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Master of Science in Mechanical Engineering

FALL DETECTION USING PASSIVE INFRA-RED SENSORS

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Abstract

The people who are old and physically challenged are taken care by lot of non-profit organisations. They have the difficulty to perform their routine itself because of their inability to handle the day to day activities. These organisations and hospitals employ helper robots to detect the patients. The helper robot has PIR sensor installed in it, which can detect the patients even in dark environments in various positions. A passive infra-red sensor is used to indicate the human body temperature as well as to indicate whether the person is in motion. The system can detect the presence of the patients based on the voltage measured by the sensors. But it cannot conclude the position of the patients based on the heat of the body. It can mislead us to a wrong assumption that the patient needs help. The detection of the fall is done based on the delta and error calculations in different environmental scenarios. So, delta and error calculation are be performed with different subjects to arrive to a conclusion, which will be certainly considered as a bad scenario, and the patients is down and needs help. The Delta temperature is considered as a measure of the detection reliability in all the scenarios.

Keywords: Human detection, PIR sensors

1 Introduction

For elderly people, fall incidents are often life changing events that might lead to degradation or even loss of autonomy. More than half of the elderly living in a nursing home and about one third of the elderly living at home fall at least once a year. Complication starts when human fallen is not being detected. Of those who fall, 10-15 suffer severe injuries. The lack of timely aid can lead to further complications. Although not all incidents lead to physical injuries, psychological consequences are equally important. Due to the high impact of falling, both fall prevention and reliable fall detection are necessities. The detection work processes, as currently employed. Human motion localization is one of the most significant and fundamental technologies in human–robot interaction applications such as person location services and assisted living (1) (2) (3).

Every person has different physical and mental characteristics according to gender, age, and race. Physical characteristics can be classified using video, audio, and medical information. Visual information – including face, skin, fingerprints, and gait – represents physical characteristics. The audio information, such as voice and speech, indicates physical and culture characteristics. Other special factors, as for instance, DNA or facial and hand thermograms, can also be used to recognize a person. As physical and psychological characteristics have a statistical similarity of gender, age, ethnicity, and culture, it is possible to predict then for a specific person through visual and audio information. The demographics similarity can be effectively used of human computer interaction, biometrics, and target advertising.

In robotics, various sensing systems for human detection and localization are based on acoustic sensors (4), ultrasonic sensors (5), and optical imaging sensors (6). However, the applicability of acoustic and ultrasonic sensors is limited due to the lack of the capability to distinguish the human from other objects. Human localization using the optical image sensors relies on sophisticated computer vision algorithms (6), which are highly sensitive to the light illumination and background changes. Thus, the optical image sensors fail to be applicable to human motion localization in human following scenarios of interest here (7)

Compare to an image sensor, a depth sensor has a lower resolution, but it can obtain the depth data using a PIR sensor in dark environment. Conventional point smoke and fire detectors typically detect the presence of certain particles generated by smoke and fire by ionization or photometry. An important weakness of point detectors is that the smoke must reach the sensor. This may take significant amount of time to issue an alarm and therefore it is not possible to use them in open spaces or large rooms. The main advantage of differential Pyro-electric Infrared (PIR) based sensor system for fire detection over the conventional smoke detectors is the ability to monitor large rooms and spaces because they analyze the infrared light reflected from hot objects or fire flames to reach a decision. Our approach uses PIR sensor as a depth sensor to detect humans at the interactive media art exhibition in dark environment. The PIR sensor is preferable for human detection, because it is sensitive to the changes of infrared radiation induced by the human motion and robust to environmental changes (8) (9) (10). A depth sensor is used to detect audiences in a dark environment, such as a PIR sensor. Some researches explore the use of PIR sensors in human motion information acquisition. Recent studies (11) show that PIR sensors with Fresnel lens arrays are capable of infrared motion sensing with high sensing efficiency, especially, in detecting and localizing moving persons.

In surveillance system the capacitive charge displacement pyroelectric infrared sensor is not only one of the crucial elements, but also provide a fast and cost-effective solution of detecting warm body in the active inspection zones. In construction of a PIR system, shape the infrared radiation from certain inspection zones to the sensor die. In applications, these sensors have been used in passive IR motion tracking system utilizing coded apertures. PIR sensor-based system was proposed for target tracking and angle-only measurements of the target from missile (12), in intelligent system to distinguish human from other objects, track and detecting.

Human and others warm blooded animals' skin radiate heat with wavelength between 8μm to 14 μm in the thermal IR region. The skin temperature of a normal human being is 37°c. For most of the commonly available PIR sensor with adequate beam focusing it is possible to detect human movement at several meters from sensor present inside and near the active Fresnel zones. Besides humans, several other things with good emissive value emits EM radiation in thermal IR region which can be detected by a PIR sensor.

1.1 State of art

Accurate measurement and monitoring of physiological parameters play an important role in a broad range of application in the field of healthcare, psycho-physiological examinations and sports training. Wearable methods for the measurement of physiological parameters are depend on the measurement of physiological parameters are dependent on the sensor to be attached to a subject, such as electrocardiogram, pulse oximetry, piezoelectric transducer and so on. The issue with such contact-based methods is that it may cause undesirable skin irritation, discomfort and soreness to the subject. Currently, laser Doppler, microwave Doppler radar, ultra-wideband radar and frequency modulated continuous wave radar systems are being investigated for contact-free measurements of physiological parameters. However, these systems require expensive hardware. Consequently, demand for low-cost and convenient non-contact methods of measuring and monitoring physiological signals has grown inquisitively. This new system provides a low cost and an effective way to estimate the resting heart rate, which is an important biological marker.

Existing approaches are mainly for extracting heart-related signals fall under two categories: wearable sensor technologies (13) and non-contact [ambient] techniques (14).

However, existing sensor that can extract these signals require physical contact with subject body, and cause interference with the user experience. Various wearable technologies, for instance, a portable ECG device, are used to detect human activities or performance. Unfortunately, the band is, uncomfortable when worn for extended periods and elders show a certain hostility versus wearable devices. It has a role to play in medical and exercise settings, but it is not a viable option for continuous use. In a similar fashion, wristband or a smart watch have shortcomings. The devices operation can be compromised by: moment of body, for instance, gesturing, exercise based on arm motion that can alter the blood circulation and the displacement of wearable device across the skin surface.

Despite the higher reliability and good signal quality of fixed-on-electrodes, that are inconvenient and inadequate for long-term and every day measurements. The presence of cable can limit he patient mobility and comfort to an extent, forcing him to maintain the position for all the monitoring period.

Non-contact techniques, on the other hand, are non-intrusive and more adequate for long-term monitoring. Despite some short-comings, the non-intrusive nature makes then an attractive option for daily monitoring. Several techniques based on laser Doppler, microwave Doppler radar, ultra-wideband radar, frequency modulated continuous wave radar and thermal imaging are investigated. The advantage of these approach is that they do not require uses to wear any sensors on their bodies. However, as they rely on outwardly expressed states, they tend to get interfered with external factors that are, however, easily controlled or suppressed. Our work is closet to prior work that uses signals to extract human presence.

Figure 1 Telecare robot and the docking section

1.2 PIR Sensor

A passive infrared sensor (PIR sensor) is an electronic sensor that measures infrared (IR) light radiating from object in its field of view. They are most often used in PIR-based motion detectors. In this paper, we describe a system capable of non-contact measuring using PIR sensor system. This system estimates the temperature from subject human body using pyroelectric infrared sensor (PIR). PIR sensor are small, inexpensive, low power, rugged, are easy to interface with, and are easy to use. One of these best features is that they do not wear out. PIR sensors have been extensively used in motion tracking systems. PIR sensor are mostly employed as occupancy (15). They have been extensively used in motion tracking systems. PIR sensors having digital output and modulation visibility of Fresnel lenses can provide capabilities for tracking human body, and counting people crossing door of room of building. However, the analog output signal of PIR sensors can provide beyond simple presence of a subject, including the instantaneous motion of the body (16).

PIR sensor are widely used for sensing motion of subjects. Infrared radiation exists in the electromagnetic spectrum at a wavelength that is longer than visible light (15). Objects that generate hear also generate infrared radiations and those objects include animals and the human body. PIR sensors are made of pyroelectric sensors that can detect the level of infrared radiations and thus are used commercially used for automation of electrical applications and home surveillance systems.

The basic functionality of differential PIR sensor is to measure the difference in infrared radiations density of two pyro-electric elements within the sensor. Normal variations in the temperature caused by the air are nullified by the two elements connected in parallel. If the element measures same amount of infrared radiations, the sensor produces zero output. Most of the commercially available PIR motion sensor circuits produce digital output. Nonetheless, analog signal output can also be obtained from PIR sensors. We exploit the analog signal obtained from the PIR sensor to detect the human and eventually help estimate the subject presence.

Our design detects the change in infrared thermal heat patterns in front of a sensor to estimate the human presence. The sensor uses a couple of pyroelectric elements that respond to temperature variations within the viewing zone. Instantaneous difference in the output of the two elements is detected as motion, especially the motion of a heat-bearing object, such as a human.

1.3 Thermopile

Thermopiles are designed to measure temperature from a distance by detecting an object's infrared (IR) energy. The higher the temperature, the more IR energy is emitted. The thermopile sensing element, composed of small thermocouples on a silicon chip, absorb the energy and produce an output signal. A reference sensor is designed into the package as a reference for compensation.

Depending on the sensor, the output signal can be the standard resistance output, or packaged with analog or digital output signals. Various sensor packages are available including hermetically sealed housings, stainless steel packaged housings, and integral circuit boards and connectors.

The basic principle behind this sensor is thermopile. Thermopile is an electronic device that converts thermal energy into electrical energy. It is composed of several thermocouples connected usually in series or, less commonly in parallel. Thermocouples operate by measuring the temperature differential from their junction point to the point in which the thermocouple output voltage is measured.

Thermocouple can be connected in series as thermocouple pairs with a junction located on either side of a thermal resistance layer. The output from the thermocouple pair will be a voltage that is directly proportional to the temperature difference across the thermal resistance layer and also to the heat flux through the thermal resistance layer. Adding more thermocouple pairs in series increases the magnitude of the voltage output. Thermopiles can be constructed with a single thermocouple pair, composed of two thermocouple junctions, or multiple thermocouple pairs.

Thermopiles do not respond to absolute temperature, but generate an output voltage proportional to a local temperature difference or temperature gradient. Thermopiles are used to provide an output in response to temperature as part of a temperature measuring device, such as the infrared thermometers widely used by medical professionals to measure body temperature, or in thermal accelerometers to measure the temperature profile inside the sealed cavity of the sensor. They are also used widely in heat flux sensors and pyrheliometers and gas burner safety controls. The output of a thermopile is usually in the range of tens or hundreds of millivolts. As well as increasing the signal level, the device may be used to provide spatial temperature averaging. Thermopiles are also used to generate electrical energy from, for instance, heat from electrical components, solar wind, radioactive materials, laser radiation or combustion. The process is also an example of the Peltier effect as the process transfers heat from the hot to the cold junctions.

Our studies are mainly about contactless sensor type and it is all about devising a system to fix in human assistant robot. Therefore, a confirmation can be made that the subject is laying on the ground and we can alert the emergency team.

1.4 Selections of sensors

There are many types of sensors in the market and we are considering only three sensors. A short description about the characteristics of these sensors is given below.

After a detailed survey of the sensors in the market, the below three sensors are considered for the experiments, the sensors are chosen based on the dimensional attributes and field of view, so that a varied amount of knowledge can be obtained based on the working of the sensors.

1.4.1 TS305-11C55 & TS318-11C55:

TE Connectivity presents IR sensors featuring better performance and reliability as well as ease-of-use and overall simplicity. TE Connectivity's thermopile sensors incorporate infrared radiation, or "IR", technology which provides many benefits over conduction methods of heat transfer. These benefits include better performance and reliability as well as ease-of-use and overall simplicity when incorporating movement into a design. IR thermopiles also allow ambient temperature readings to be factored-in, thus providing greater accuracy and temperature control.

Both the sensors have same parameter specifications but the field of view of the sensors are different and is given below.

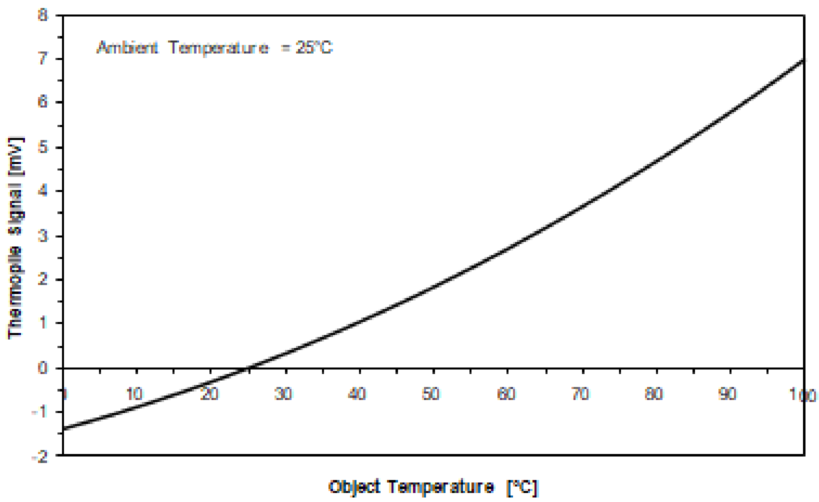


Figure 2 **Thermopile signal versus object temperature at 25°C ambient temperature**

1.4.1.1 Performance specifications

Parameter	Symbol	Value	Unit	Condition
Operating Ambient Temperature	T_{am}	-20 to +85	°C	Permanent
Operating Ambient Temperature	T_{amb}	-20 to +100	°C	non-permanent
Package		TO-5		
Absorber Area	A	0.8	mm^2	
Thermopile Resistance	R_{TP}	70 ± 30	k□	T_{amb} = +25°C
Temperature Coefficient of Thermopile Resistance	TCR_{TP}	-0.06 ± 0.04	%/K	T_{amb} = +25°C to +75°C
Voltage Response	V_{TP}	7.0 ± 2.1	mV	T_{amb} = +25°C, T_{obj} = +100°C, DC, totally filled field of view
Temperature Coefficient of Voltage Response	TCV_{TP}	-0.45 ± 0.08	%/K	T_{amb} = +25°C to +75°C
Noise Equivalent Voltage	NEV	45	nV/Hz^{½}	T_{amb} = +25°C
Rise Time	□$_{63}$	12 ± 5	ms	
Ambient Temperature Sensor		NTC		
Ambient Temperature Sensor	R_{NTC}	100 ± 5	k□	T_{amb} = +25°C
Beta Value of NTC	□-Value	3955 ±0.3%	K	T_{amb} = 0°C to +50°C

Table 1 Parameters Specification

1.4.2 ZTP-115

This thermopile sensor is used for non-contact surface temperature measuring. The ZTP-115 model consists of thermo-elements, flat IR filter, a thermistor for temperature compensation and a hermetically-sealed small-size package. There is also a variety of filters available to maximize performance in specific applications.

ZTP Thermopile Infrared (IR) Sensors are industry-leading higher sensitivity level sensors. These devices respond to a broad infrared spectrum, offer an inherently stable response to DC radiation, and do not require source of bias voltage or current. Consisting of thermo-elements, flat IR filter, and a thermistor for temperature compensation in a hermetically-sealed TO package, the series has a variety of filters available to maximize performance in specific applications.

ZTP Thermopile IR Sensors offers industry-leading Thermopile Infrared (IR) Sensors and Modules. The unique properties of Thermopile respond to a broad infrared spectrum, do not require source of bias voltage or current, and have an inherently stable response to DC radiation. The ZTP IR Thermopile devices are used to provide non-contact temperature measurement in thermometry, microwave ovens, induction heater cookers, air conditioners, occupancy detection, lighting, underfloor heating control, and HVAC / automotive applications.

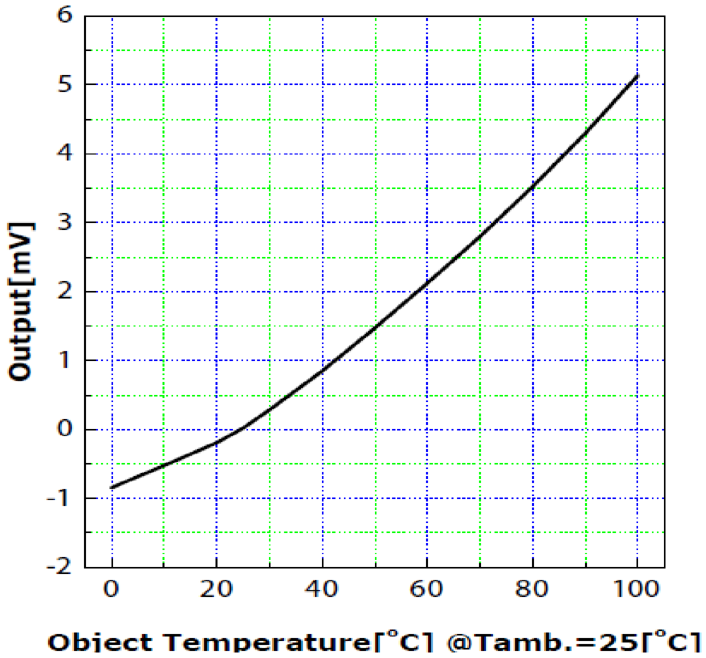


Figure 3 **Thermopile signal versus object temperature at 25°C ambient temperature**

1.4.2.1 Performance specifications

Parameter	Value	Unit	Condition
Chip Size	1.8 * 1.8	mm^2	
Diaphragm Size	1.0 * 1.0	mm^2	
Active Area	0.5 * 0.5	mm^2	
Thermopile Resistance	50 ± 15	k□	T_{Amb} = +25°C
Temperature Coefficient of Thermopile Resistance	-0.06 ± 0.04	%/K	T_{amb} = +25°C to +75°C
Voltage Response	7.0 ± 2.1	mV	T_{amb} = +25°C, T_{obj} = +100°C, DC, totally filled field of view
Temperature Coefficient of Voltage Response	-0.45 ± 0.08	%/K	T_{amb} = +25°C to +75°C
Noise Equivalent Voltage	45	$nV/Hz^{½}$	T_{amb} = +25°C
Rise Time	12 ± 5	ms	
Ambient Temperature Sensor	NTC		
Ambient Temperature Sensor Resistance	100 ± 5	k□	T_{amb} = +25°C
Beta Value of NTC	3955 ±0.3%	K	T_{amb} = 0°C to +50°C

Table 2 Performance Specification

1.4.2.2 Field of view

Sensor	Symbol	Value	Unit	Description
ZTP-115	FOV	55	deg	at 50% of maximum signal
TS305-11C55	FOV	88	deg	at 50% of maximum signal
TS318-11C55	FOV	110	deg	at 50% of maximum signal

Table 3 Field of view of sensors

1.4.3 Modeling of the sensor support

The below given design is modeled using Creo modeling software based on the external diameter of the sensors and the design is adopted to provide enough area to comfortably mount the sensor holder on the experimental setup. From the below image, the extremely smaller left hole is for TS318-11C55, the middle one is for TS305-11C55 and the extreme right one is for ZTP115 sensor.

The CAD model is converted into a physical part by 3D printing using the available printers in the university laboratory.

Figure 4 CAD Model

The below given image provides a clear view of the experimental setup to acquire the signals for the sensors. The setup includes the sensor holder, the vertical mount and the ground slider. The sensor holder accommodates the three sensors and the wires are taken from the rear side of the holder and connected to the acquisition board and finally fed into the MeasLAB software.

The vertical mount allows the sensor to acquire signals at 20 cm from the ground. The ground slider promotes the vertical mount to slide on it, so that the distance from the subject can be modified.

Figure 5 Setup with Slider and Markings

The thermal camera is used to recheck the ambient temperature of the environment which can be changed by conducting the experiments in a heat-controlled room.

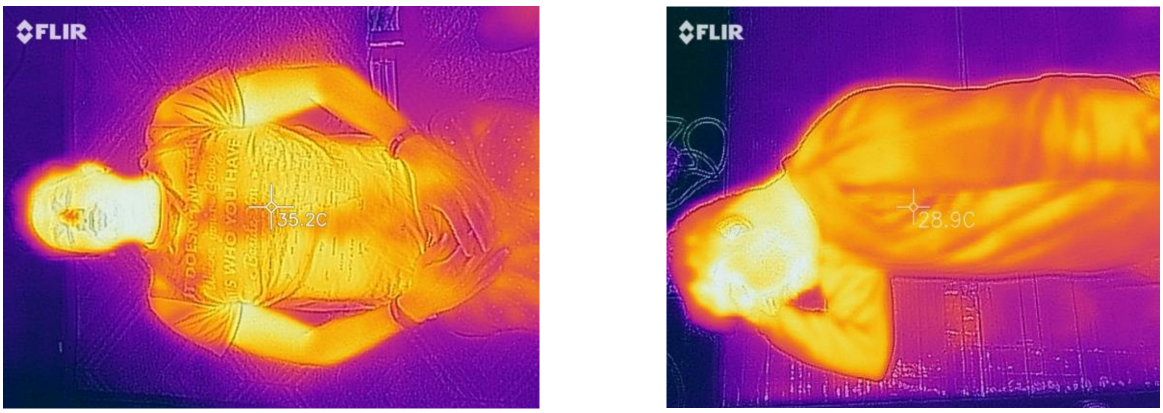


Figure 6 Thermal Camera Images

2 Experiments and factors considered for the experiments

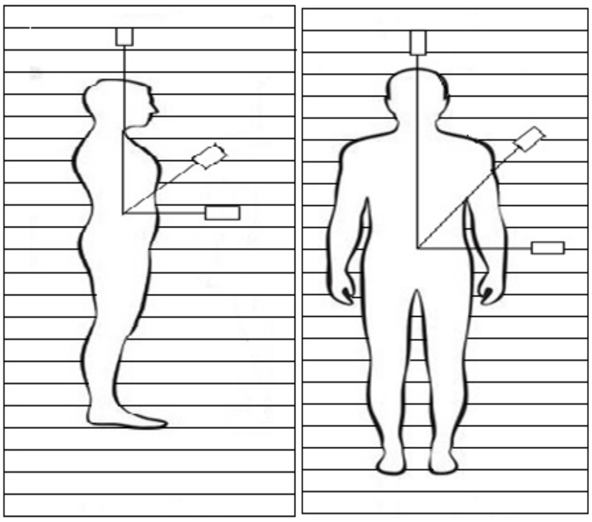
The parameters to be considered are many in number and so the number of experiments will also be high which would consume more time. So many experiments were conducted, and the number of parameters is narrowed down to,

- Angular positions 0, 45 and 90.
- Sensor height 15cm mounted on a rail of 5cm height.
- 6 sensor distances (10, 20, 30, 40, 50 and 60)
- Two subject positions

2.1 Experimental procedure

The experimental procedure is given below,

- Three sensors were placed in the sensor setup and was mounted on the rail.
- At two position which is A & B where A is facing the sensor and B is body facing upward.
- Sensor height from the ground is 15cm and is mounted on a rail of 5cm height.
- 6 sensor distances (10, 20, 30, 40, 50 and 60) are considered and the markings are done on the ground slider.
- Angular positions of the sensors will be 0º, 45º and 90º.
- For each angle and each position, six readings are taken which are at 10 20 30 40 50 60 cm away from the body silhouette. Each of the readings are taken for 30 s with an interval of 20 sec.
- Before experiment subjects' medical status is updated and personal details are noted such as height, age, weight etc.
- Measurements are done based on the silhouettes of a person.
- 2048 samples/sec and buffer time 1s.
- Reading are noted through accusation board (board no. 9234



Position A Position B

Figure 7 Subject Positions

The subject is very much informed about the experiments and procedures to conduct the experiments and the **subject consent form** is signed by the subject before performing the experiments.

