DEVELOPMENT OF MEAN SKIN TEMPERATURE MODEL FOR INDIAN FARM WOMEN

भारतीय महिला कृषि श्रमिकों के लिए औसत त्वचा तापमान प्रतिरुपण का विकास

Kavitkar Chhaya Ragho

Thesis

Doctor of Philosophy

In

Agricultural Engineering

(Farm Machinery and Power Engineering)

2023

Department of Farm Machinery and Power Engineering,
College of Technology and Engineering,
Maharana Pratap University of Agriculture & Technology,
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Submitted to the

Maharana Pratap University of Agriculture and Technology, Udaipur

In Partial Fulfillment of the Requirement for the Degree of

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By

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2023

COLLEGE OF TECHNOLOGY AND ENGINEERING,
MAHARANA PRATAP UNIVERSITY OF AGRICULTURE &TECHNOLOGY,
UDAIPUR

CERTIFICATE – I

CERTIFICATE OF ORIGINALITY

The research work embodied in this thesis entitled "**Development of mean skin temperature model for Indian farm women**" submitted for the award of Doctor of Philosophy in Agricultural Engineering in the subject of Farm Machinery and Power Engineering to Maharana Pratap University of Agriculture and Technology, Udaipur (Rajasthan), is original and bonafide record of research work carried out by me under the supervision of **Dr. A. K. Mehta**, Ex. Professor, Department of Farm Machinery and Power Engineering, College of Technology and Engineering, Udaipur. The contents of the thesis, either partially or fully, have not been submitted or will not be submitted to any other Institute or University for the award of any degree or diploma.

The work embodied in the thesis represents my ideas in my own words and where others' idea or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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MAHARANA PRATAP UNIVERSITY OF AGRICULTURE & TECHNOLOGY, UDAIPUR

CERTIFICATE-II

Date: **/ /2023**

This is to certify that this thesis entitled "**Development of mean skin temperature model for Indian farm women**" submitted for the degree of **Doctor of Philosophy** in Agricultural Engineering in the subject of Farm Machinery and Power Engineering embodies bonafide research work carried out by **Ms. Kavitkar Chhaya Ragho** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation has been fully acknowledged. The draft of the thesis was also approved by the advisory committee on 24/12/2022.

The manuscript has been subjected to plagiarism check by software Urkund. It is certified that as per the check, the similarity index of the content is 8% and is within permissible limit as per the MPUAT guidelines on checking Plagiarism.

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CERTIFICATE – III

Date: / /2023

This is to certify that this thesis entitled **"Development of mean skin temperature model for Indian farm women"** submitted by **Ms. Kavitkar Chhaya Ragho** to Maharana Pratap University of Agriculture and Technology, Udaipur in partial fulfillment of the requirement for the degree of **Doctor of Philosophy** in the subject of **Farm Machinery and Power** after recommendation by the external examiner was defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination held on 13/05/2023 was found satisfactory; we therefore, recommend that the thesis be approved.

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Date: / /2023

This is to certify that **Ms. Kavitkar Chhaya Ragho** student of **Doctor of Philosophy** in **Agricultural Engineering** in the subject of **Farm Machinery and Power Engineering,** Department of Farm Machinery and Power Engineering has made all the corrections/modifications in the thesis entitled **"Development of mean skin temperature model for Indian Farm women"** which were suggested by the external examiner and the advisory committee in the oral examination held on 13/05/2023. The final corrected and bound copies of the thesis were submitted on /05/2023.

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I offer my salutations at the feet of the lord, who kindly imbued the energy and enthusiasm through ransifying path of thick and thin of my efforts.

Place: Udaipur

Date : / /2022 **(Kavitkar Chhaya Ragho)**

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LIST OF SYMBOLS AND ABBREVIATIONS

&	And
=	Equal to
%	Percent
^{o} C	Degree Celsius
^{o} F	Degree Fahrenheit
>	Greater than
<	Less than
ACGIH	American Council of Governmental Industrial Hygiene
ASHREE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Am	Ante meridian
BIS	Beauro of Indian Standards
BMI	Body Mass Index
BP	Blood Pressure
Cm	Centimetre
CTAE	College of Technology and Engineering
CV	Coefficient of Variation
DBT	Dry Bulb Temperature
e.g	Example
et al	et alia (And others)
Fig	Figure
H	Hour
HR	Heart Rate
i.e	That is
ISO	International Standard Organisation
kg	Kilogram
Kg/m^2	Kilogram per square meter
L	Litre
l/min	Litre per minute
l/s	Litre per second
Max	Maximum
mm	Millimeter
m^2	Square meter
m/s	Mitre per second

MRI	Magnetic Resonance Imaging
MST	Mean Skin Temperature
No	Number
OCR	Oxygen Consumption Rate
OSHA	Occupational Safety and Health Association
pm	Post meridian
RH	Relative Humidity
R^2	Correlation Coefficient
rpm	Revolutions per Minute
s	Second
SA	Surface Area
SD	Standard Deviation
SE	Standard error
S. No.	Serial Number
T_a	Ambient temperature
T_c	Core temperature
T_d	Dry bulb temperature
T_g	Globe temperature
T_{max}	Maximum temperature
T_{sk}	Skin Temperature
T_w	Wet bulb temperature
VO_{2max}	Maximum Oxygen Uptake
WBGT	Wet Bulb Globe Temperature
$WBGT_i$	Wet Bulb Globe Temperature, indoor
$WBGT_o$	Wet Bulb Globe Temperature, outdoor
WBT	Wet Bulb Temperature
WHO	World Health Organisation
WHR	Working Heart Rate

CHAPTER I
INTRODUCTION

Skin covers the whole human body and is by far the largest organ. Skin plays vital role in maintaining the thermal balance of human body. In many ways, skin allows humans to interact with the environment. The temperature of the skin is crucial for effective thermoregulation, together with the temperature of inner organs and the brain. Mean skin temperature (MST) is an average skin temperature of human body and important physiological parameter reflecting human response to heat or thermal stimulus and states of heat exchange between human body and a thermal environment. Skin temperature measurement is commonly used to explore the interaction between human thermo-physiology and the external environment (Livingstone et al., 1987).

Mean skin temperature is a physiological parameter of interest for the evaluation of thermal comfort and heat stress in working human being. Human thermal comfort is defined as "being that condition of mind in which satisfaction is expressed with the thermal environment". The close relationship between mean skin temperature and thermal comfort has been found in some studies. According to Fanger (1967), one will experience thermal comfort if thermal balance is satisfied and mean skin temperature and sweat rate are within a comfort range. In Hoppe (2002) research, the mean skin temperature was shown to play a dominating role in the thermo physiological definition and the energetic definition of thermal comfort. Bulcao et al. (2000), indicated that thermal comfort in humans could be determined to a great extent by skin temperature. McIntyre (1972), concluded thermal sensation is roughly a linear function of mean skin temperature between 29˚C and 34˚C.

The initial interest in estimation of mean skin temperature originated from the findings of Burton, 1934; and Hardy and DuBois, 1938, they found the term mean body temperature (MBT).Mean body temperature includes mean skin temperature and core (inner) body temperature of human body. Mean body temperature regulates the proper thermal balance of the human body. The change in mean body temperature reflects body heat storage which is a necessary term to quantify heat exchange between human body and the environment. Skin temperature helps in heat exchange between the human body and environment. Satisfaction with the thermal environment is important for its own sake and because it influences productivity and health. It is well known that temperature varies across the surface of the skin, so that an average skin temperature may only be obtained by taking the mean of local temperatures weighted according to the relative surface of the area they are supposed to characterise.

Many methods and calculation formulae for calculating mean skin temperature have been developed incorporating body points from one to fifteen local skin temperatures. Values of mean skin temperature are obtained by summing the products of local skin temperatures and the corresponding weighting factors. Up to now, many mean skin temperature calculation methods have been formulated from the field of physiology, which are separated by the number of skin temperature sites and weighting factors. The true mean skin temperature (T_{sk}) will be measured only by obtaining an infinite number of measuring sites of temperature on the skin. However, it is virtually impossible to determine the skin temperatures over the entire surface of the body. Therefore, T_{sk} estimates are generally limited to a finite number of skin temperatures and their corresponding weighting factors. The T_{sk} can be estimated by the following general formula: $T_{sk} = f1 \cdot T1 + f2 \cdot T2 + \ldots + fn \cdot Tn$, where $T1$, $T2$, …, Tn are local skin temperatures, and $f1$, $f2$, …, fn are corresponding weighting factors.

The crucial role of calculating mean skin temperature in evaluation of body heat exchanges as well as in the evaluation of thermal comfort has resulted in a number of attempts to derived equations being made in order to estimate mean skin temperatures with various logics (e.g. simple average, one point, skin surface area ratio, skin surface area ratio and thermal sensitivity of the skin and skin surface area ratio and heat transfer coefficient ratio, etc). Among the various methods employed, mean skin temperature that is based on the skin surface area ratio to the total body surface area has been the most widely accepted. This is because this method more faithfully represents the definition of "Mean skin temperature" (Lee, 2010).

Agriculture is of paramount importance in most developing countries because of large proportion of the population's dependence and concern of national food security. This is of particular relevance because many agricultural tasks in developing countries demand high levels of labour input. Even with mechanization in developing country like India there is still need of human workforce for agricultural activity. Women workers contribute significantly in agricultural activity as compared to men. Besides their household work they are also involved in agricultural activity like weeding, transplanting, harvesting and threshing. There is significant role of farm workers in the country's agriculture and due attention needs to be given to their capabilities and limitations during design and operation of various farm equipments so as to get higher productivity, enhanced comfort and better safety. India is having a work force of 430 million, out of which 241 million workers are in agriculture as compared to 33 million in industries and remaining in service/other sectors. Of these 430 million, about 140 million (32.2 %) are women workers (Census of India, 2011). Most of the farm operations are performed dominantly by women workers. Workers in agriculture are regularly exposed to warm to hot and cold working conditions. Because of the physically demanding nature of work in the sector, workers often produce considerable excess heat, increasing their risk of heat stress in even moderately warm conditions. Climatic heat affects labour productivity, primarily because of dehydration. For India, very few researchers have developed the mean skin temperature calculation model for Indian subjects, based on the general population, there is no specific mean skin temperature model available for farm workers or no model is available from the field of agriculture. There is no specific mean skin temperature model available for Indian farm women, as they play the major role in Indian agriculture. As mean skin temperature is the key parameter while measuring the heat stress while working in the agricultural field. The mean skin temperature model development is necessary for Indian farm women while assessing the heat stress. Keeping this in view the research work was conducted on Indian farm women workers to develop the mean skin temperature model by considering the data of Indian farm women.

