load the excess load on air conditioner units resulting a further saving of power. The importance of demand control is immense in this supermarket application since unless controlled in proposed manner, the set temperatures will be the same throughout the day if controlled manually.

The peak power demand reduction is one more observation which is visible in provided data. The reason behind this observation is with the introduction of centralized controlling, the system had brought in an overall control to the standalone units which would have acted on their own unless otherwise. The excessive demands on certain air conditioner units have reduced due to this fact hence, lowering the peak power demand. The reduction of peak power demand leads to more energy saving as well as money saving since peak power demand is separately being charged from the customer.

Based on observations furnished under results section, the proposed energy saving system designed for split type air conditioner units has proven its capability of saving energy as well as huge sums annually when it comes to financial terms.

## 5. 2 Recommendations for Future Work

The current system was designed with keeping split type non centralized air conditioner units in mind. A similar approach can be designed and tested for air conditioner systems which are used in large buildings with centralized chiller systems.

Also this system can be adopted to be used in applications with much lesser dynamic loads such as lecture halls, offices etc. fixed with split type air conditioners to deliver more promising results.

The possibility of implementing a similar system in a building fixed with inverter type air conditioners can be tested for further energy saving. Since inverter type air conditioner units already deliver more energy savings by controlling the compressor speeds, providing such machines with a stronger feedback system than the inbuilt feedback system could lead to a further energy saving.

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[07] J. Wang et al., "Non-invasive Zigbee wireless controller for air conditioner energy saving", in *7th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM)*, Wuhan, 2011, pp. 1 – 4.

[08] *XBee®/XBee-PRO® RF Modules Product Manual*, v1.xEx - 802.15.4 Protocol, Digi Int. Inc., Minnetonka, MN, 2009.

[09] *LM35 Precision Centigrade Temperature Sensor Datasheet*, Rev. D, Texas Instruments Inc., Dallas, TX, 2013.

[10] *Honeywell HIH-4030 Humidity Sensor Datasheet*, Honeywell International Inc., Minneapolis, MN, 2008.

[11] *DS1307 Real Time Clock IC Datasheet*, Maxim Integrated Products, Sunnyvale, CA, 2015.

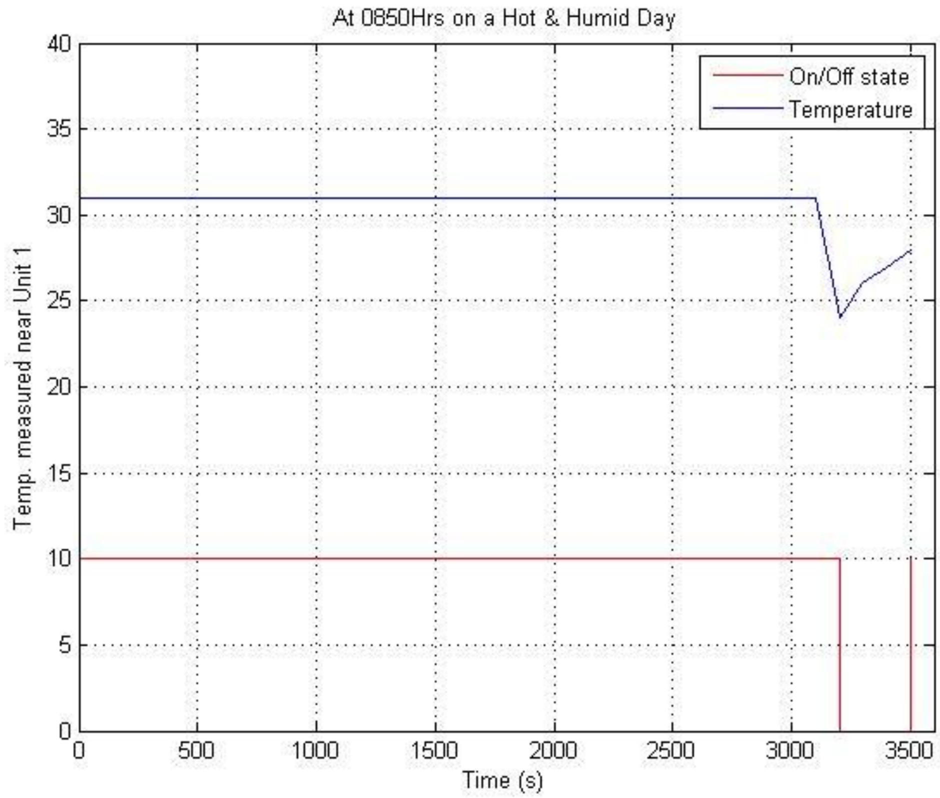
[12] *LM317 Adjustable Regulator IC Datasheet*, Rev. W, Texas Instruments Inc., Dallas, TX, 2014.

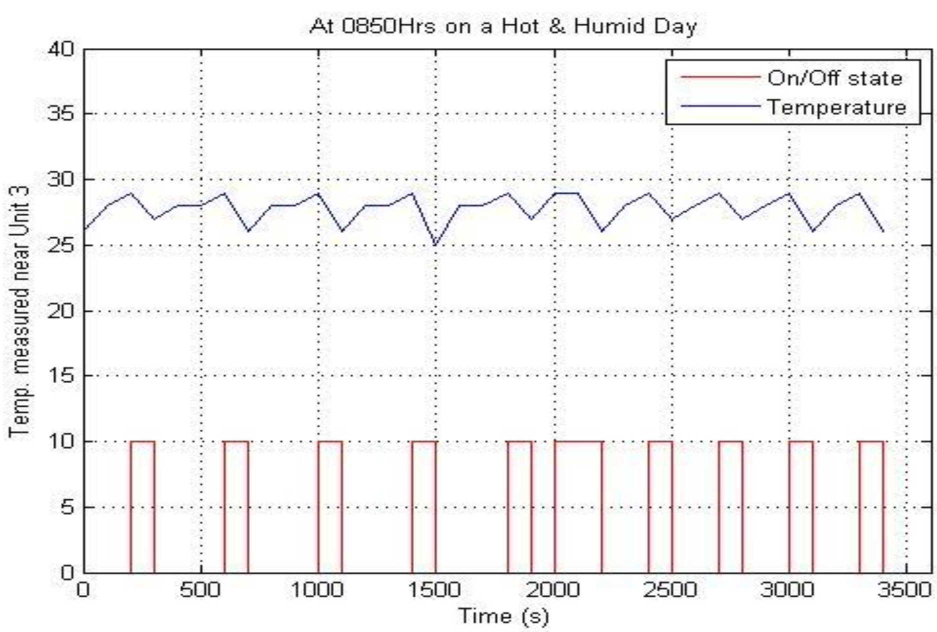
[13] *SN74HC595 8-bit Shift Register Datasheet*, Rev. I, Texas Instruments Inc., Dallas, TX, 2015.

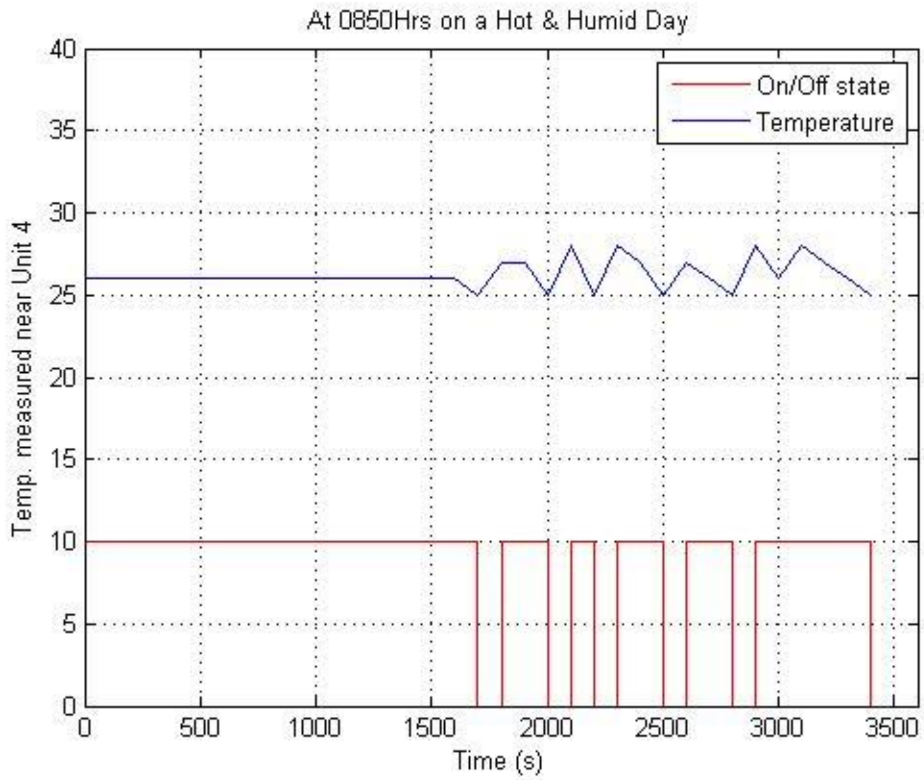
[14] *LM324 Low Power Quad Operational Amplifier Datasheet*, Rev. D, Texas Instruments Inc., Dallas, TX, 2015.

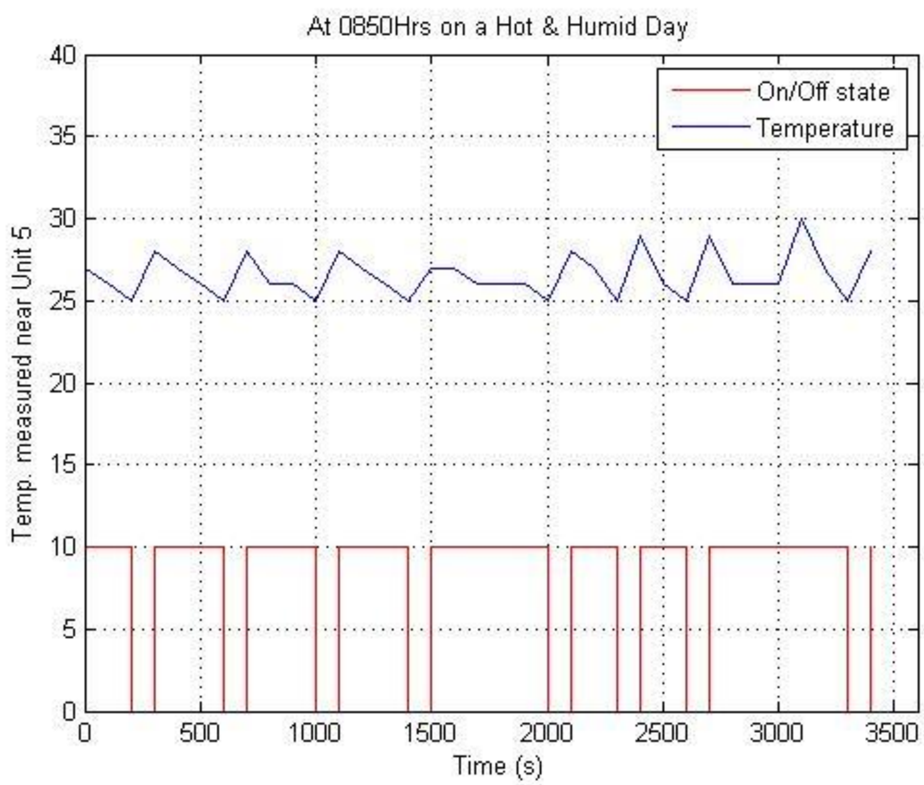
# Appendix 01

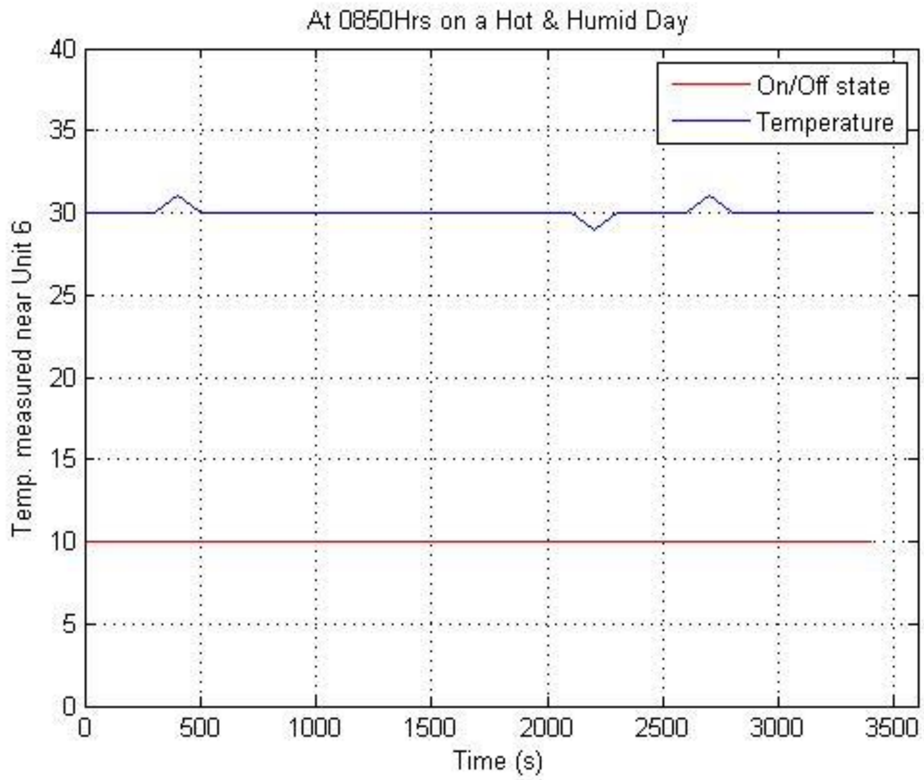
Start time - 0850 Hrs and measured for 3500 s