The experiment is started first from 0 angle where the head reading is noted. This head reading is done for six different distance (10-60) cm and the values are noted. And its resistance values are noted with the help of the multimeter. Each reading is noted for 30 seconds.

Then the experiments are taken for position A which includes two angles and six distances. Each reading of 30 sec with interval of 20 sec between each experiment.
And for position B same procedure is carried out with two angles and six distance position.

In Measlab software, after the connecting the acquisition board to the PC in USB port, the channels which are connected to the sensors will be indicated. The required configuration and the measurement type are chosen, and a new project is created with sub files for every experiment conducted.

The signal is acquired for 30 seconds under various positions and angles with the subject at various distances from the sensor.

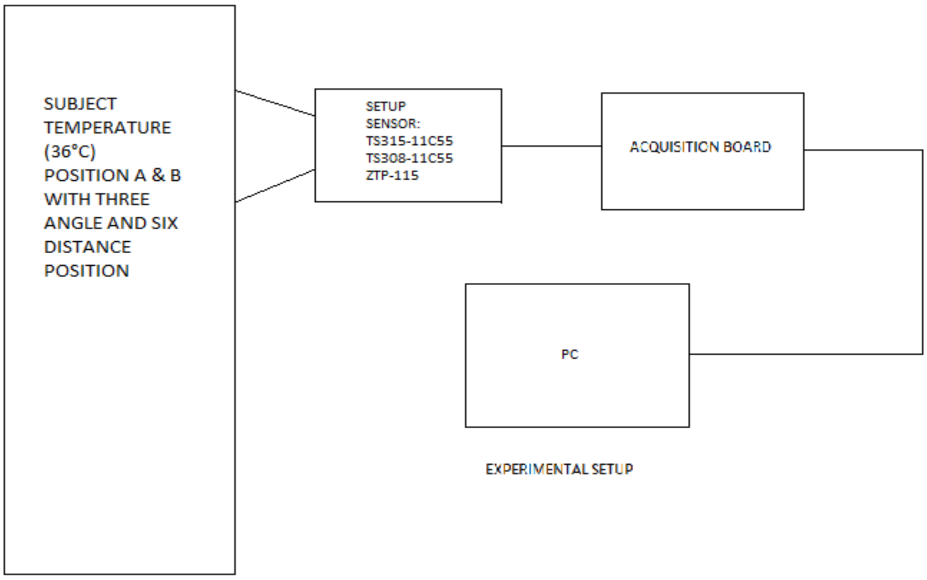


Figure 8 Overall experimental skeleton

The output form of the acquired signal from the sensor will be in analog form of millivolts which should be converted into relevant temperature by also considering the temperature compensations.

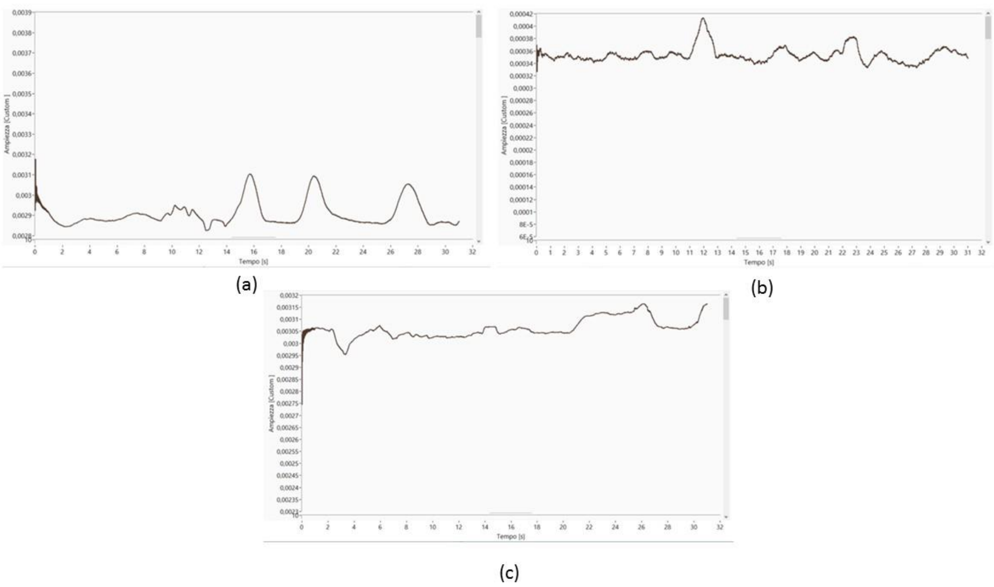


Figure 9 Analog MeasLab output sample in millivolts for (a) TS305-11C55 (b) TS310-11C55 and (c) ZTP 115

The acquired signal is exported to excel in terms of time and millivolts and is used for the post processing of the signals to get the temperature.

2.2 Scenarios

To study the behavior of these sensor at different ambient conditions to arrive to a conclusion, we have considered higher and lower temperatures from the ambient working temperature of the sensor (25°C) to see the behavior of the sensor at higher and lower sensor working temperatures. And other two was to study the position and motion of the subject.

2.2.1 Higher ambient temperature

In this higher ambient temperature, the sensors considered in this experiment works above the ambient temperature of 25°C. To study the behavior of these sensors at an elevated ambient temperature. The experiments are performed in a room where the temperature is set to 26°C and waited for 3 hours to allow the room to settle on 26°C.The experiment was taken for two positions A and B by placing these sensors in the rail. Six sensor distances and three angular positions of the sensors are taken. Then, the post processing is conducted, and graphs are plotted.

Figure 10 Room temperature (Higher Ambient)

2.2.2 Lower ambient temperature

In this lower ambient temperature, the sensor considered is lower than the ambient temperature of 25°C. So, the experiments are performed in a room where the temperature is set to 23°C and waited for 3 hours to allow the room to settle on 23°C.The experimental procedure was followed same as the higher ambient temperature and the post processing is done and graphs are plotted.

Figure 11 Room temperature (Lower Ambient)

2.2.3 Walking subject

The above two are environmental scenarios whereas the other two will be dealing with the position and motion of the subject. This experiment was performed in a room where the ambient temperature was found to be 24°C. In this experiment, three sensors are placed in front of five subjects which was asked to walk in in front of the sensor, at 30cm and the readings are taken for 90 seconds. The readings are taken. Then, the post processing is done, and graphs are plotted.

2.2.4 Random positions of 15 subjects

This scenario also deals with the positions and motion of the subject. This experiment was performed in a room where the ambient temperature was also found to be 24℃. Three sensors are placed in front of the subjects, at a distance of 30cm and the readings are taken for 90 seconds. This experiment involves 15 subjects are asked to randomly take some positions (fall, lie down, bend etc.,) in front of the sensor and the readings are taken.

2.3 Data analysis

From the experiments, the voltage output from the MeasLAb software from the sensor is converted into temperature of the body also considering the compensation.

The ambient temperature of the environment is calculated from the sensor readings with no subject present and the multimeter readings from the sensor's junctions considering the respective sensor specifications. The multimeter reading changes with respect to the exposure of the subject from the sensor. Therefore, as the distance between the subject and sensor increases the multimeter gives out different readings.

Since the sensor has k-type thermocouple and the ambient temperature of the sensor is 25º Celsius. The value is chosen from the chart, a temperature compensation is made, and the final temperature of the subject is calculated for every distance.

The reading obtained from the system are in millivolt and for this voltage corresponding temperature are taken from thermocouple K data sheet. And from the resistance value noted temperature compensation is calculated from the respective sensor specification and added to the main temperature reading to obtain the actual temperature of the human body.

2.3.1 K Type thermocouple conversion table

A Thermocouple is a part of the PIR sensor used to measure temperature. Thermocouples consist of two wire legs made from different metals. The wires legs are welded together at one end, creating a junction. This junction is where the temperature is measured. When the junction experiences a change in temperature, a voltage is created. The voltage can then be interpreted using thermocouple reference tables to calculate the temperature.

There are many types of thermocouples, each with its own unique characteristics in terms of temperature range, durability, vibration resistance, chemical resistance, and application compatibility. Type J, K, T, & E are "Base Metal" thermocouples, the most common types of thermocouples. Type R, S, and B thermocouples are "Noble Metal" thermocouples, which are used in high temperature applications.

When different metals are joined at the ends and there is a temperature difference between the joints, a magnetic field is observed. This consequence as thermo-magnetism. The magnetic field he observed was later shown to be due to thermo-electric current. In practical use, the voltage generated at a single junction of two different types of wire is what is of interest as this can be used to measure temperature at very high and low temperatures. The magnitude of the voltage depends on the types of wire being used. Generally, the voltage is in the microvolt range and care must be taken to obtain a usable measurement. Although very little current flows, power can be generated by a single thermocouple junction. Power generation using multiple thermocouples, as in a thermopile, is common.

In our system we are using type K thermocouple. Type K (Chromel–alumel) is the most common general-purpose thermocouple with a sensitivity of approximately 41 µV/°C. It is inexpensive, and a wide variety of probes are available in its −200 °C to +1350°C (−330°F to +2460°F) range. Type K was specified at a time when metallurgy was less advanced than it is today, and consequently characteristics may vary considerably between samples. One of the constituent metals, nickel, is magnetic; a characteristic of thermocouples made with magnetic material is that they undergo a deviation in output when the material reaches its Curie point, which occurs for type K thermocouples at around 185°C.

With the below given thermocouple reference tables, it is then easy to determine any given temperature for known millivolts values. Thermocouple reference tables are based on a reference junction of 0º C. If the reference junction is not at 0º c, then a correction factor must be applied.

Calculating temperature from voltage (reference junction = 0º C)

The steps involved are:

- Select the correct reference table for the thermocouple type in use. E.g. J, S, T etc.
- Locate the mV reading in the body of the table and read from the margins the temperature value.

Interpolation considers the proportionate part of the difference between the two values read from the table. The little sketch below illustrates how the interpolation method, which is more accurate, is used to arrive at temperature values.

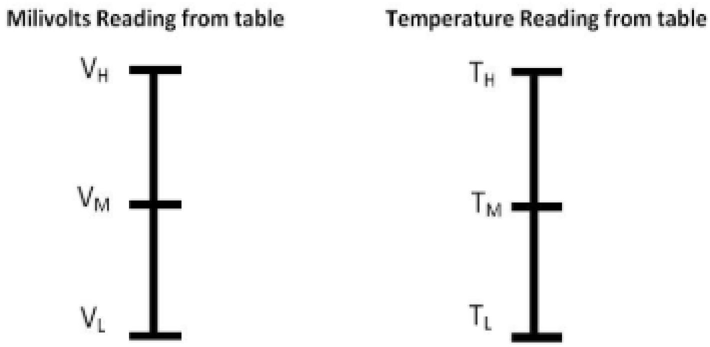


Figure 12 mV and Temperature Reading

From the little sketch above, suppose we give the millivolts reading of a thermocouple to be V_H and V_L and the corresponding temperatures are T_H and T_L from the thermocouple K datasheet, the temperature T_M corresponding to the measured voltage V_M is given by,

$$(V_M - V_L)(V_H - V_L) = (T_M - T_L)(T_H - T_L)$$

This simplifies to

$$T_M = T_L + [(V_M - V_L)(V_H - V_L)/ (T_H - T_L)]$$

Where,

V_M Is the measure voltage

V_H Is the higher voltage read from the table based on V_m

V_L Is the lower voltage read from the table based on V_m

T_M Is the calculated temperature

T_H Is the higher temperature read from the table(corresponding to V_H)

T_L Is the lower temperature from the table(corresponding to V_L)

These values of V_H, V_L, T_H and T_L are reading from the thermocouple reference tables, interpolation is then done using the formula above to determine the more precise temperature.

ITS-90 Table for Type K Thermocouple (Ref Junction 0°C) http://reotemp.com

K

Thermoelectric Voltage in mV

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023
50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096
100	4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468	4.509
110	4.509	4.550	4.591	4.633	4.674	4.715	4.756	4.797	4.838	4.879	4.920
120	4.920	4.961	5.002	5.043	5.084	5.124	5.165	5.206	5.247	5.288	5.328
130	5.328	5.369	5.410	5.450	5.491	5.532	5.572	5.613	5.653	5.694	5.735
140	5.735	5.775	5.815	5.856	5.896	5.937	5.977	6.017	6.058	6.098	6.138
150	6.138	6.179	6.219	6.259	6.299	6.339	6.380	6.420	6.460	6.500	6.540
160	6.540	6.580	6.620	6.660	6.701	6.741	6.781	6.821	6.861	6.901	6.941
170	6.941	6.981	7.021	7.060	7.100	7.140	7.180	7.220	7.260	7.300	7.340
180	7.340	7.380	7.420	7.460	7.500	7.540	7.579	7.619	7.659	7.699	7.739
190	7.739	7.779	7.819	7.859	7.899	7.939	7.979	8.019	8.059	8.099	8.138
200	8.138	8.178	8.218	8.258	8.298	8.338	8.378	8.418	8.458	8.499	8.539
210	8.539	8.579	8.619	8.659	8.699	8.739	8.779	8.819	8.860	8.900	8.940
220	8.940	8.980	9.020	9.061	9.101	9.141	9.181	9.222	9.262	9.302	9.343
230	9.343	9.383	9.423	9.464	9.504	9.545	9.585	9.626	9.666	9.707	9.747
240	9.747	9.788	9.828	9.869	9.909	9.950	9.991	10.031	10.072	10.113	10.153
250	10.153	10.194	10.235	10.276	10.316	10.357	10.398	10.439	10.480	10.520	10.561
260	10.561	10.602	10.643	10.684	10.725	10.766	10.807	10.848	10.889	10.930	10.971

K

Figure 13 mV Reading for type K Thermocouple

So, the major purpose of this entire thesis is to study the behavior of the three different sensors at various environmental conditions. To observe that, four different scenarios are created, and the sensor behavior is studied under these scenarios and the performance of the sensors are evaluated.

3 Results

After post processing the millivolts acquired from the sensors to temperature, it is plotted as a graph for all the experiments as given below,

A45 – Body facing sensor at angle 45

A90 – Body facing sensor at angle 90

B0 - Body facing up sensor at angle 0

B45 - Body facing up sensor at angle 45

B90 - Body facing up sensor at angle 90

Since A0 and B0 positions are almost same (head region if the body silhouette), only one (B0) is considered.

The standard deviation of the SUBJECT TEMPERATURE for every distance is taken and MAXSD and MINSD is also plotted in the graph.

The plots for each scenario are given below and discussed.