Keeping this in view and considering the necessity of mean skin temperature model for Indian farm women, the present study was conducted with the following objectives:

1. Assessment of environmental heat on human skin temperature.
2. Evaluation of selected existing mean skin temperature model for Indian farm women.
3. Development of mean skin temperature model for Indian farm women.
4. Validation of developed mean skin temperature model in controlled conditions.
5. Evaluation of developed model in open field conditions.

CHAPTER II
REVIEW OF LITERATURE

Skin temperature plays major role in regulating the body temperature of the human being. Skin temperature is said to be one of the indices useful for estimating thermal environments of human being. Skin temperature is a physiological value arising as a result of heat exchange between the human bodies to the environment. In many ways skin allows human to interact with environment. Physiologists and biological engineers have proposed formulae for calculating the mean skin temperature and weighting factors of wide variety. Although all the formulae proposed can be written by a general equation i.e. the sum of total of the product of the skin temperature at each part of the skin surface and weighting factors related to the parts. Mean skin temperature is an average skin temperature and an important physiological parameter in the regulation of thermal balance of the human being. In many past studies on calculating mean skin temperature, several methods, calculating formulae have been developed.

The present investigation is concerned, to develop mean skin temperature model for Indian farm women. An attempt has been made to review the related areas. The literature surveyed includes relevant field of research work, which were discussed as under:

- Skin temperature measurement
- Evaluation methods for mean skin temperature
- Fundamentals of weighting factors
- Area-Weighted reference mean skin temperature models
- Calculation of mean skin temperature with weighting factors
- Calculation of body surface area
- Segmental body weights of human body

2.1 Skin Temperature Measurement

LeBlanc (1954) conducted study on subcutaneous fat and skin temperature. He found that the insulation of the fat layer increases as the environmental temperature is lowered. The variations in fat thickness explain not only the differences in average skin temperature of different persons, but also, to a certain extent, the regional variations of skin temperatures observed over the body. He concluded that, more the body fat there is at given site, cooler the skin at that site and the relationship was significant at the abdomen and lower back.

Singh *et al*, 2017 examined Effect of WBGT on body thermal responses for agricultural workers in Southern Rajasthan, India. The study was conducted on 12 farm workers. Different WBGT of 28°C, 29°C, 30°C, 31°C and 32°C were selected for this study. Forehead temperature was observed to decrease with an increase in WBGT. Heavy sweating was observed at high WBGT and this resulted in the decrease in skin and forehead temperature. Forehead temperature exhibited a negative linear trend while oral and head temperatures showed positive linear trend with increase in WBGT.

2.2 Evaluation Methods for Mean Skin Temperature

Nishi and Gagge (1970) conducted the study on direct evaluation of convective heat transfer coefficient by naphthalene sublimation. They measured the convective heat transfer coefficient (h_c) directly by observing the sublimation rate of ten 3cm diameter naphthalene balls located evenly over and 3 cm off the body surface. Observations were made on subjects while sitting-resting, treadmill and free walking at 2, 3,and 4 mph, and bicycling on an ergometer at 50 and 60 rpm-all in normally ventilated environments approximately 30 ft^3/min. They found that results agree with comparable values from partitional calorimetry for sitting-resting and a man-sized calorimetric manikin but are less so for bicycle exercise. Equations, prediction, as a function of treadmill or free walking speed, were developed. They used the results to measure more accurately total and regional dry heat losses, for calculating average skin temperature by convective heat transfer coefficient. They presented the formula for calculation of mean skin temperature-

$$0.07\ T_{sk}\text{Forehead} + 0.16\ T_{sk}\text{Chest} + 0.08\ T_{sk}\ \text{Upper arm} + 0.08\ T_{sk}\text{Lower arm} + 0.18\ T_{sk}\ \text{Thigh} + 0.21\ T_{sk}\text{Lower leg} + 0.16\ T_{sk}\text{Back} + 0.06\ T_{sk}\text{Palm}$$

Nadel E.R. *et al.* (1973) conducted the study on differential thermal sensitivity of human skin. They concluded that face has a relatively greater thermal sensitivity than other skin areas. Thermal irradiation was applied to selected skin areas to determine whether particular areas demonstrate a greater thermal sensitivity than others in determination of a physiological thermoregulatory response. Thermal sensitivity of the face, as measured by its effect on sweating rate change from the thigh, was found to be approximately three times that of the chest, abdomen and thigh. Lower legs were found to have about one-half the thermal sensitivity of the thigh. A table of weighting factors for calculation of physiological mean skin temperature, based upon thermal sensitivity and area, is presented as follow:

Table2.1 Mean skin temperature weighting factors as determined by area weighting and as weighted by area and thermal sensitivity

S. No.	Body Parts	T_s(area weighting only)	T_s (area weighting and thermal sensitivity)
1	Face	0.07	0.21
2	Chest and back	0.18	0.21
3	Abdomen	0.18	0.17
4	Upper leg	0.16	0.15
5	Lower leg	0.16	0.08
6	Upper arms	0.13	0.12
7	Lower arms	0.12	0.06
		1.0	1.0

Crawshaw et al. (1975) estimated the effects of local cooling on sweating rate and cold sensation. They concluded that cooling different body regions produces generally equivalent changes in the sweat rate and sensation, with the forehead showing a much greater sensitivity per unit area and temperature decrease than other areas. They corrected the thermal sensitivity coefficients of the changes in sweating rate and magnitude estimate for differences in size of the area of stimulation and change in skin temperature and were normalized to the responses of the chest. The normalized coefficients showed the following relative sensitivities for changes in sweat rate and magnitude estimate respectively: forehead 3.3, 2.2; back 1.2, 1.4; lower leg 1.1, 0.9; chest 1.0, 1.0; thigh 0.9, 1.0; and abdomen 0.8, 0.8. They varied the area stimulated from 122 cm^2 to 384 cm^2 produced greater changes in the sweating response than in the magnitude estimate. Rate of skin cooling during the period of stimulation had more effect on the sweating response than on the magnitude estimate.

Donald (1974) estimated the mean skin temperature during exercise. Six male college students worked at 25, 50 and 75 per cent of their VO_2 max for 30 min each alternated with 30 min of rest in three environments 18/12, 28/17 and 36/22ºC db/wb. Wind velocity was constant at 1 m/s. Skin temperatures were recorded every 5 min from 10 sites, weighted according to their respective surface areas and using an IBM 360 computer an optimal mean skin temperature (T_s) was calculated. This formula varied from subject to subject depending upon variations in surface area coefficients. He concluded that for precise estimates of mean skin temperature during exercise, the optimal skin temperature should be computed. Mean skin temperature models QREC, Teichner, Hardy and DuBois, Palmes-Park, Ramanathan, Newburgh-Spealman, and Burton predicted the optimal mean skin temperature within 1ºC more than 90 per cent of the time.

Mochida (1977) computed a calculation formula for mean skin temperature weighted with both ratios of heat transfer coefficient and body surface area and also to run a comparison against ordinary mean skin temperature formulae and presented the general equation for calculating mean skin temperature weighted with the heat transfer coefficient and skin area is derived and a concrete calculating formula in the case of dividing the entire human body into six main parts is proposed by substituting definite values into the weighting factors in the general equation.

Mochida (1983) calculated the mean skin temperature weighted by skin area, heat transfer coefficients and thermal sensitivity. Classification of the weighting factors into five groups were done from the point of content and compared the concrete value. Further based on the heat equilibrium between man and his environment, the author newly derived a mean skin temperature formula weighted by skin areas and heat transfer coefficients with reference to the thermal sensitivity coefficient given by Nadel et al. (1973). Presentation of the mean skin temperature weighted by the skin area, heat transfer coefficients and the thermal sensitivity as-

T_{sk}- 0.198 T_{sk} Face+ 0.179 T_{sk} Chest and Back + 0.145 T_{sk} Abdomen + 0.153 T_{sk}Upper legs+ 0.092 T_{sk}Lower legs + 0.138 T_{sk}Upper arms+ 0.076 T_{sk}Lower arms

Olesen (1984) concluded the study on number of sites necessary for estimating the mean skin temperature is dependent on the accuracy required. The number of sites which are necessary will certainly depend on the test conditions. In warm conditions 2-4 sites may be enough,in neutral conditions 4-8 sites and in cold conditions 8-12 sites shall be considered. The number of sites necessary might very well be correlated to the non-uniformity of the skin temperature distribution.

Pradhan and Nag (1993) conducted study on influence of air flow on skin temperature. They studied the topographical differences in skin temperature under varied levels of air flow and to examine the possible body temperature regulatory mechanism. Observations were made on different ambient temperatures and air speeds. They noted that, the deep body temperature increased significantly with the continued air flow and, following withdrawal of air flow, the deep body temperature tended to drop. For selected ambient temperatures and air speed there was a heat gain by the body with a consequent increase in deep body temperature. They found, body temperature responses indicate that the central regulatory mechanism has an intricate function in increasing deep body temperature and consequent lowering in skin temperature, as an adjustment towards control heat dissipation through skin.