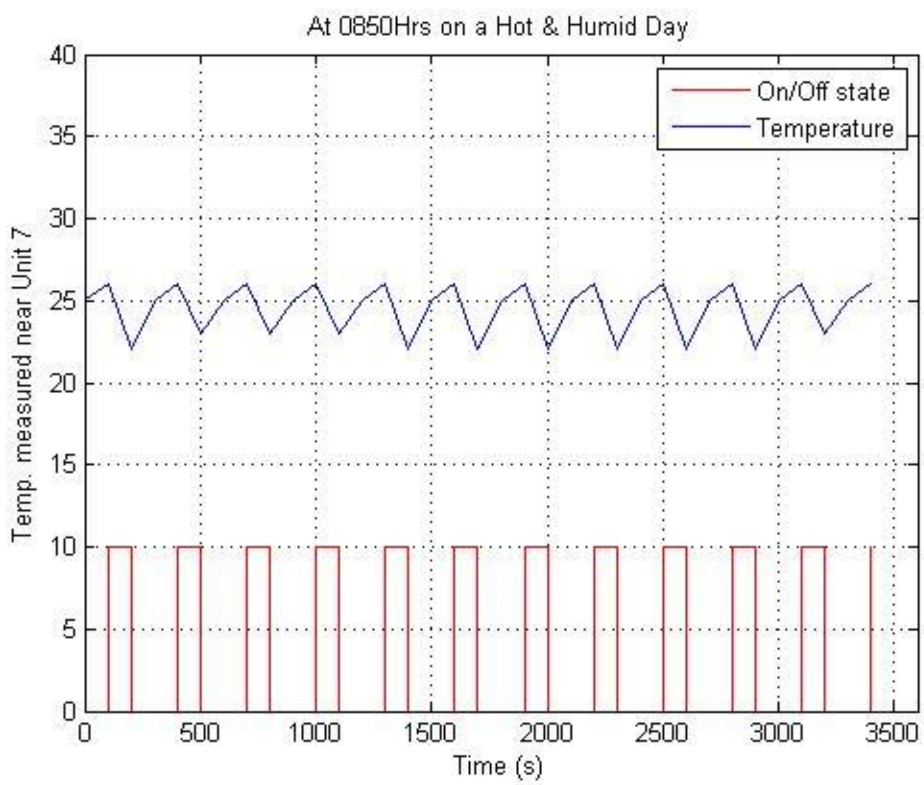


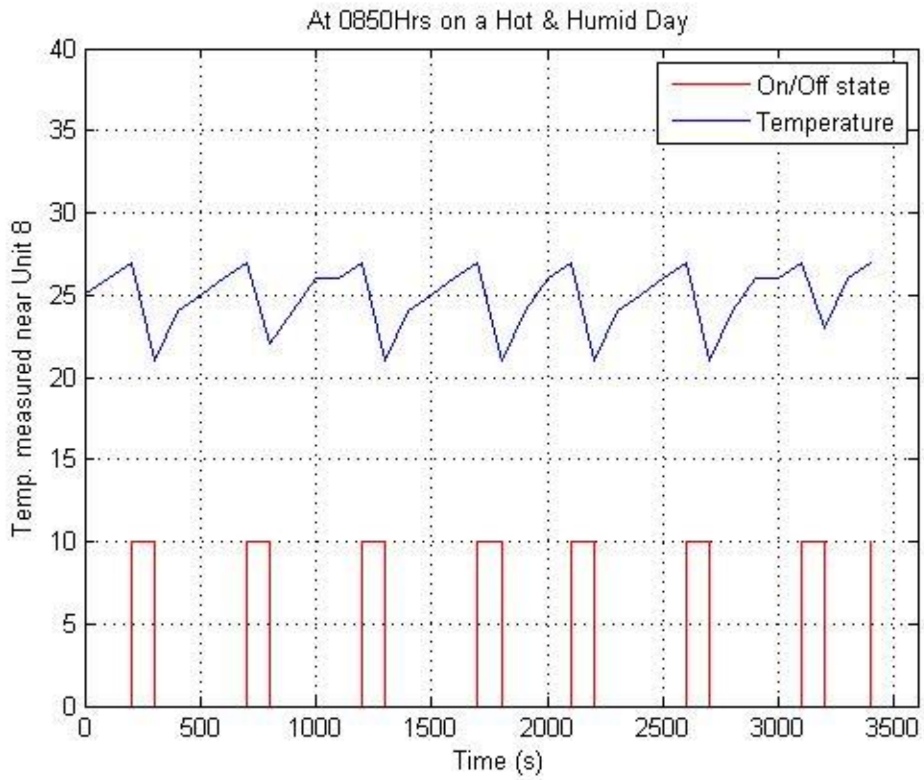




At 0850Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 4
Time (s)
0
5
10
15
20
25
30
35
40
500
1000
1500
2000
2500
3000
3500

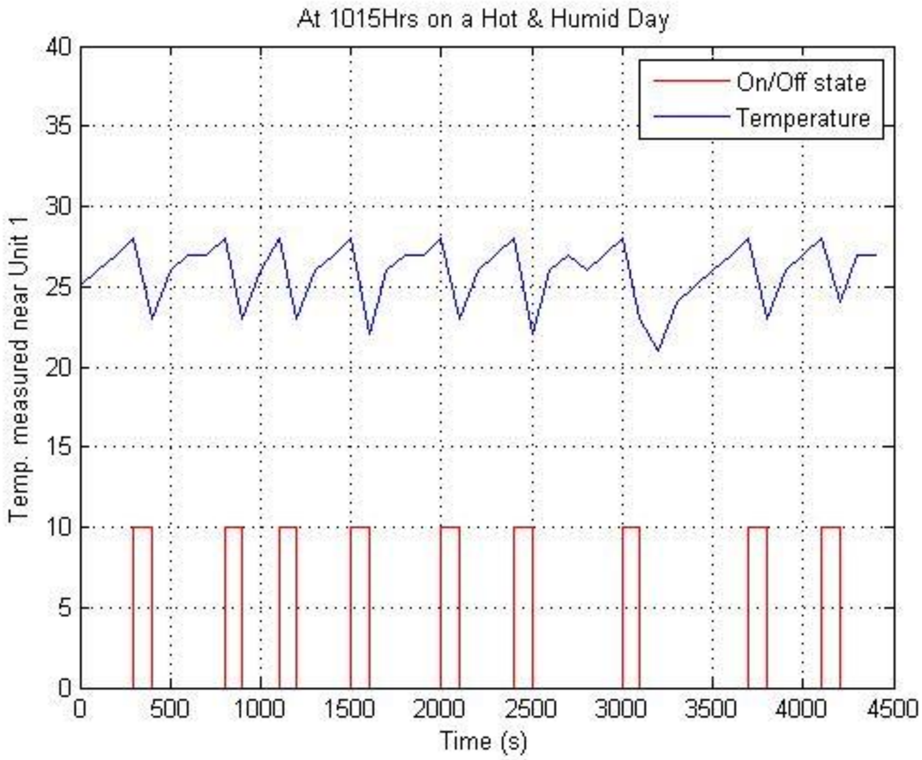

At 0850Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 5
Time (s)
0
5
10
15
20
25
30
35
40
500
1000
1500
2000
2500
3000
3500

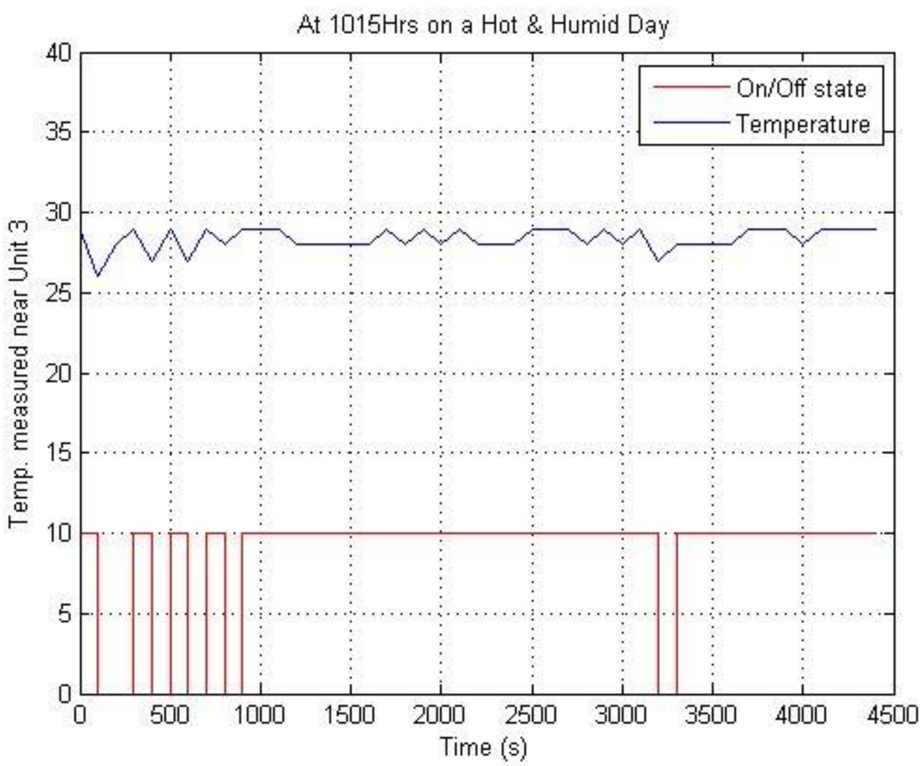

At 0850Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 6
Time (s)
0
5
10
15
20
25
30
35
40
500
1000
1500
2000
2500
3000
3500

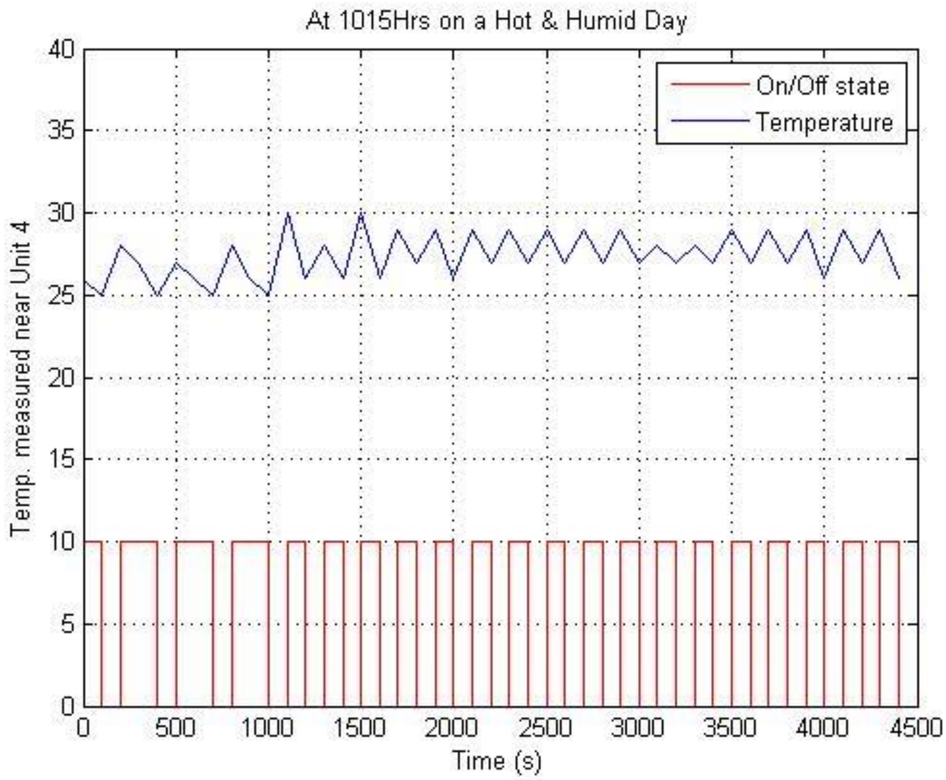

At 0850Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 7
Time (s)
0
5
10
15
20
25
30
35
40
500
1000
1500
2000
2500
3000
3500

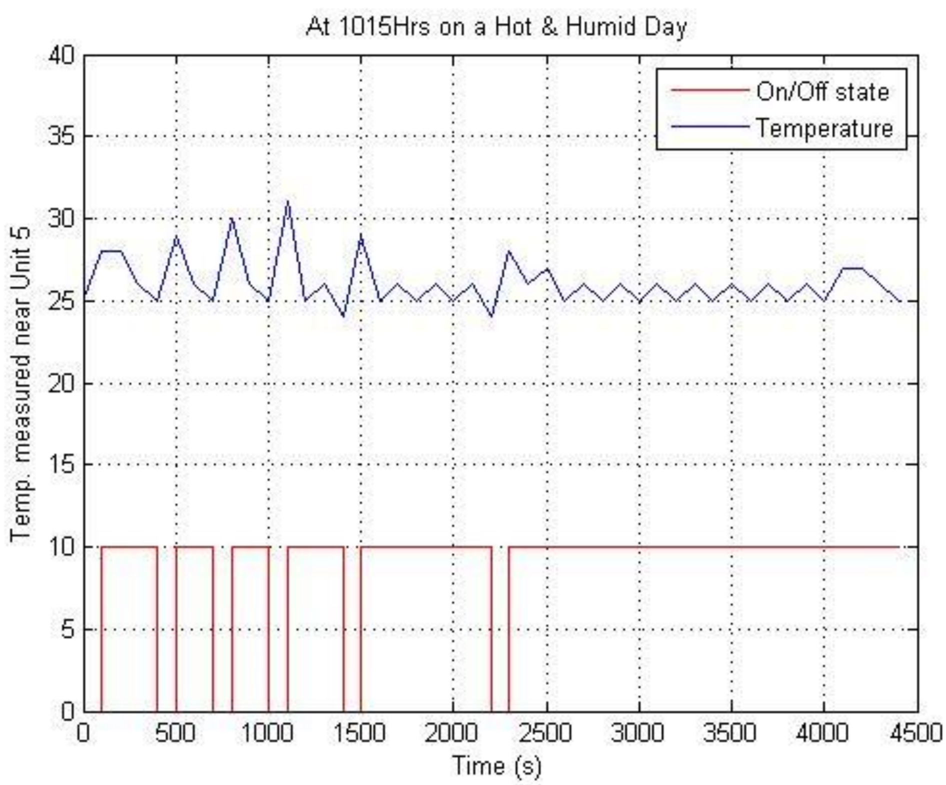

At 0850Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 8
Time (s)
40
35
30
25
20
15
10
5
0
0
500
1000
1500
2000
2500
3000
3500

Start time - 1015 Hrs and measured for 4500 s




At 1015Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 4
Time (s)
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000
2500
3000
3500
4000
4500


At 1015Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 5
Time (s)
0
5
10
15
20
25
30
35
40
0
500
1000
1500
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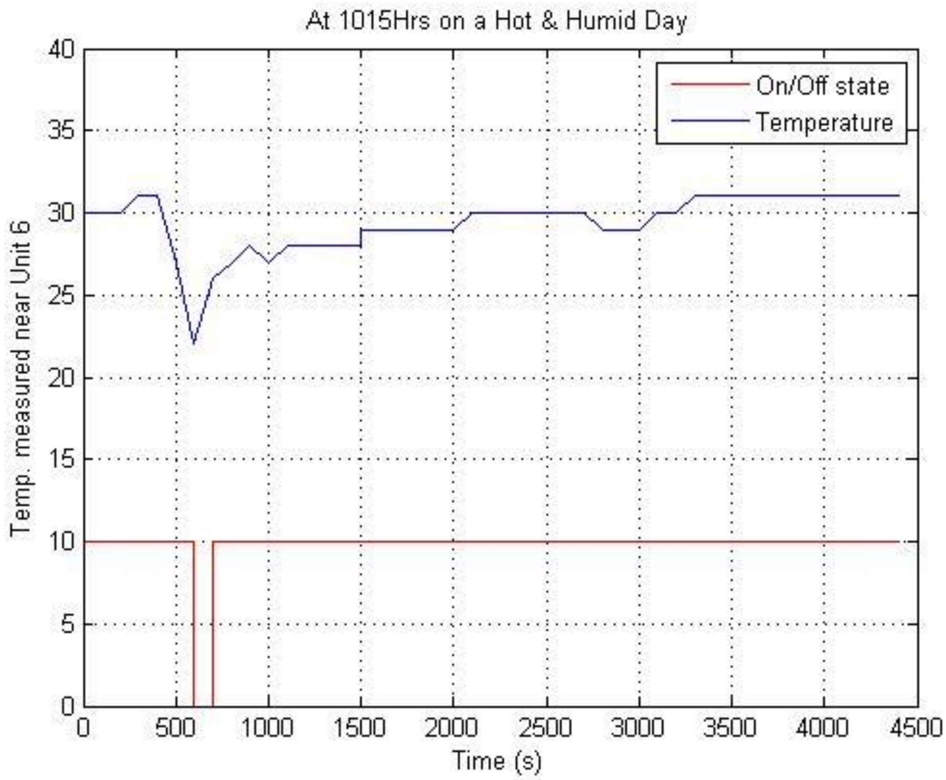
2500
3000
3500
4000
4500