3.1 TS305-11C55

3.1.1 Higher ambient temperature of 26℃

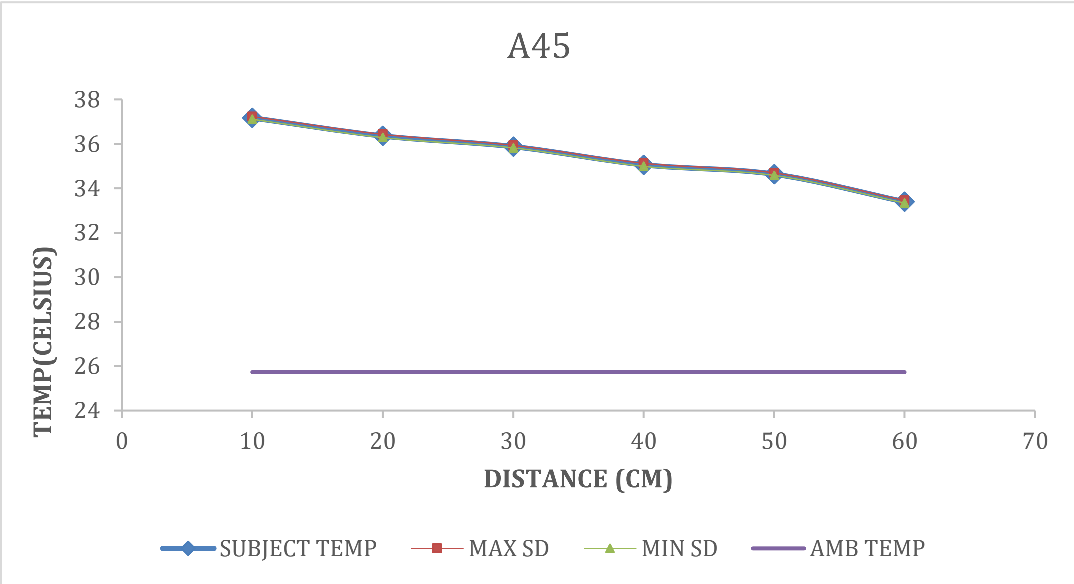


Figure 14 TS305-11C55-A45

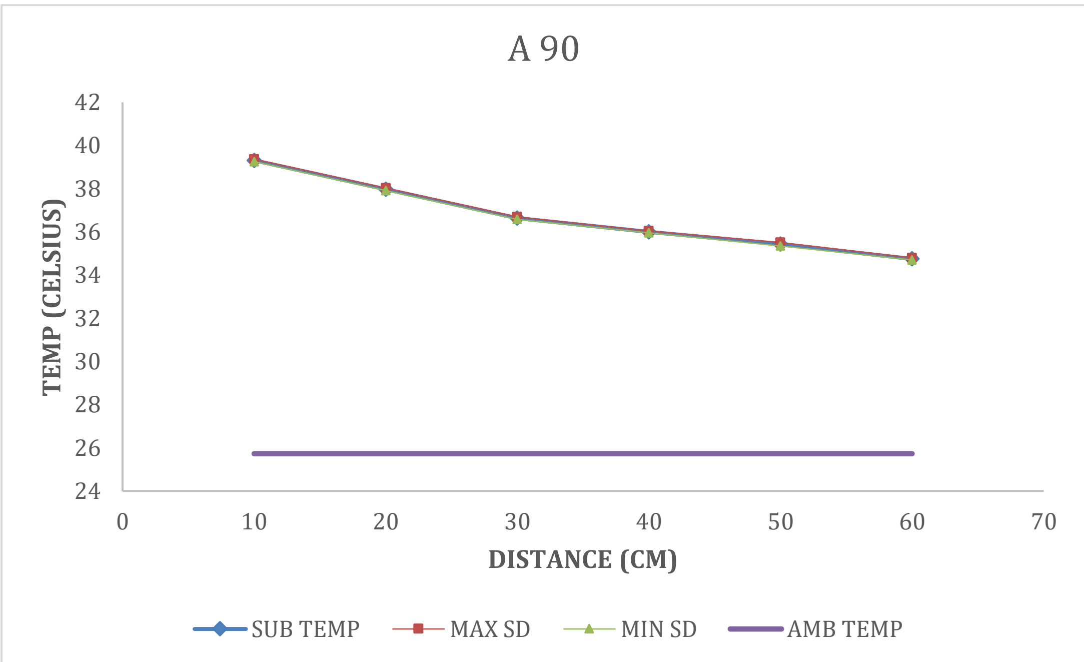


Figure 15 TS305-11C55-A90

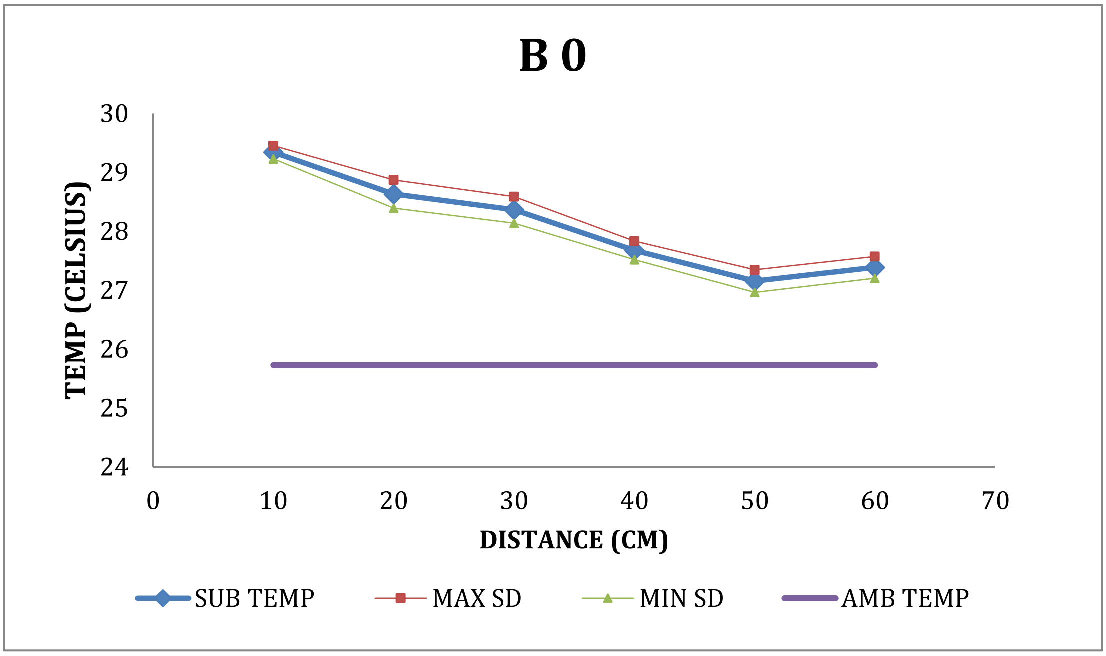


Figure 16 TS305-11C55-B0

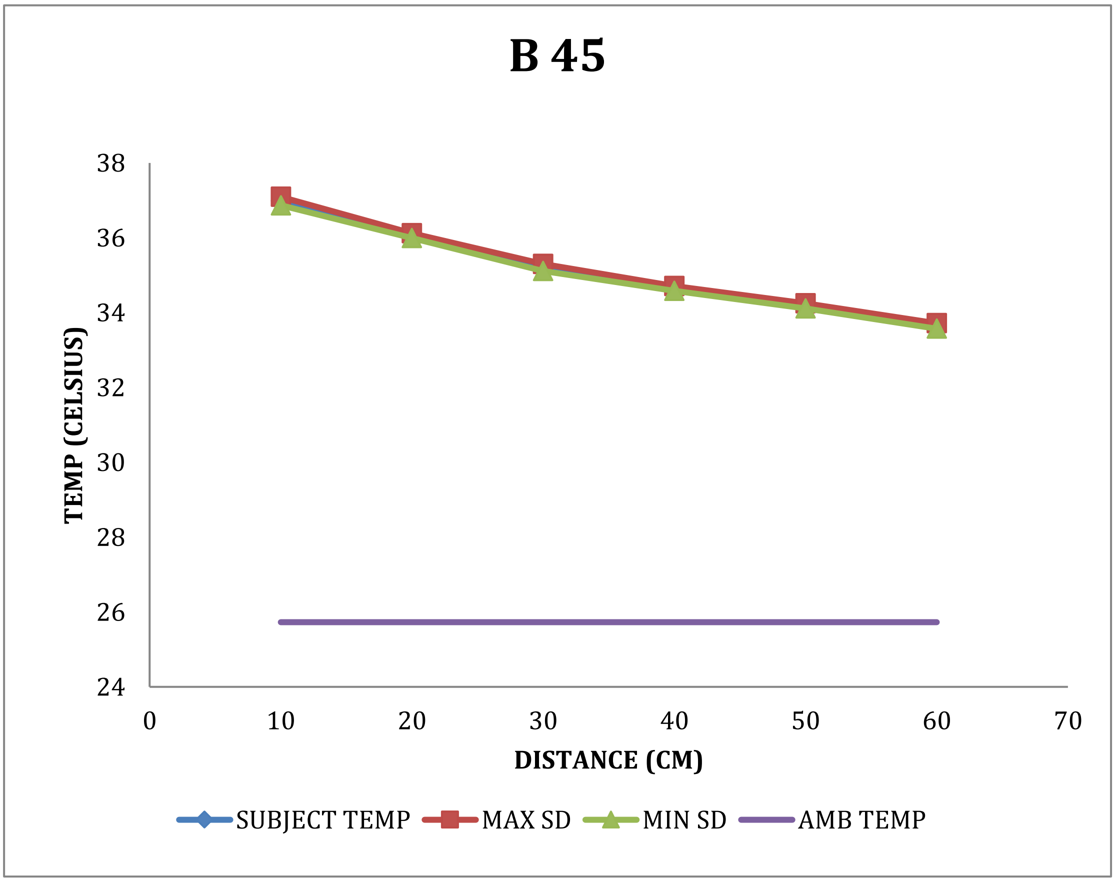


Figure 17 TS305-11C55-B45

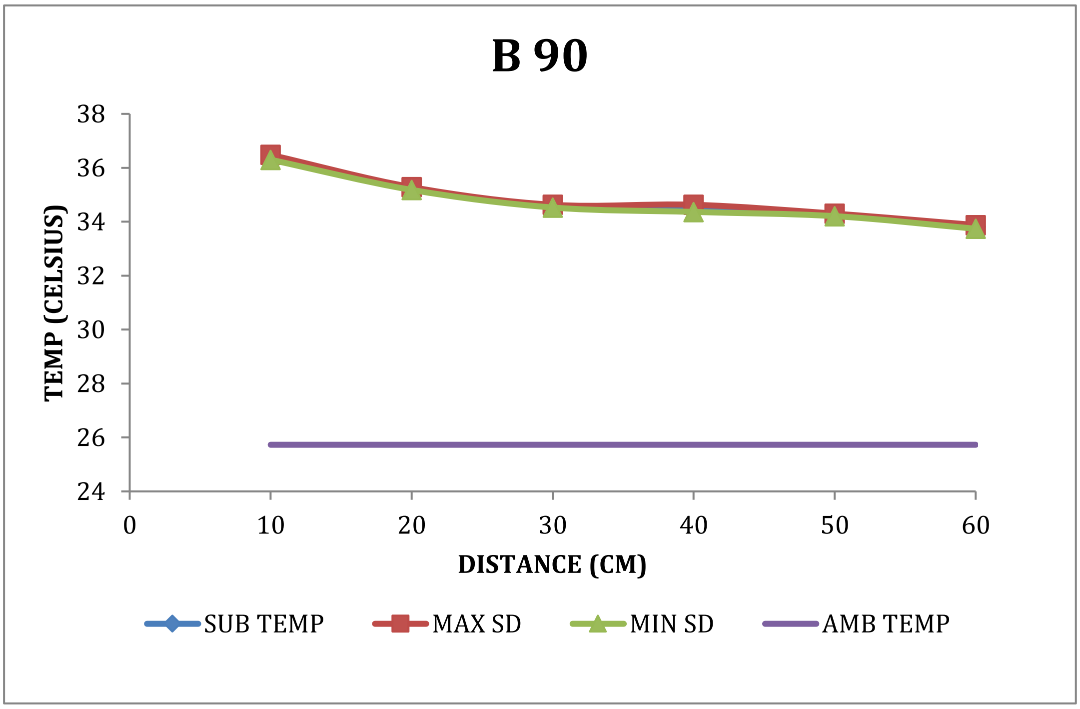


Figure 18 TS305-11C55-B90

The above plots are from the experiments conducted at a higher ambient temperature of 26°C in the sensor TS305 11C55

3.1.2 Lower ambient temperature of 23℃

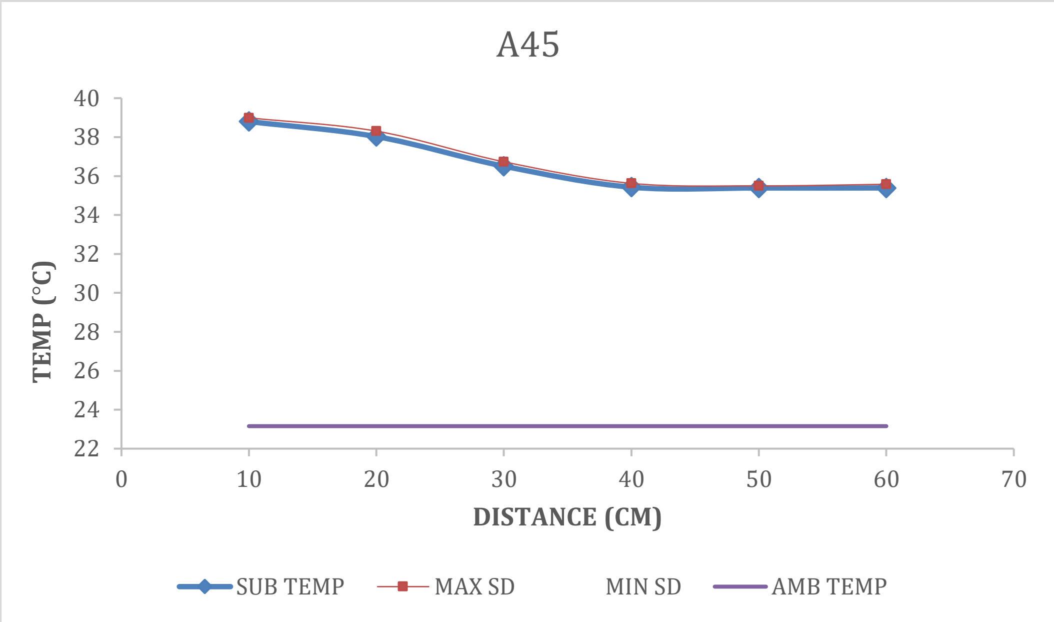


Figure 19 TS305-11C55-A45

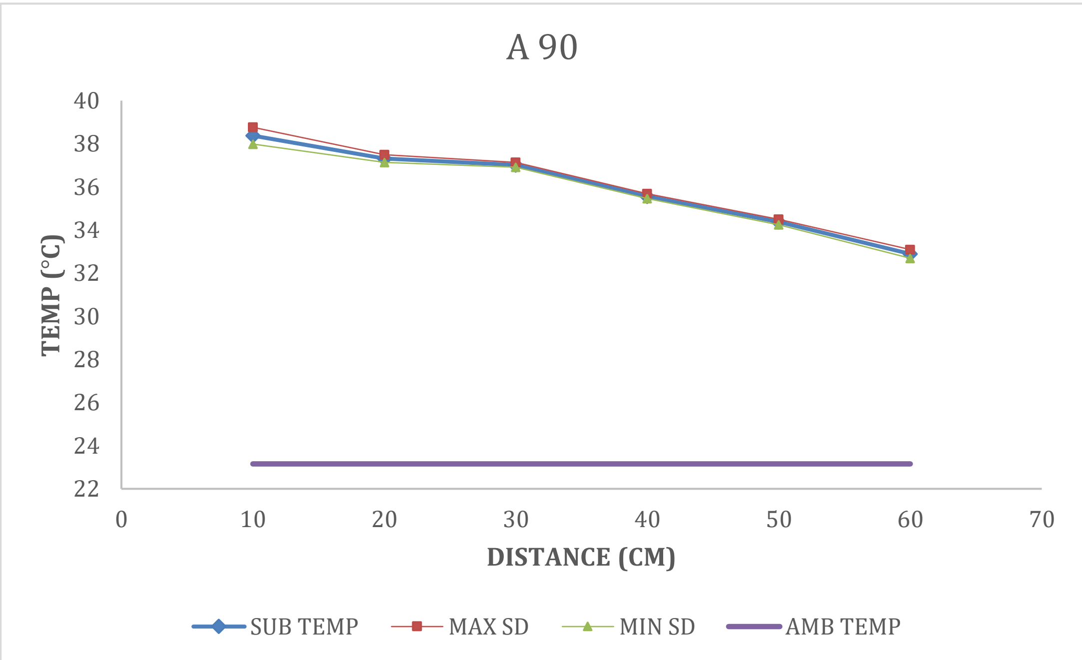


Figure 20 TS305-11C55-A90

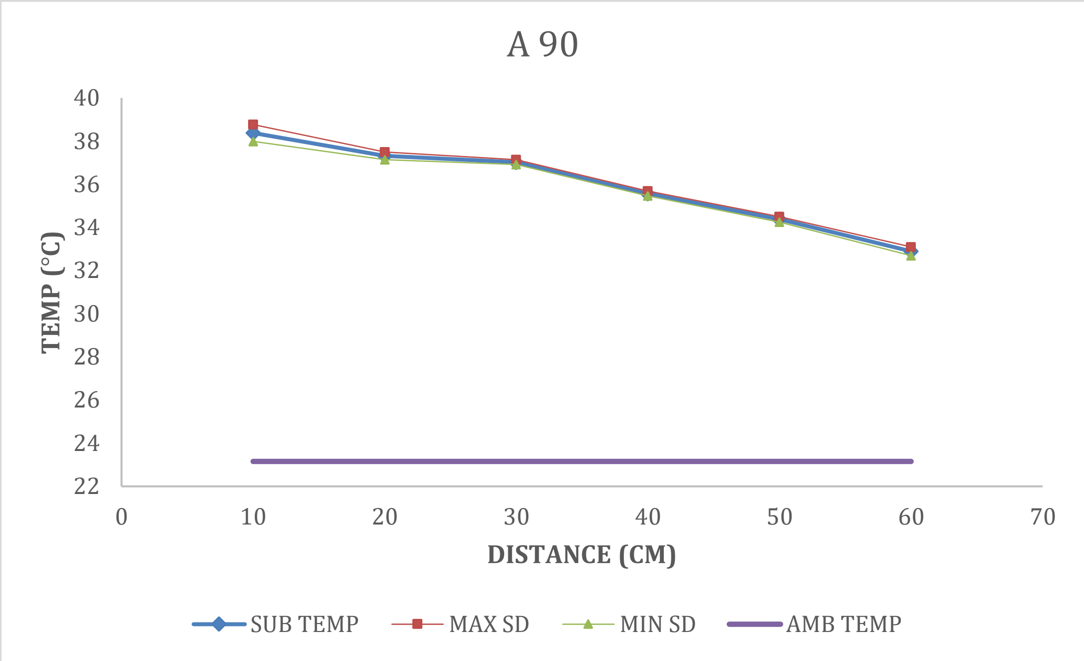


Figure 21 TS305-11C55-B0

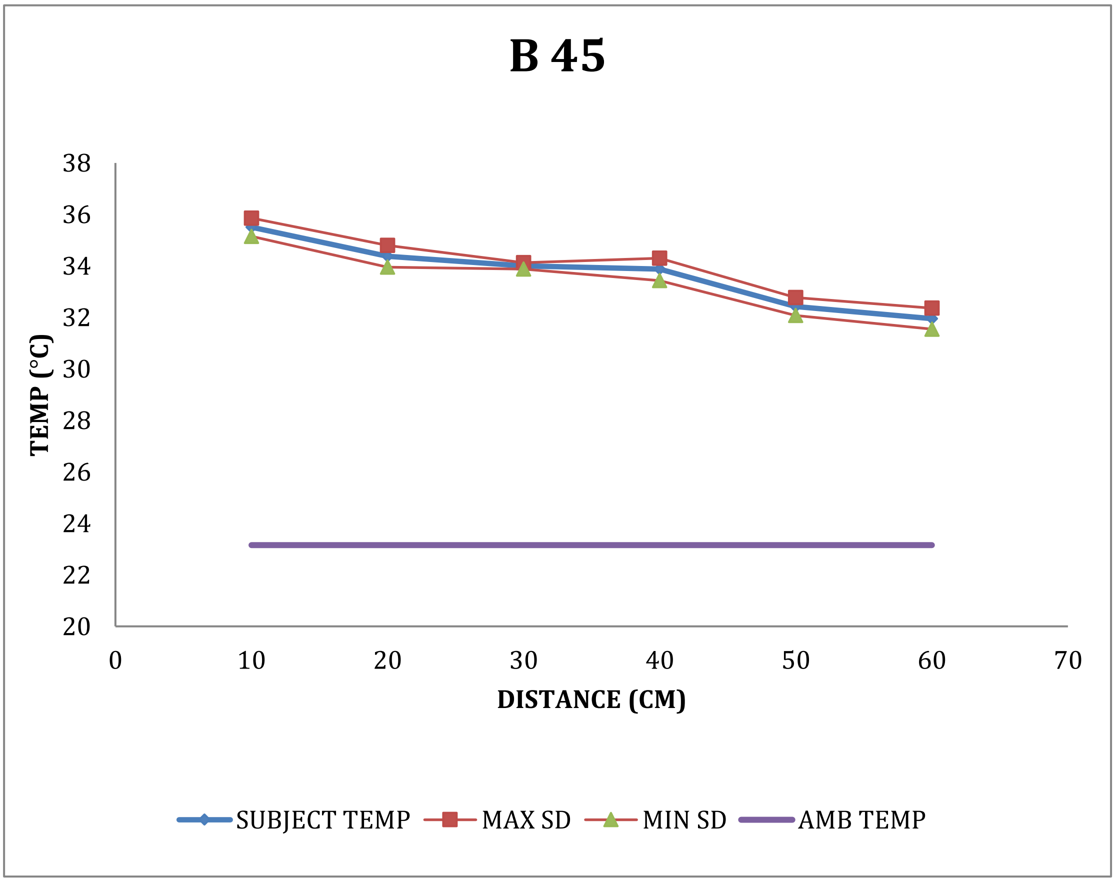


Figure 22 TS305-11C55-B45

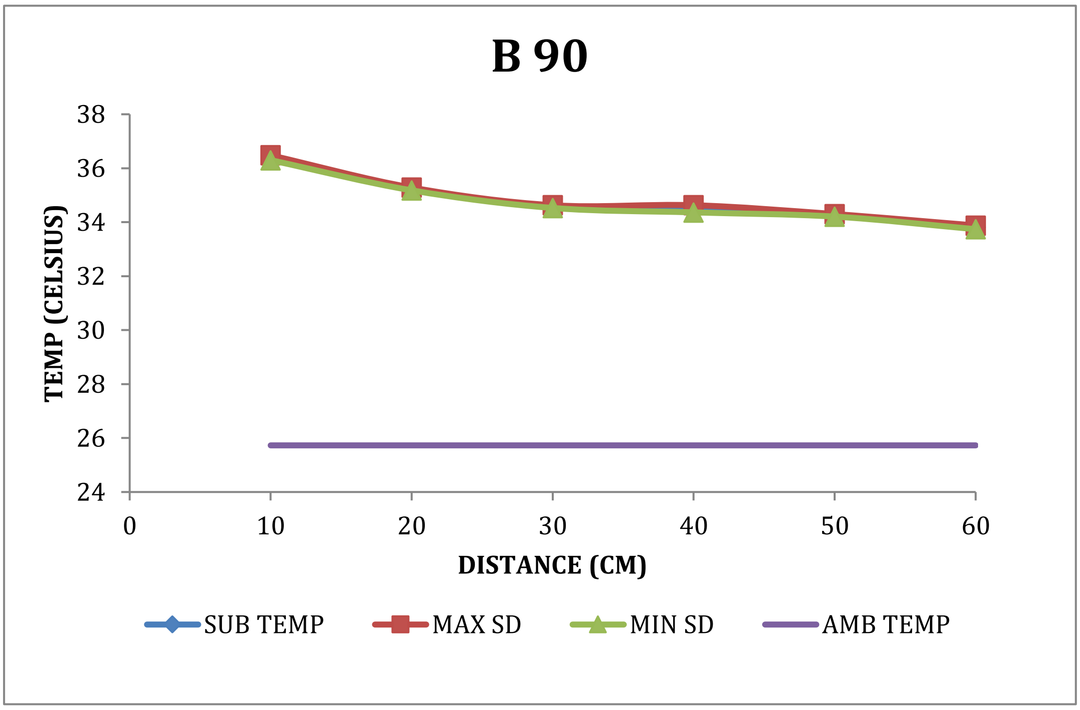


Figure 23 TS305-11C55-B90

The above plots are from the experiments conducted at lower ambient temperature of 23°C in the sensor TS305 11C55