Puhakka *et al.* (1994) calculated the mean skin temperature and changes in body heat content in several different ways from measurements made in five children during operation. Mean skin temperatures were calculated from 162 sets of measurements using 15, 12, 8, 7 and 4 skin sites with various formulae modified according to age. The results of other formulae were compared with age-adjusted, area weighted 15-site mean skin temperature which was used as a reference.

Nielsen *et al.* (1984) measured the mean skin temperature of clothed persons in cool environments and developed the new mean skin temperature formula. The skin temperature data were obtained from experiments on ten clothed persons who were resting and working at an environmental temperature of 10˚C. With the data, they compared eleven calculation formulae in current use to a reference mean skin temperature based on a weighting formula involving thirteen local skin temperatures. They concluded that no formula including less than seven points gave a reasonably accurate mean skin temperature in the cool temperature. A stepwise correlation analysis involving linear regression was performed on the data. This gave twelve new calculation formulae, which were evaluated for accuracy in estimating mean skin temperature.

Choi *et al.* (1997) studied the reliability of formulas for calculatingmean skin temperature (T_{sk}), values were computed by 18 different techniques and were compared with the mean of 10,841 skin temperatures measured by infrared thermography. One hundred whole-body infrared thermographs were scanned in ten resting males while changing the air temperature from 40° C to 4° C. Local, regional average and mean skin temperatures were obtained using an image processing system.

The agreement frequency, defined as the percentage of the calculated T_{sk} values which agreed with the corresponding infrared thermo graphic T_{sk} within ±0.2° C, ranged for with the various formulas from 7 per cent to 80 per cent.

Lenhardt *et al.* (2006) studied about estimation of mean body temperature (MBT) from mean skin and core temperature is generally accurate and precise. Peripheral compartment temperatures were estimated using fourth-order regression and integration over volume from 18 intramuscular needle thermocouples, nine skin temperatures, and “deep” hand and foot temperature. MBT was determined from mass weighted average of core and peripheral tissue temperatures and estimated from core temperature and mean skin temperature (15 area-weighted sites) using Burton’s formula. Nine hundred thirteen data pair s from 44 study subjects were included in the analysis. Measured MBT ranged from 18° to 36.5°C. There was a remarkably good relation between measured and estimated MBT.

Boniol *et al.* (2008) observed the increase of skin surface area varies according to anatomical body sites. Head and neck, trunk, shoulders, abdomen, and buttocks present a linear increase insize with no sign of plateau from 14 to 18 years. In contrast, upper and lower limbs present a plateau in their increase. These anatomical sites acquire their adult size at around14–16 years. However, this plateau starts earlier for girls(around 14 years) than for boys (around 16 years). This may reflect a faster growth for girls who are more rapidly reaching their adult stature.

Liu *et al.* (2011) established a method to evaluate calculation methods of mean skin temperature, in order to find appropriate ones for use in human thermal comfort study. Three indices were proposed to evaluate MST calculation methods viz; reliability, sensitivity and number of measurement sites. Human heart rate variability indicated the physiological relation between mean skin temperature and ambient temperature for the sensitivity evaluation. Adopting the evaluation method, 26 types of mean skin temperature calculation methods were evaluated based on the experimental data. The results indicate that a calculation method of mean skin temperature with 10 sites was the most appropriate one, due to its high reliability, excellent sensitivity and fewer measuring sites. When it was applied to reflect thermal comfort, the performance was good.

Wang *et al.* (2013) estimated the cold radiation from the outer window might result in the decreases of local skin temperatures, especially for calf andback, which contributed to thermal discomfort for the local and overall body. The mean skin temperature was 33^0 C when subjects felt thermally neutral for the whole body. The results appeared that asymmetrical radiation from the exterior window and clothing has no influence on the preferred mean skin temperature. Overall thermal sensation and mean skin temperature showed a good linear relationship, which showed that human overall thermal sensations may be predicted by their mean skin temperatures. Mean skin temperatures would have less influence on local thermal sensation when local skin temperature was higher than that in neutral condition.

Maniar *et al*. (2015) conducted the study on the effects of using different regions of interest on local and mean skin temperature. They investigated the effects of using multiple regions of interest when calculating weighted mean skin temperature from four local sites. When calculating weighted mean skin temperature from four local sites they selected twenty six healthy males completed a single trial in a thermo natural laboratory (mean ±SD): 24.0 (1.2)˚C; 56 (8%), relative humidity; <0.1 m/s air speed). Mean skin temperature was calculated from four local sites (neck, scapula, hand and shin) in accordance with International standards using digital infrared thermography. They observed the significant differences between the six regions at the neck ($P<0.01$),scapula ($P<0.001$) and shin ($P<0.05$); but not at the hand ($P=0.482$). The largest difference (±SEM) at each site was as follows: neck 0.2(0.1) °C; scapula0.2 (0.0) °C; shin 0.1(0.0) °C and hand 0.1(0.1) °C. The largest potential error (mean ±SD) in weighted mean skin temperature was 0.4(0.1) °C ($P<0.001$) and the associated 95% limits of agreement for these differences was 0.2 to 0.5 °C. They further observed differences in local and mean skin temperature based on the region of interest employed, these differences were minimal and are not considered physiologically meaningful.

Taylor *et al*. (2015) studied about considerations for the measurement of core, skin and mean body temperatures. They found that inter-site differences and similarities may have no mechanistic relationship unless those sites have similar metabolic rates, are in close proximity and are perfuse by the same blood vessels. Therefore, it is proposed that a gold standard deep-body temperature does not exist. Instead, the validity of each measurement must be evaluated relative to one's research objectives, whilst satisfying equilibration and positioning requirements. When using thermometric computations of heat storage, the establishment of steady-state conditions is essential, but for clinically relevant states, targeted temperature monitoring becomes paramount. However, when investigating temperature regulation, the response characteristics of each temperature measurement must match the forcing function applied during experimentation. Thus, during dynamic phases, deep-body temperatures must be measured from sites that track temperature changes in the central blood volume.

Formenti *et al.* (2016) worked on skin temperature evaluation by infrared thermography comparison of two image analysis methods during the non steady state induced by physical exercise. Aim of this study was to investigate the relationship between maximum temperature (T_{max}) and temperature of region of interest (T_{roi}) under the non steady-state conditions induced by physical exercise. Thermal images of quadriceps of 13 subjects performing a squat exercise were recorded for 120 s before (basal steady state) and for 480 s after the initiation of the exercise (non steady state). The thermal images were then analysed to extract T_{roi} and T_{max}. As a result, T_{roi} 15 deviated a little from the 50th percentile, while T_{max} remained constantly higher than the 95th percentile. Despite their differences, T_{roi} and T_{max} showed a substantial agreement in assessing the changes in skin temperature following physical exercise.

Zhu *et al*. (2017) did experimental study on the variations in human skin temperature under simulated weightlessness. The results showed that the mean skin temperature increased with the air temperature both before and after head down bed rest (HDBR) in low and neutral air temperatures and that the mean skin temperature was found to be higher before HDBR. However, a higher mean skin temperature was observed after HDBR when the air temperature was high. Moreover, the mean skin temperature in low and neutral air temperatures was found to increase with the relative humidity both before and after HDBR, and a higher mean skin temperature was also observed before HDBR. So they found that the skin temperature distribution changed greatly under simulated weightlessness by HDBR, which might suggest an altered thermal regulatory mechanism in humans experiencing weightlessness.

Lai *et al*. (2017) concluded with the use of human subjects, the investigation measured outdoor thermal environmental parameters, monitored the subjects' skin temperature at different body segments, and recorded the subjects' thermal sensation. A total of 26 subjects participated in the study, which generated 94 sets of data under different climatic conditions with outdoor air temperatures ranging from -0.1 to 35.^{o}C. The outdoor measurements showed that the wind speed and solar radiation fluctuated significantly during the tests, while the air temperature and relative humidity were relatively stable. The strong fluctuation in wind speed and solar radiation led to rapid changes in the convective and radiative thermal loads, which affected the mean skin temperature of the human subjects and the thermal sensation that they reported. This investigation developed a human heat transfer model that accounts for fluctuations in the outdoor thermal environment.

T_{sk} = 9.429 + 0.137 *T_{sk} Forehead+ 0.102 * T_{sk}Hand+ 0.290 *T_{sk}Lower back+ 0.173 * T_{sk}Lower leg.

2.3 Fundamentals of Weighting Factors

Kurazumi *et al.* (2004) suggested different methods of calculating the weighting coefficients and estimated weighting coefficients for calculating mean skin temperature that take into account convective heat transfer areas for standing and sitting positions. The tendency was that the smaller the ratio of convective heat transfer area to the total body surface area, the greater the difference in mean skin temperature using the Hardy and DuBois technique. The results of the present study also clarify that by taking into account convective heat transfer areas, the skin temperature of the extremities can be reflected in mean skin temperature for both standing and sitting positions.

Kuwabara *et al.* (2006) suggested different methods for calculating weighting coefficients and calculated a formula for mean skin temperature weighted with both the heat transfer coefficient and skin surface area ratios. Calculating the mean skin temperature based on the heat balance equation between the human body and the environment yielded the formula with the weighting factor including not only the skin surface area ratio but also the heat transfer coefficient ratio. Local heat transfer coefficients in the weighting factor for calculating mean skin temperature were measured using a thermal manikin. New weighting factors were determined at seated and standing postures. The weighting factors were not influenced by either air velocity or the temperature difference between the skin surface and the air. Mean skin temperature calculated using the weighting factor of the present study was compared with that calculated using the weighting factor previously proposed.