At 1015Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 6
Time (s)
0
5
10
15
20
25
30
35
40
0
500
1000
1500
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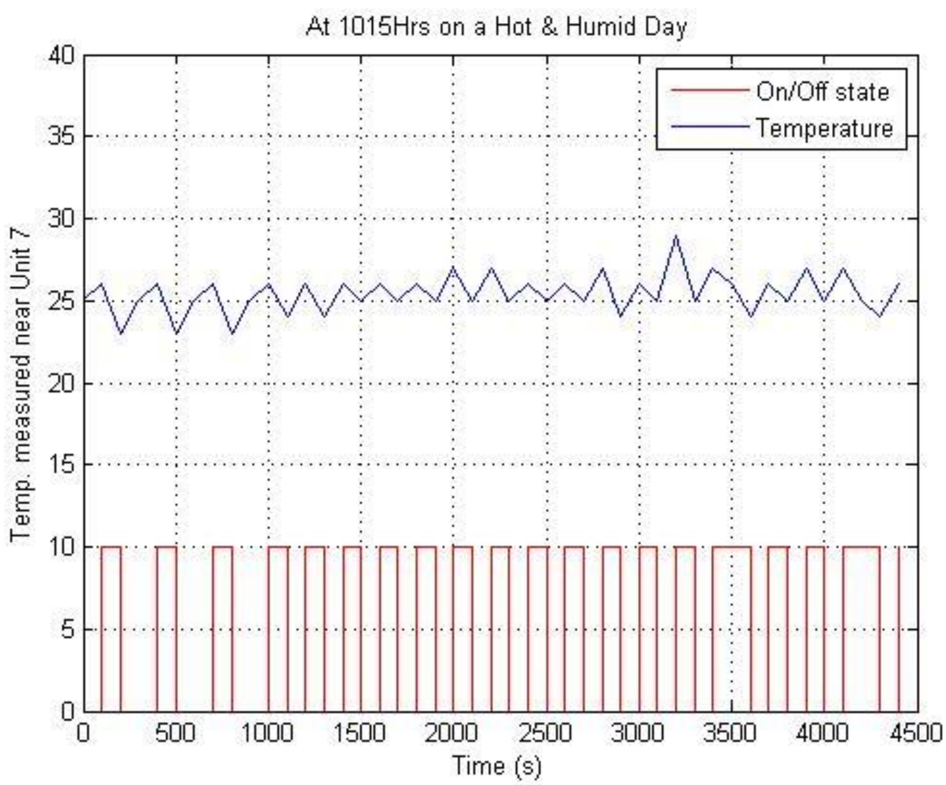
2500
3000
3500
4000
4500


At 1015Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 7
Time (s)
0
5
10
15
20
25
30
35
40
0
500
1000
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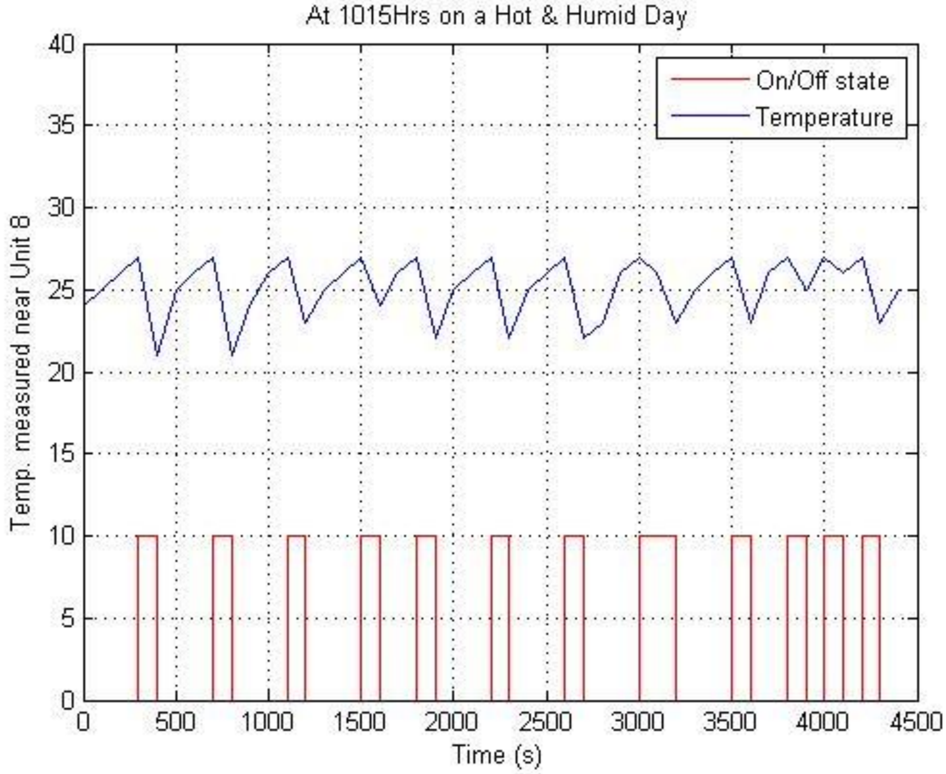
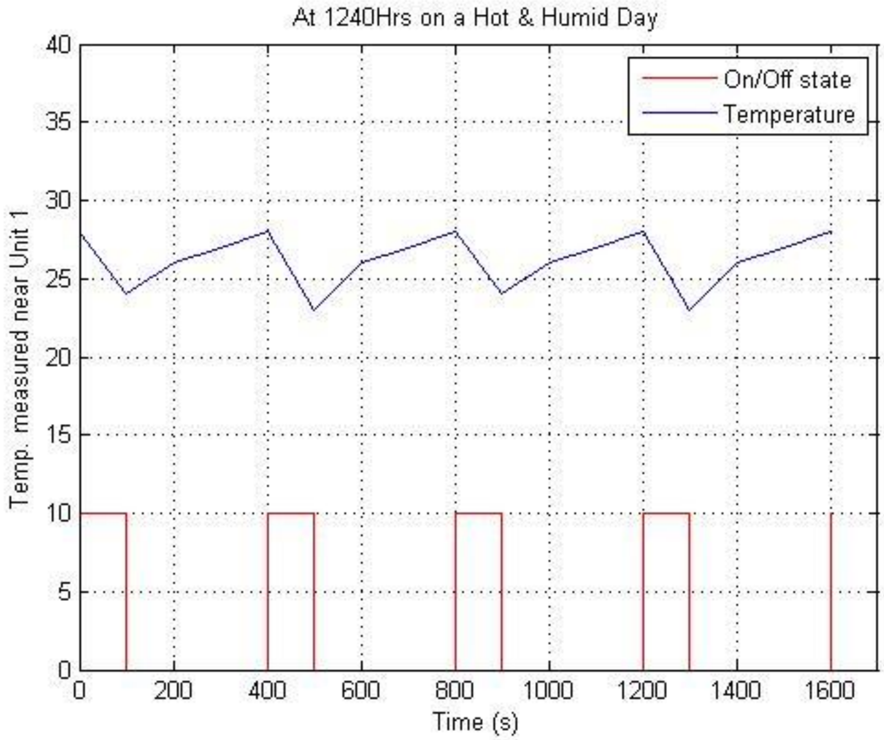
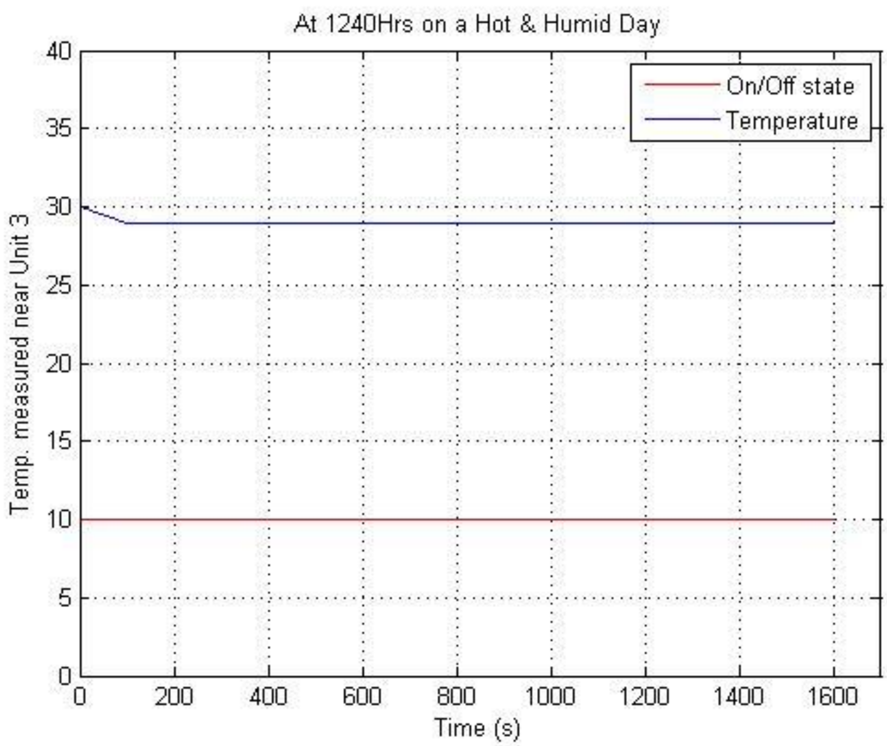
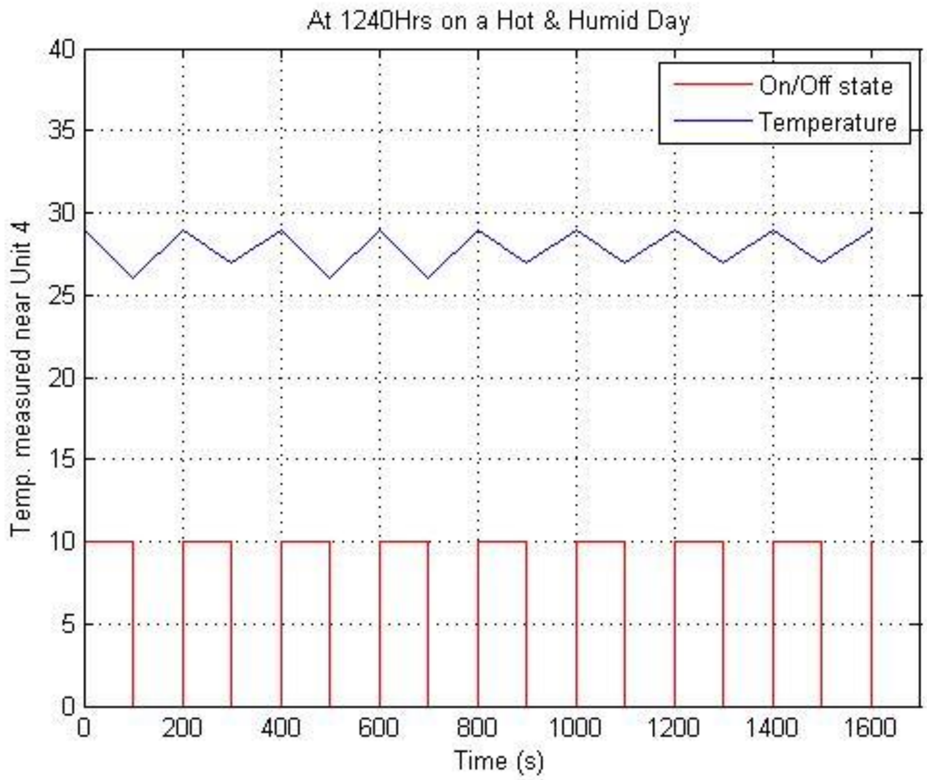
2500
3000
3500
4000
4500


At 1015Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 8
Time (s)
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000
2500
3000
3500
4000
4500

Start time - 1240 Hrs and measured for 1600 s




At 1240Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 4
Time (s)
0
200
400
600
800
1000
1200
1400
1600
0
5
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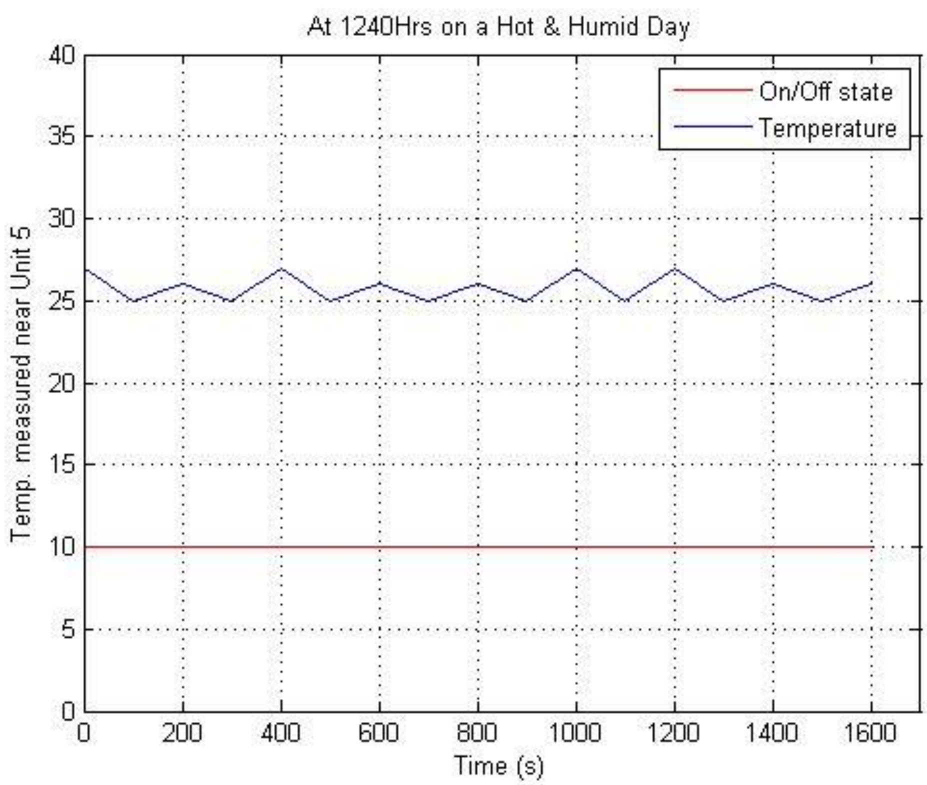
20
25
30
35
40


At 1240Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 5
Time (s)
0
200
400
600
800
1000
1200
1400
1600
0
5
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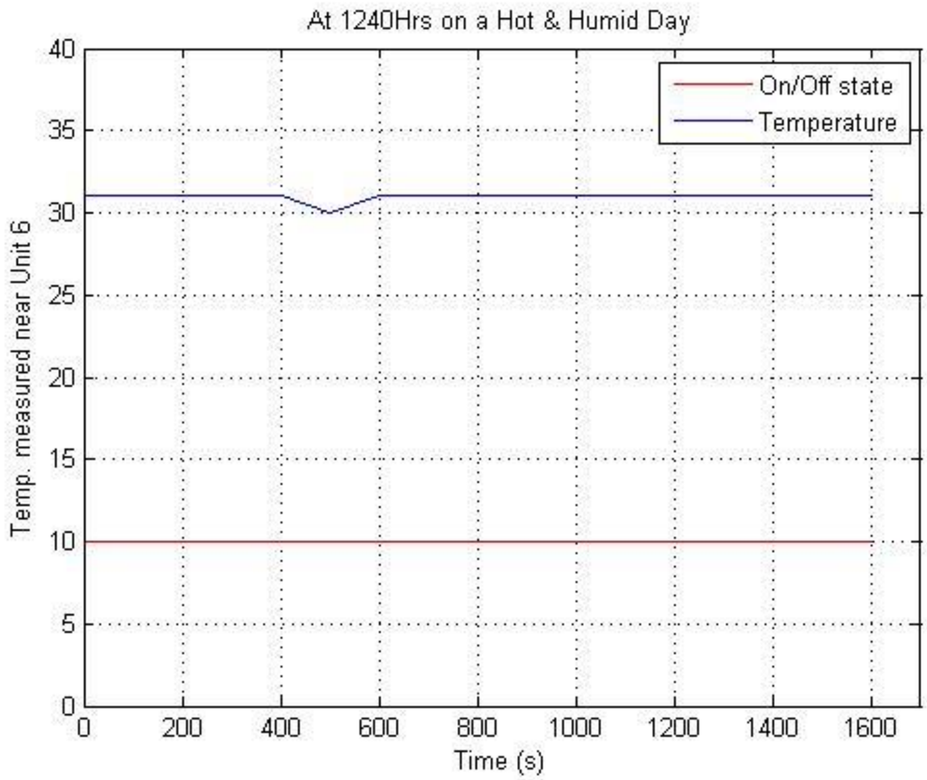
20
25
30
35
40