3.2 TS318-11C55

3.2.1 Higher ambient temperature of 26°C

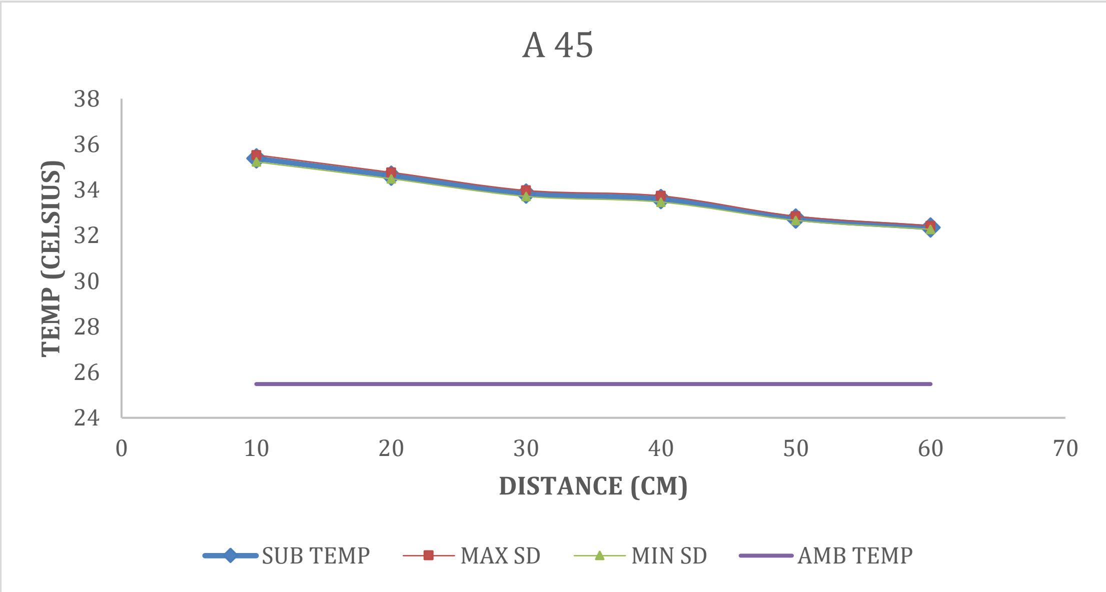


Figure 24 TS318-11C55-A45

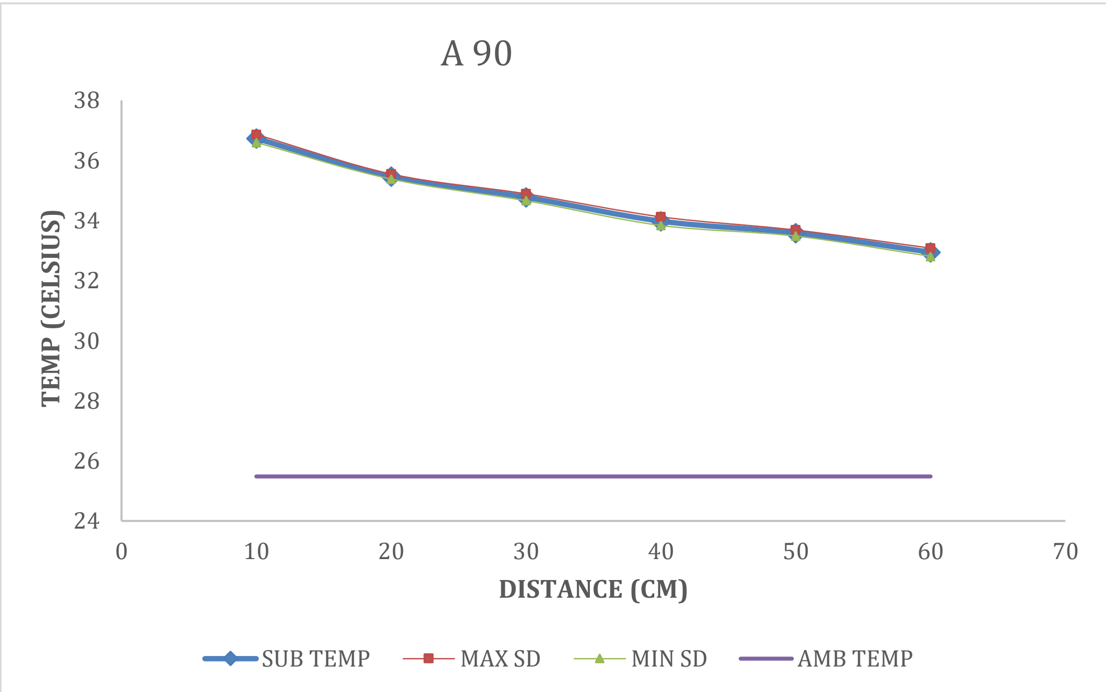


Figure 25 TS318-11C55-A90

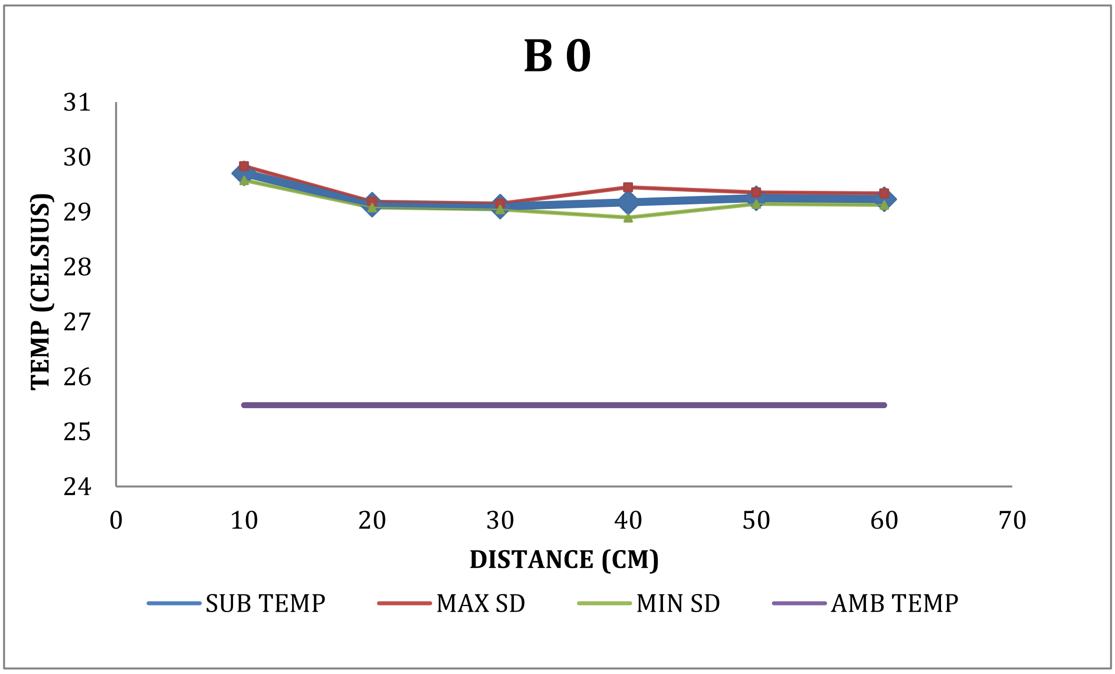


Figure 26 TS318-11C55-B0

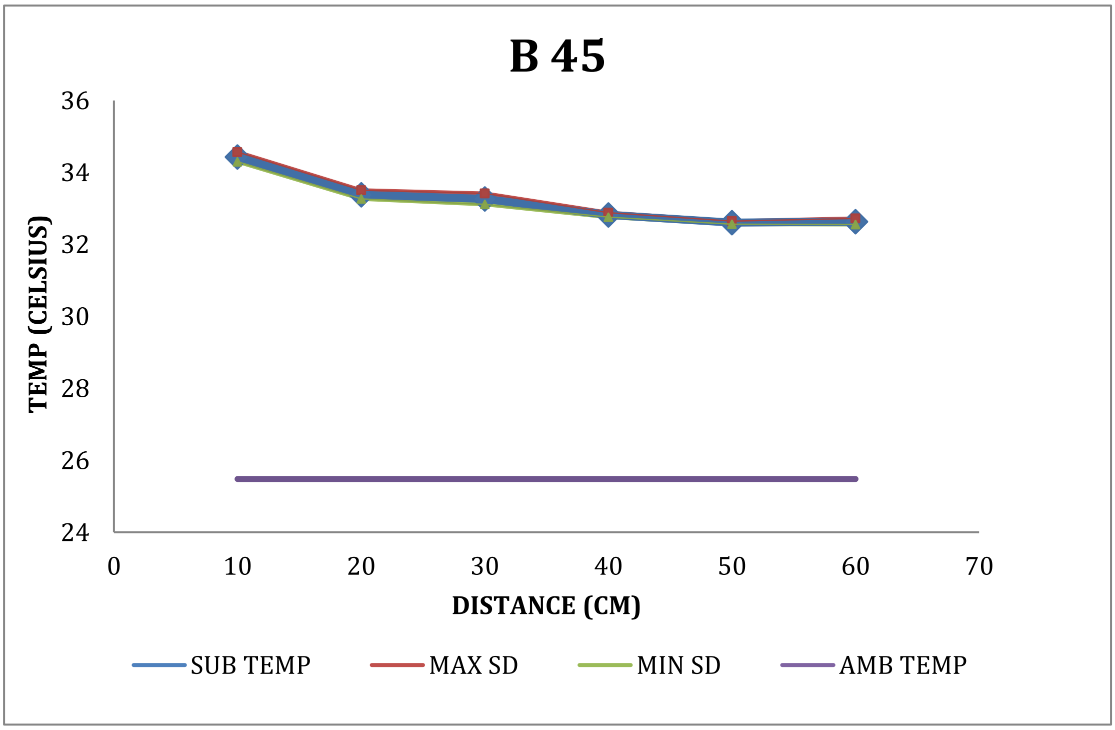


Figure 27 TS318-11C55-B45

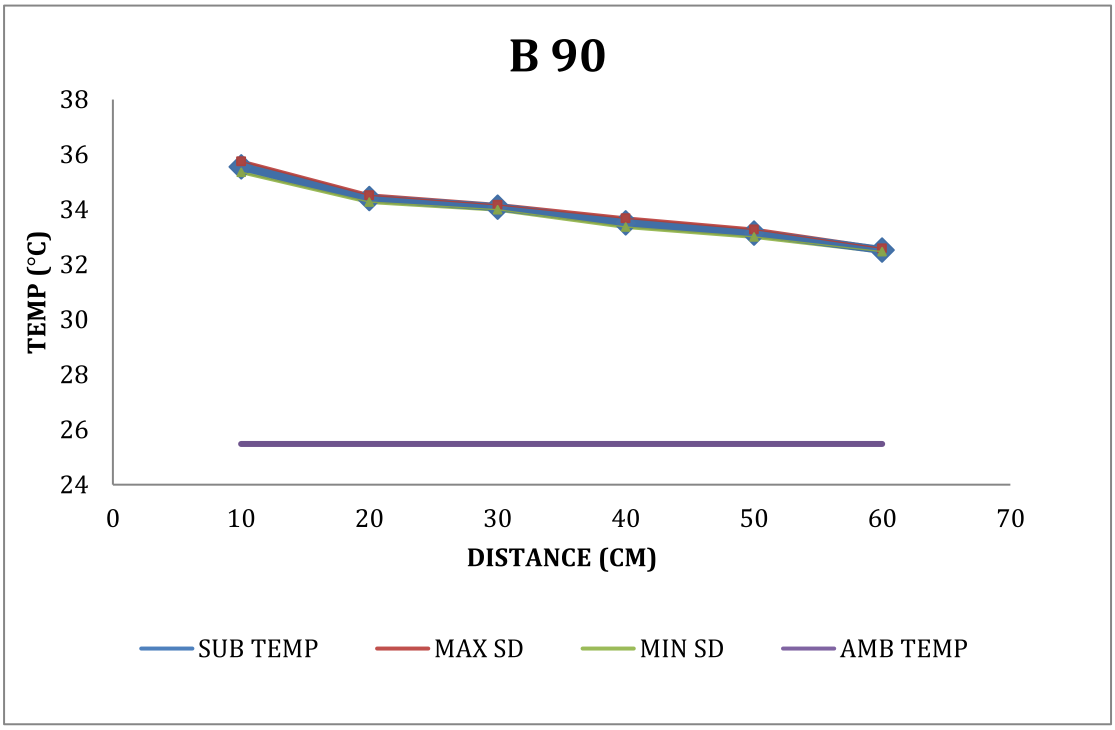


Figure 28 TS318-11C55-B90

The above plots are from the experiments conducted at higher ambient temperature of 26°C in the sensor TS318 11C55

3.2.2 Lower ambient temperature of 23℃

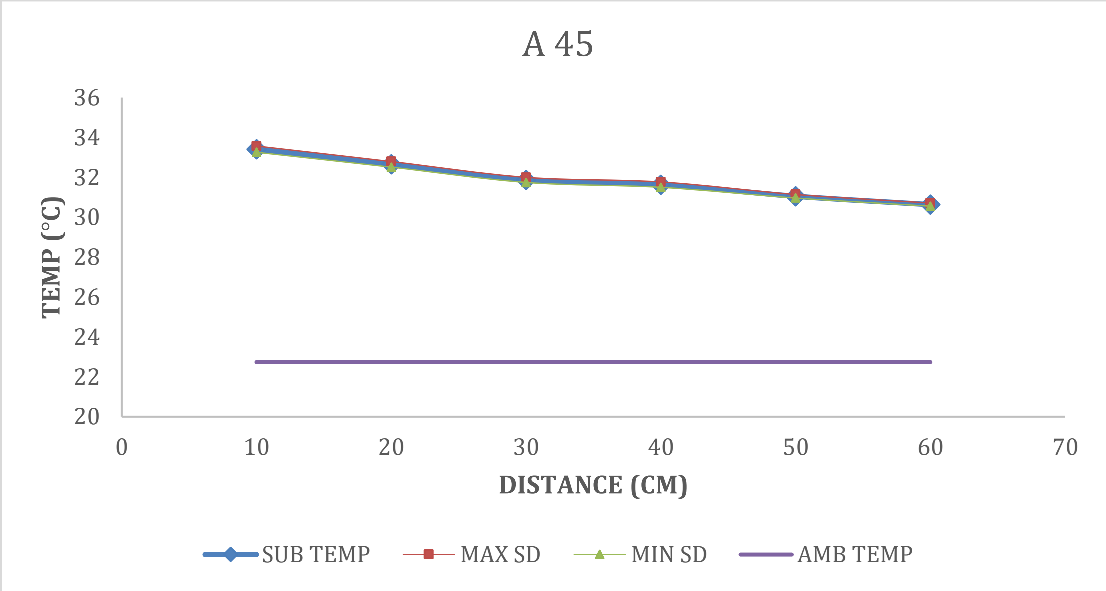


Figure 29 TS318-11C55-A45

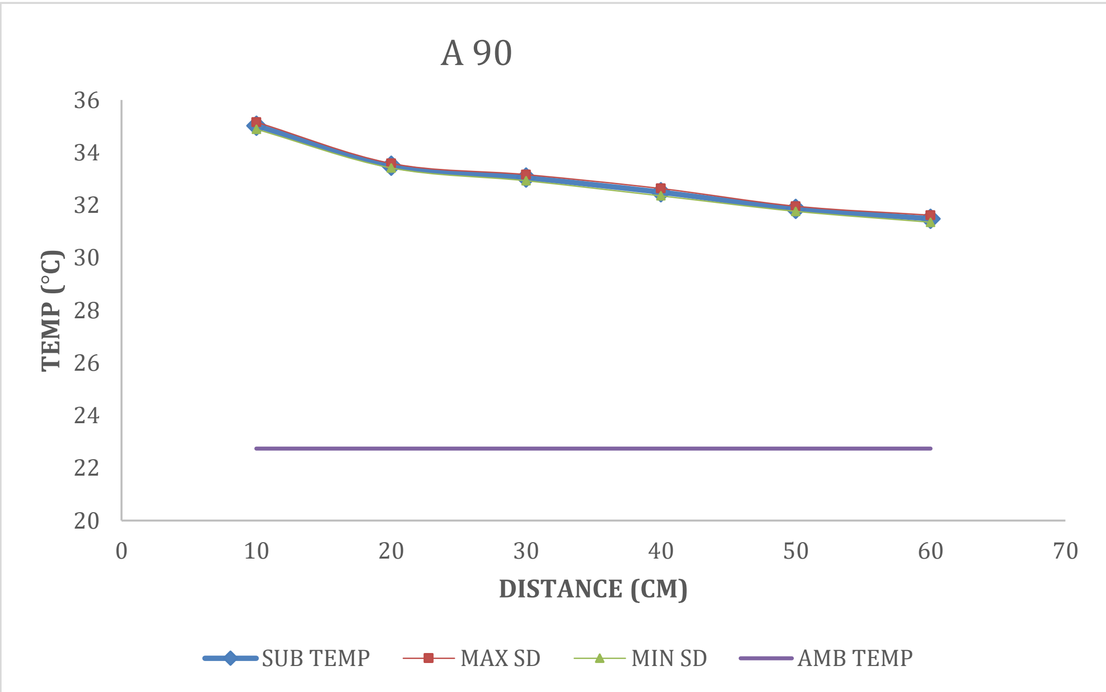


Figure 30 TS318-11C55-A90

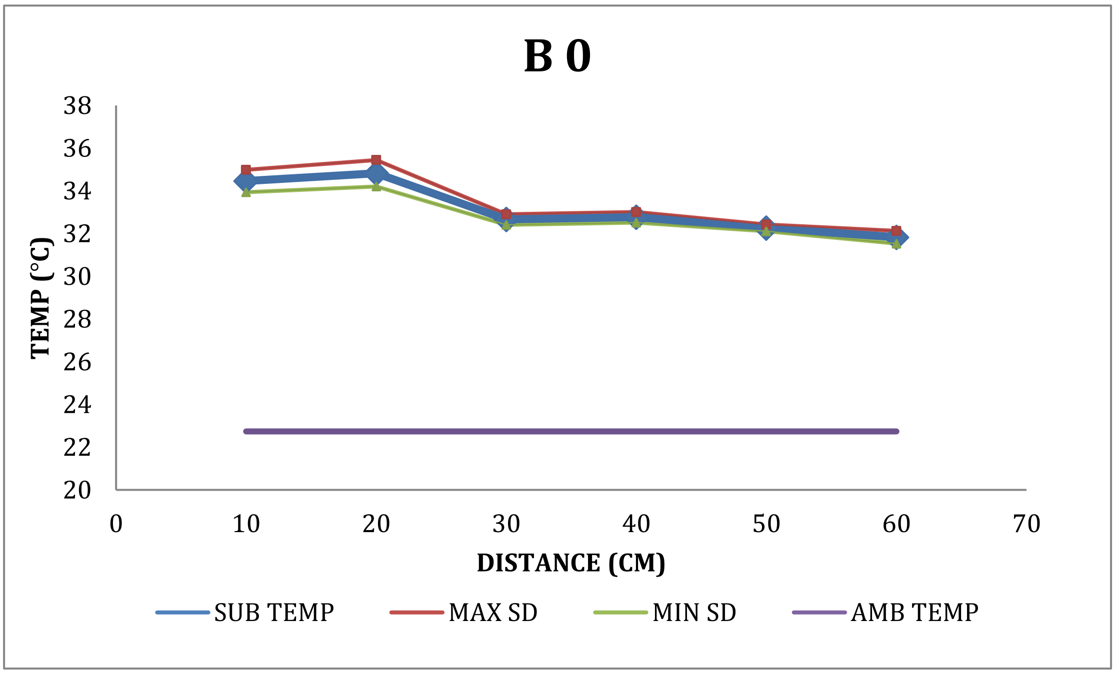


Figure 31 TS318-11C55-B0

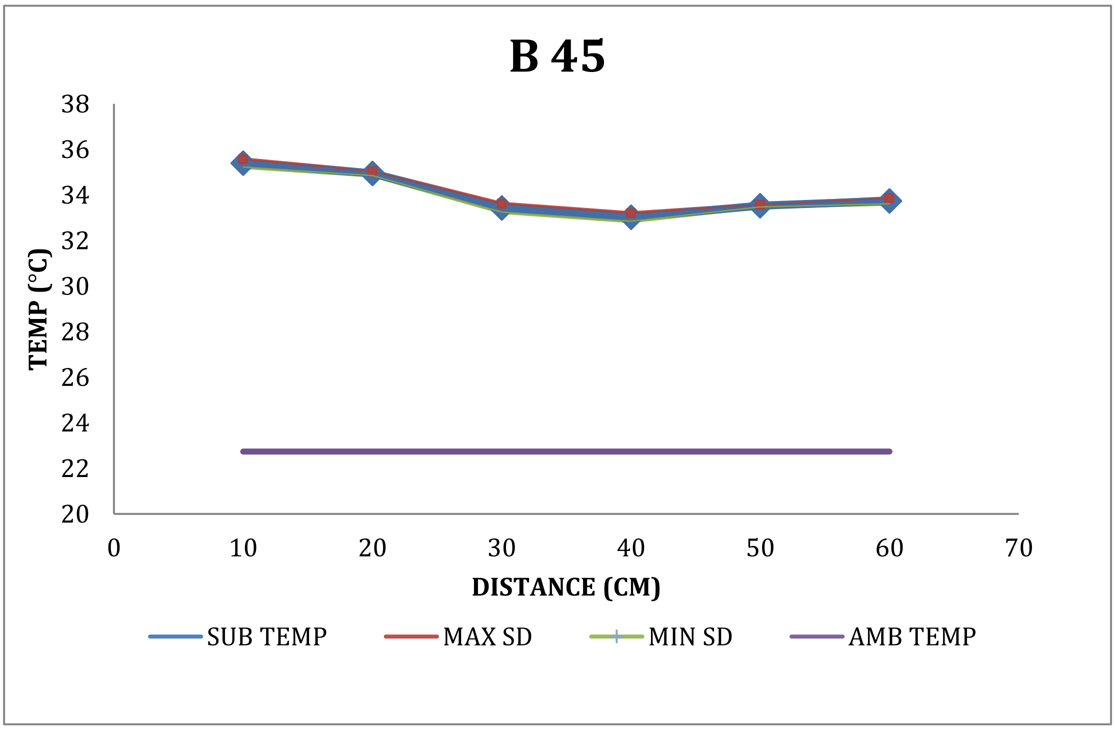


Figure 32 TS318-11C55-B45

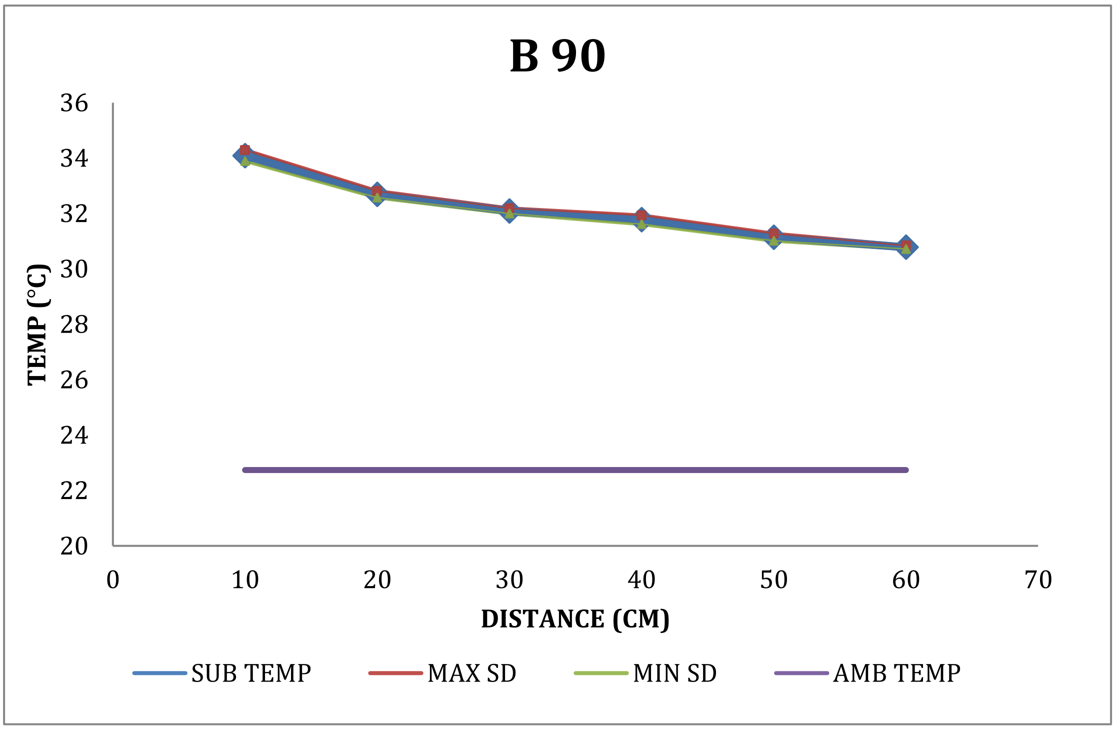


Figure 33 TS318-11C55-B90

The above plots are from the experiments conducted at lower ambient temperature of 23°C in the sensor TS318 11C55.