2.4 Area-Weighted Reference Mean Skin Temperature Models

Winslow *et al*. (1936) estimated the area weighted 15 point model with the fractions of local area on the total body area. Because of calculating the area of each body region of subjects, the accuracy model for calculation of MST is high. The model gives the skin temperature of 15 body sites including forehead (T_1), cheek (T_2), occiput (T_3), chest(T_4), abdomen (T_5), shoulder (T_6), back (T_7), upper arm (T_8), lower arm (T_9), back of the hand (T_{10}), fore thigh (T_{11}), posterior thigh (T_{12}), shin (T_{13}), calf (T_{14}), dorsal foot (T_{15}). An area weighted reference mean skin temperature can be calculated from the temperatures measured at all 15 sites according to the following equation:

$$T_{skref} = C_{head}(T_1+ T_2+ T_3)/3 + C_{ant\ trunk} (T_4+T_5)/2 + C_{post\ trunk} (T_6+T_7)/2+C_{upperarm}.T_8+ C_{forearm} T_9+C_{hand} T_{10}+ C_{thigh} (T_{11}+T_{12})/2+C_{leg} (T_{13}+T_{14})/2 + C_{foot} T_{15}.$$

Teichner (1958) concluded that l0-point weighted mean can be estimated with no more than six selected points with no loss in reliability, when high reliability is not required, as point weighted mean may suffice at least under the 12 conditions of this study, with the use of regression equations which were developed, the weighted mean may be closely estimated from any one of five selected points; at least under the 12 conditions of this experiment, the weighted mean is closely estimated by the uncorrected temperature of the medial thigh.

Mitchell and Wyndham (1969) revealed that for accurate work the unweighted mean temperature of 15 carefully located sites provides an estimate agreeing very well with an optimal method of calculating weighted mean skin temperature. The handling of the data is considerably simpler. In instances where the large number of measuring sites presents a problem, and in field studies, where simplicity of experimental technique and calculation become important, the use of a four-point mean, based on a system devised by Ramanathan is recommended. Teichner claims that smaller discrepancies between weighting systems occur in clothed men than in nude men. However, only these systems that proved suitable for resting men in dry conditions need be considered. A system that rated badly in these conditions will certainly be of no value in a wider range of conditions.

2.5 Calculation of Mean Skin Temperature with Weighting Factor

Burton (1934) studied about the temperature of the surface of the human body is 4° or 5° lower than the interior temperature, which is not reached until a depth of several centimetres. A theoretical estimate is made of how the rectal and surface temperatures should be combined to give the true average. From the results of forty hour periods with the respiration calorimeter upon a group of subjects in basal and absorptive condition, the formula giving the least average discrepancy between direct and indirect heats is found experimentally. It agrees closely with that deduced theoretically, and is average temperature equals 0.65 X rectal temperature plus 0.35 X average surface temperatures. The latter temperature is found from measurements over the trunk, the lower leg and the fore arm. The average error is reduced from 7.5 per cent using rectal temperature alone to 5.5 per cent using the formula.

Hardy *et al.*(1938) developed seven point model for estimation of mean skin temperature. The total radiation from the surface of the body can be determined. The proportions of surface contributed by head, trunk, arms, legs, hands and feet are calculated from the linear formula and the average radiation per square centimetre from each of these is then multiplied by the percentage of the total area contributed by that part of the body.

Ramanathan (1964) formulated new weighting system for mean surface temperature of the human body.On the basis of an analysis of the skin temperature data on three resting human subjects from 112 experiments, a simple weighting system for computing the mean skin temperature from observations on four areas of the body, namely, chest, arms, thighs, and legs, has been proposed. The proposed system of weighting yields mean skin temperature values identical with the elaborate Hardy and DuBois weighting formula. The value of the medial thigh temperature as an index of the mean skin temperature has also been investigated and discussed.

Nadel *et al.*(1971)conducted a study on the importance of skin temperature in the regulation of sweating. They concluded that at a constant skin temperature, sweating rate was proportional to core temperature. At a constant core temperature, sweating rate was proportional to skin temperature, and at a given combination of core and mean skin temperatures, local sweating was dependent on the local skin temperature.

2.6 Calculation of Body Surface Area of Human.

DuBois *et al.* (1915) determined the body surface area of human by weight and height. He computed the area of each part of the body by linear measurements alone a formula has been devised on the principle of length times the average breadth times a constant. The sum of these parts gives the total surface area of the body. Five individuals of widely varying shapes have been measured and the surface area as calculated from the formulas compared with the surface area as actually measured. In the five cases the average error was 1.7 per cent. In discussing the question as to whether the basal metabolism is proportional to surface area or to weight it is preferable to determine the surface area by a formula which is not of necessity a function of the weight. They suggested the following formula on the basis of weight and height. BSA (m^2)= 0.2024 * (height, m)$^{0.725}$ *(weight, kg)$^{0.425}$

Gehan and George (1970) conducted study on estimation of human body surface area from height and weight. They presented the model for estimation of human body surface area which is identical in form to one proposed in 1916 by Du-Bois and Du-Bois. They proposed the following model SA =$a^0H^{a1}W^{a2}$ in which SA is surface area in square meters, H is height in centimetres and W is weight in kilograms. The estimation of the parameter was based on direct measurements of surface area and was a_0-0.02350, a_1-0.42246, and a_2- 0.51456. The separate models for children and adults and several models of different form were considered but rejected because no real improvements resulted in surface area estimates. The estimates of surface area were compared with those obtained using the original model of Du-Bois and Du-Bois and later estimates proposed by Boyd. They provided the simple tables and charts which contain the estimates of surface area from height and weight.

Lee *et al*. (2008) determined the body surface area and formulas to estimate body surface area using the Alginate Method. They directly measured the entire body surface area of 34 males (20–60 years old, 158.5–187.5 cm in height, 48.5–103.1 kg in body weight) and 31 females (20–63 years old, 140.6–173.1 cm, 36.8–106.1 kg) using alginate. The measurements showed that the BSA had a mean of 18,339 cm^2 for males, and 16,452 cm^2 for females. Based on these measurements, a regression model to estimate BSA was derived. They suggested the following formula based on two variables and the DuBois exponents,

Estimated BSA (cm^2)=73.31* (Height, cm)$^{0.725}$* (Body weight, kg)$^{0.425}$ this formula did not show any tendency of overestimation or underestimation by body shape, even when applied to the datasets composed of other races.

2.7Segmental Body Weights of Human Body

Dempster (1955)reported an intensive study of human biomechanics which included data on weight, volume, center of mass and moments of inertia of the segments of eight cadavers.The limb segments were separated at each of the primary joints and the trunk divided into a shoulder, neck, thorax and abdomen and pelvis units. The planes of segmentation were fairly similar to those established by Braune and Fischer, except that before the dismemberment, joints were flexed to mid-range, which Dempster believed would provide a more equitable distribution of tissue mass in each segment. He presented the average weights of body segments expressed as percentages of total body weight as given in table 2.2

Table 2.2 Segmental weight of human body in percent

S. No.	Segments	Percent of segment (%)
1	Head	7.1
2	Trunk	45.4
3	Total right arm	4.9
4	Upper arm	2.7
5	Forearm and Palm	2.2
6	Forearm	1.6
7	Palm	0.6
8	Total Left Arm	4.8
9	Total right leg including thigh	15.7
10	Thigh	9.6
11	Leg and Foot	6.0
12	Leg	4.5
13	Foot	1.4
14	Total left leg including Thigh	15.7
Total		**93.6**

Drills and Contini (1966) published a detailed study of characteristics body segments. Their initial interest was in the design of improved prosthetic devices, but this necessitated good estimate of the weight, centre of mass and moments of inertia of limb segments. A sample of 20 young male subjects was studied, and complete data were obtained. Body segments volumes were determined using immersion and segment zone methods. The weight of segments was determined by the method of reaction change, using a highly sensitive apparatus based upon the general principles. They calculated the segmental body weights and presented the data.

Clauser*et al*. (1969) performed a study designed to supplement the existing knowledge of the mass, volume and centre of mass of body segments and to permit a more accurate estimation of these measurements from anthropometric dimensions. The study was based on the 13 preserved male cadavers, which each were dissected into 14 body segments. The mass, volume and centre of mass were measured for each segment. Anthropometric measurements like length, circumference and breadth or depth of each body segment were also measured and series of regression equations estimating the body segment parameters based on anthropometric measurement were defined. It was concluded that the anthropometry of the body and regression equations effectively can be used to estimate the mass and centre of mass of body segments.

Sen*et al.*(1976) estimated the relationship between the segmental and whole body weights of some Indian subjects. They weighted the five Indian adult male cadavers by a servoindicator. The whole body was dissected into fourteen subjects, serving each of the primary joints across its approximate centre of rotation and weighting the resultant segment on a baby weighting platform balance. The relative weights of the limbs (total arm 4.3 percent and total leg 12.9 percent of body weight) were much lower in Indians than values reported for western and Japanese subject. On the other hand, the relative weight of the trunk (58.2 percent) was much higher in Indian cadavers. The segmental volume of the trunk and limb represents 59.4 and 32.4 percent of the total body volume respectively. Average weights of body segments expressed as percentages of total body weight as given in table 2.3

Table 2.3Segmental weight of human body in percent

Sr. No	Segments	Percent of segment (%)
1	Head	9
2	Trunk	58.2
3	Total right arm	4.3
4	Upper arm	2.1
5	Forearm and Palm	2.2
6	Forearm	1.4
7	Palm	0.8
8	Total Left Arm	3.9
9	Total right leg including thigh	12.2
10	Thigh	6.8
11	Leg and Foot	5.4
12	Leg	3.5
13	Foot	1.9
14	Total left leg including Thigh	12.2
Total		**100**

Martin *et al.* (1989) performed a study to determine whether valid estimations of body segment parameters can be generated from a series of cross sectional MRI scans of the tissue. The study was based on eight baboon cadaver segments (four forearms, two upper arms and two lower legs), which were MRI scanned and the boundaries between different tissue in each image were manually digitised to divide the total areas into areas corresponding to muscle, bone and fat. The volume of each mass of tissues and subsequently the mass distribution and body segment parameters were then calculated based on these areas, the distance between the scanned images and the densities, obtained experimentally of the tissues. Further they compared the results by standard experimental technique and it was concluded that, MRI represents a promising technique for estimation of body segment parameters.