At 1240Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 6
Time (s)
0
5
10
15
20
25
30
35
40
0
200
400
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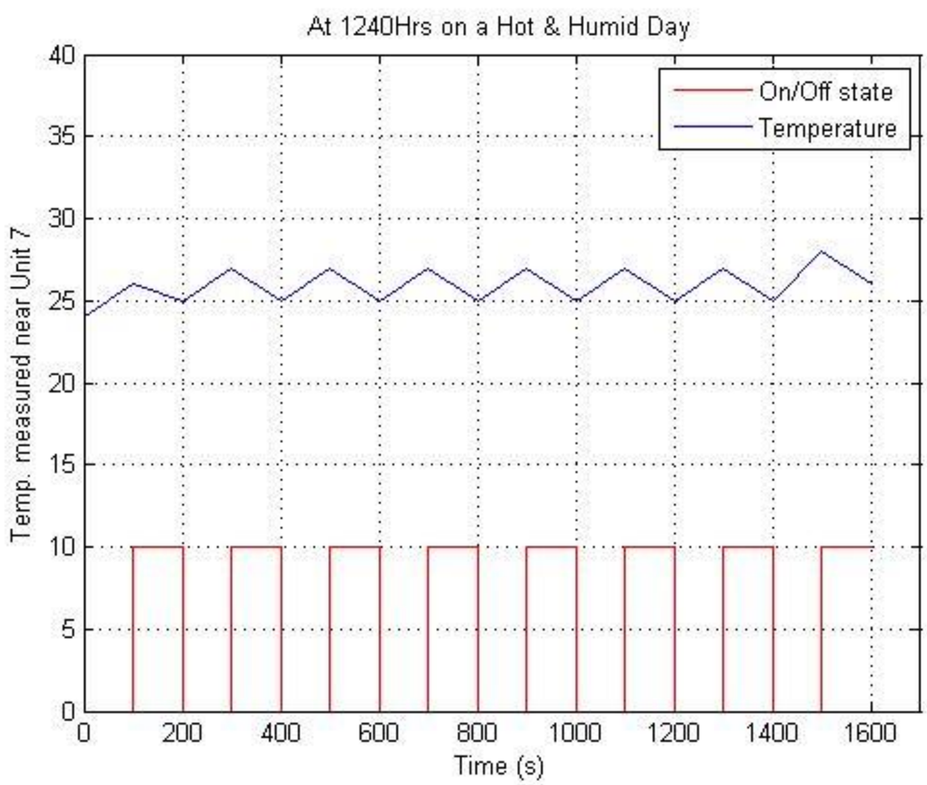
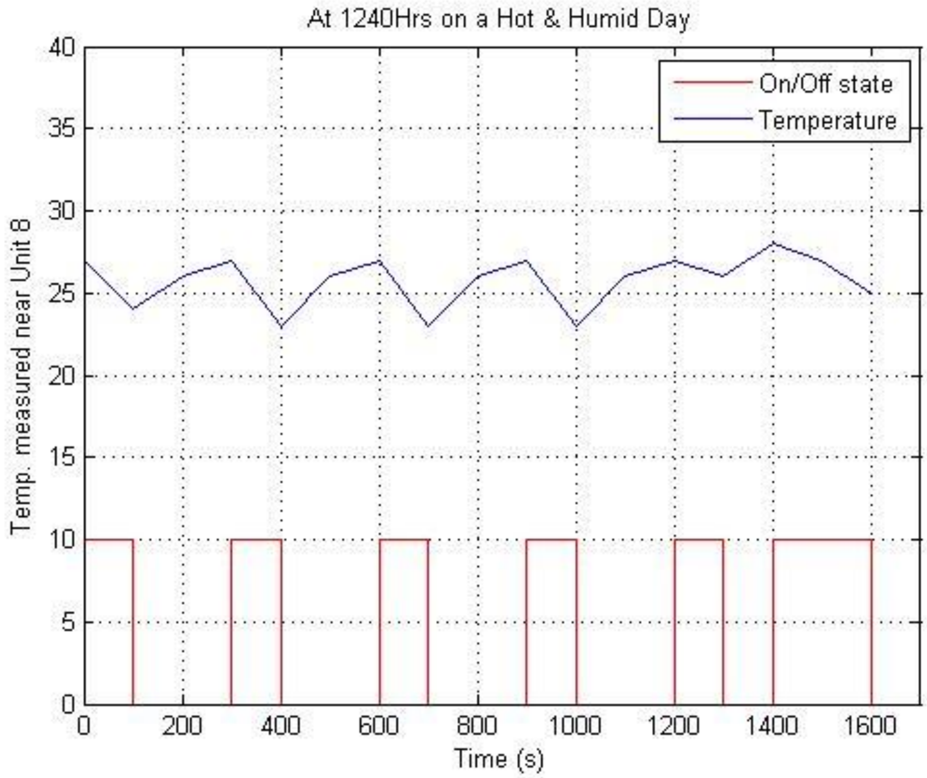
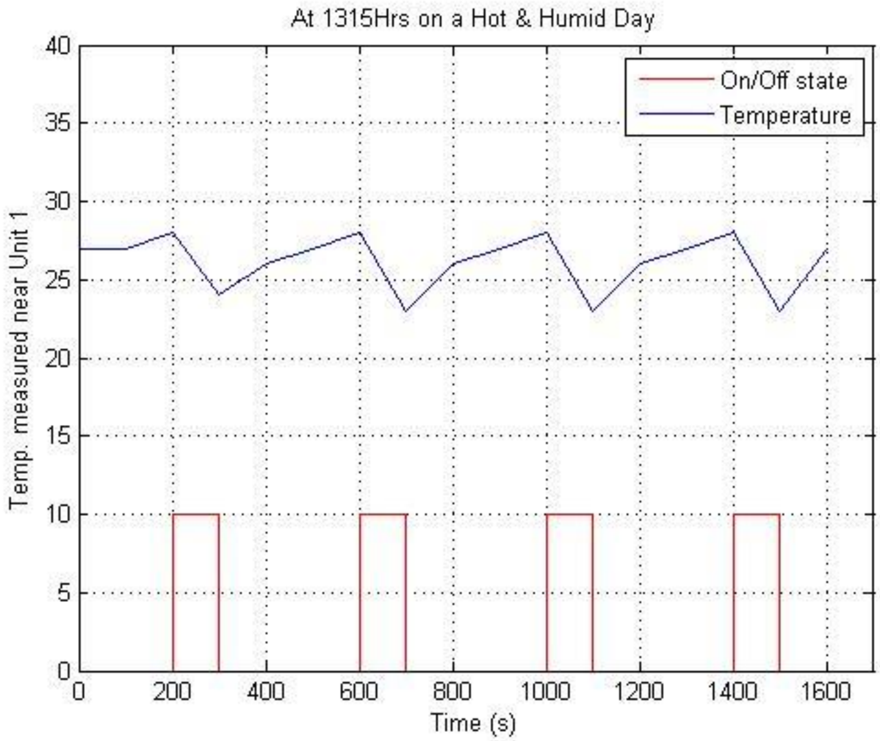
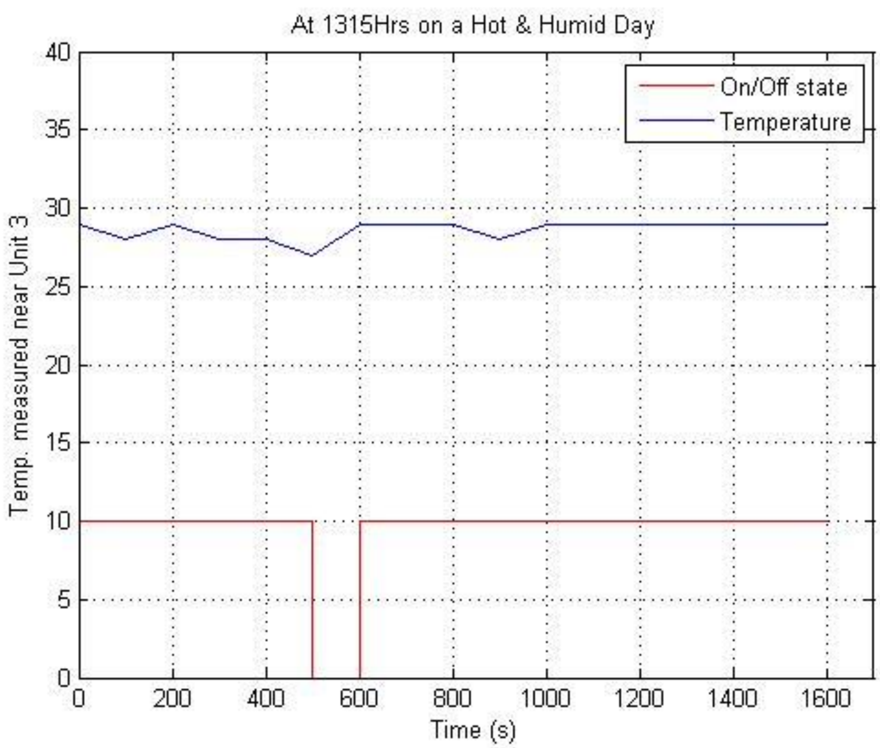
800
1000
1200
1400
1600

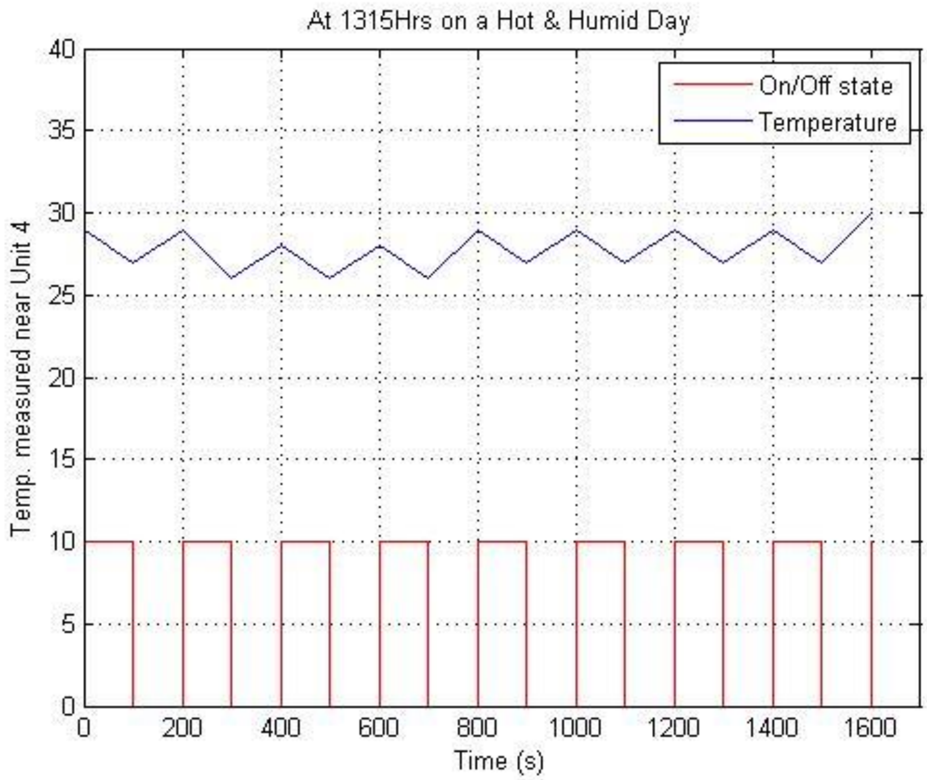

At 1240Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 7
Time (s)
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600

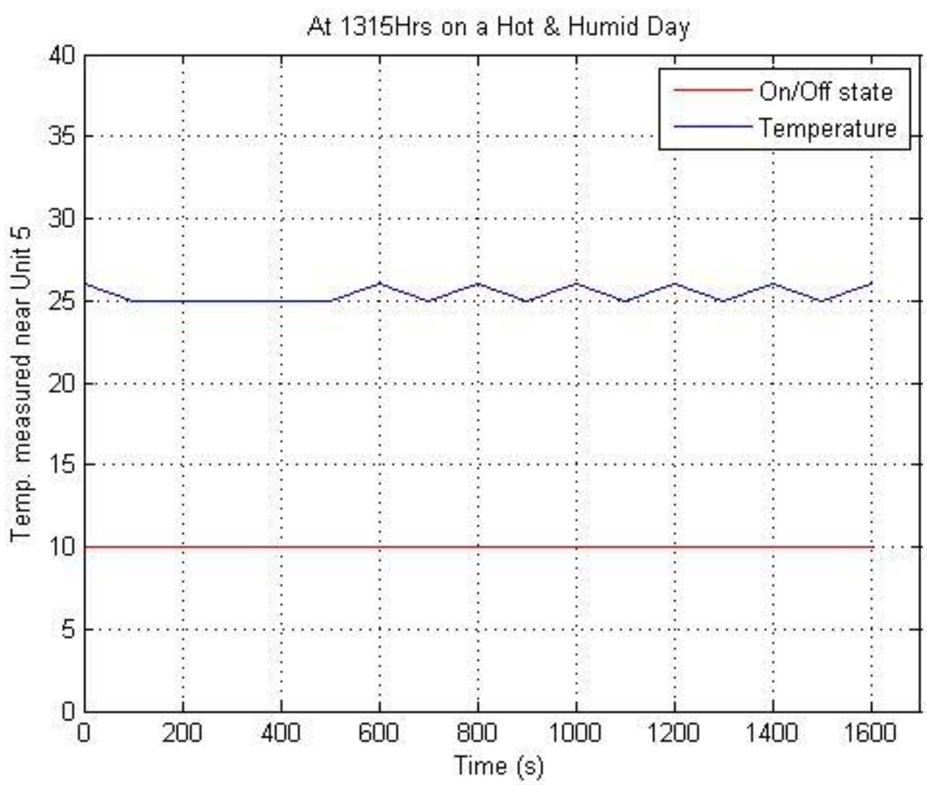

At 1240Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 8
Time (s)
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600