3.3 ZTP-115

3.3.1 Higher ambient temperature of 26℃

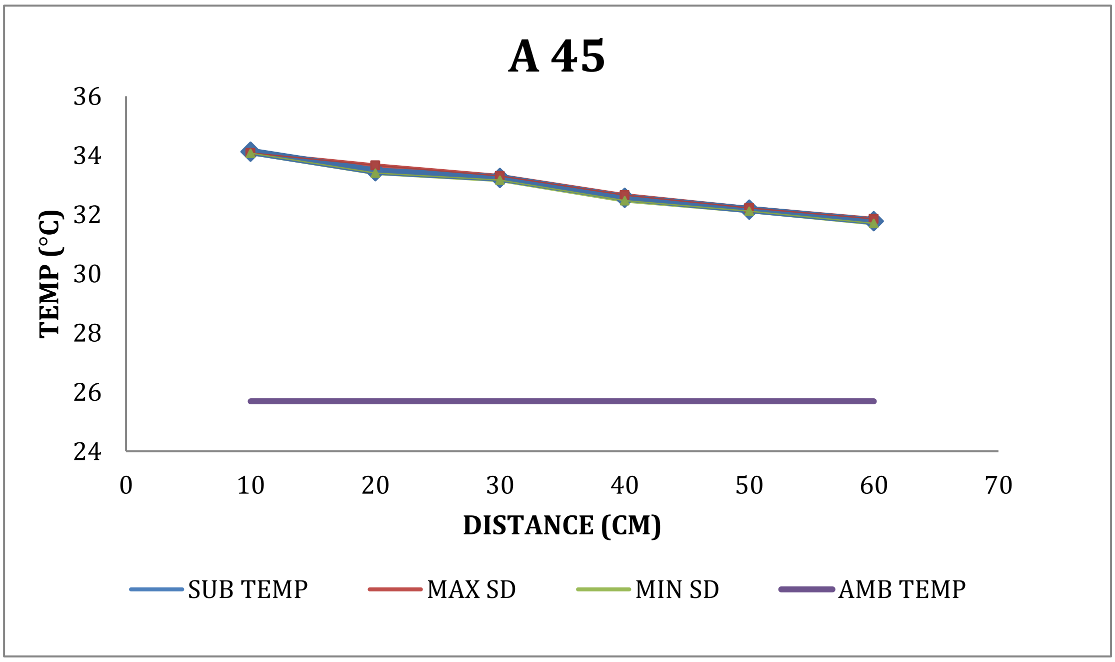


Figure 34 ZTP-115-A45

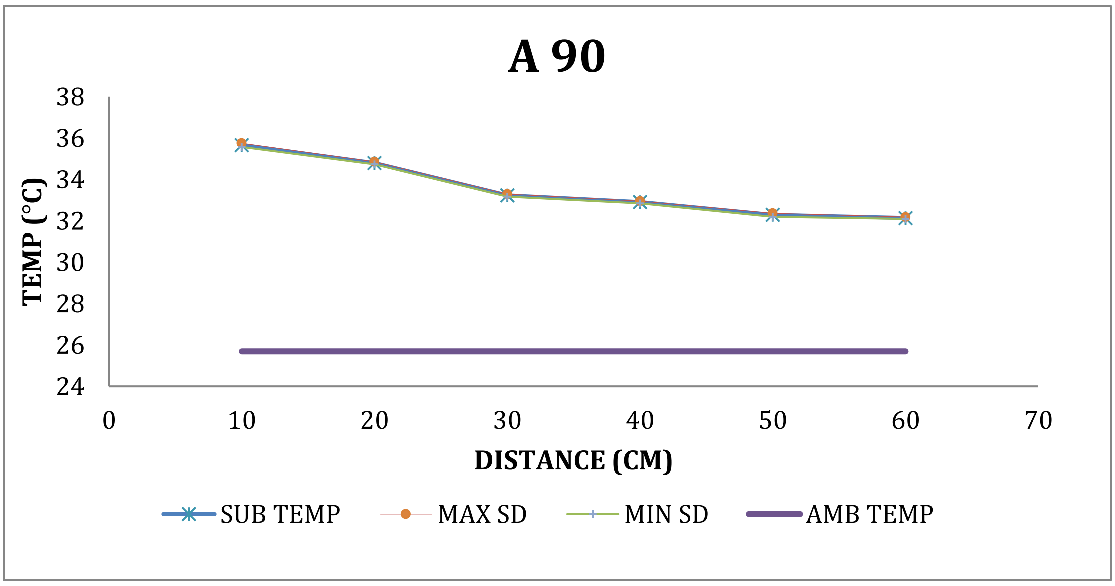


Figure 35 ZTP-115-A90

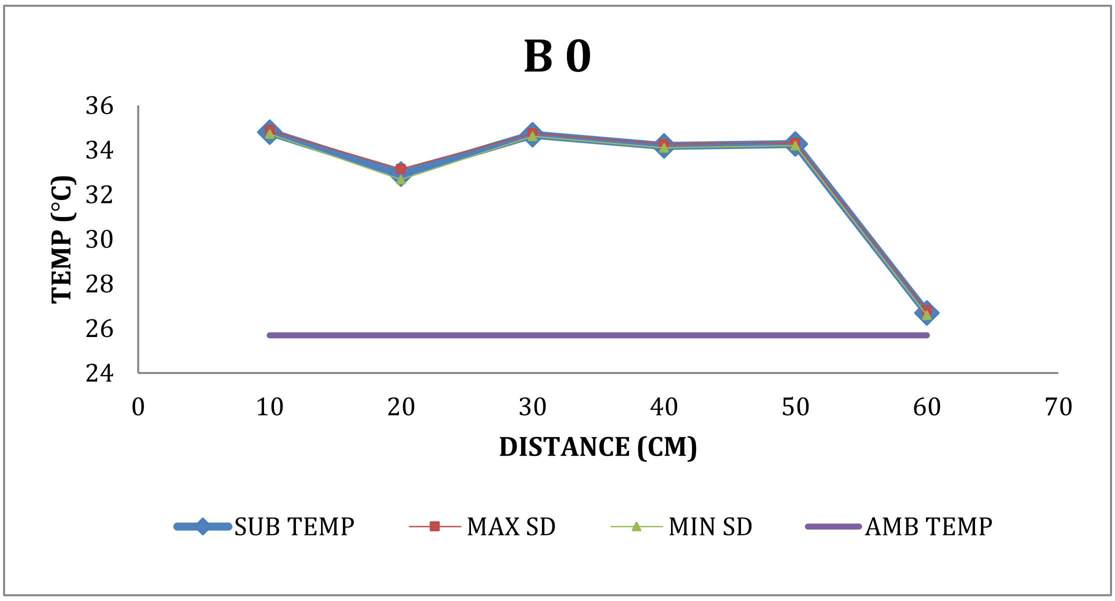


Figure 36 ZTP-115-B0

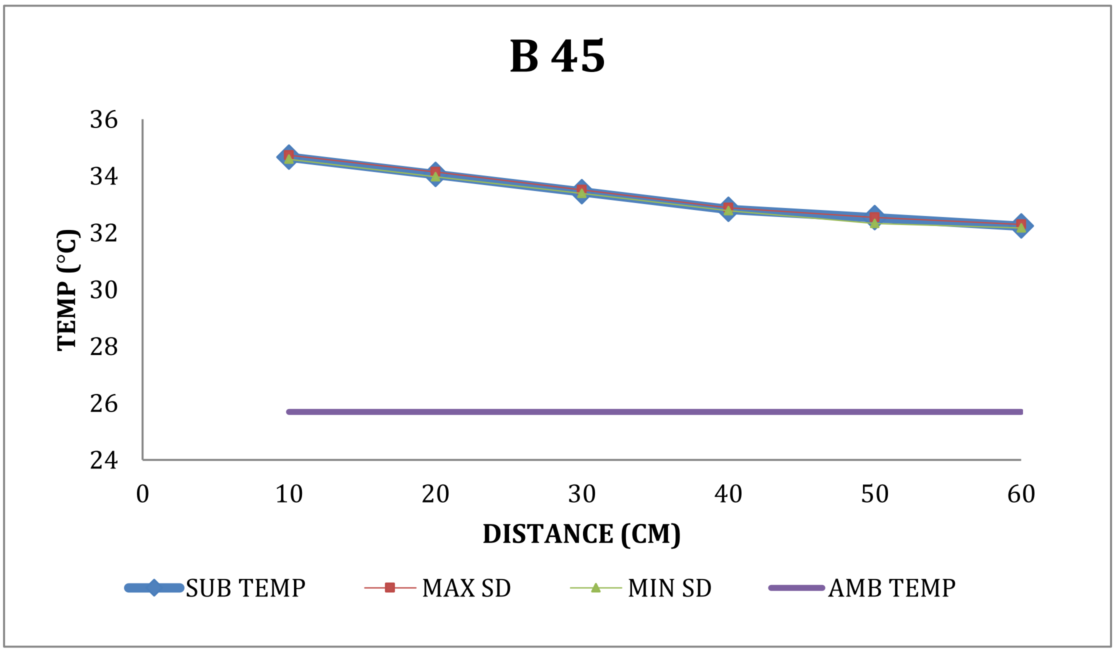


Figure 37 ZTP-115-B45

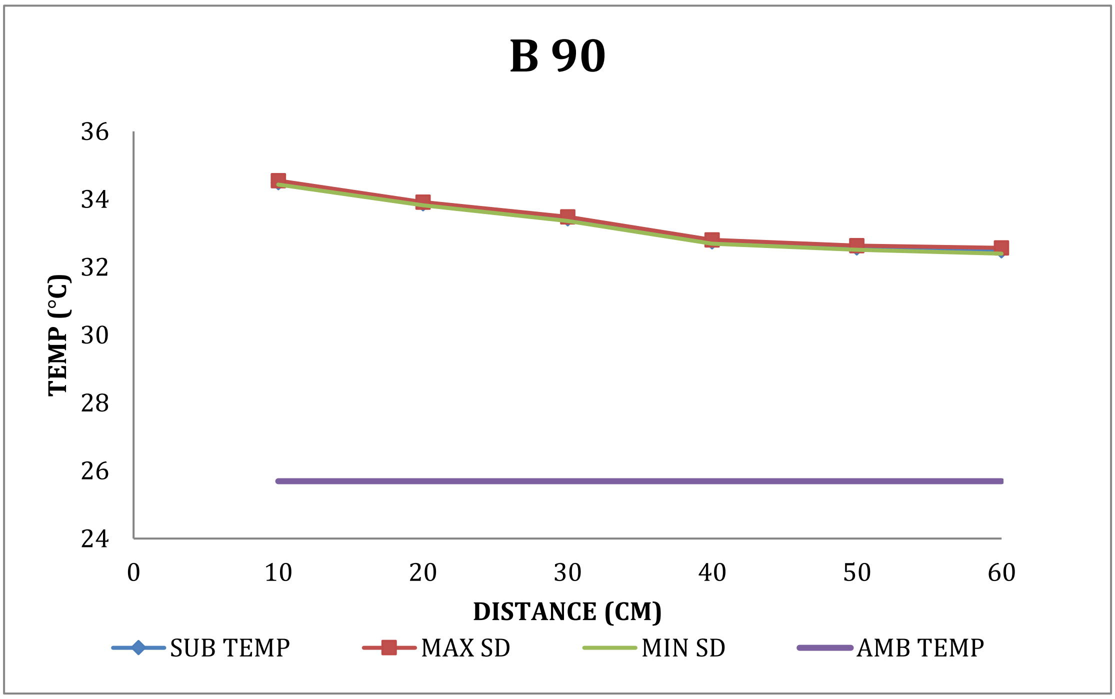


Figure 38 ZTP-115-B90

The above plots are from the experiments conducted at higher ambient temperature of 26°C in the sensor ZTP-115.

3.3.2 Lower ambient temperature of 23℃

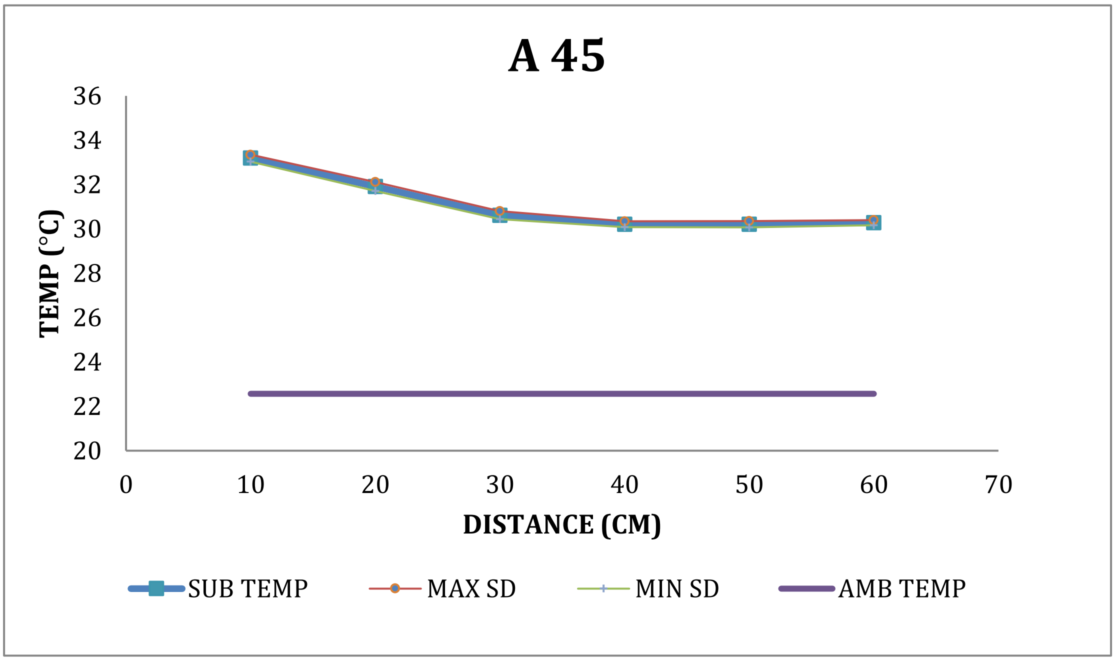


Figure 39 ZTP-115-A45

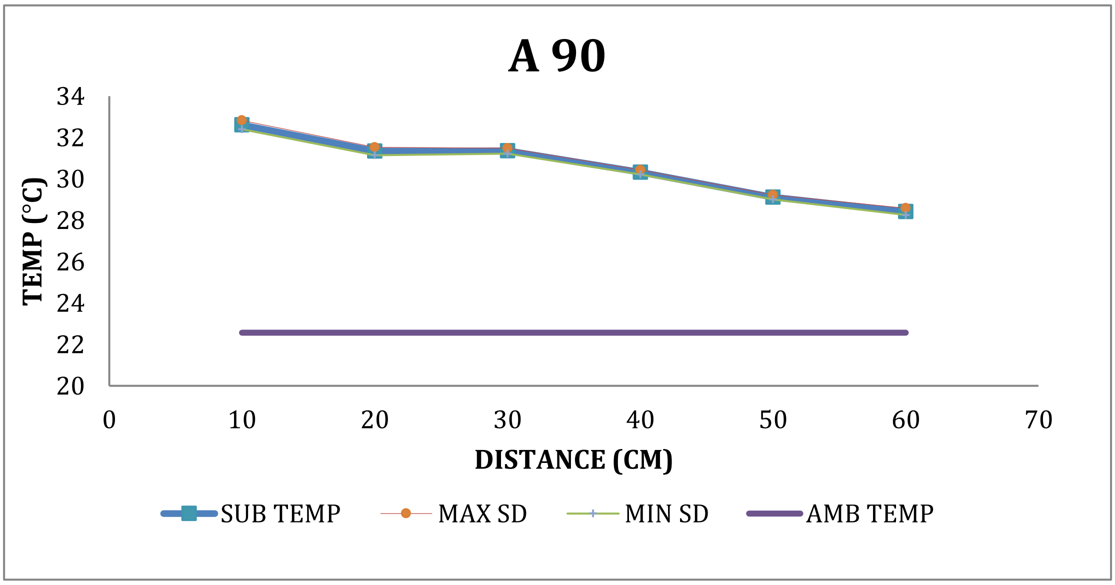


Figure 40 ZTP-115-A90

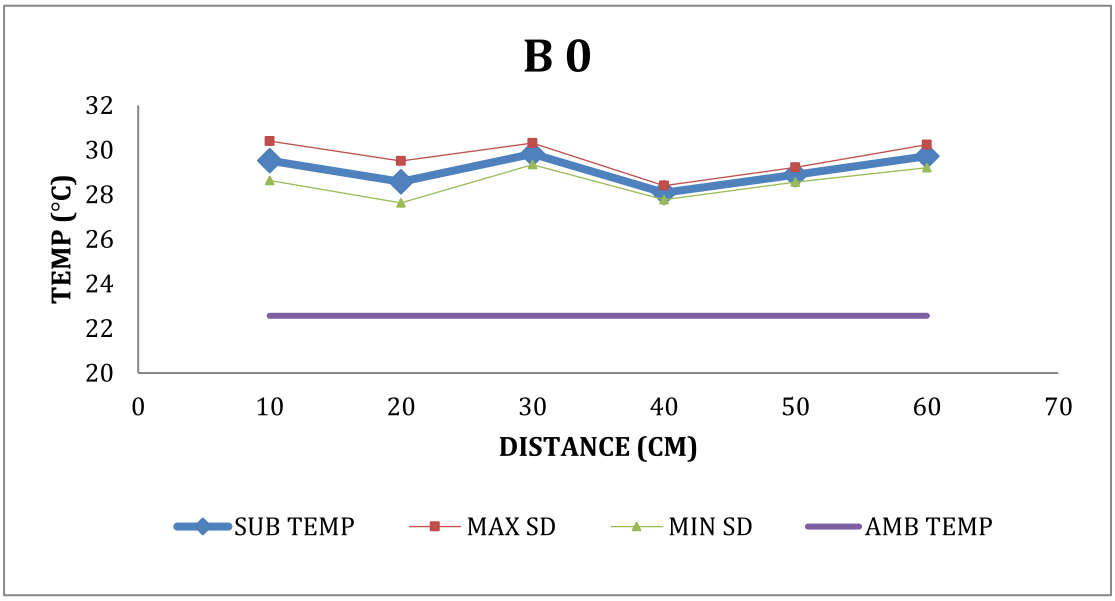


Figure 41 ZTP-115-B0

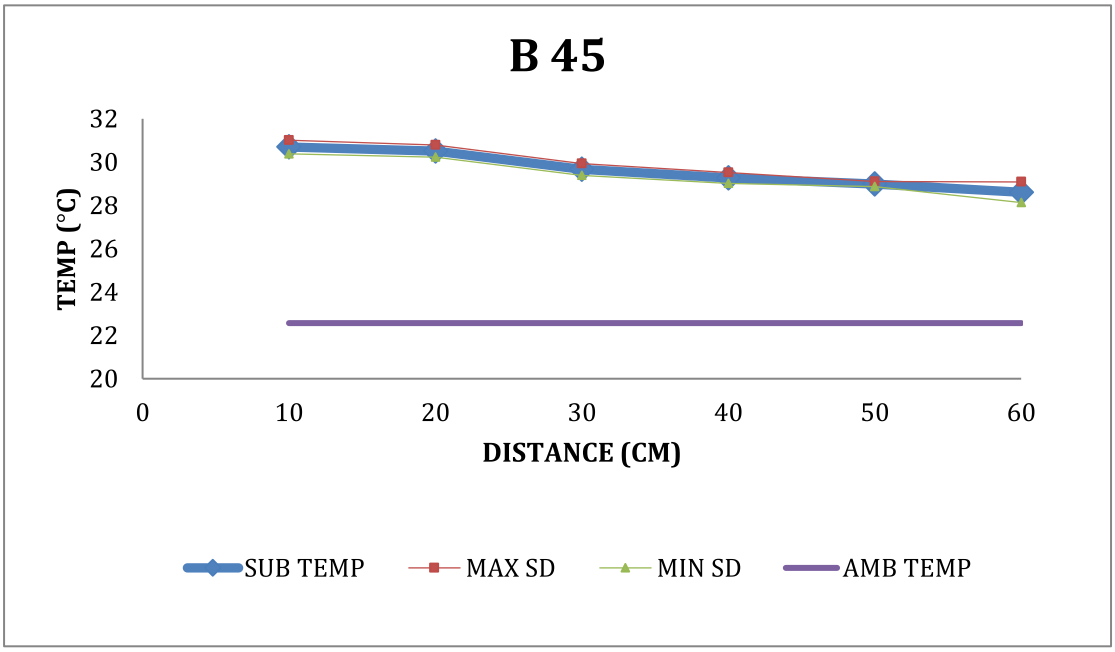


Figure 42 ZTP-115-B45

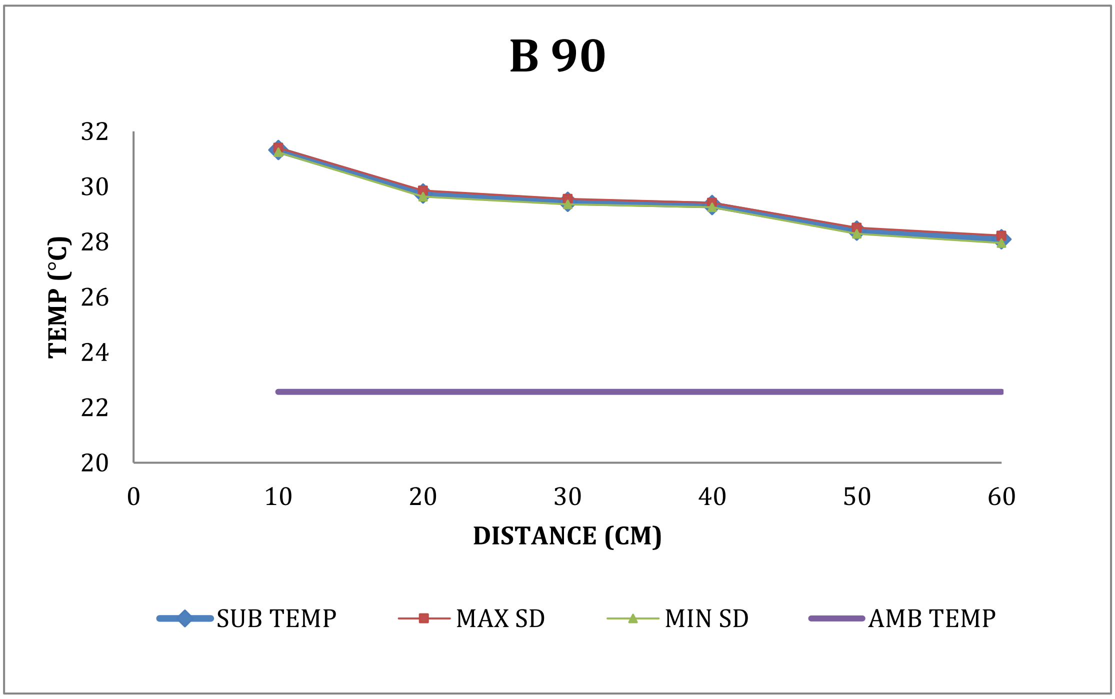


Figure 43 ZTP-115-B90

The above plots are from the experiments conducted at lower ambient temperature of 23°C in the sensor ZTP-115.

4 Delta temperature calculations

The delta temperature is the difference between the ambient temperature and the subject temperature in every experiment. It is calculated for all the angular positions and distances of the sensor from the body silhouette.

The average mean value of the body temperature calculated from the sensor values at the first three sensor distances 10cm, 20cm and 30cm is considered as the normal body temperature for that experiment. More than 30cm sensor distances, the delta temperature will be lesser mainly because of longer distance from the subject.