CHAPTERIII

MATERIAL AND METHODS

This chapter deals with the assessment of environmental heat on human skin temperature, evaluation of selected existing mean skin temperature model in Indian conditions, development of mean skin temperature model for Indian farm women, validation of developed mean skin temperature model in controlled conditions and evaluation of developed mean skin temperature model in open field conditions.

Skin temperature is said to be one of the indices useful for estimating thermal environments. The skin temperature, which is closely related to the thermal sensation, is a physiological value regulated by both the conditions of man and his working environment. Mean skin temperature is an important physiological parameter reflecting the human response to heat. For India, very few researchers have developed the mean skin temperature calculation model for Indian subjects, and they have developed the model for general population. There is no specific mean skin temperature model available for farm workers or no model is available from the field of agriculture. There is no specific mean skin temperature model available for Indian farm women, as women workers play the major role in Indian agriculture. The mean skin temperature is the key parameter for measuring the heat stress while working in the agricultural field. The mean skin temperature model development is necessary for Indian farm women for assessing the heat stress. Keeping this in view the research work was conducted on Indian farm women workers to develop the mean skin temperature model by considering the data of Indian farm women. The attempt was made to develop the mean skin temperature model with fewer points which gives the best estimation of mean skin temperature. Skin temperature measurement was carried out in environmental conditions of temperature and humidity. Environmental chamber was prepared for measurement of skin temperature in controlled environmental condition. Before development of the mean skin temperature model for the Indian farm women, the assessment of environmental heat on human skin temperature was carried out in environmental chamber. Twelve female subjects and the thirty three skin temperature measurement sites were selected. Body sites were selected on the basis of eight selected existing mean skin temperature model and fifteen point area weighted reference mean skin temperature model. The details of subject selection and model selection discussed as follow:

3.1 Subject Selection

Selection of subjects plays a vital role in conducting the performance and physiological studies of human. Twelve female were selected as subjects for the study. The subjects should be without any major illness and shall not be handicaps. The maximum strength or power can be expected from the age group 20 to 35 years (Gite and Singh, 1997), hence, subjects were selected within the age group of 21 to 35.The selected subjects were asked to report in the morning for the skin temperature measurement. Subjects were asked to have breakfast before reporting. It was ensured that they had good sleep in the previous night. It was also ensured that they are free from the influence of stimulants such as alcoholic drinks, cigarettes, tobacco etc. and has no cardiac disease. Subjects were asked to remain in the standing position. The informed consent was taken from the subjects which was approved by the Ethical Committee of the university. The duly signed consent is given in Appendix- A.

Each subject's weight, height, blood pressure, heart rate, Body Mass Index (BMI), body surface area (BSA) and core body temperature were measured before experimentation. The subjects having abnormal heart rate or blood pressure were not included in the study. After confirming core body temperature within normal ranges (36.5 to 37˚C) subjects entered the environmental chamber that was maintained at the targeted environmental conditions. Subject's having BMI as normal, overweight and underweight was selected for the study. The body mass index category was decided on the basis of standard given by the WHO. The WHO standard for the body mass index is given in table 3.1

Table 3.1 Body mass index category.

S. No.	Body Mass Index (BMI)	Weight status
1	18.5-24.9	Underweight
2	25-29.9	Normal
3	30 and above	Overweight

Source- World health organization (WHO)

3.2 Selection of Models

Study of mean skin temperature development model started in 1934. The first mathematical thermal model including the body anatomy and control function was published in 1934. (Fu, 1995).Up to now, many different mean skin temperature calculation models are in current use and according to their aim of use they are divided into the different groups. Selection of the model plays an important role while developing the new mean skin temperature model, because numerous studies have been done to develop the mean skin temperature models based on the weighting coefficients. Although all the models can be written by a general equation as follow:

$$T_s = \sum F_n * T_{sn}$$

Where,

T_s- Mean skin temperature, ˚C

F_n- Weighting factor for calculating mean skin temperature

T_{sn}- Skin temperature at a specific site, n on the body, ˚C

Mean skin temperature models differ from each other by weighting coefficients and number of sites or (body points).Weighting factor proposed by some researchers is classified into six categories as shown in table 3.2

Table 3.2 Types of weighting factors

S. No.	Content of weighting factor	Form of weighting factor
1	Weighting factor with unity	$F_i = 1$
2	Equal weighting factor	$F_i = \frac{1}{n}$
3	Weighting factor by skin surface area ratio	$F_i = \frac{Ai}{A}$
4	Skin area-thermal sensitivity weighting factor	$F_i = \frac{Ai}{A} * S$
5	Skin area-heat transfer coefficient weighting factor	$F_i = \frac{Ai}{A} * \frac{hci + hri}{hc + hr}$
6	Skin area-heat transfer coefficient-thermal sensitivity weighting factor	$F_i = \frac{Ai}{A} * \frac{hci + hri}{hc + hr} * S$

Where, Fi = Weighting factor

Ai = Skin segment area at a specific site of the body, m^2

A = Total body surface area, m^2

S = Thermal sensitivity

h_{ci} = Local convective heat transfer coefficient at the site of human body, kcal/m^2h˚C

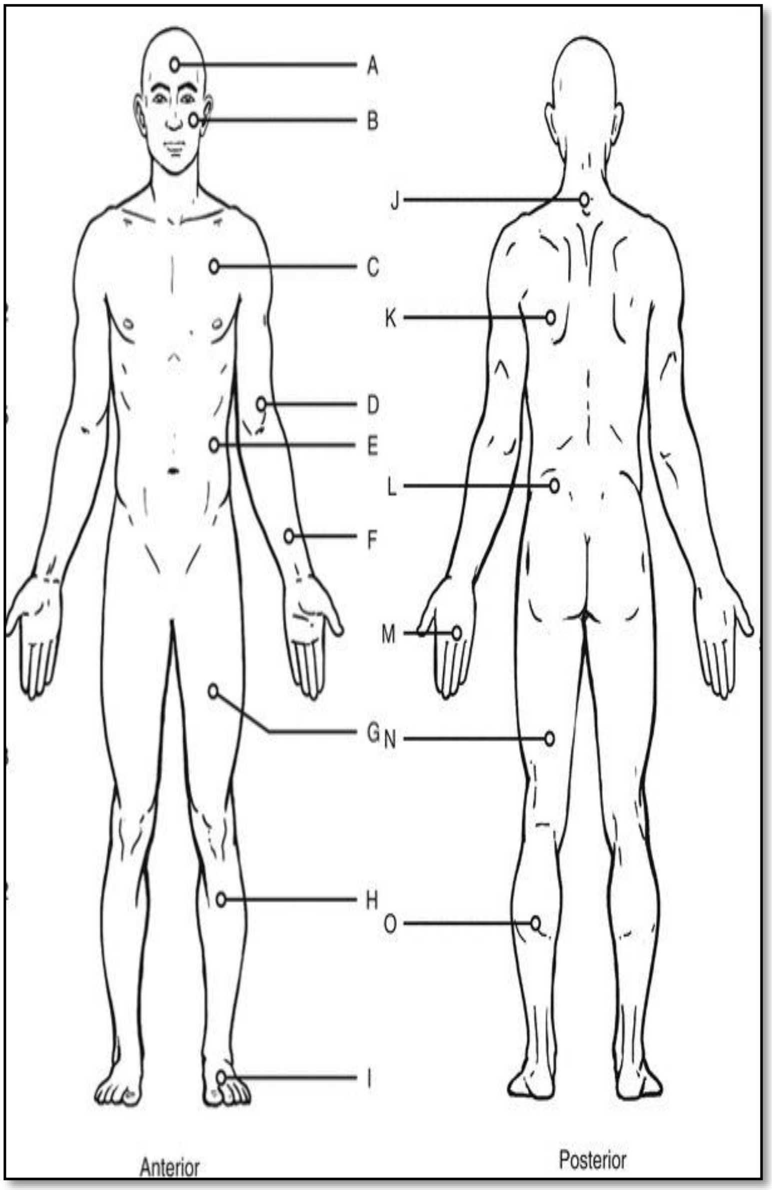
h_{ri}=Local radiative heat transfer coefficient at the site of human body, kcal/m^2h˚C

h_c= Mean convective heat transfer coefficient at the site of human body, kcal/m^2h˚C

hr = Mean radiative heat transfer coefficient at the site of human body, kcal/m^2h˚C

Among the various methods employed, mean skin temperature that is based on the skin surface area ratio to the total body surface area has been the most widely accepted. This is because this method more faithfully represents the definition of "Mean skin temperature" (Lee, 2010), therefore, the models based on the skin surface area ratio were selected for the study.

Eight existing mean skin temperature models were selected for the study. These are Burton (1934) three point model, Ramanathan (1964) four point model, Newburgh and Spealman (1943) four point model, ISO (2004) four point model, Palmes and Park (1947) six point model, Teichner (1958) six point model, Nadel (1971) seven point model and Hardy and DuBois (1938) seven point model. All these mean skin temperature models represent the weighting factors based on the skin surface area ratio. Many methods and calculation models for determining mean skin temperature have been developed incorporating one to 15 local skin temperatures. The 15 sites recommended by Winslow et al. (1936) appear to constitute a reasonable maximum. (Mitchell and Wyndham, (1969), and therefore this fifteen point area weighted model was selected as reference mean skin temperature model. The temperature sensors were placed on the sites on skin areas of the forehead (T_1), cheek (T_2), occiput (T_3), chest (T_4), abdomen (T_5), shoulder (T_6), back of the trunk (T_7), upper arm (T_8), forearm (T_9), back of the hand (T_{10}), anterior thigh (T_{11}), posterior thigh (T_{12}), left shin (T_{13}), calf (T_{14}), dorsal foot (T_{15}) shown in figure.3.1.