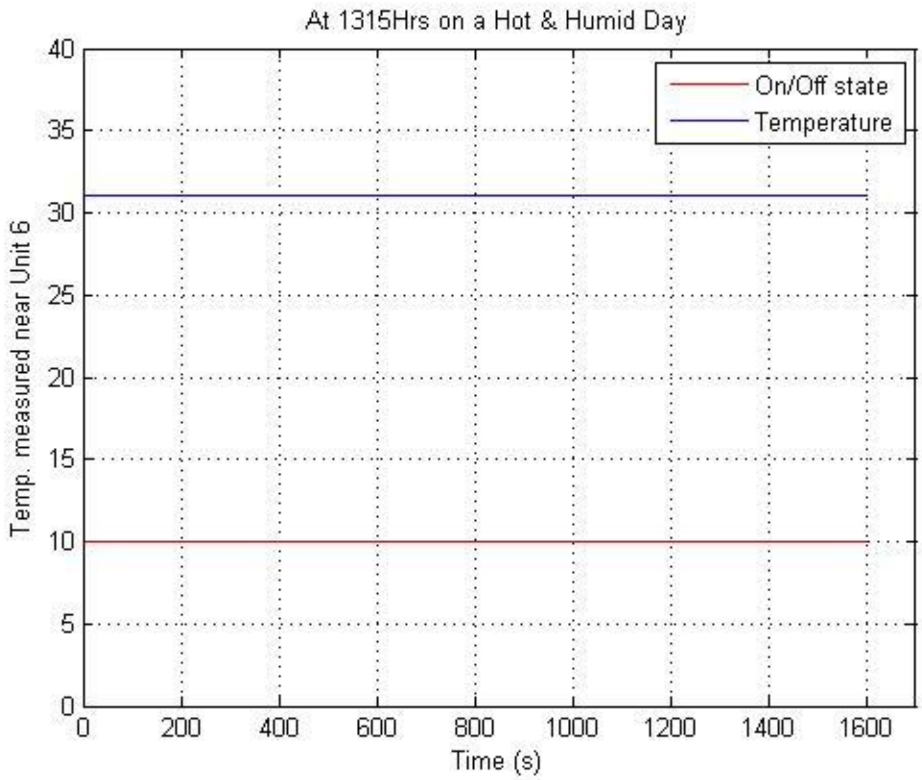
Start time - 1315 Hrs and measured for 1600 s




At 1315Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 4
Time (s)


At 1315Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 5
Time (s)


At 1315Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 6
Time (s)
0
200
400
600
800
1000
1200
1400
1600
0
5
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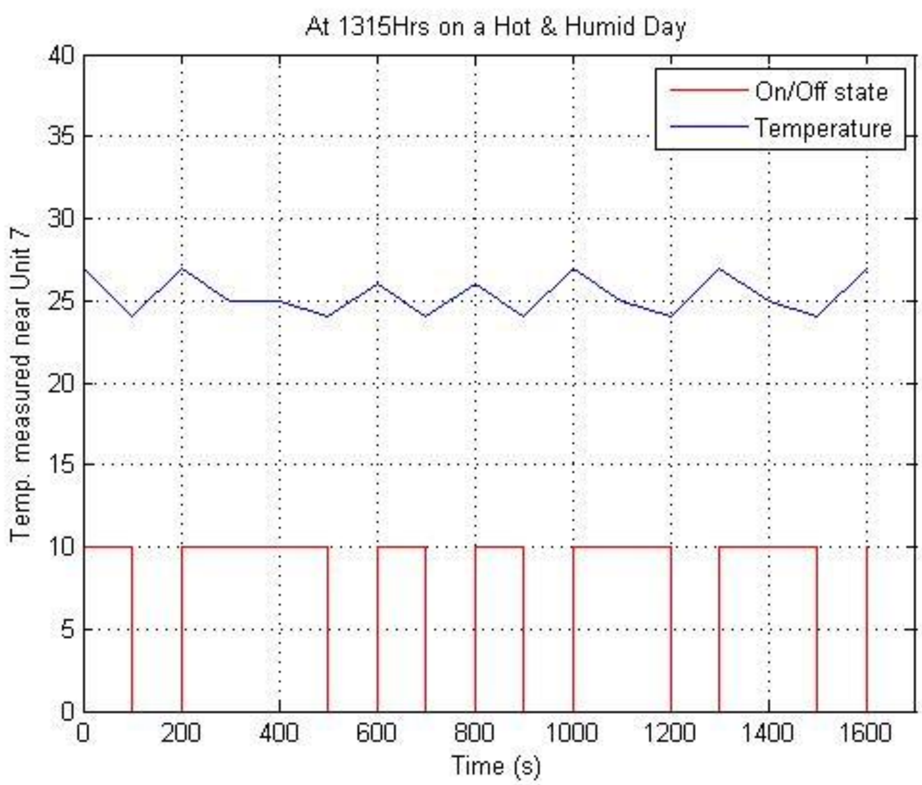
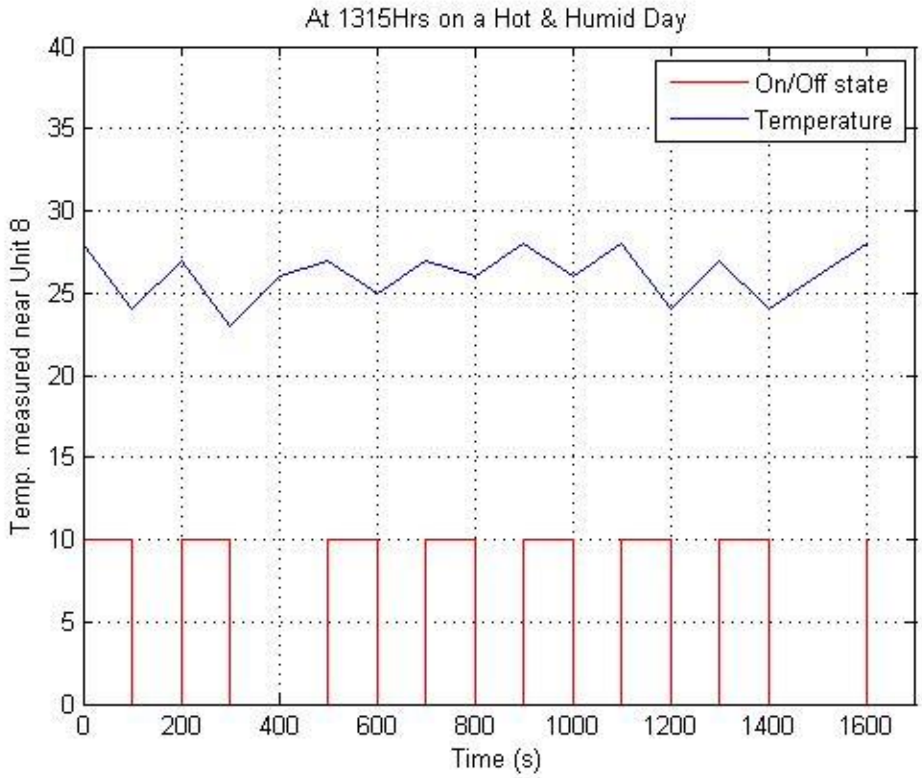
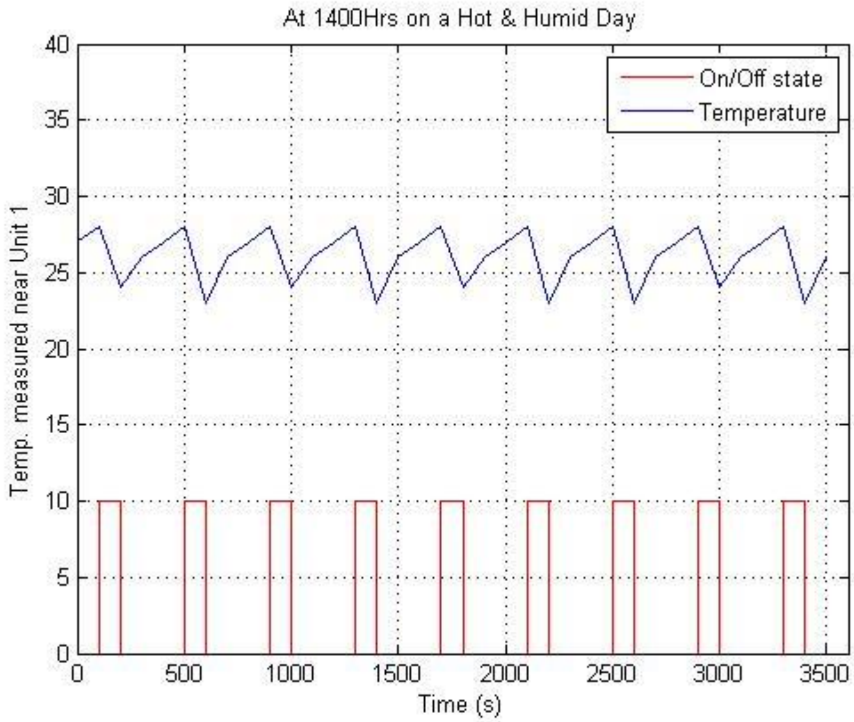
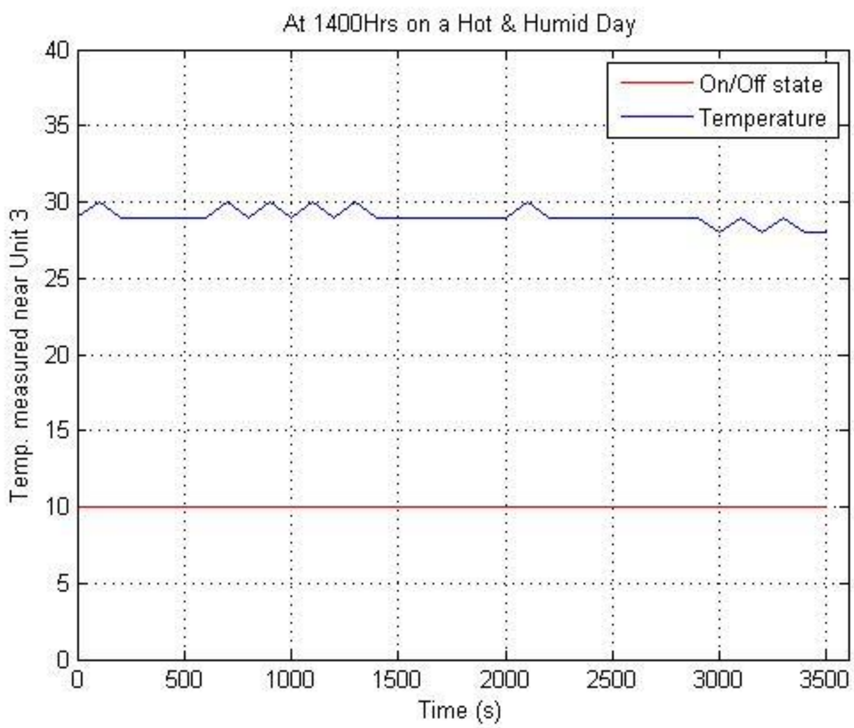
20
25
30
35
40

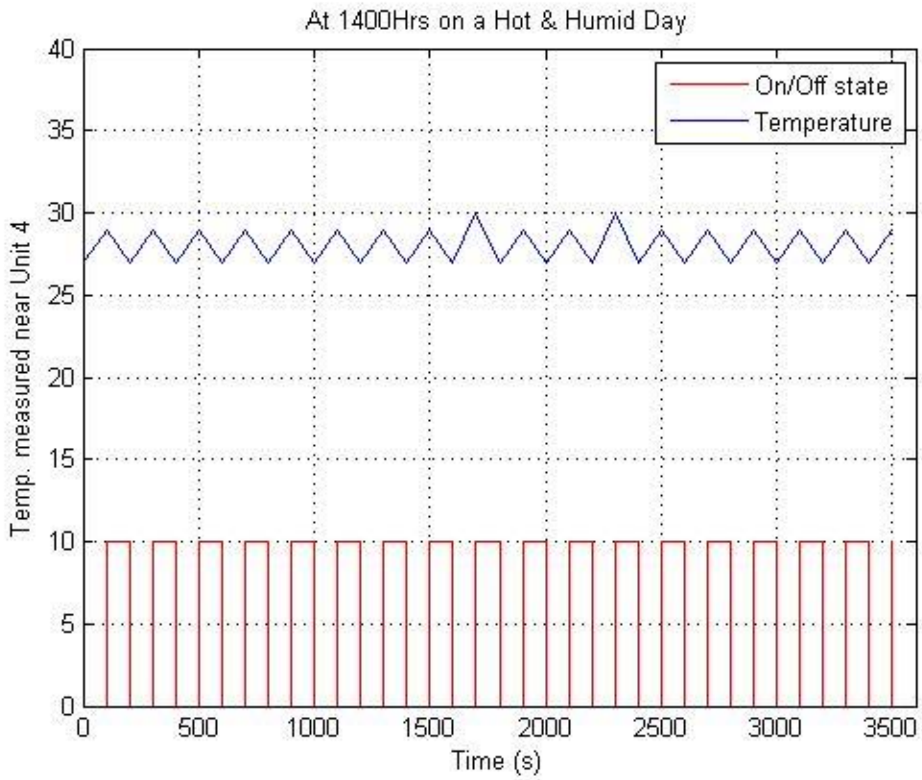

At 1315Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 7
Time (s)
0
200
400
600
800
1000
1200
1400
1600
0
5
10
15
20
25
30
35
40

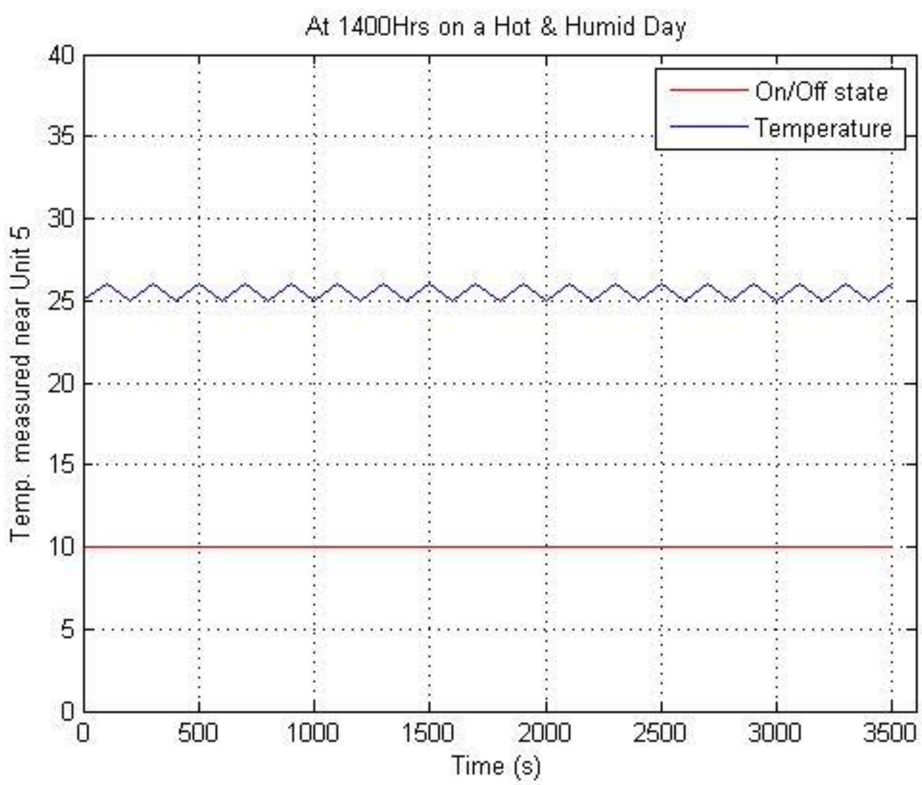

At 1315Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 8
Time (s)
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200
1400
1600