4.1 Delta temperature comparison TS305-11C55

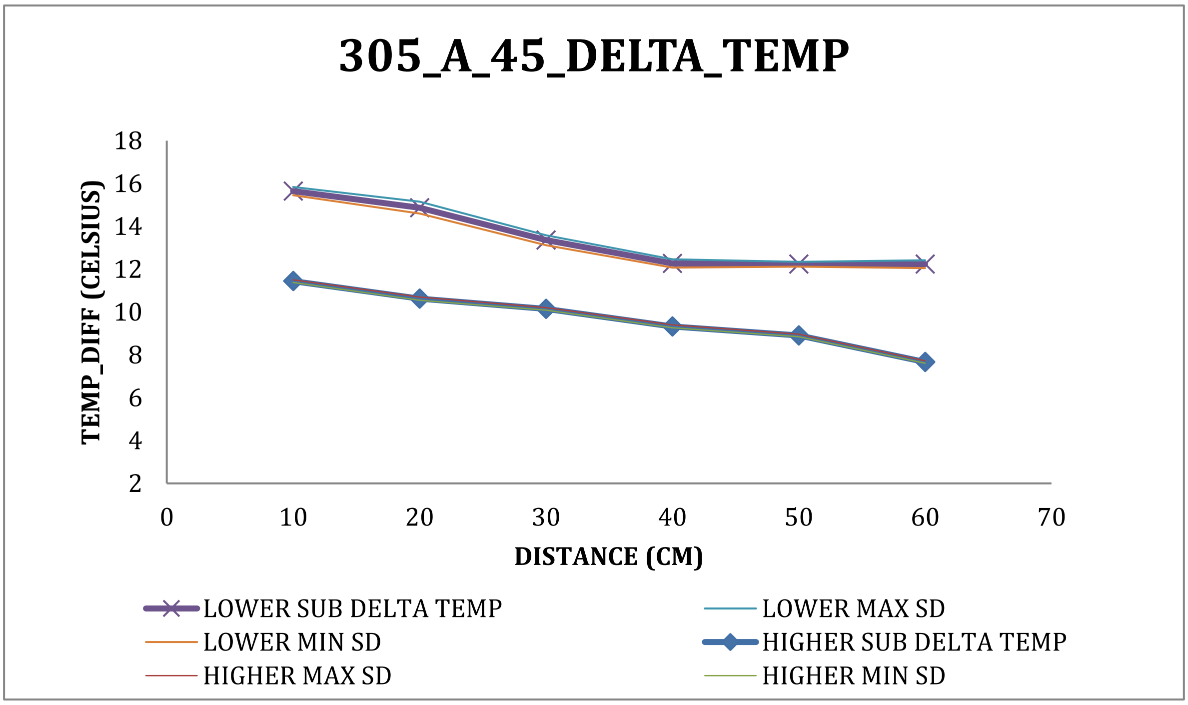


Figure 44 TS305-11C55-A45

TS305		
Position_A_Angle_45		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	23,1	25,7
Normal body temperature of the subject observed by the sensor	37,7	36,4
Delta temperature from the sensors	14,6	10,7

Table 4 TS305-11C55 Position_A_45

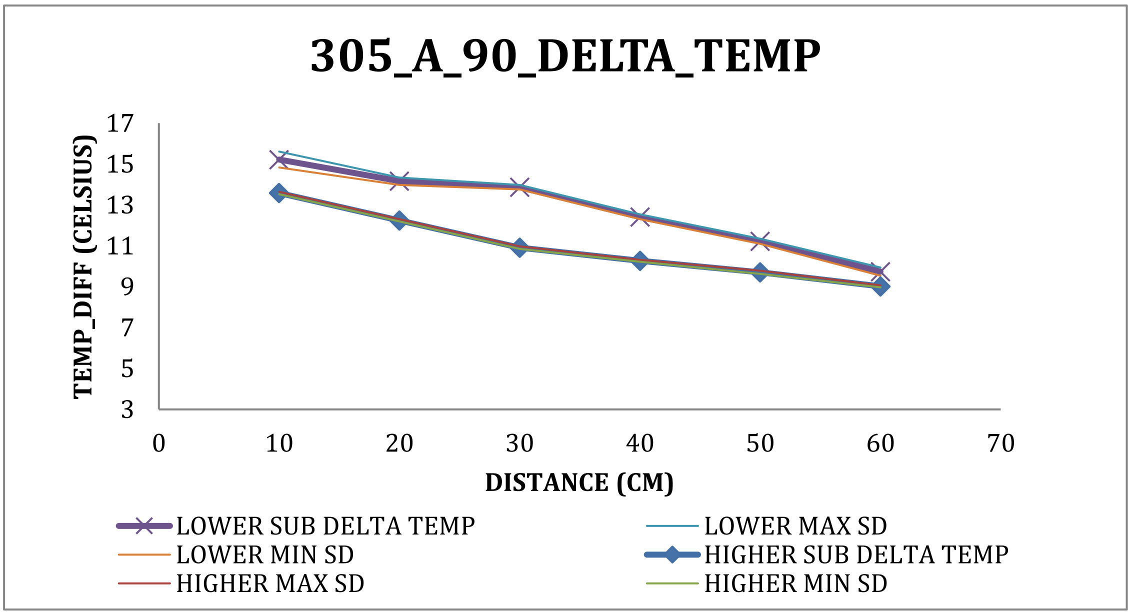


Figure 45 TS305-11C55-A90

TS305		
Position_A_Angle_90		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	23,1	25,7
Normal body temperature of the subject observed by the sensor*	37,5	36,4
Delta temperature from the sensors	14,4	10,7

Table 5 TS305-11C55 Position_A_90

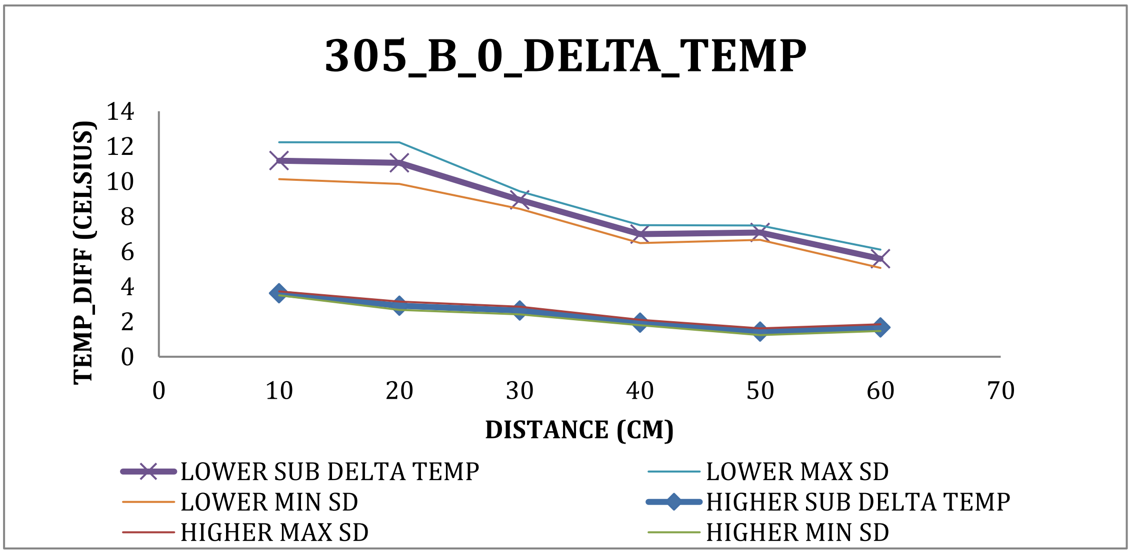


Figure 46 TS305-11C55-B0

TS305		
Position_B_Angle_0		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	23,1	25,7
Normal body temperature of the subject observed by the sensor	33,5	28,7
Delta temperature from the sensors	10,3	3,0

Table 6 TS305-11C55 Position_B_0

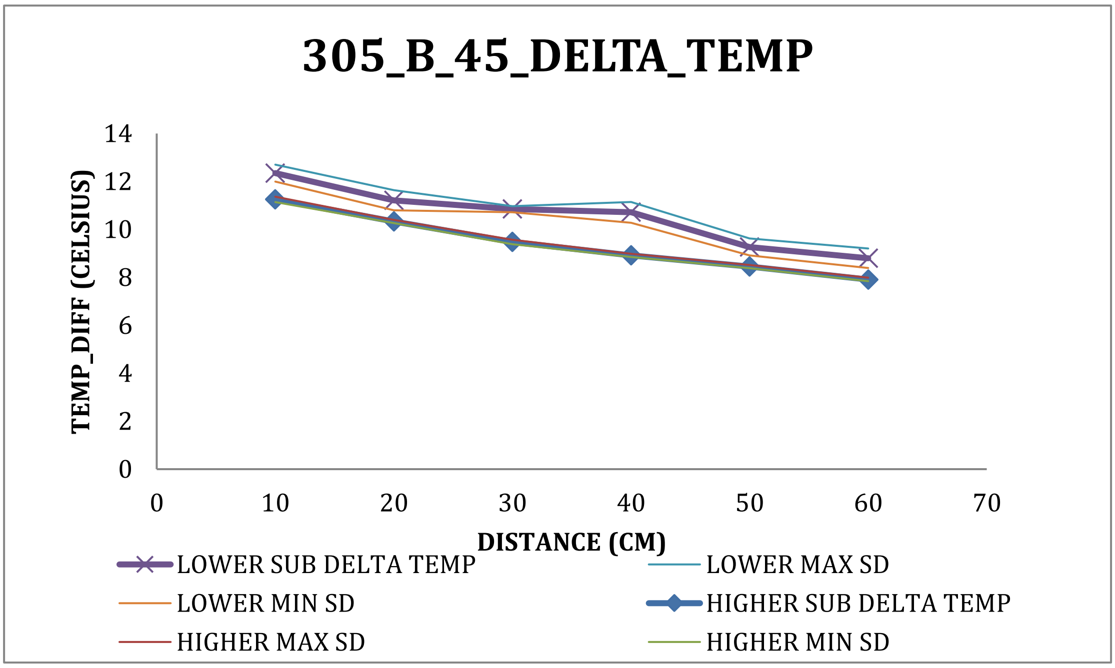


Figure 47 TS305-11C55-B45

TS305		
Position_B_Angle_45		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	23,1	25,7
Normal body temperature of the subject observed by the sensor	34,6	36,0
Delta temperature from the sensors	11,4	10,3

Table 7 TS305-11C55 Position_B_45

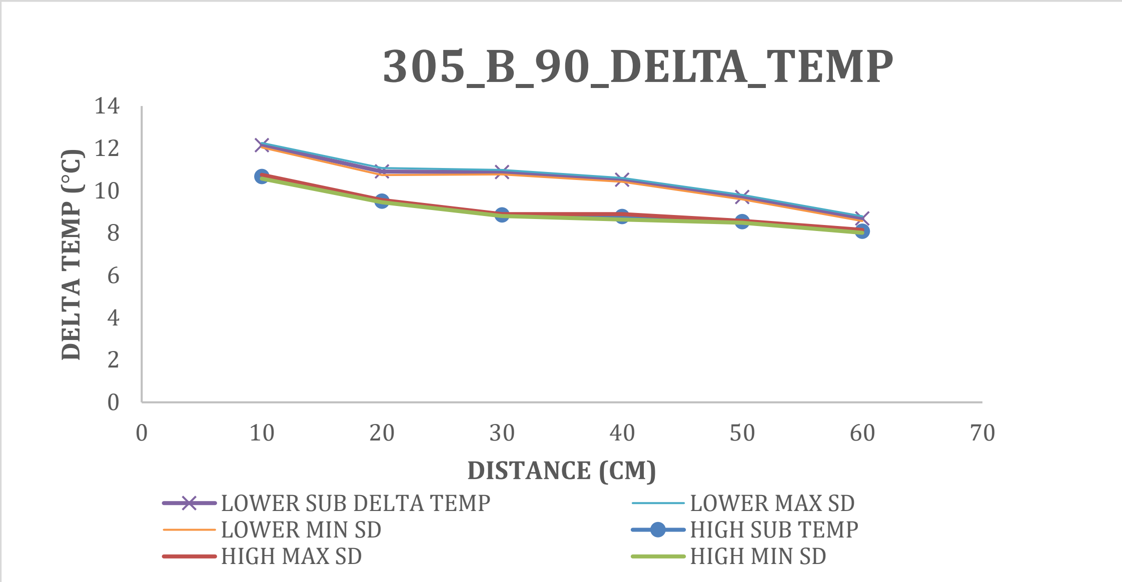


Figure 48 TS305-11C55-B90

TS305		
Position_B_Angle_90		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	23,1	25,7
Normal body temperature of the subject observed by the sensor*	34,4	35,3
Experimental Delta temperature from the sensors	11,3	9,6

Table 8 TS305-11C55 Position_B_90

4.2 Delta temperature comparison TS318-11C55

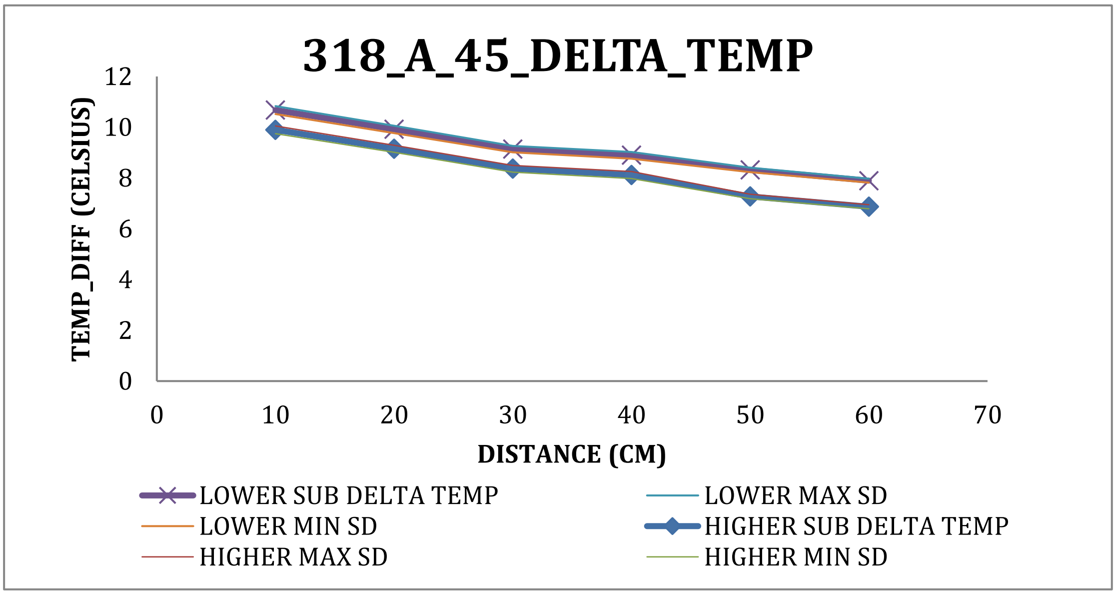


Figure 49 TS318-11C55-A45

TS318		
Position_A_Angle_45		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	22,7	25,4
Normal body temperature of the subject observed by the sensor*	32,6	34,6
Experimental Delta temperature from the sensors	9,9	9,1

Table 9 TS318-11C55 Position_A_45

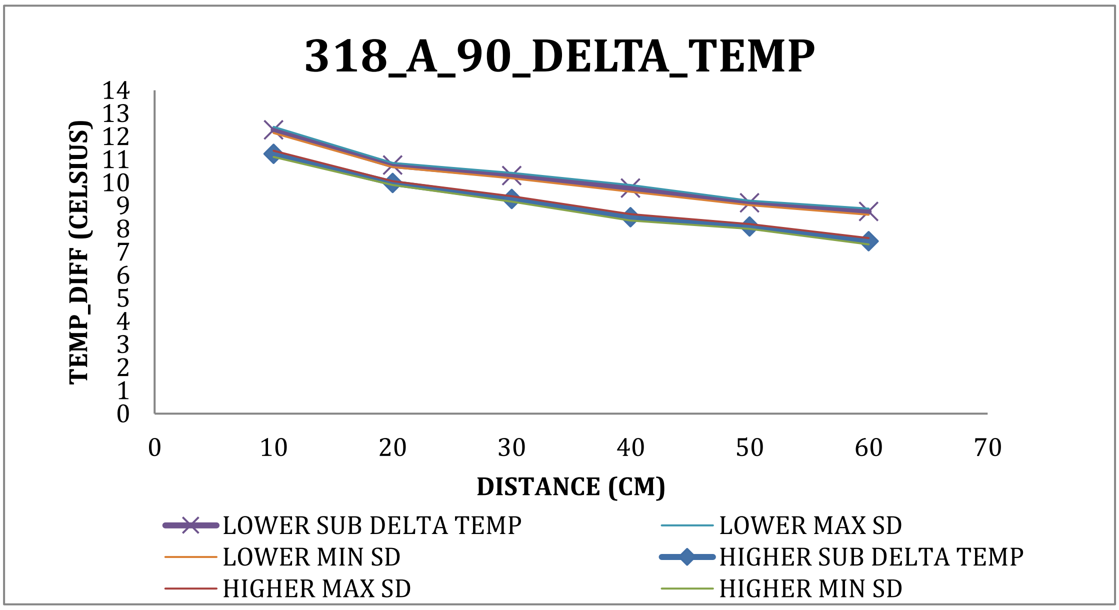


Figure 50 TS318-11C55-A90

TS318		
Position_A_Angle_90		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	22,7	25,4
Normal body temperature of the subject observed by the sensor*	33,8	34,6
Experimental Delta temperature from the sensors	11,1	9,1

Table 10 TS318-11C55 Position_A_90

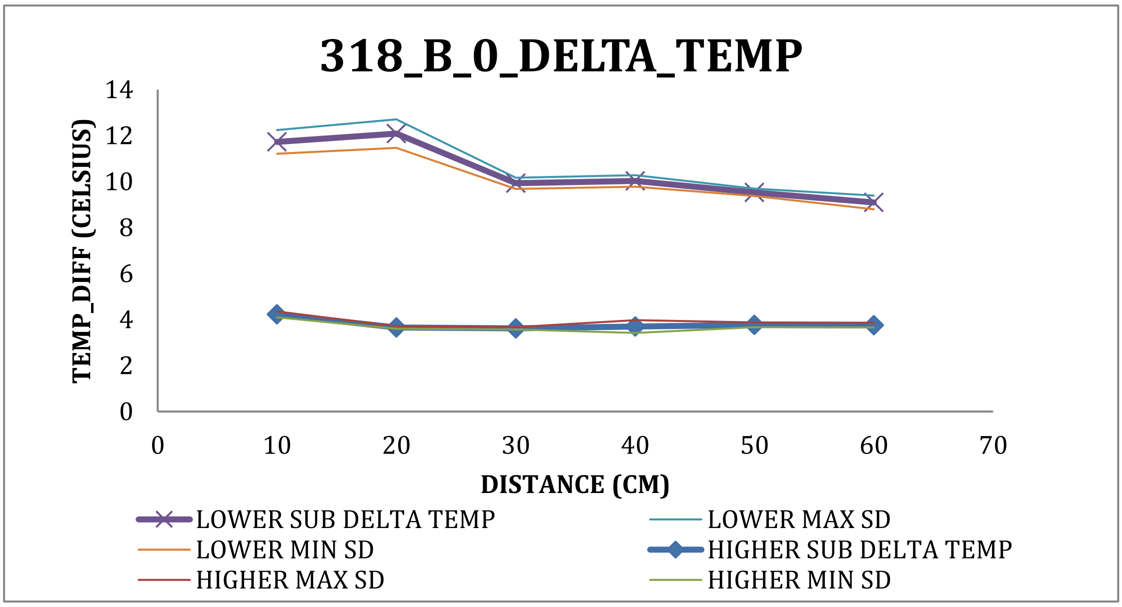


Figure 51 TS318-11C55-B0

TS318		
Position_B_Angle_0		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	22,7	25,4
Normal body temperature of the subject observed by the sensor*	33,9	29,3
Experimental Delta temperature from the sensors	11,2	3,8

Table 11 TS318-11C55 Position_B_0

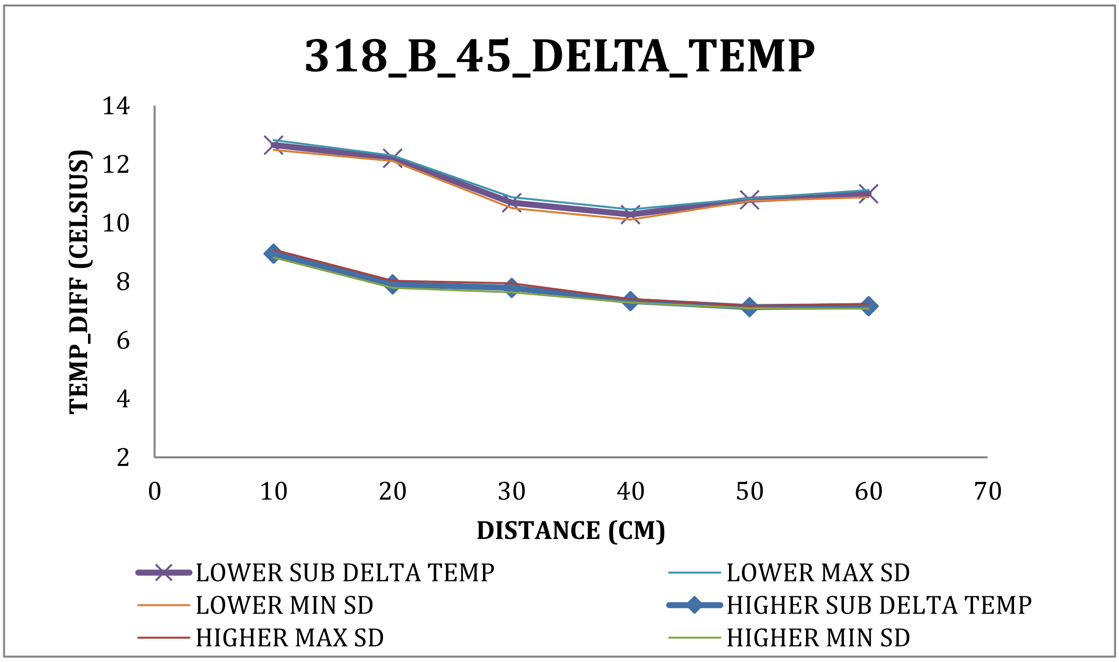


Figure 52 TS318-11C55-B45

TS318		
Position_B_Angle_45		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	22,7	25,4
Normal body temperature of the subject observed by the sensor*	34,5	34,6
Experimental Delta temperature from the sensors	11,8	9,1

Table 12 TS318-11C55 Position_B_45

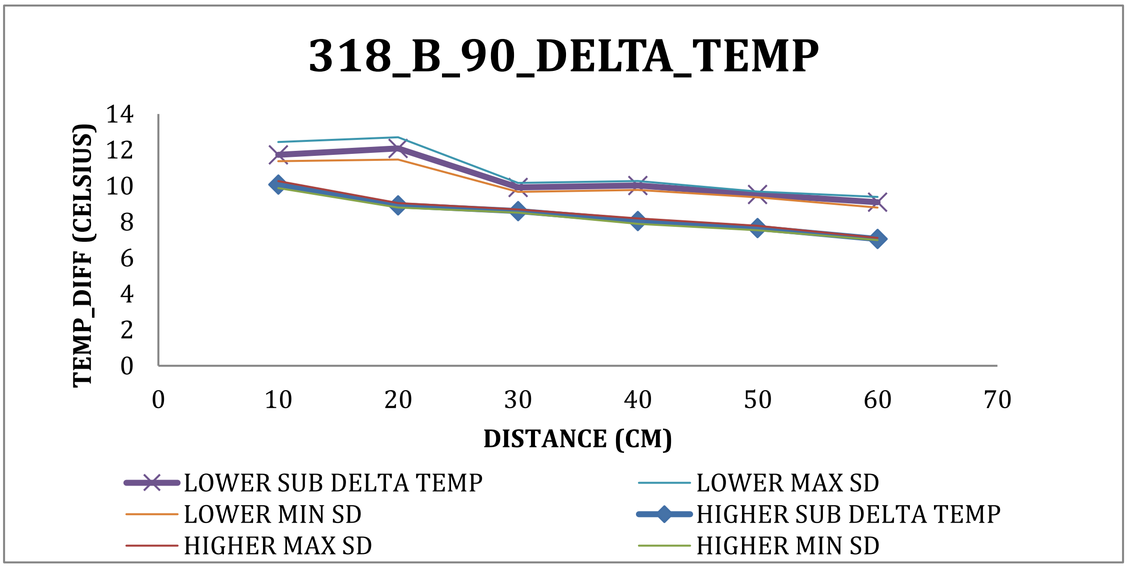


Figure 53 TS318-11C55-B90

TS318		
Position_B_Angle_90		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	22,7	25,4
Normal body temperature of the subject observed by the sensor*	33,9	34,6
Experimental Delta temperature from the sensors	11,2	9,1

Table 13 TS318-11C55 Position_B_90

4.3 Delta temperature comparison ZTP-115

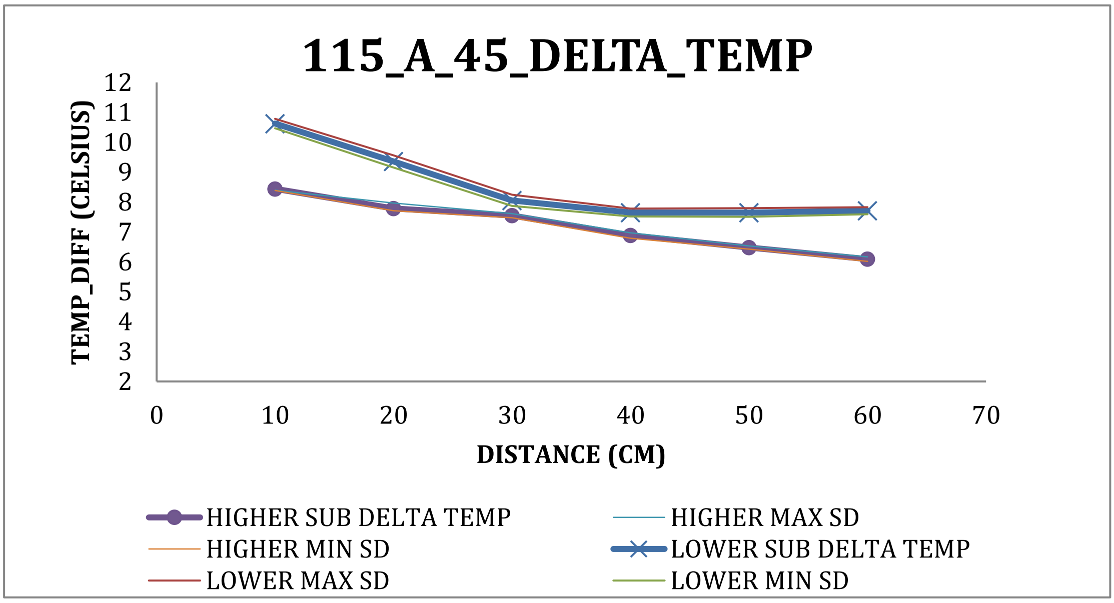


Figure 54 ZTP-115-A45

ZTP-115		
Position_A_Angle_45		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	22,5	25,6
Normal body temperature of the subject observed by the sensor*	31,9	33,6
Experimental Delta temperature from the sensors	9,3	7,9