A	Forehead
B	Left cheek
C	Left upper chest
D	Left upper arm
E	Left abdomen
F	Left forearm
G	Left Anterior thigh
H	Left Shin
I	Dorsal foot
J	Occiput
K	Back of the trunk
L	Left lumbar
M	Back of the hand
N	Posterior thigh
O	Calf

Figure 3.1Measurement sites used in a 15 sites area weighted mean skin temperature model. (Winslow et al; 1936)

An area weighted reference mean skin temperature was calculated from the temperatures measured at all 15 points according to the following equation.

$$T_{skref} = C_{Head}(T_1 + T_2 + T_3)/3 + C_{Ant\ trunk}(T_4+T_5)/2 + C_{Post\ trunk}(T_6+T_7)/2 + C_{Upperarm}.T_8 + C_{Forearm}T_9 + C_{Hand}T_{10} + C_{Thigh}(T_{11}+T_{12})/2 + C_{Leg}(T_{13}+T_{14})/2 + C_{Foot}T_{15}$$

Where the weighting coefficients (C) correspond to the fractions of the total body surface area to which the temperature measurements correspond. Weighting coefficients for 15 point area weighted reference mean skin temperature model are given in table 3.3

Table 3.3 Weighting factors corresponds to 15 point area weighted reference mean skin temperature model

S. No.	Body Sites	Weighting factor
1	Head (Forehead, cheek, Occiput)	0.07
2.	Anterior trunk (Chest and Abdomen)	0.14
3	Posterior trunk (Shoulder and back)	0.2
4	Upper arm	0.08
5	Forearm	0.06
6	Back of the hand	0.05
7	Thigh (Anterior thigh and posterior thigh)	0.19
8	Leg (Shin and Calf)	0.14
9	Foot	0.07

Eight existing mean skin temperature models were selected for the study based on the surface area ratio. The weighting coefficient of the models corresponds to the fractions of the total body surface area to which the temperature measurements correspond. Selected existing mean skin temperature models having body points (sites) minimum three to maximum seven were selected for the study and the sum of the weighting coefficients is unity. Selected existing mean skin temperature models are given as follows:

3.2.1 Burton- 3 Point model

Burton (1934) studied about the temperature of the surface of the human body is 4° or 5° lower than the interior temperature, which is not reached until a depth of several centimeters. A theoretical estimate is made of how the inner and surface temperatures should be combined to give the true average. From the results of forty hour periods with the respiration calorimeter upon a group of subjects in basal and absorptive condition, the model giving the least average discrepancy between direct and indirect heats is found experimentally fit. The proposed Burton three point model is given below:

$$0.5\ T_{sk}\text{Left upper chest} + 0.36\ T_{sk}\text{Left anterior calf} + 0.14\ T_{sk}\text{ Left forearm}$$

3.2.2 Teichner- 6 Point model

Teichner (1958) used resting subjects dressed in arctic clothing. Using the QREC, MST model as a reference, he found a close relationship to the models proposed by Hardy and DuBois

(1938a) and Palmesand Park (1947), while the model of Burton (1934) correlated only moderately well. However, all three methods estimated T_{sk}too high, compared to the reference T_{sk}. Based on this data, Teichner suggested a new 6-point model agreeing well with the reference. Also, he recommended the use of the temperature of the medial thigh as an expression of T_{sk}". He proposed the mean skin temperature model with six points as follow:

0.149 T_{sk}Left cheek + 0.186 T_{sk} Right anterior mid inner thigh + 0.186 T_{sk} Left lumbar + 0.186 T_{sk} Left anterior thigh + 0.186 T_{sk} Left upper chest + 0.107T_{sk} Left upper arm

3.2.3 Hardy and DuBois- 7 Point model

Hardy and DuBois (1938) developed 7 point model for estimation of mean skin temperature. The proportions of surface contributed by head, trunk, arms, legs, hands and feet are calculated from the linear formula and the average radiation per square centimetre from each of these is then multiplied by the percentage of the total area contributed by that part of the body. The model for calculation of mean skin temperature is as follows:

0.07 T_{sk} Forehead + 0.14 T_{sk} Left forearm + 0.05 T_{sk} Left hand + 0.07 T_{sk} Left foot + 0.13 T_{sk} Left anterior calf + 0.19 T_{sk} Left anterior thigh + 0.35 T_{sk} Left abdomen

3.2.4. Palmes/ Park- 6 Point model

Palmes and Park (1947) developed six point mean skin temperature model. The proposed mean skin temperature model is as follow:

0.14 T_{sk} Left cheek + 0.19 T_{sk} Left upper chest + 0.19 T_{sk} Left lumbar + 0.32 T_{sk} Left anterior thigh + 0.11 T_{sk} Left forearm + 0.05T_{sk} Left hand

3.2.5. Ramanathan- 4 Point model

Ramanathan (1964) used nude, resting subjects, under various experimental conditions. He used a Tsk calculated by the 7-pointformula of Hardy and DuBois (1938a) as a reference, and found a high correlation of Tsk. Based on an analysis of skin temperature data from three resting human subjects from 112 studies, a basic weighting system for calculating the mean skin temperature from measurements on four areas of the body namely chest, arms, thighs and legs has been proposed.

The proposed mean skin temperature model is as follow:

0.3 T_{sk} (Left upper chest + T_{sk} Left upper arm) + 0.2 (T_{sk} Left anterior thigh + T_{sk} Left anterior calf)

3.2.6. ISO- 4 Point model

ISO 9886 (2004) was prepared by technical committee ISO/TC 159, studied on evaluation of thermal strain by physiological measurements, and developed four point mean skin temperature model. The proposed mean skin temperature model as follow:

0.16 T_{sk} Left hand + 0.28 T_{sk} Right shin + 0.28 T_{sk} Neck + 0.28 T_{sk} Right scapula

3.2.7. Nadel -7 Point model

Nadel et al. (1973) conducted the study on differential thermal sensitivity of human skin. They concluded that face has a relatively greater thermal sensitivity than other skin areas. Thermal irradiation was applied to selected skin areas to determine whether particular areas demonstrate a greater thermal sensitivity than others in determination of a physiological thermoregulatory response. Thermal sensitivity of the face, as measured by its effect on sweating rate change from the thigh, was found to be approximately three times that of the chest, abdomen and thigh. Lower legs were found to have about one-half the thermal sensitivity of the thigh. Based on the thermal sensitivity they suggested the weighing factors for calculation of mean skin temperature. They proposed seven point mean skin temperature model based on area weighting is follow:

0.07 T_{sk} Forehead + 0.18 T_{sk} Left upper chest + 0.13 T_{sk}Upper arm + 0.18 T_{sk}Abdomen + 0.12 T_{sk}Forearm + 0.16 T_{sk}Left anterior thigh + 0.16 T_{sk} Lower leg

3.2.8. Newburgh and Spealman- 4 point model

Newburgh and Spealman (1943) proposed four point model for mean skin temperature measurement. They devided the human body areas in terms of whole limbs and weightages are in single digits, making computations quite simple. Proposed four point mean skin temperature model as follows:

0.34_{sk} Chest +0.33 T_{sk}Thigh + 0.18 T_{sk}Leg + 0.15 T_{sk}Lower arm.

Eight existing mean skin temperature models were selected for the study based on the body surface area ratio. Skin temperature measurement were taken for the body sites based on the selected eight existing mean skin temperature models and fifteen point area weighted reference mean skin temperature model to assess the effect of environmental heat on human skin temperature. Effect of environmental heat was observed by measuring the skin temperature for thirty two sites selected according to the existing mean skin temperature models. Skin temperature for body sites like forehead, left and right upper chest, left and right anterior calf, left and right abdomen, left chest, left and right upper arm, left hand, left foot, left and right anterior thigh, left shin, neck, lower leg, occiput, left and right shoulder, back of the trunk, left and right forearm, left and right back of the hand, left and right posterior thigh, left and right dorsal foot, right interior mid inner thigh and left and right lumbar were measured. The experiments were carried out in an environmental chamber. The details of the preparation of environmental chamber for calculation of skin temperature are discussed in section 3.3.

3.3 Environmental Chamber for Measurement of Skin Temperature

Environmental controlled chamber can simulate temperature and humidity conditions, including: high and low temperature, high and low humidity. In the open field environment, it is impossible to control the temperature and humidity within required range. In order to maintain the stable environmental parameters, the experiments were carried out using the controlled environmental chamber to simulate thermal characteristics of human body. The environmental chamber was prepared inside the lab of 3 m x 3 m size. The walls of the chamber were made from reinforced masonry construction which can control temperature and relative humidity inside the chamber. The windows and door of the chamber were sealed and no direct sunlight, air entered into the chamber. The windows of the environmental chamber were sealed by multi-layered insulation using the polyethylene sheets, cardboard paper and the black coloured paper sheet. Inner layer was sealed by using 2 mm thick polyethylene paper and then cardboard paper of 5 mm thickness was attached. Windows of the environmental chamber was finally enclosed by using the black coloured paper sheet. Gadgets like oil based heat convector, room humidifier, room dehumidifier, incandescent lamps were used for maintaining the temperature, humidity and radiation inside the environmental chamber.

Environmental chamber was prepared for the measurement of the skin temperature data. The experiment was conducted in controlled environmental conditions (chamber) of temperature and humidity. Five wet bulb globe temperature (WBGT) conditions 24˚C, 26˚C, 28˚C, 30˚C and 32˚C were created for the study. WBGT stands for wet bulb globe temperature which is a commonly used heat stress index. The WBGT is derived from a combination of temperatures from three thermometers, wet globe for humidity, black globe for radiations, and dry bulb for the ambient temperature.

The heat stress monitors calculate the WBGT index as follows: (For measurements made indoors and outdoors, respectively):

WBGT (Outdoor) = 0.7 WB + 0.2 G.T + 0.1 DB

WBGT (Indoor) = 0.7 WB + 0.3 GT

Where, WB- Wet bulb temperature

DB- Dry bulb temperature

GT- Globe temperature

Globe temperature accounts for the effects of radiant heat. Radiant heat can be proved to be a significant source of heat load on the worker. Traditionally, the bulb of mercury in glass thermometer is placed in a metal sphere which is painted matte black. Any radiant heat (from the sun or from any other objects) is absorbed by the sphere and heats up the thermometer. In many situations, measurements of globe temperature are essential if the true nature of the thermal environment is to be evaluated.