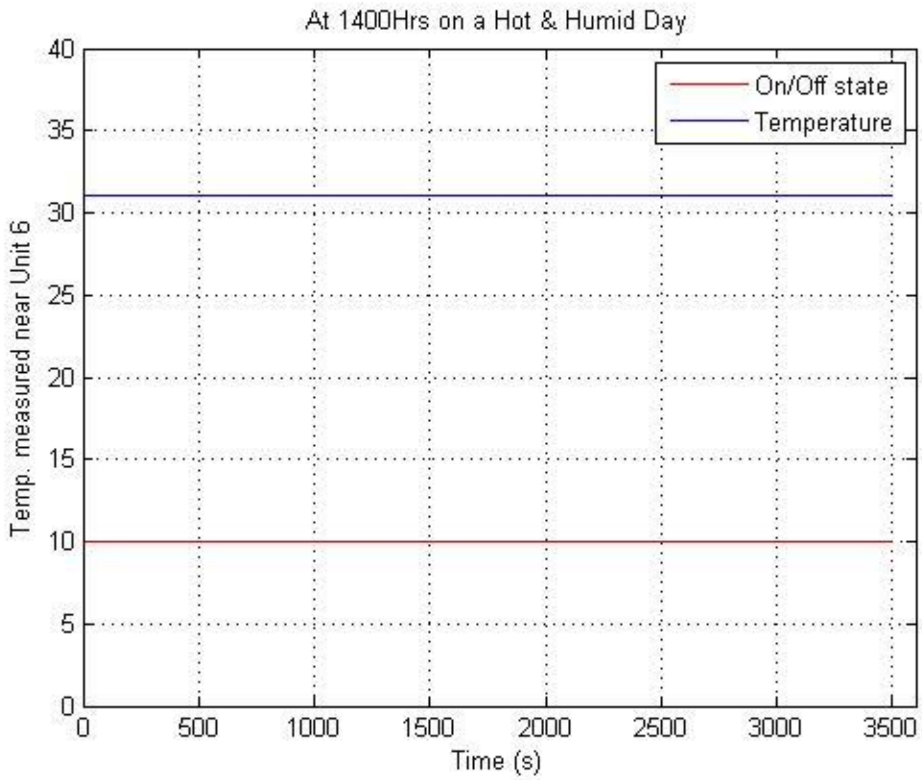
Start time - 1400 Hrs and measured for 3500 s




At 1400Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 4
Time (s)
0
5
10
15
20
25
30
35
40
500
1000
1500
2000
2500
3000
3500


At 1400Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 5
Time (s)
0
5
10
15
20
25
30
35
40
500
1000
1500
2000
2500
3000
3500


At 1400Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 6
Time (s)
0
500
1000
1500
2000
2500
3000
3500
0
5
10
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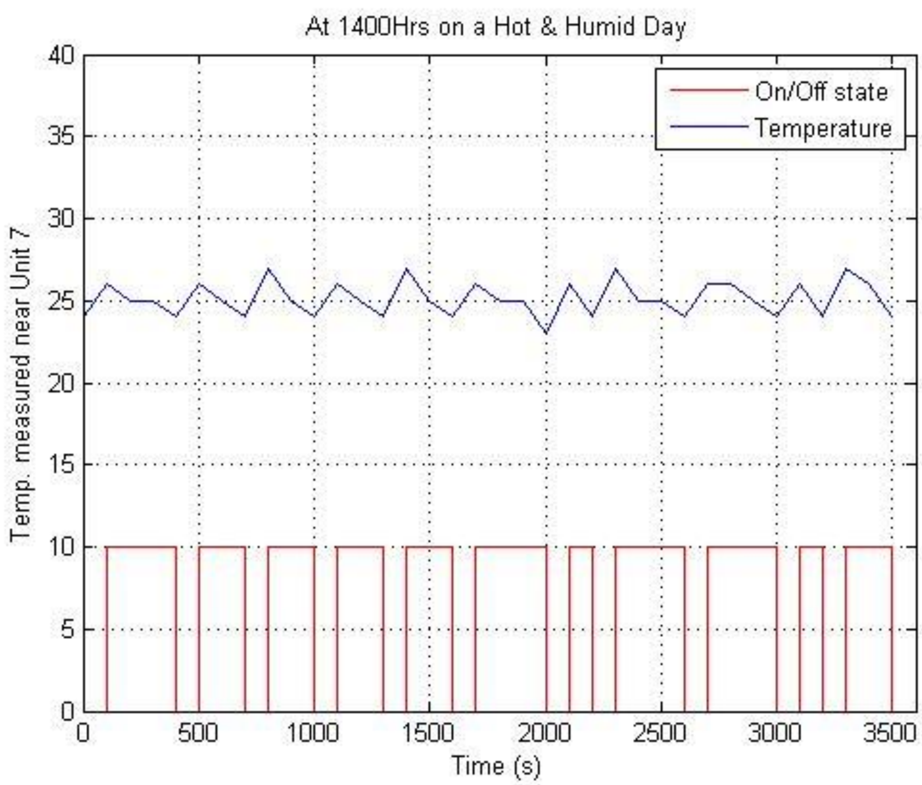
20
25
30
35
40


At 1400Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 7
Time (s)
0
500
1000
1500
2000
2500
3000
3500
0
5
10
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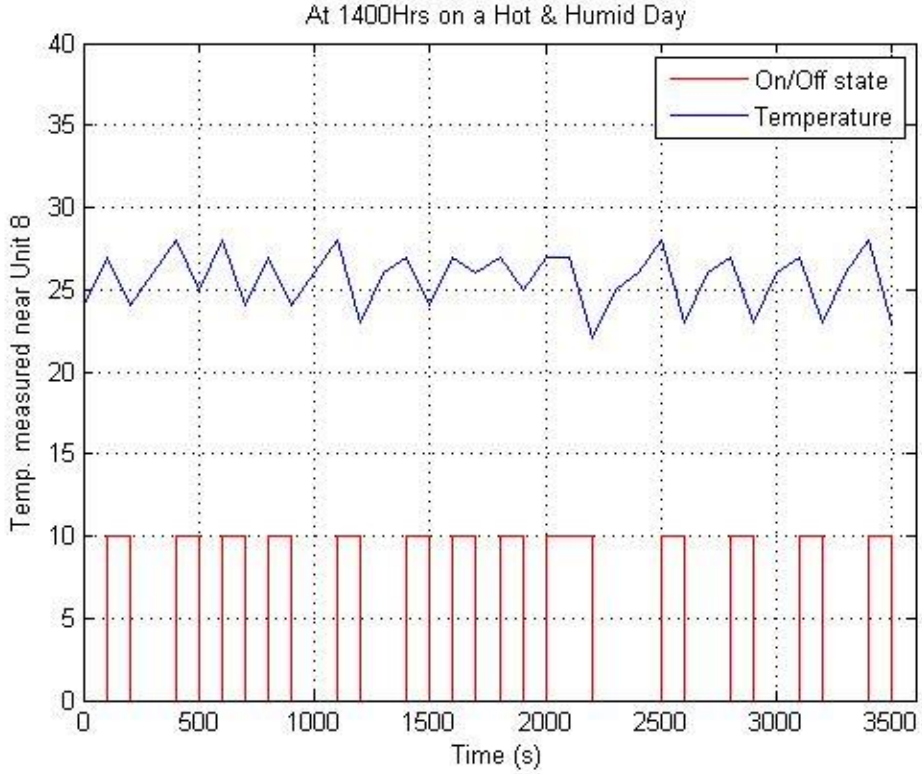
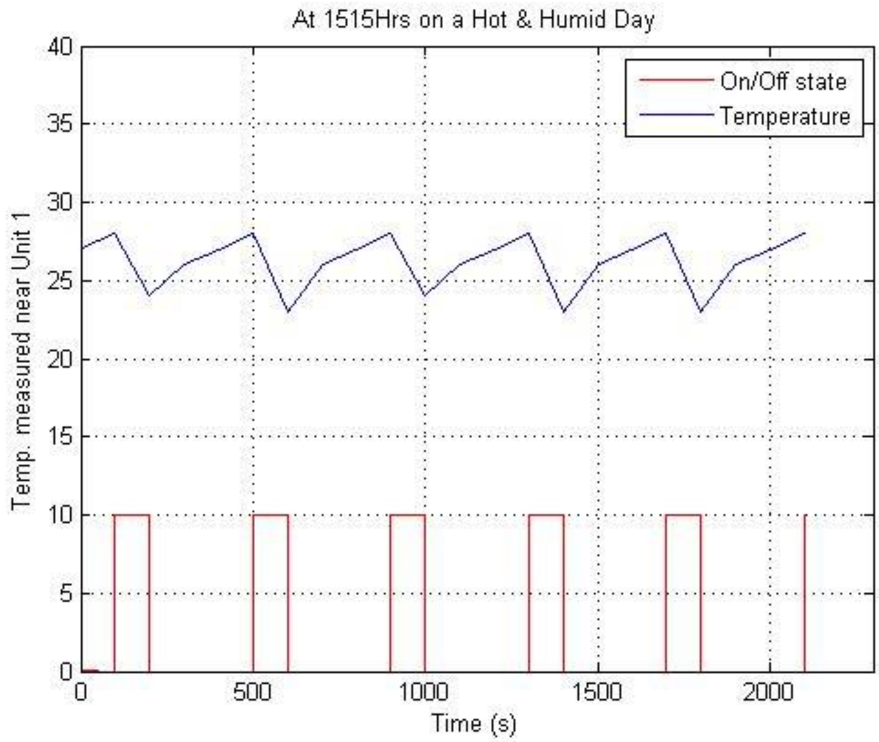
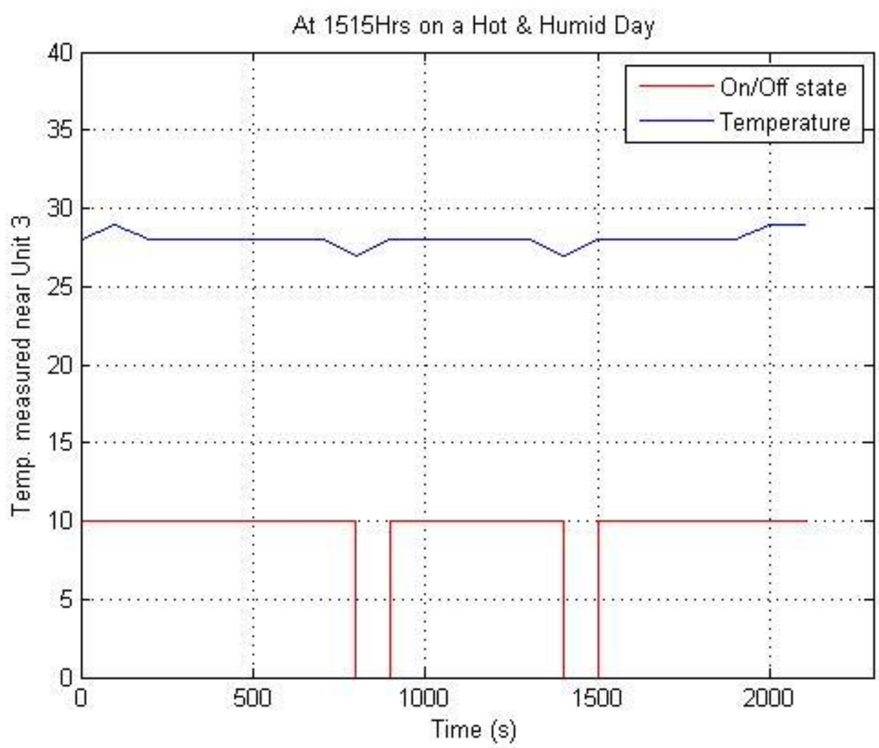
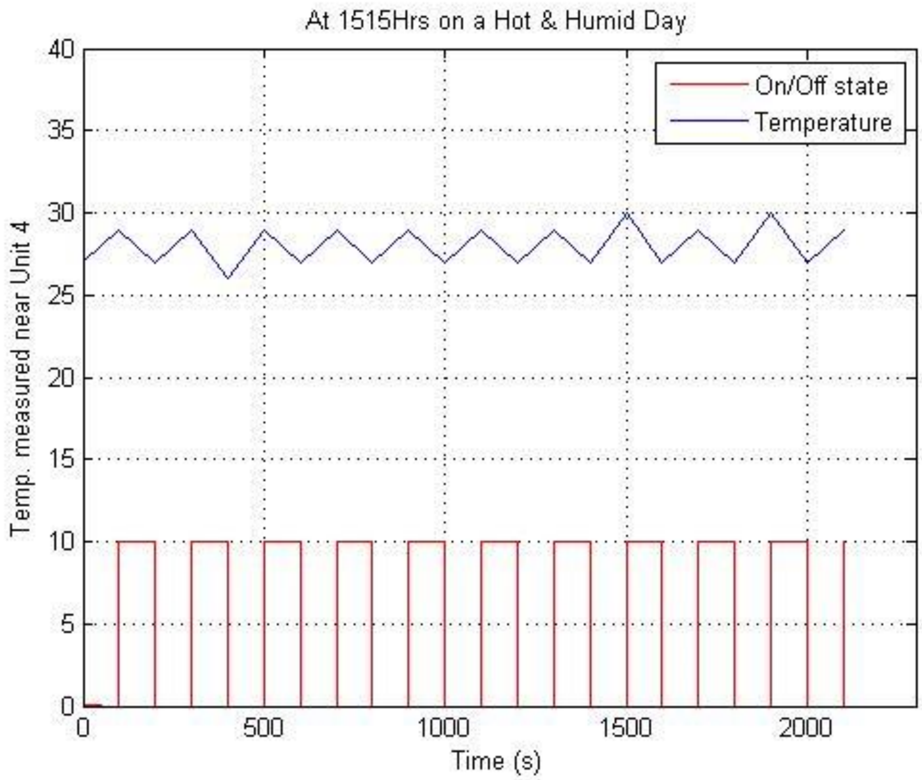
20
25
30
35
40

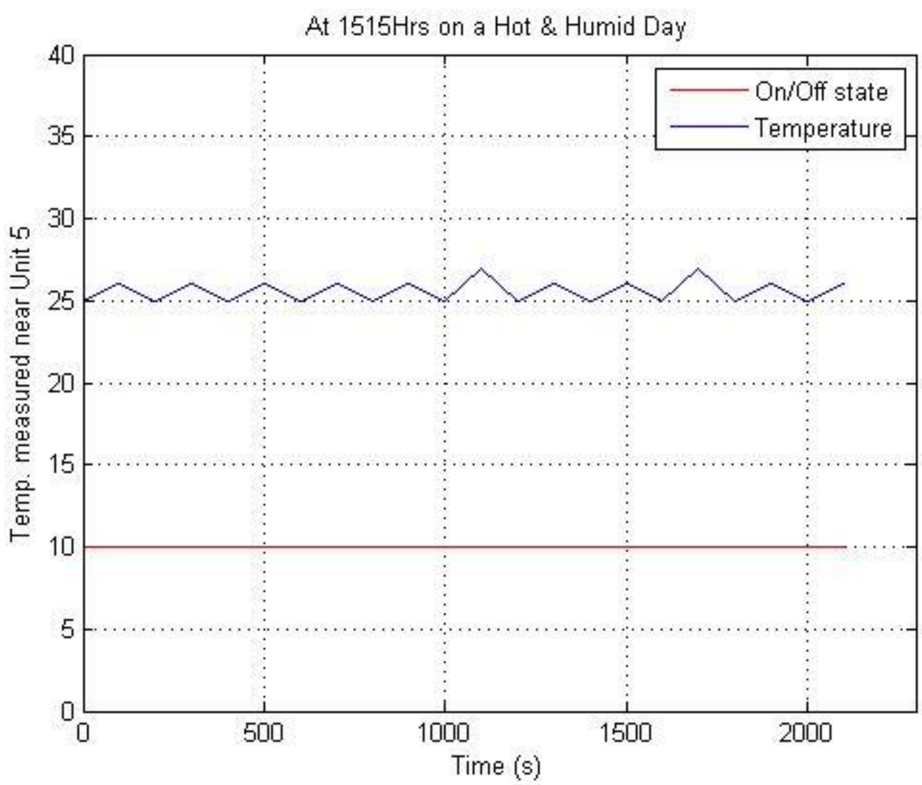

At 1400Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 8
Time (s)
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000
2500
3000
3500