Table 14 ZTP-115 Position_A_45

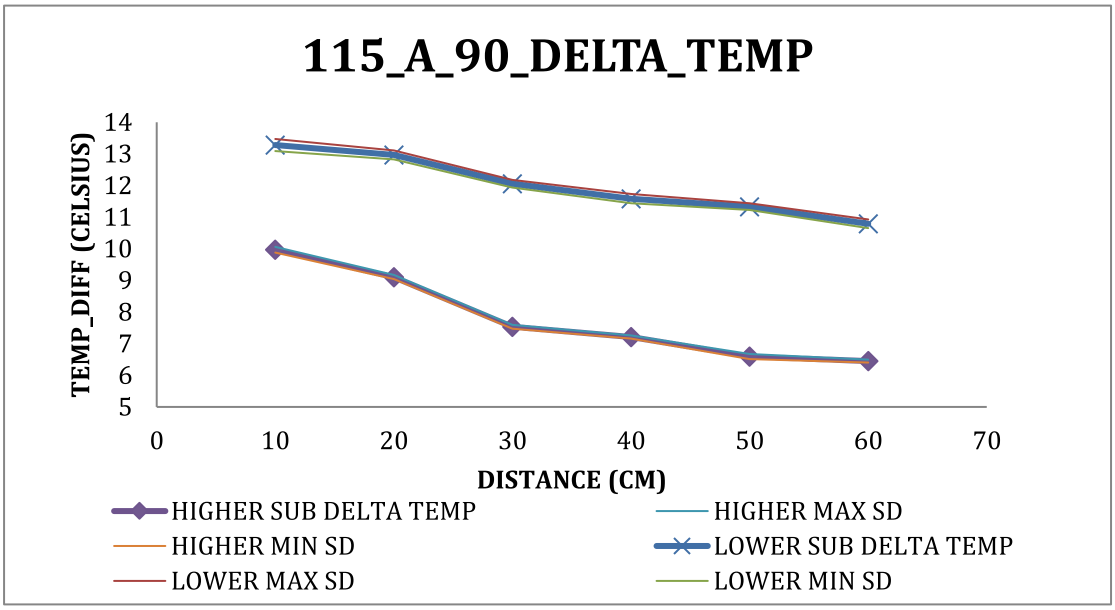


Figure 55 ZTP-115-A90

ZTP-115		
Position_A_Angle_90		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	22,5	25,6
Normal body temperature of the subject observed by the sensor*	35,3	33,6
Experimental Delta temperature from the sensors	12,7	7,9

Table 15 ZTP-115 Position_A_90

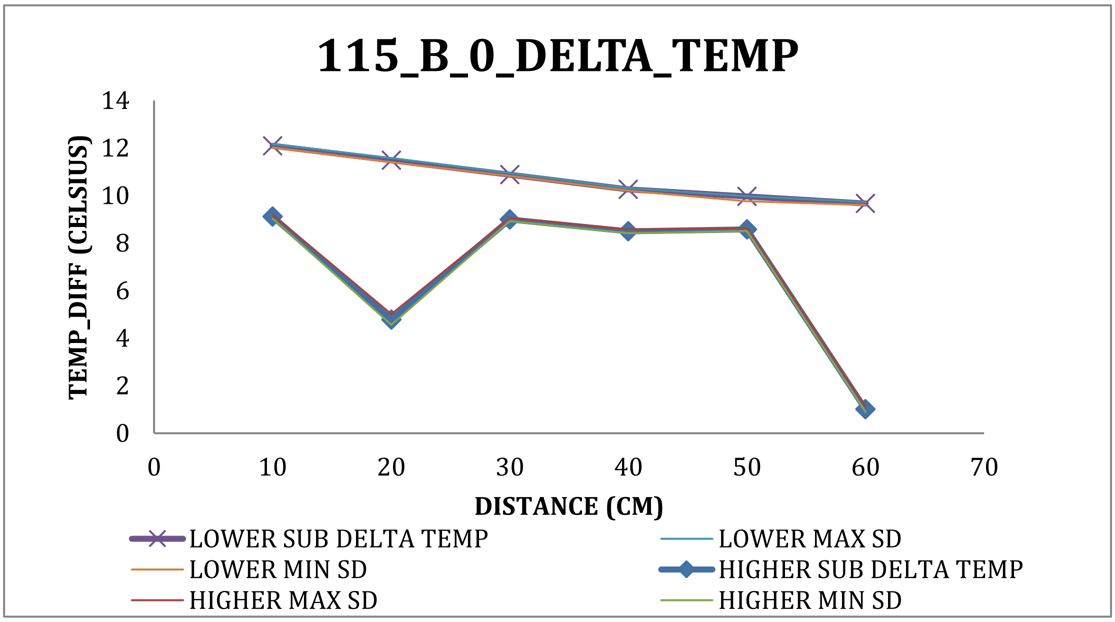


Figure 56 ZTP-115-B0

ZTP-115		
Position_B_Angle_0		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	22,5	25,6
Normal body temperature of the subject observed by the sensor*	34,0	33,3
Experimental Delta temperature from the sensors	11,4	7,6

Table 16 ZTP-115 Position_B_0

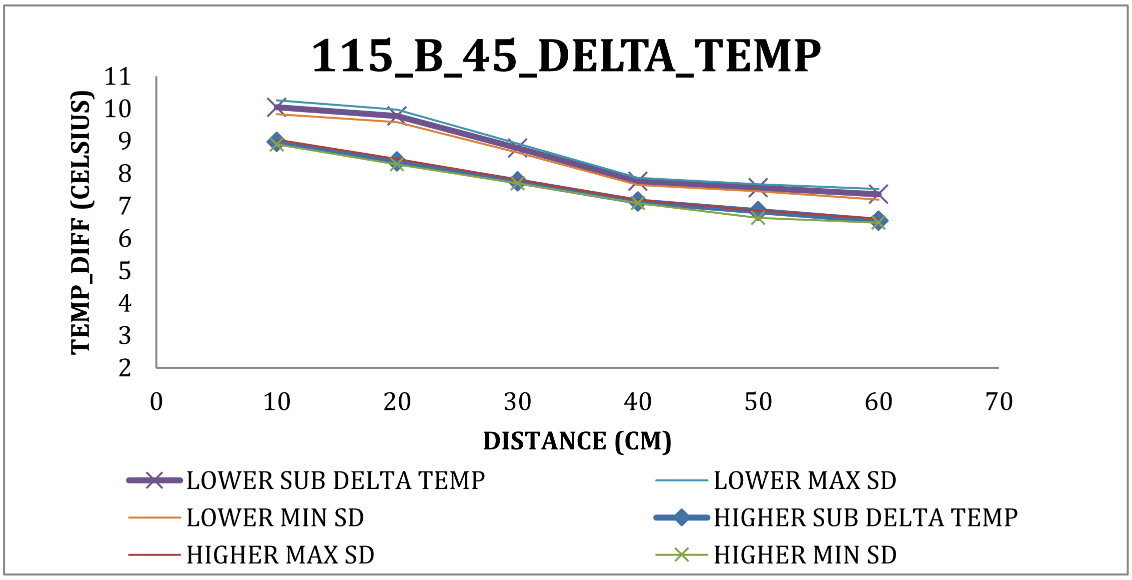


Figure 57 ZTP-115-B45

ZTP-115		
Position_B_Angle_45		
Parameters	With Subject at Lower ambient temperature (degree celsius)	With Subject at higher ambient temperature (degree celsius)
Ambient temperature observed by the sensor	22,5	25,6
Normal body temperature of the subject observed by the sensor*	32,1	34,0
Experimental Delta temperature from the sensors	9,5	8,3

Table 17 ZTP-115 Position_B_45

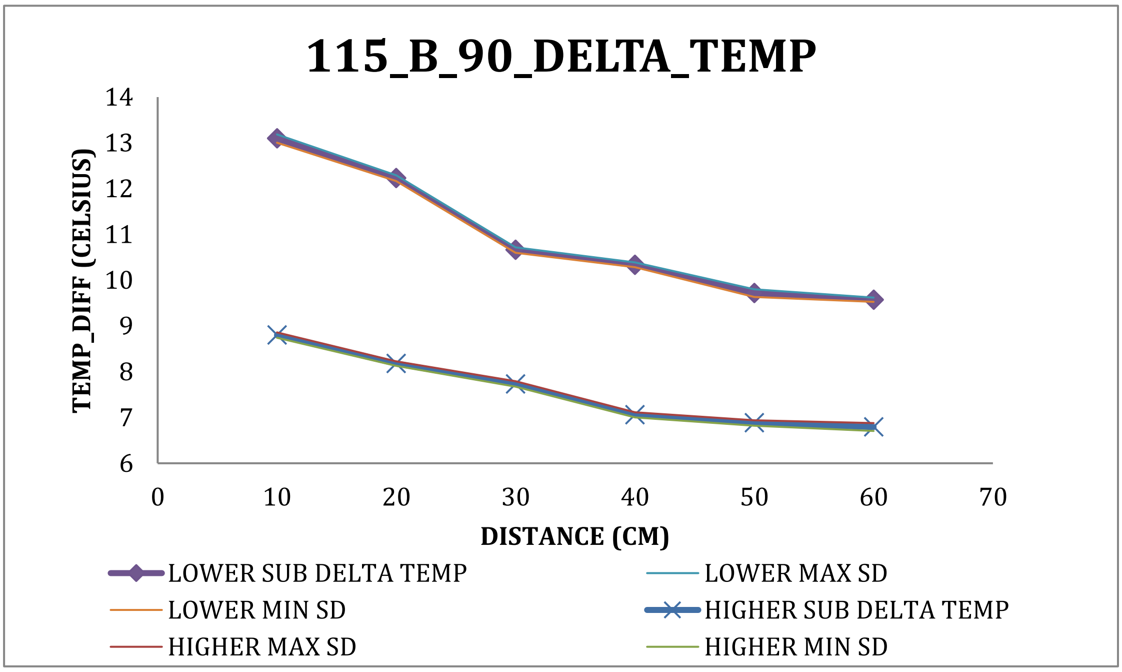


Figure 58 ZTP-115-B90

ZTP-115		
Position_B_Angle_90		
Parameters	With Subject at Lower ambient temperature (degree Celsius)	With Subject at higher ambient temperature (degree Celsius)
Ambient temperature observed by the sensor	22,5	25,6
Normal body temperature of the subject observed by the sensor*	34,5	34,0
Experimental Delta temperature from the sensors	11,9	8,3

Table 18 ZTP-115 Position_B_90

4.4 Delta temperature comparison_walking subject

We have considered 5 subjects for this experiment. The subjects are made to walk in front of the sensors at the distance of 30cm and the readings are taken. The experiment is repeated three times to check on the variability of the signal acquired. The subject temperature is calculated from the conversion table procedure. The delta temperature is calculated for all the three sensors and are given in Table 19 Delta temperature values for walking subjects & random position of subjects.

4.5 Delta temperature comparison_random positions

We have considered 10 subjects for this experiment. The subjects are made to take random positions except the positions A and B (or any laying floor positions) at 30cm distance from the sensor and the readings are taken. The experiment is repeated three times to check on the variability of the signal acquired. The subject temperature is calculated from the conversion table procedure. The delta temperature is calculated for all the three sensors and are given in Table 19 Delta temperature values for walking subjects & random position of subjects.

	Delta temperature with walking subject °C		Delta temperature with subject taking random positions(other than laying down) °C	
Sensor Name	Mean Delta temperature°C	Standard deviation°C	Mean Delta temperature°C	Standard deviation°C
TS305-11C55	5.6	1.3	7.7	1.4
TS318-11C55	5.4	1.2	8.5	1.3
ZTP 115	2.7	0.6	5.6	1.3

Table 19 Delta temperature values for walking subjects & random position of subjects

5 Discussion

The major focus of the experiments is to understand the behavior of the sensors under different ambient conditions. We have a small brief about the working of the sensors under the higher and lower ambient temperature conditions.

	DELTA TEMPERATURE AT LOWER AMBIENT TEMPERATURE			DELTA TEMPERATURE AT HIGHER AMBIENT TEMPERATURE		
POSITIONS	TS305 11C55	TS318 11C55	ZTP115	TS305 11C55	TS318 11C55	ZTP115
A45	14,6	9,9	9,3	10,7	9,1	7,9
A90	14,4	11,1	12,7	10,7	9,1	7,9
B0	10,3	11,2	11,4	3,0	3,8	7,6
B45	11,4	11,8	9,5	10,3	9,1	8,3
B90	11,3	11,2	11,9	9,6	9,1	8,3

Table 20 Delta temperature in all angular positions

From the Table 20 Delta temperature in all angular positions, we can see that the position B0 has a comparatively smaller delta temperature of 3°C to 8°C at higher ambient temperature. This is mainly because the sensor is placed on the head region of the subject. So, the area of exposure of the subject on the sensor is very less and so the lesser delta temperatures are justified. We will not be considering the values of B0 (sensor facing the head region of the subject) for further assessment.

The temperature values calculated from the sensor signals are very close to the normal human body temperature with a little variation of ±2°C mainly because of the factors like emissivity of the clothes on the subject.

From the Table 20 Delta temperature in all angular positions , the **best angle of observation** and subject posture is **A90 (body facing sensor where the sensor is placed at 90° to the body silhouette)** which is observed. For this position, the delta temperature value is almost equal to the normal human body temperature in all scenarios and all the three sensors.

It implies that when a sensor is placed at 90° with the body of the subject facing the sensor within 30cm of sensor distance, it gives us almost the expected delta temperature value for that environmental conditions, which is 14.4°C.

5.1 Delta temperature variation

To have a better clarity, the graphs are plotted to show the delta temperature variation across different angles of sensor from the subject and to observe the differences in the behavior of the sensors. Two plots are made for both subject positions (Position A and position B) and it is repeated for both environment scenarios (higher and lower ambient temperatures).The plot is made for different angular positions of the sensor at 0°,45°and 90°.

This can give us the sensor range within which the detection of the subject can be trusted for the both environmental scenarios considered.

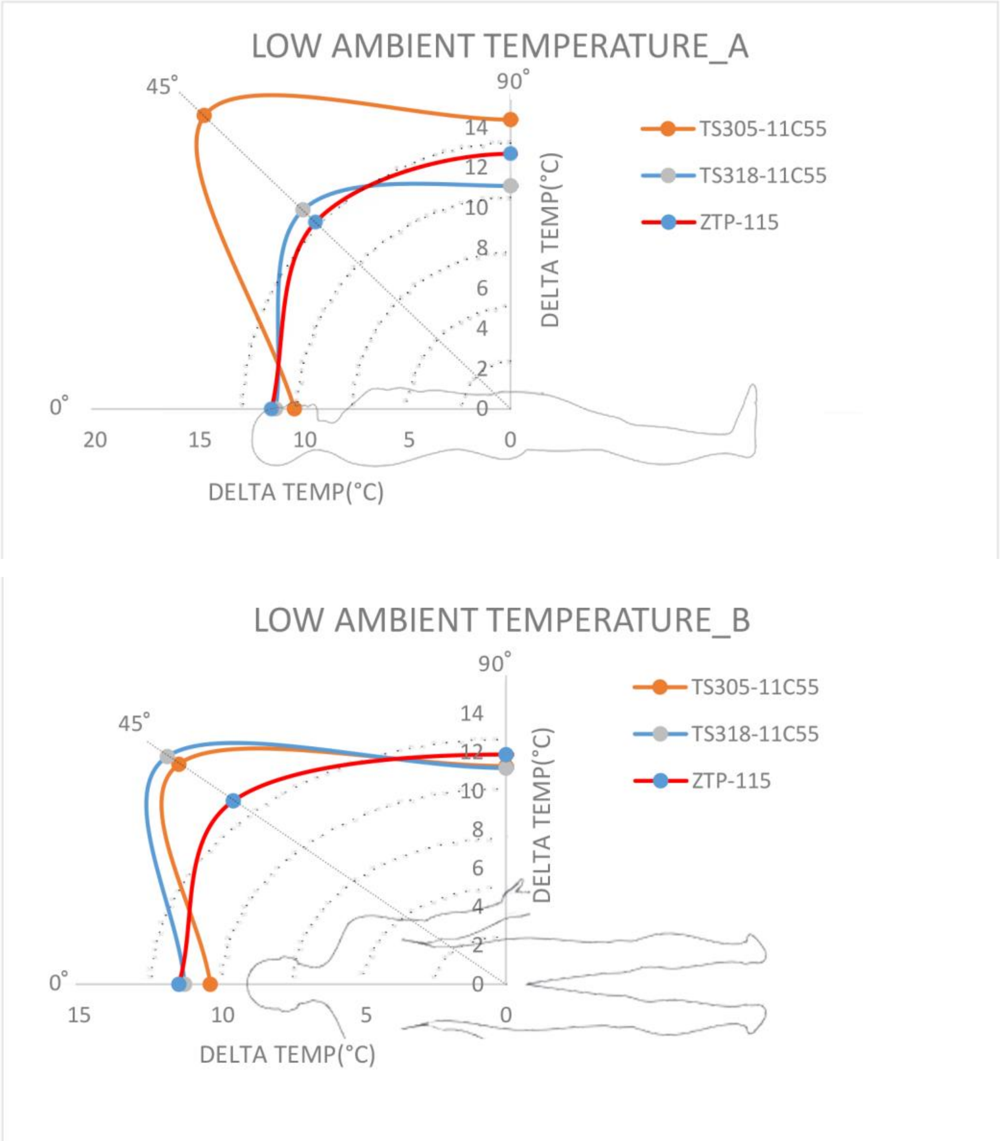
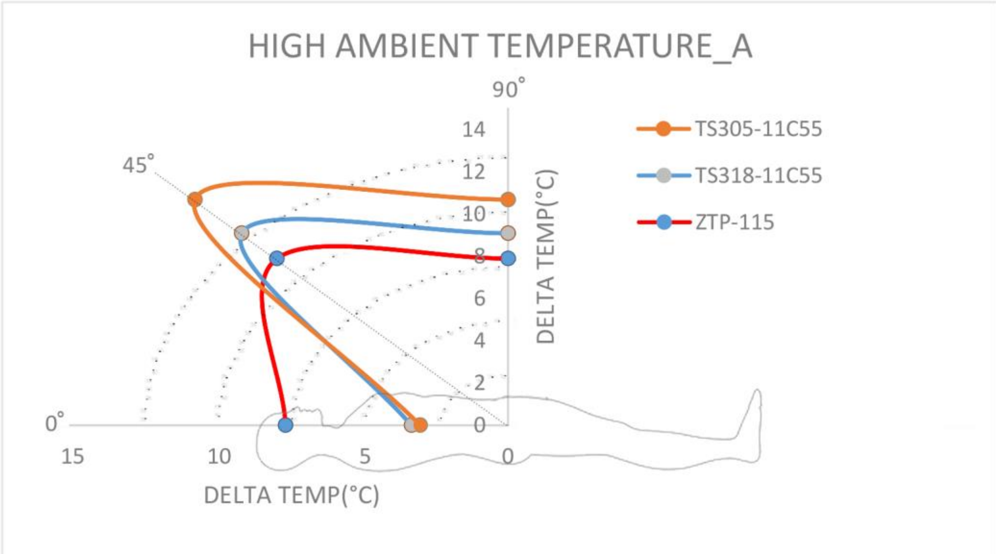