WBGT is used to estimate the effect of temperature, radiation and wind speed on the human body. The WBGT is not the same as the ambient (dry) temperature, as it takes into account the levels of radiation, wind movement, humidity and the ambient temperature. Wet bulb globe temperature (WBGT) was measured using the Quest 36 heat stress monitor. The details of the instruments are discussed at section 3.4.6

Temperatures of the controlled chamber were regulated by using the oil based heat convector while humidity was regulated by using room humidifier, and, room dehumidifier. Incandescent lamps of 200 watts were used to increase the radiation inside the environmental chamber. Oil based room heat convector of 2400 watts was used because of its multiple advantages as, the fan doesn't make noise, won't dry the air, neither they burn the oxygen nor reduce the humidity of the chamber. The controlled environmental chamber was designed by keeping in mind that it should maintain the required temperature level for at least one hour after simulating the temperature and humidity. Simulation for radiation inside the environmental chamber was carried out by using the incandescent lamp of 200 watts. Incandescent lamps were hung up on the wall in a position as it reflects the radiation on the WBGT monitor which was placed at the centre of the controlled chamber as well as upon the subject. It was found that, due to the reflections of incandescent lamp, radiation increased.

The measurements of skin temperature were carried out inside the environmental chamber. Skin temperature was measured using the Thermocouple SDL-200. The measurement of skin temperature was carried out on female subject.

Schematic view of environmental chamber is shown in figure 3.2.

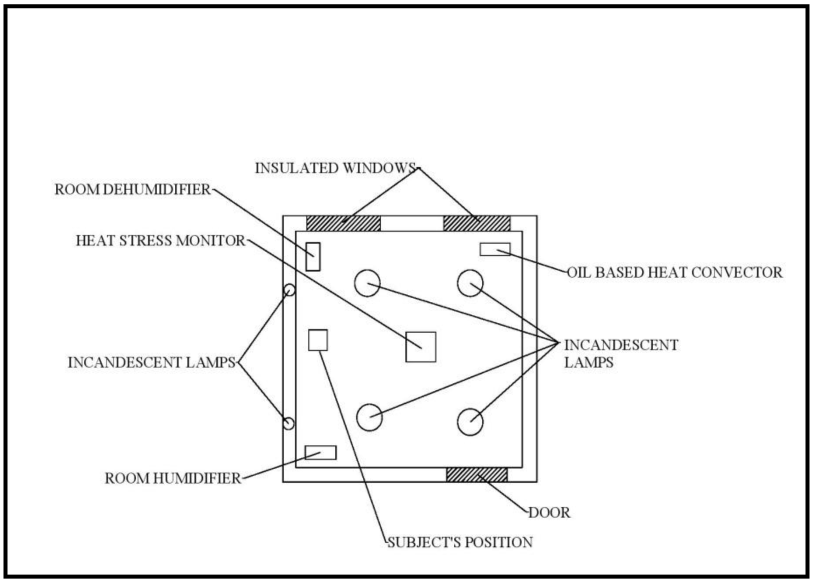


Figure 3.2: Schematic view of prepared environmental chamber

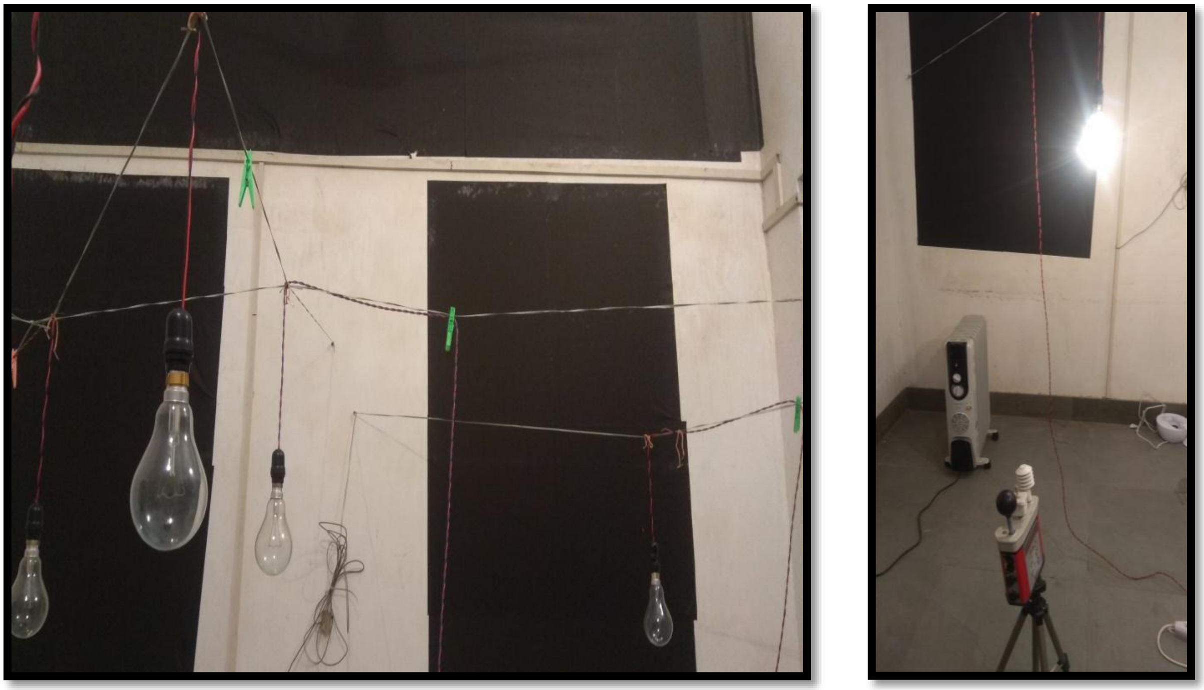


Figure 3.3 Controlled environmental chamber

3.4 Instruments Used in Environmental Chamber

Simulation of temperature inside the controlled chamber was done using different instruments and gadgets. Oil based heat convector, room humidifier, room dehumidifier, and incandescent lamps were used to create the environmental conditions inside the chamber. Oil based room heater of 2400 watts was used to maintain the temperature inside the environmental chamber, while humidifier and dehumidifier were used to maintain the humidity inside the environmental chamber. Incandescent lamps of 200 watts were also used to increase the temperature and radiation. Window and door sealant was used for sealing purpose. The details are as follows:

3.4.1 Oil Based Heat Convector

Oil based heat convector of Murphy Richards make shown in figure 3.4 was used for maintaining the temperature inside the controlled chamber. It has overheat protection and cut off the supply automatically. It is advantageous because of many reasons as given below:

1. Oil based room heater warm the environmental chamber uniformly and maintain the temperature for considerable time even after electricity failure.

2. Oil based heat convectors are more comfortable. Oil based heat convectors neither burn oxygen nor reduce humidity.
3. Oil filled room heaters best fit for large room and all night usage as well
4. Oil based heat convectors are less noisy, and, quite.

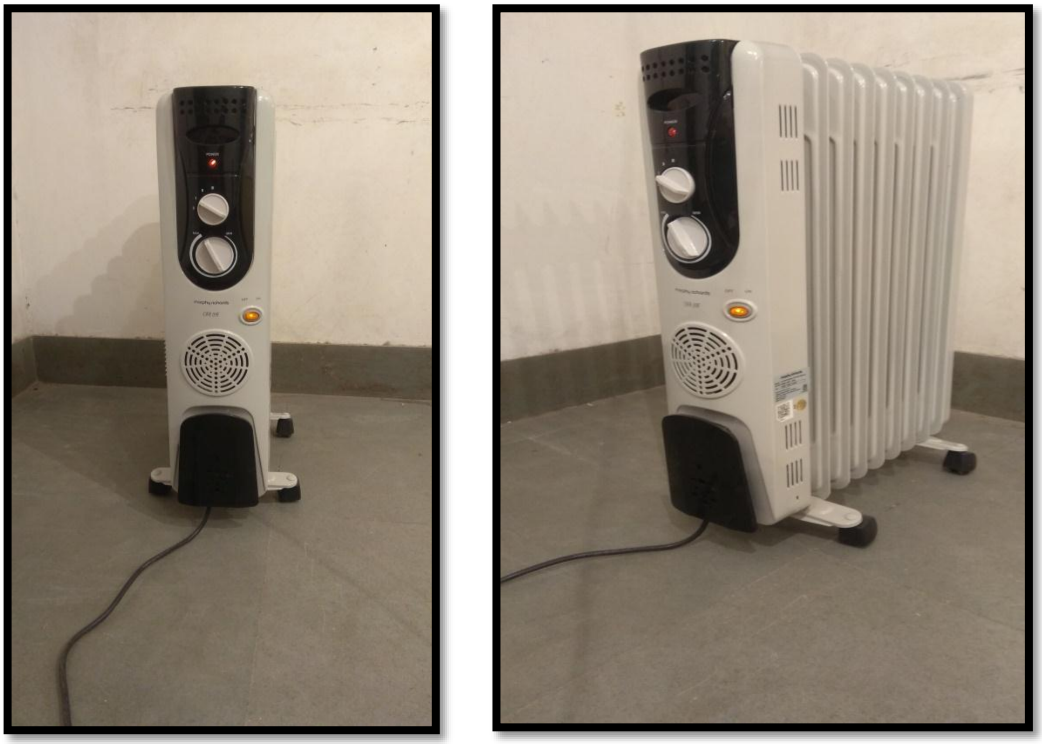


Figure 3.4 Oil based heat convector

3.4.2 Room Humidifier

Room humidifier of Allin Exporters make was used for increasing the humidity of the controlled environmental chamber. Allin Exporters 2.4 -Litre Cool Mist Ultrasonic Humidifier is the perfect solution to keep the air moisturized. This cool mist humidifier is featured with ultrasonic vibration technology that instantly converts water into fine and visible cool mist to improve the humidity level and air quality in the dry areas of room. Cool mist ultrasonic room humidifier is shown in figure: 3.5

Figure 3.5 Room humidifier

3.4.3 Room Dehumidifier

Dehumidifier of ANSIO Electric portable mini dehumidifier shown in figure 3.6was used to reduce the humidity of controlled chamber. ANSIO mini electric dehumidifier helps in removing moisture. It has dehumidifying capacity of approximately 250ml per day. The automatic shut off feature when the water tank is full, it makes the dehumidifiers operation safe.