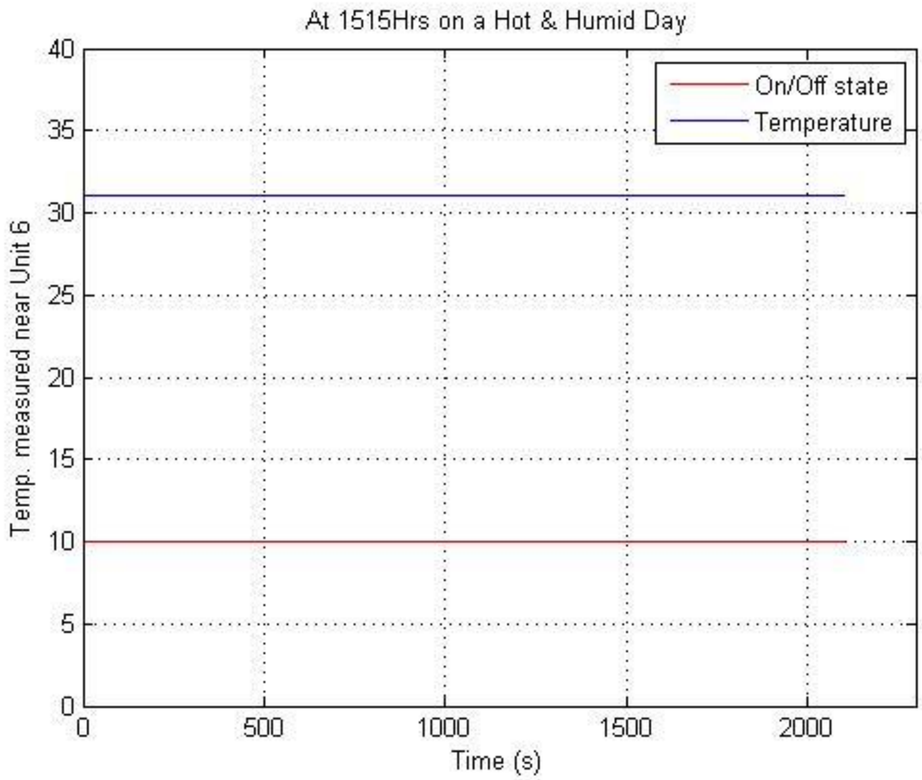
Start time - 1515 Hrs and measured for 2000 s

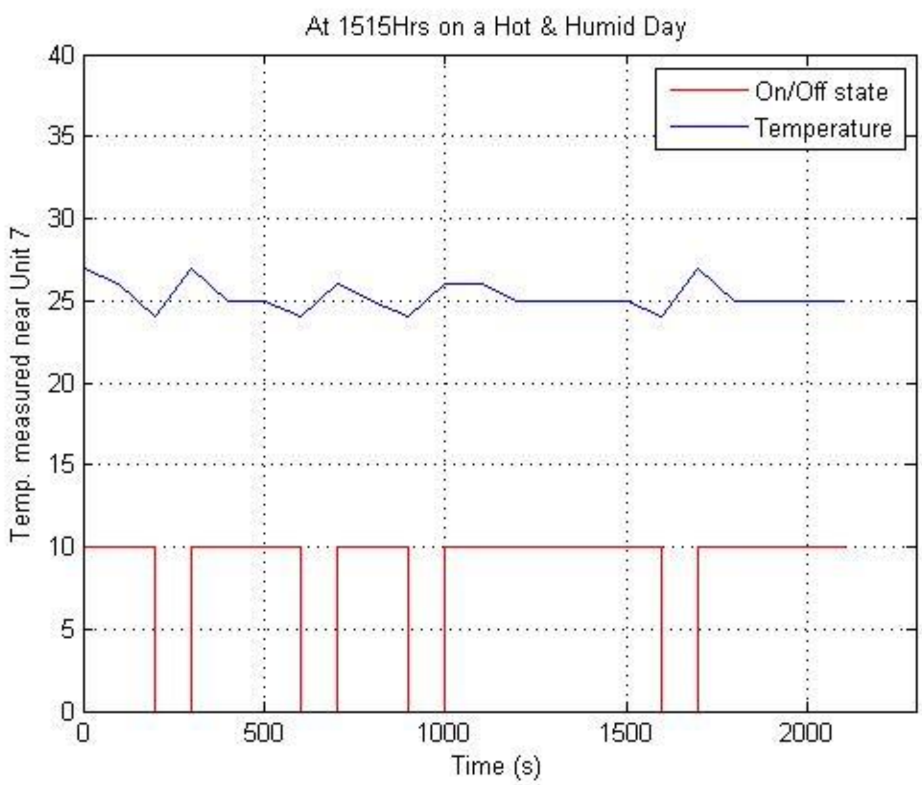


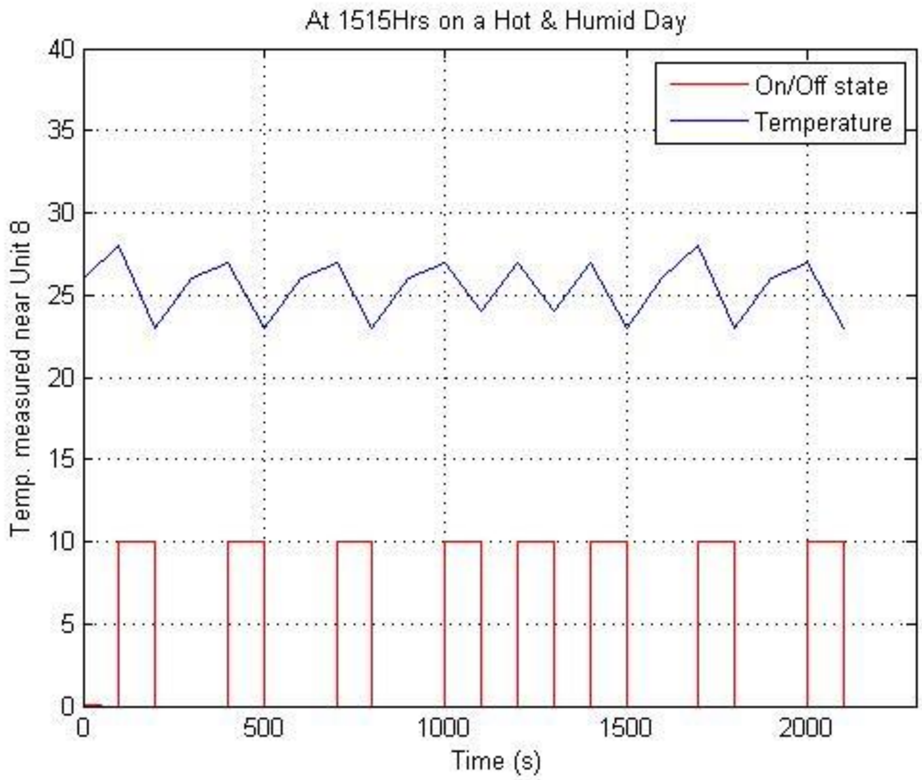




At 1515Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 4
Time (s)
0
500
1000
1500
2000
0
5
10
15
20
25
30
35
40

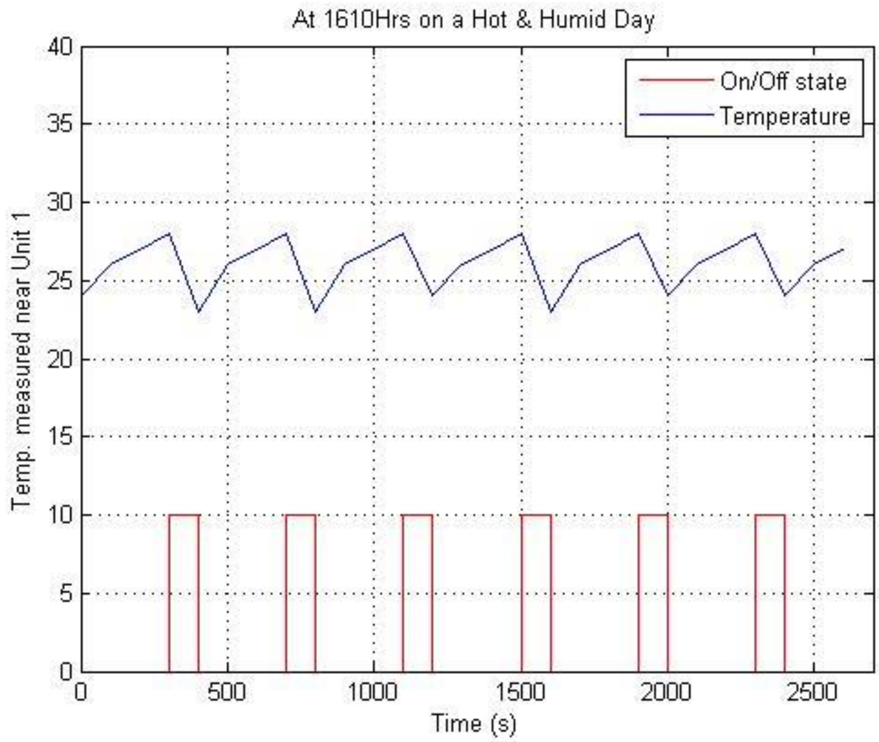

At 1515Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 5
Time (s)
0
500
1000
1500
2000
0
5
10
15
20
25
30
35
40

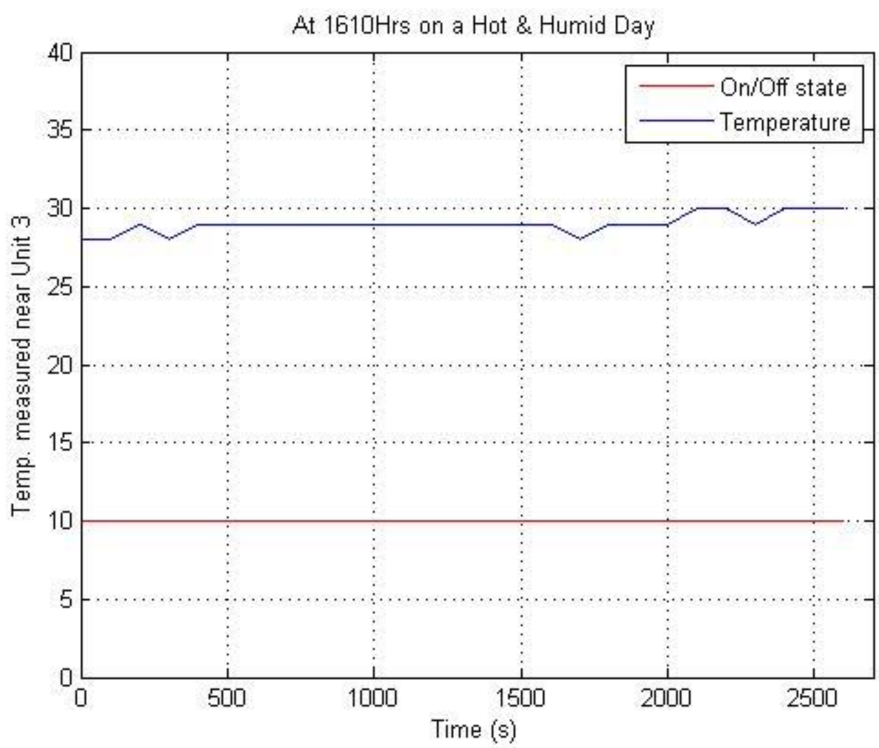

At 1515Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 6
Time (s)
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000

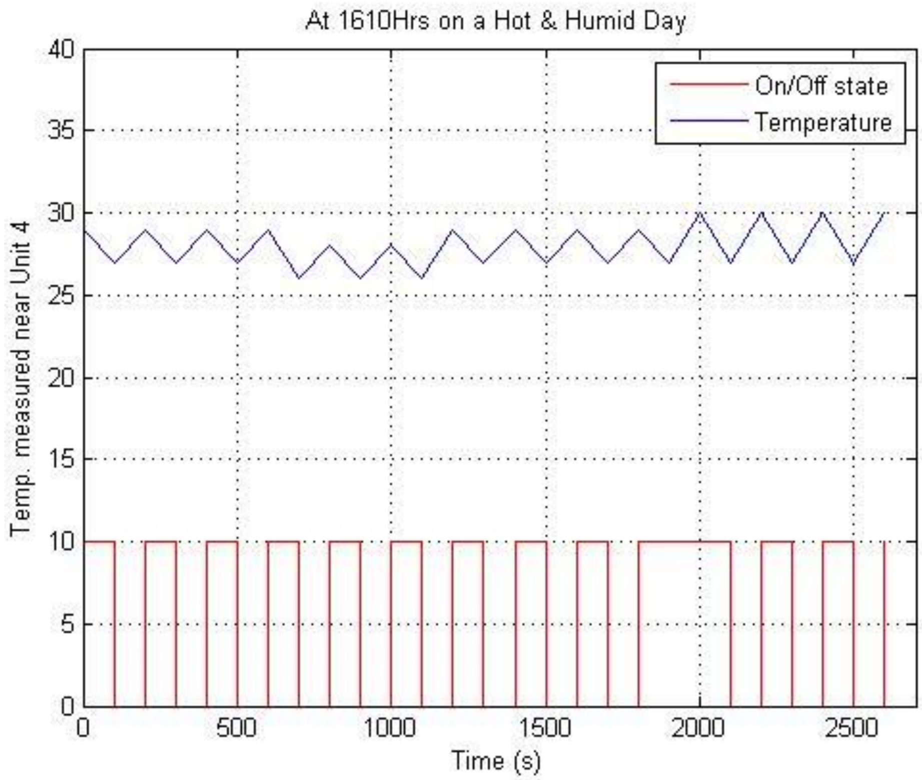

At 1515Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 7
Time (s)
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000

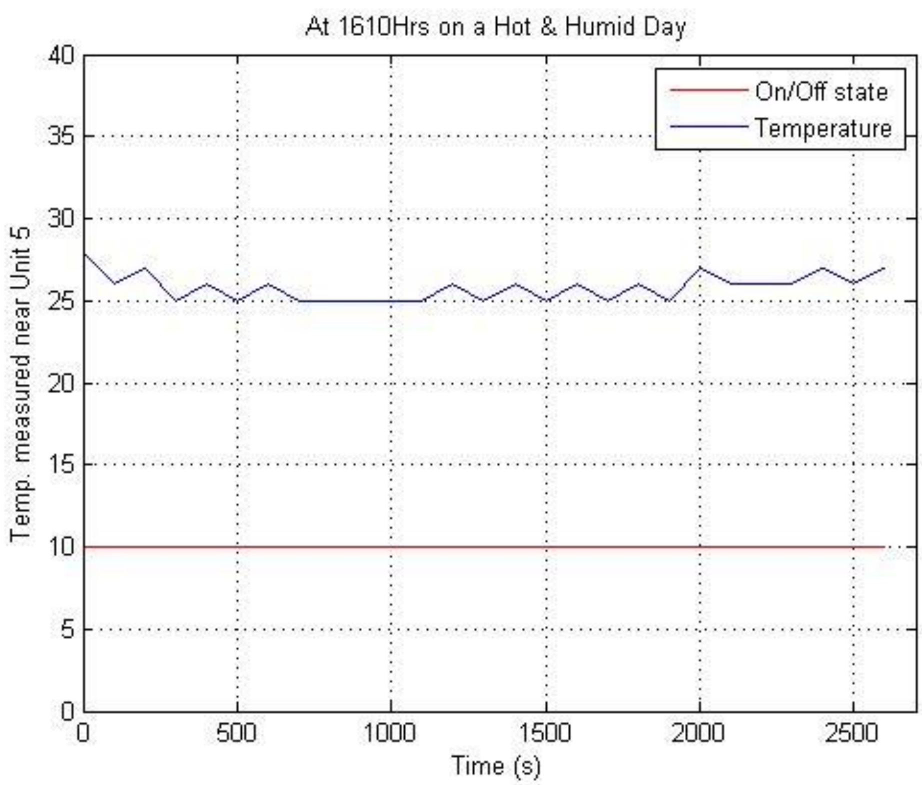

At 1515Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 8
Time (s)
0
500
1000
1500
2000
5
10
15
20
25
30
35
40