Figure 59 Delta temperature variation at 23°C at position A and B



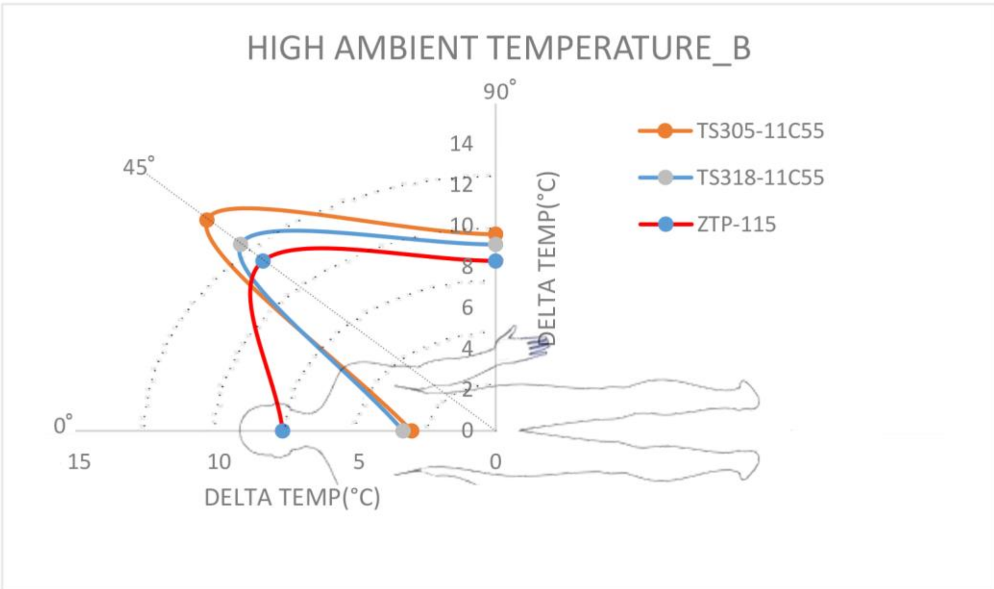


Figure 60 Delta temperature variation at 26°C at position A and B

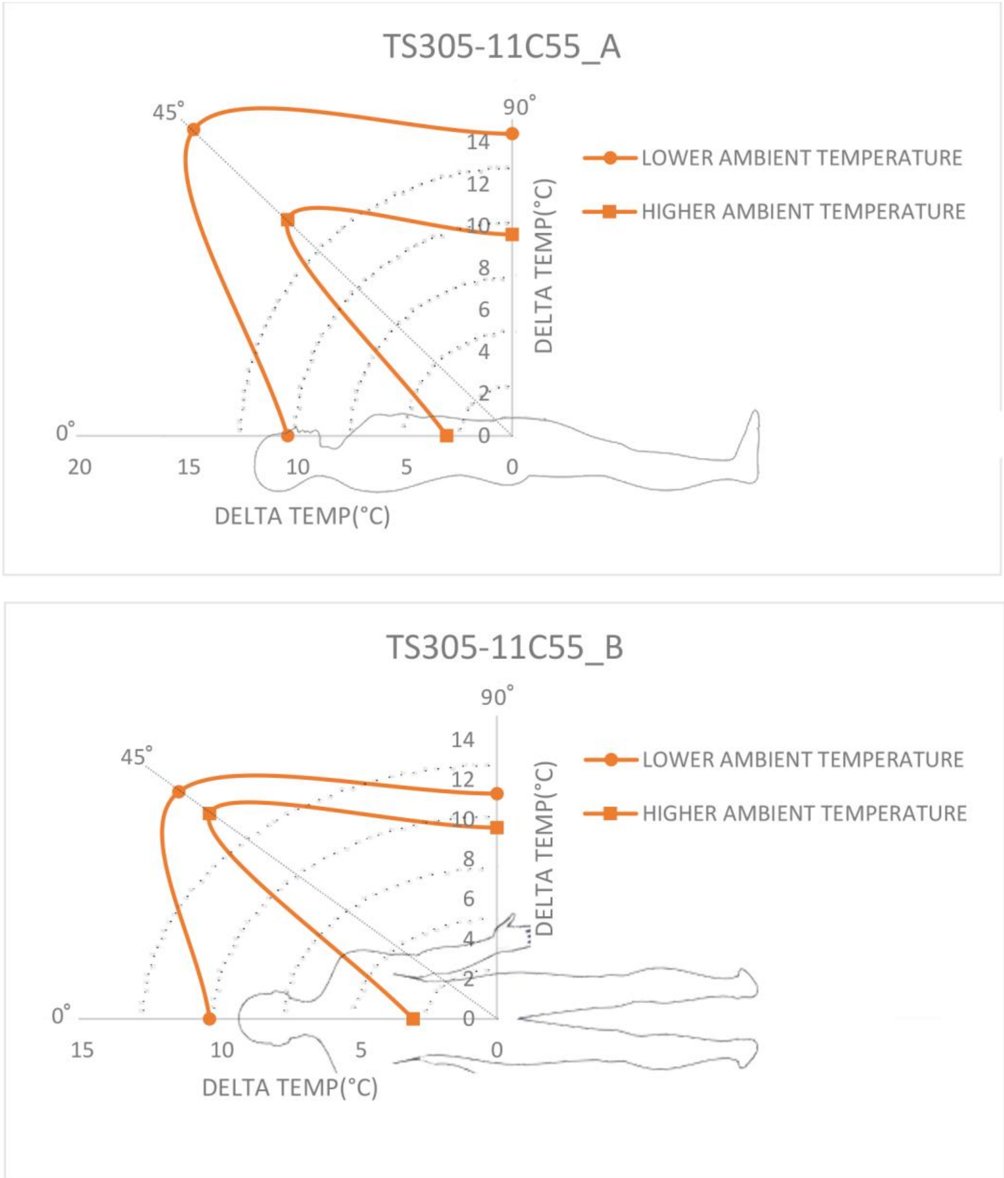


Figure 61 Delta temperature variation at position A and B for TS305 11C55

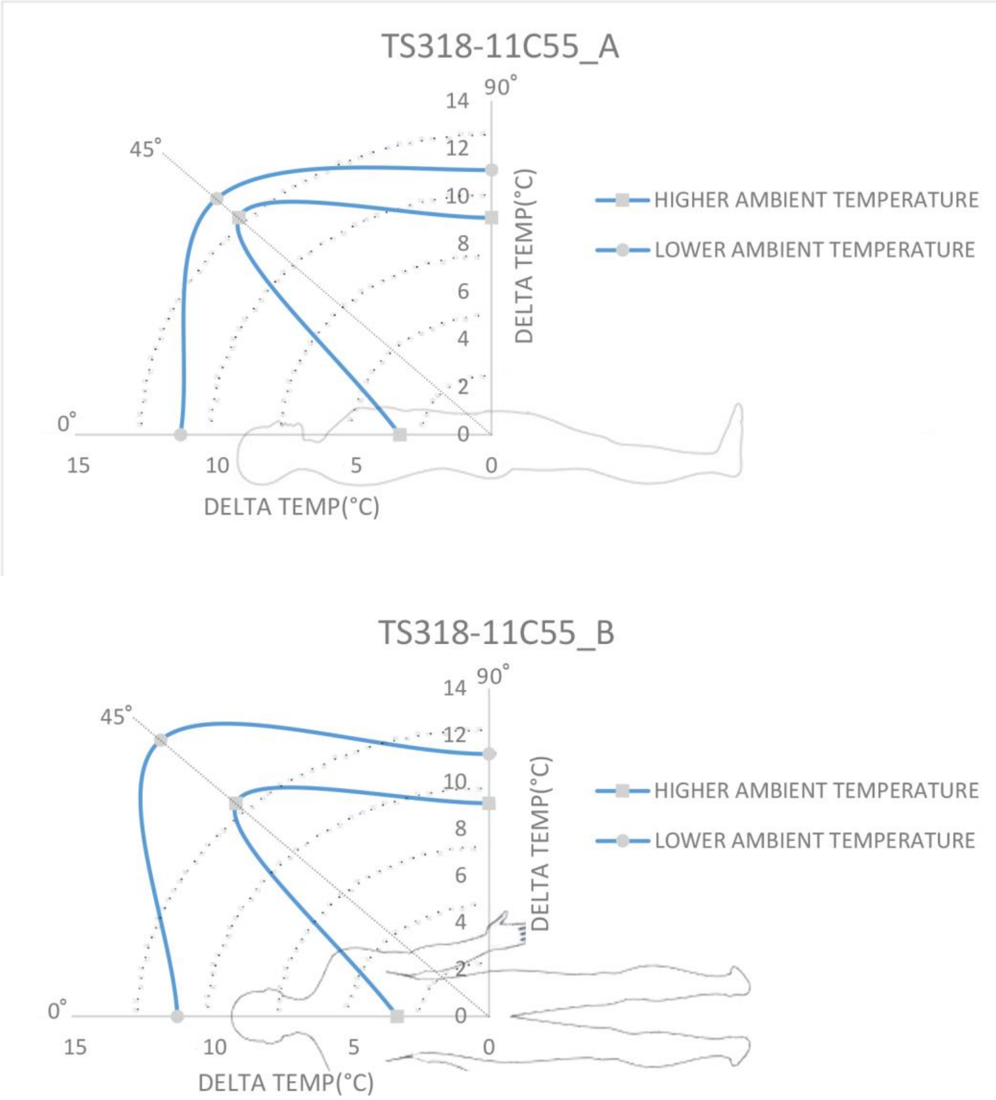
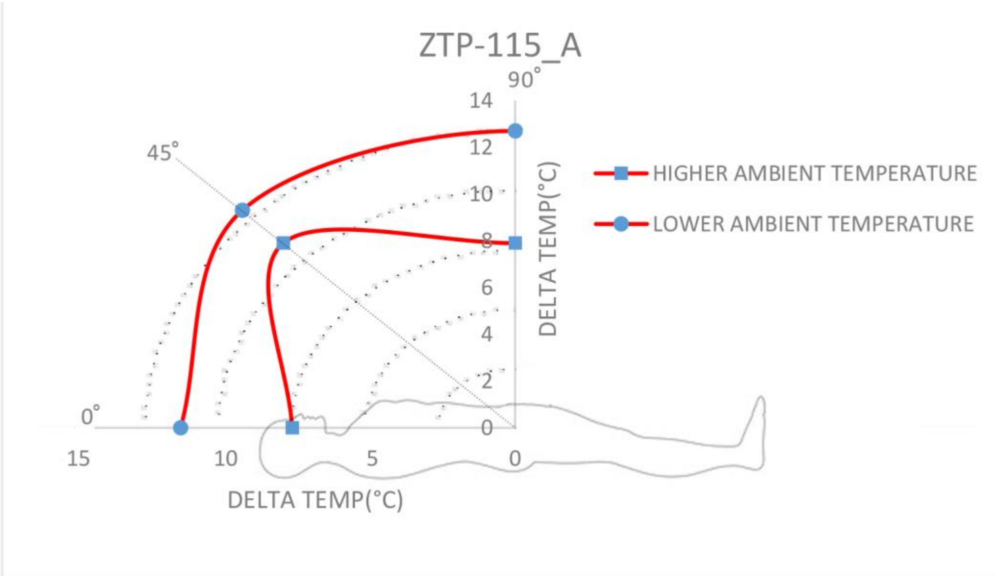


Figure 62 Delta temperature variation at position A and B for TS318 11C55



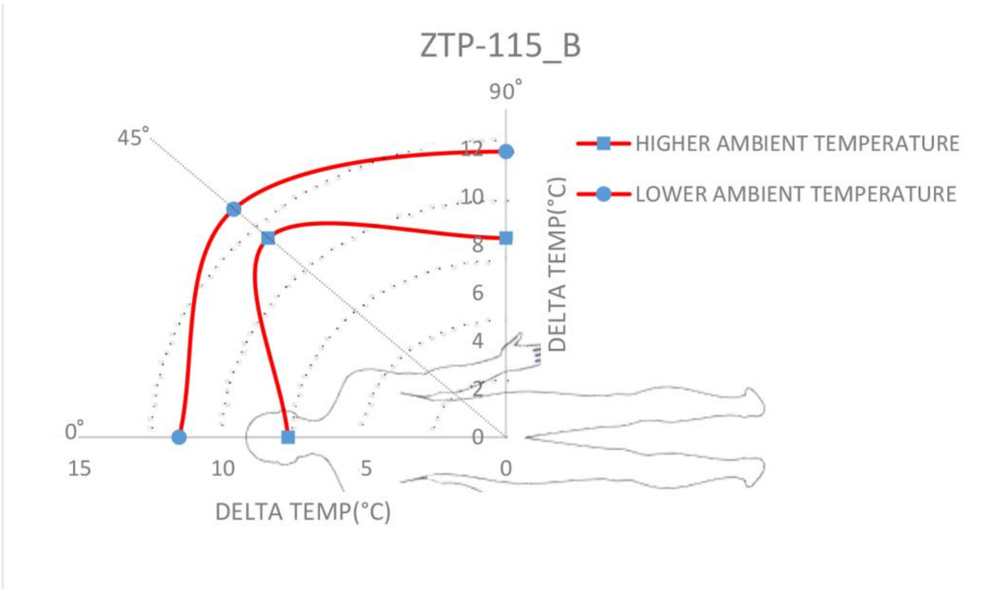


Figure 63 Delta temperature variation at position A and B for ZTP115

5.2 Detection reliability

There must be a factor that should be reliable and confirm us if the patient is down. The detection reliability can be measured in terms of delta temperature. The angular position A90 where the sensor is placed at 90° from the subject (perpendicular to the subject) and the subject is facing the sensor is considered, so that the maximum exposure of the subject is acquired.

The behavior of the sensors will be clear from the below plots under various subject positions and environment conditions.

5.2.1 TS305-11C55

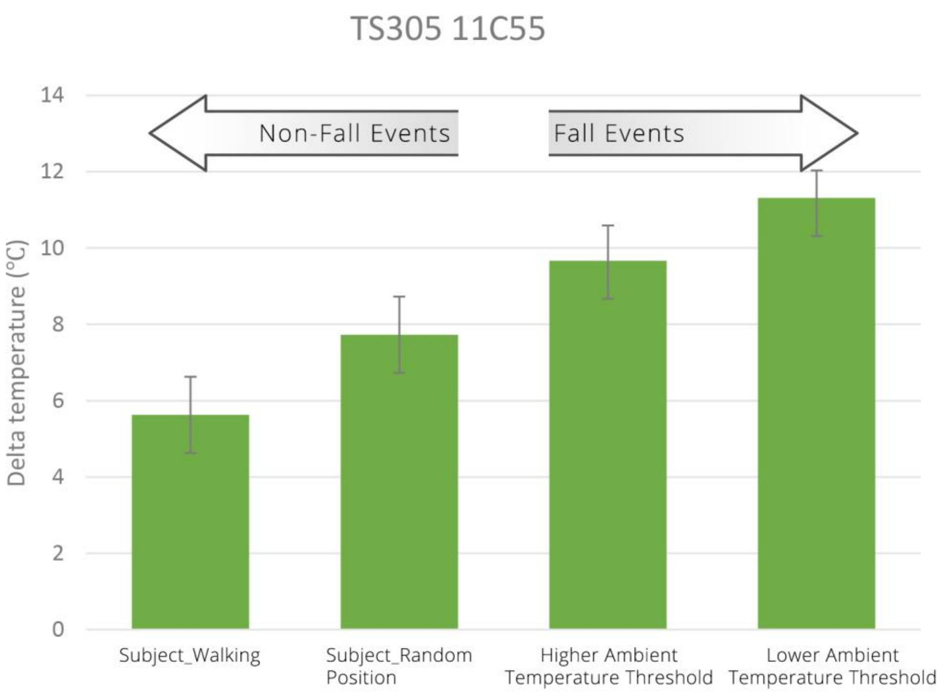


Figure 64 Overall Behavior of TS305 11C55

From 2.2.3, we have fixed the sensor distance as 30 cm and made five subjects to walk in front of the sensor, stay still with only the leg region exposed to the sensor. We have got the delta temperature of 5.6°C with a standard deviation of 1.3°C. Based on results, we would say, even when the sensor is placed at 30cm (which is a reliable distance) if the delta temperature is around 5.6 °C then we can consider this situation as false alarm. This gives out that the sensor senses some heat based on the exposure of a walking subject but not enough heat to conclude that the person is completely down.

From 2.2.4, we made ten subjects to randomly take any position (except positions A and B lying on the floor positions) at the same 30cm sensor distance which gave us a delta temperature of 7.7°C with a standard deviation of 1.4°C. The error bars are calculated based on the standard deviation.

From all these experiments, for the position A90, we can infer that, at higher ambient conditions of 26℃, only if the subject is laying on the floor, we can get the delta temperature of more than 10.7°C else we get less than 10.7°C (for all possible vertical positions) with a standard deviation of 0.9°C.

At lower ambient conditions of 23℃, only if the subject is laying on the floor, we can get the delta temperature of more than 14.6°C else we get less than 14.6°C (for all possible vertical positions) with a standard deviation of 0.7°C.

So, we can say if the sensor gives out a delta temperature of more than 10.7℃, for an ambient of 26℃, at a sensor distance of 30cm or less, for a duration of 3 minutes or more, we can confirm that the subject is down and needs help.

5.2.2 TS318-11C55

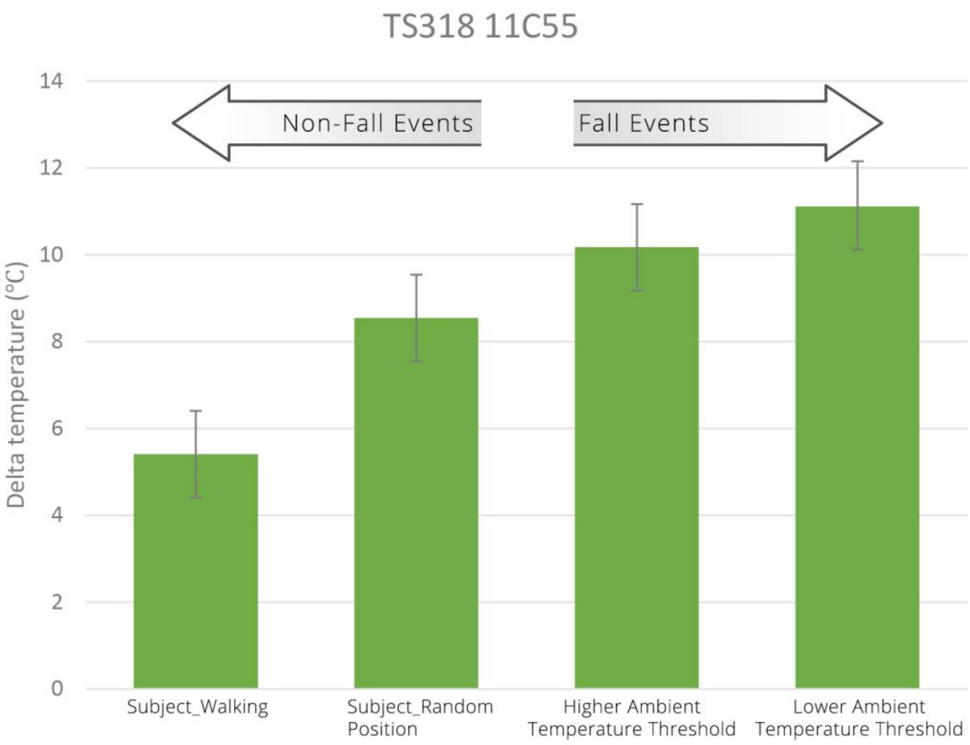


Figure 65 Overall Behavior of TS318 11C55

From 2.2.3, We have fixed the sensor distance as 30 cm and made five subjects to walk in front of the sensor, stay still with only the leg region exposed to the sensor .We have got the delta temperature of 5.4°C with a standard deviation of 1.2°C. Based on results, we would say, even when the sensor is placed at 30cm (which is a reliable distance) if the delta temperature is around 5.4°C then we can consider this situation as false alarm. This gives out that the sensor senses some heat based on the exposure of a walking subject but not enough heat to conclude that the person is completely down.

From 2.2.4, we made ten subjects to randomly take any position (except positions A and B lying on the floor positions) at the same 30cm sensor distance which gave us a delta temperature of 8.5°C with a standard deviation of 1.3°C. The error bars are calculated based on the standard deviation.

From all these experiments, for the position A90, we can infer that, at higher ambient conditions of 26°C, only if the subject is laying on the floor, we can get the delta temperature of more than 9.1°C else we get less than 9.1°C (for all possible vertical positions) with a standard deviation of 0.9°C.

At lower ambient conditions of 23°C, only if the subject is laying on the floor, we can get the delta temperature of more than 11.1°C else we get less than 11.1°C (for all possible vertical positions) with a standard deviation of 1.0°C.

So, we can say if the sensor gives out a delta temperature of more than 9.1℃ for an ambient of 26°C, at a sensor distance of 30cm or less, for a duration of 3 minutes or more, we can confirm that the subject is down and needs help.

5.2.3 ZTP 115

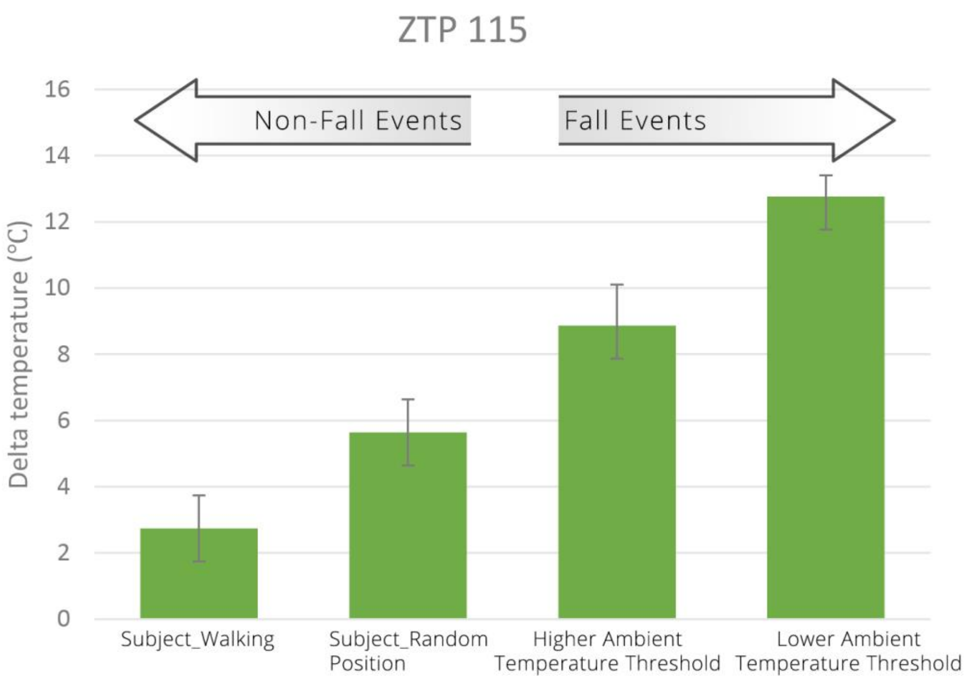


Figure 66 Overall Behavior of ZTP 115

From 2.2.3, We have fixed the sensor distance as 30 cm and made some subjects to walk in front of the sensor, stay still with only the leg region exposed to the sensor .We have got the delta temperature of 2.7°C with a standard deviation of 0.6°C. Based on results, we would say, even when the sensor is placed at 30cm (which is a reliable distance) if the delta temperature is around 2.7°C then we can consider this situation as false alarm. This gives out that the sensor senses some heat based on the exposure of a walking subject but not enough heat to conclude that the person is completely down.

From 2.2.4, we made some subjects to randomly take any position (except positions A and B lying on the floor positions) at the same 30cm sensor distance which gave us a delta temperature of 5.6°C with a standard deviation of 1.3°C. The error bars are calculated based on the standard deviation.

From all these experiments, for position A90, we can infer that, at higher ambient conditions of 26℃, only if the subject is laying on the floor, we can get the delta temperature of more than 7.9°C else we get less than 7.9°C (for all possible vertical positions) with a standard deviation of 1.2°C.

At lower ambient conditions of 23℃, only if the subject is laying on the floor, we can get the delta temperature of more than 12.7°C else we get less than 12.7°C (for all possible vertical positions) with a standard deviation of 0.6°C.

So, we can say if the sensor gives out a delta temperature of more than 7.9℃, for an ambient of 26°C, at a sensor distance of 30cm or less, for a duration of 3 minutes or more, we can confirm that the subject is down and needs help.

6 Conclusion and future work

From the experiment results, we can know that these PIR sensor-based modules mounted on the sensor could classify the presence of human body. A robot mounted PIR based sensors can even identify the human but does not perform the subject identification as well.

In case of confirmed emergency with the signal that the subject is down, the robot installed with PIR sensors can be made to travel in the respective trajectory of the installed sensor based on the ambient conditions and check if we are getting the respective delta temperatures from Figure 59 Delta temperature variation at 23℃, if it is a lower ambient environment and Figure 60 Delta temperature variation at 26℃, if it is a higher ambient environment and additionally confirm the emergency situation of the subject.

Accordingly, we can imagine extensions to this study adapting a smart environment, where a set of PIR sensor are attached on the robot which is placed at different locations. In the smart environment, the robot mounted PIR sensor system could identify the human presence at different location, including direction, distance and robustly tracking the user and thus, helping the system built a rich model of the human and to test by orthogonally aligning the sensors, which could possibly improve the recognition accuracy, in particular, in the experiment for identifying subject. We also believe that implications of this work extent beyond our work.

Our system shows a similar performance to the previous PIR sensor-based systems in classifying human presence. For identifying human presence, our system has shown better performance than the previous PIR sensors-based identification methods. However, we cannot compare with the other PIR based systems, because the number of subjects identified, and the data set for identification might be collected in different environment. Consequently, although there would still be a question of which method is better in terms of identification the human presence accuracy, we can conclude with confidence that the output signal of PIR sensors installed in robot can be used to reliably classify the human presence in different environment.

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