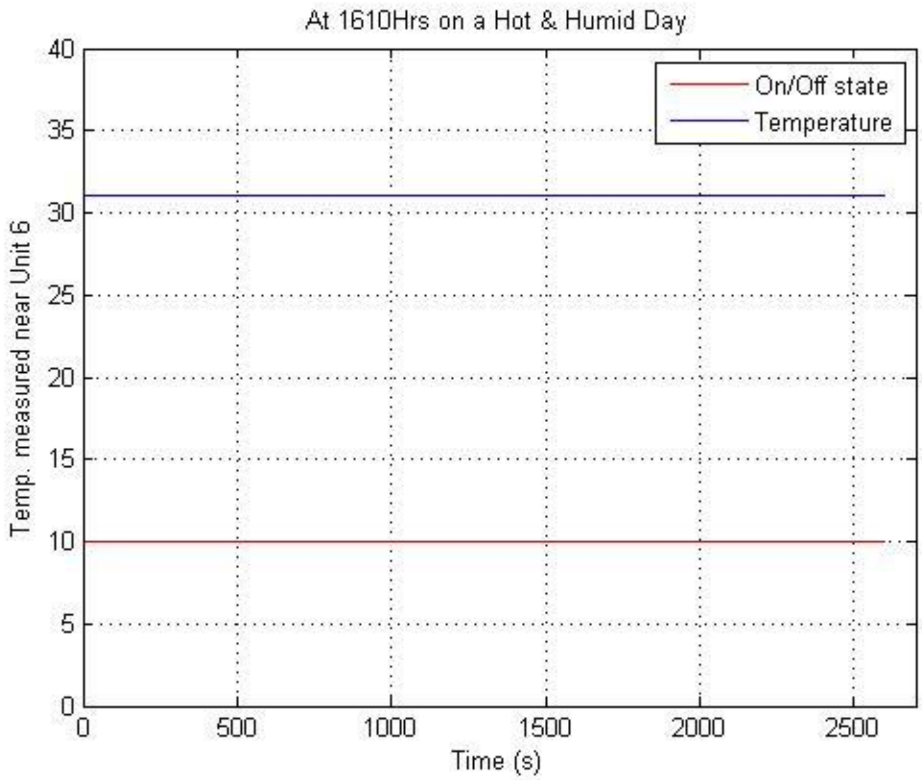
Start time - 1610 Hrs and measured for 2500 s

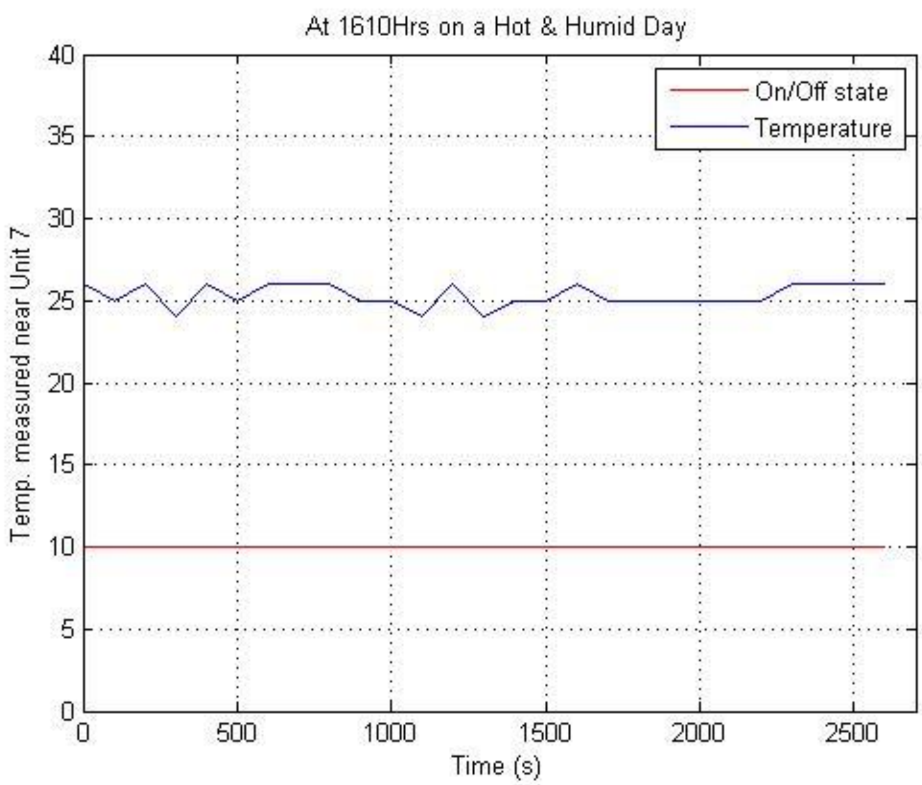


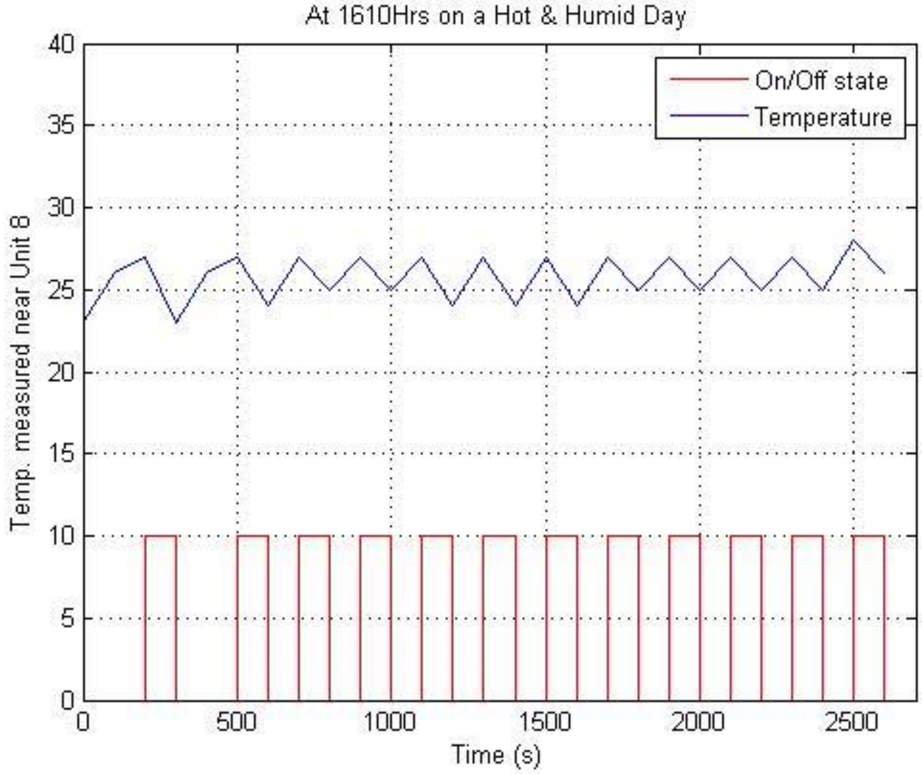




At 1610Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 4
Time (s)
0
5
10
15
20
25
30
35
40
500
1000
1500
2000
2500

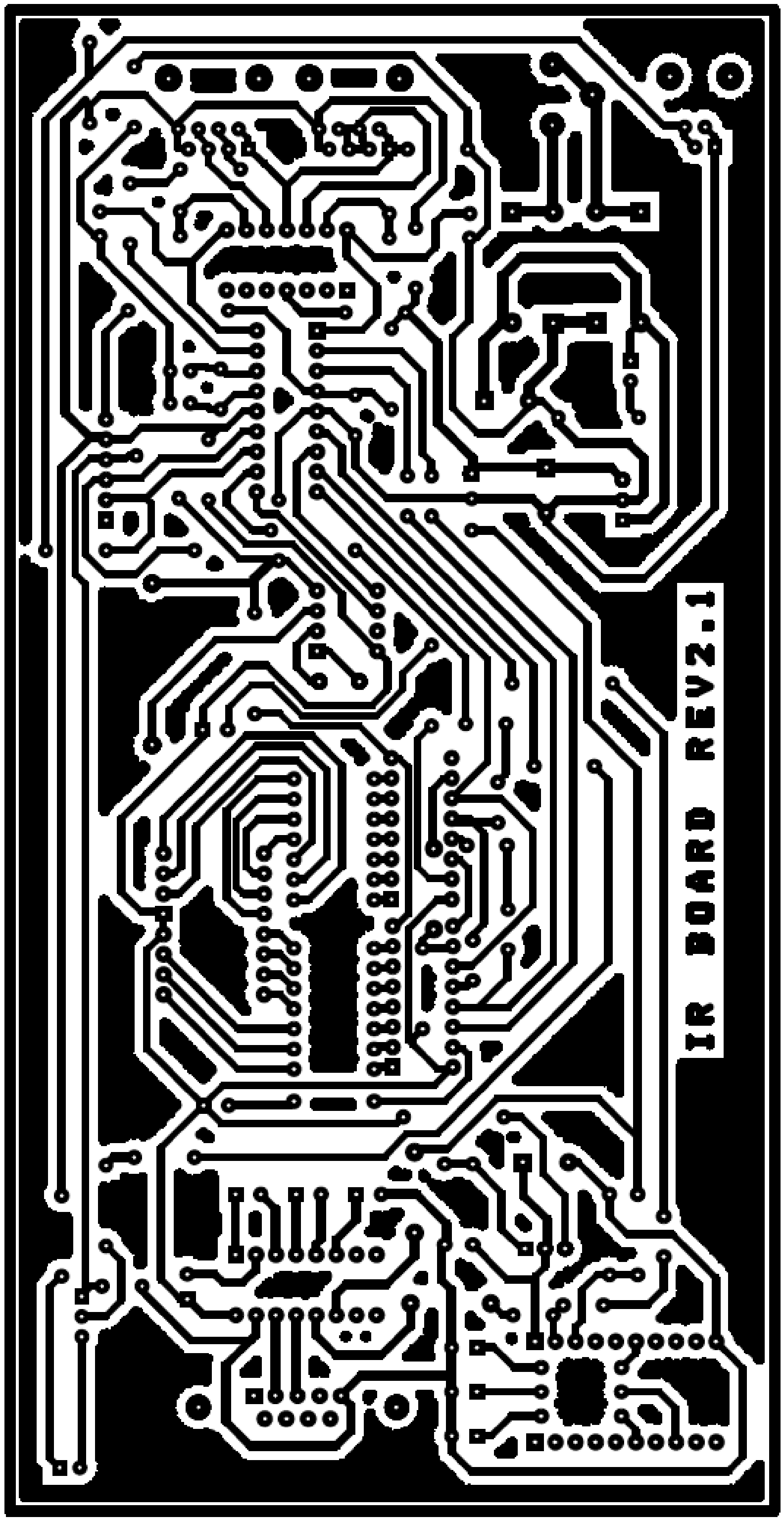

At 1610Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 5
Time (s)
0
5
10
15
20
25
30
35
40
500
1000
1500
2000
2500

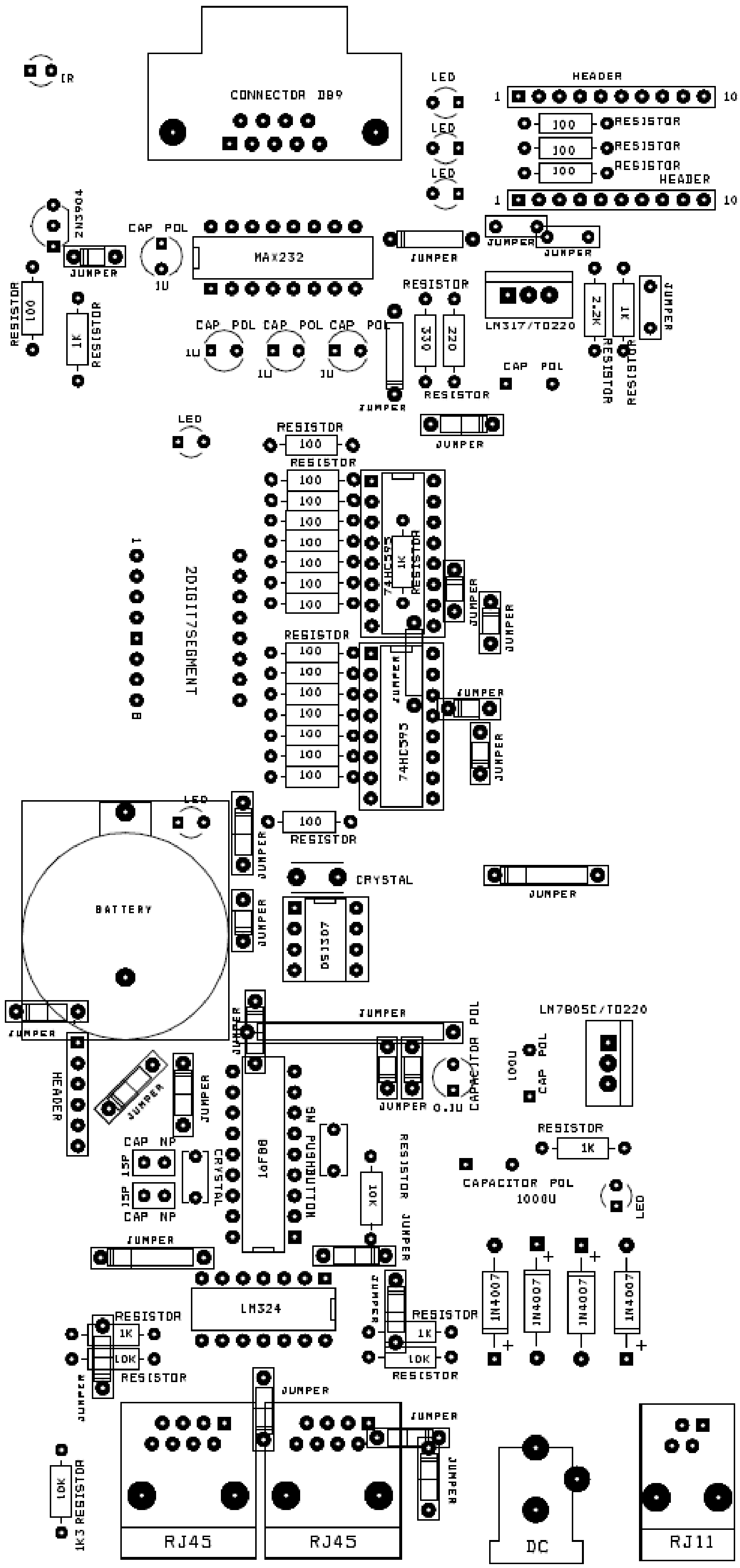

At 1610Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 6
Time (s)
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000
2500


At 1610Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 7
Time (s)
0
5
10
15
20
25
30
35
40
0
500
1000
1500
2000
2500


At 1610Hrs on a Hot & Humid Day
On/Off state
Temperature
Temp. measured near Unit 8
Time (s)
0
500
1000
1500
2000
2500
0
5
10
15
20
25
30
35
40

## Appendix 02




IR
CONNECTOR DB9
LED
HEADER
1
10
100
RESISTOR
2N3904
CAP POL
MAX232
JUMPER
1U
LM317/TO220
2.2K
1K
330
220
2DIGIT7SEGMENT
74HC595
BATTERY
CRYSTAL
DS1307
LM7805C/TO220
CAPACITOR POL
0.1U
100U
16F88
SW PUSHBUTTON
10K
CAP NP
15P
1000U
1N4007
LM324
RJ45
DC
RJ11
1K3