Figure 3.6 Room Dehumidifier

3.4.4 Incandescent Lamp

Incandescent lamps of 200 watts were used for increasing the temperature and radiation inside the environmental chamber. Six incandescent lamps of 200 watt each were used to increase the WBGT. Incandescent lamps which were used for simulation of radiant heat inside the environmental heat chambers are shown in figure: 3.7

Figure 3.7 Incandescent lamp of 200 watt

3.4.5 Insulation of the Environmental Chamber

Sealant shown in figure 3.8 was used to completely block drafts around doors and windows. The sealant strip was easy to install and was used to seal the gap in the windows and doors. It stops the flow of air, therefore do not affect the temperature and humidity inside the environmental chamber. It also does not allow the sound and dust to enter inside the environmental chamber, so it was helpful in maintaining the environmental chamber temperature by reducing the heat gain and loss in the environmental chamber.

Figure 3.8 Door and window sealant

3.4.6 Heat Stress Monitor

Heat stress monitor make Quest Temp 36, as shown in figure 3.9was used to measure the Wet Bulb Globe Temperature. Wet bulb globe temperature (WBGT) is a composite temperature used to estimate the effects of temperature, humidity, radiations (usually sunlight) i.e. globe temperature and wind speed

Table 3.4 Specifications of heat stress monitor Quest Temp 36 (WBGT monitor)

S.No.	Particular	Specifications
(A)	Sensor	
1.	Temperature	RTD
2.	Relative humidity	Capacitive Polymer
3.	Air velocity	Hot wire
(B)	Measurement range	
1.	Temperature,˚C	-5 to 100˚C
2.	Relative humidity, per cent	0 to 100 per cent
3.	Air velocity, m/s	0-20

(C)	Accuracies	
1.	Temperature,˚C	± 0.5
2.	Relative humidity, per cent	± 5
3.	Air velocity, m/s	± 5
(D)	User Programmable parameters	
1.	Temperature scale	˚C or ˚F
2.	Display Language	Multiple
3.	Data logging intervals, min	1, 2,5, 10, 15, 30 or 60
4.	Heat index, Humidex	Yes
(E)	Output	
1.	Computer Interface	RS232
2.	Printer interface	Yes
(F)	Power	
1.	Disposable battery	9V
2.	Rechargeable battery	Ni-MH
3.	AC Power adapter	Yes
(G)	Physical Dimensions	
1.	Size	23.5 x 18.3 x 7.5
2.	Weight	1.2 kg

Figure 3.9 Heat stress monitor, Quest 36

3.4.7 Thermocouple SDL-200

The mean skin temperature was measured using the thermocouple SDL 200. The specifications of the thermocouple are shown in table 3.5

Table 3.5 Specifications of Thermocouple SDL-200

Specifications	
Type J	-148 to 2102°F (-100 to 1150°C)
Type K	-148 to 2372°F (-100 to 1300°C)
Type T	-58 to 752°F (-50 to 400°C)
Type E	-58 to 1652°F (-50 to 900°C)
Type R	32 to 3092°F (0 to 1700°C)
Type S	32 to 2732°F (0 to 1500°C)

RTD pt 100	-327 to 1562°F (-200 to 850°C)
Resolution	0.1°/1°
Basic Accuracy	±0.4% rdg (+1.8°F/+1°C) Types J,K,E,T, Pt100 ±0.5% rdg (+2°F/+1°C) Types R,S
Data logging	20M data records using a 2G SD card
Dimensions	7.2 x 2.9 x 1.9" (182 x 73 x 47.5mm)
Weight	17.6oz (500g)

Figure 3.10 Thermocouple SDL-200

3.4.8 Blood Pressure Measuring Apparatus

Blood pressure of the subjects was measured to check any cardiac disorder. Blood pressure measuring meter is a device used to measure blood pressure, composed of an inflatable cuff to restrict blood flow, and motor to pump the air in the cuff. It is used in conjunction with a means to determine at what pressure blood flow start and at what impeded. The systolic and diastolic blood pressure along with pulse rate are displayed on electric display meter. Blood pressure measuring apparatus is shown in figure 3.11

Figure 3.11 Blood pressure measuring apparatus

3.4.9 Heart rate monitor

A heart rate monitor is a personal monitoring device which allows the subjects to measure their heart rate in real time or record their heart rates. Polar made heart rate monitor was used to measure heart rate of the subjects during the operation. It consisted of a heart rate sensor and a receiver monitor. The sensor was mounted at the chest of the subject which sends the real time heart rate signals to the monitor.

Figure 3.12Heart rate monitor

3.4.10 Clinical Thermometer

A clinical thermometer is a device that measures human body temperature. It has two important elements; the temperature sensor in which physical change occurred with temperature, plus some means of converting this physical change into a digital numerical value on the visible scale. The thermometer was put in the mouth of subject to measure the oral temperature. The thermometer produces beep sound when the temperature stabilizes. The reading was noted down and the thermometer was reset. It was cleaned by disinfectant before using it for next subject. Clinical thermometer as shown in figure 3.13

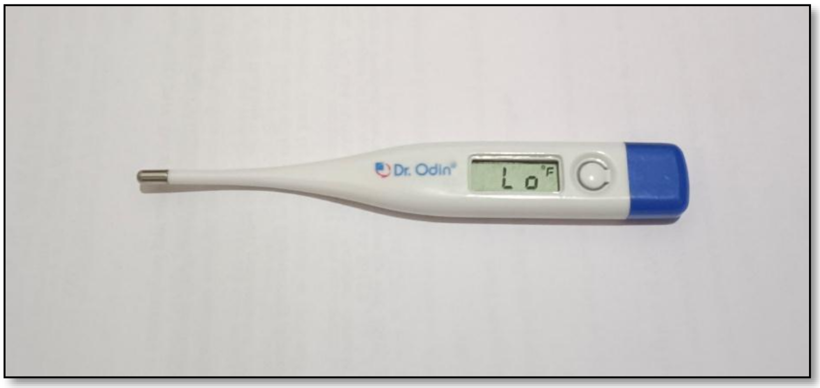


Figure 3.13 Clinical thermometer

3.5 Assessment of Environmental Heat on Human Skin Temperature

The assessment of environmental heat on human skin temperature was carried out in an environmental chamber of temperature and humidity. WBGT conditions 24˚C, 26˚C, 28˚C, 30˚C and 32˚C were simulated for the study. As per the ACGIH norms heat stress conditions starts from 28˚C,therefore two temperature ranges which falls below and above 28˚C was selected to observe the mean skin temperature. The skin temperature of the subject was measured for all selected WBGT. Skin temperature sites selected based on selected existing mean skin temperature models and by reference mean skin temperature model mentioned in section 3.2. Skin temperature measurement was carried out in controlled conditions for different simulated values of WBGT. Skin temperature measurement were carried out using thermocouple SDL-200, 4 channel data logging displays T1, T2 T3 and T4 at a time through thermal sensor probes. Thermal sensors probes were attached firmly on the skin sites for which the temperature was measured. Surgical tape was used to attach the thermal sensor probe firmly on the skin sites. The recording of skin temperature was begun after acclimatization of subjects inside environmental chamber. Effects of environmental heat on skin temperature at different simulated WBGT were assessed. The response of skin sites was observed with increase in WBGT. Protocol was followed while measuring the skin temperature inside the environmental chamber and described below:

3.5.1 Experimental Protocol

In order to consider the assessment of environmental heat on human skin temperature, subjects were asked to remain in standing position. The experimental data in the earlier studies indicated that skin temperature and thermal sensation became stable within 40 min under a new thermal environment (the change of environmental temperature was less than 10˚C). (Liu, *et al.*, 2011). In the present study, the measurements were made after the subject had stayed at targeted WBGT temperature for at least 40 min. Subject state of heat acclimatisation is the important factor which significantly affect the magnitude of the skin temperature variations. During the exposure to the heat, heat acclimatized subjects exhibit higher sweat rates together with higher skin wettedness and lower mean skin temperature than those observed in unacclimatised subjects (Candas, 1980). The experiment was performed in controlled environmental chamber during March 2020.Before measurement of skin temperature the informed consent was taken from the subjects which was approved by the Ethical Committee of the university. The duly signed consent is given in Appendix- A.

After the measurement at one targeted WBGT temperature was finished, the exposure temperature was set to the next value. The experimental temperature reached the new value in 60 min. After the regulation of the environmental temperature in the controlled environmental chamber began, the subject accommodated to the new targeted WBGT temperature for the measurement of skin temperature.

To maximize the number of body parts exposure to the environmental parameters like temperature and humidity and increase accuracy, subjects were semi naked wearing only undergarments. Prior to the study, the measurements involved were thoroughly explained to the subjects and their consent to participate in the present study was obtained. During the exposure and skin temperature measurement the subjects were asked to remain in sitting position. During the skin temperature measurement at the targeted WBGT of 28, 30 and 32˚C which falls under the heat stress conditions (ACGIH), to reduce the liquid loss, water and electrolytes were provided for the subjects to remained stable while measurement of the skin temperature.

Skin temperature measurement on subjects for different body sites shown in figure3.14

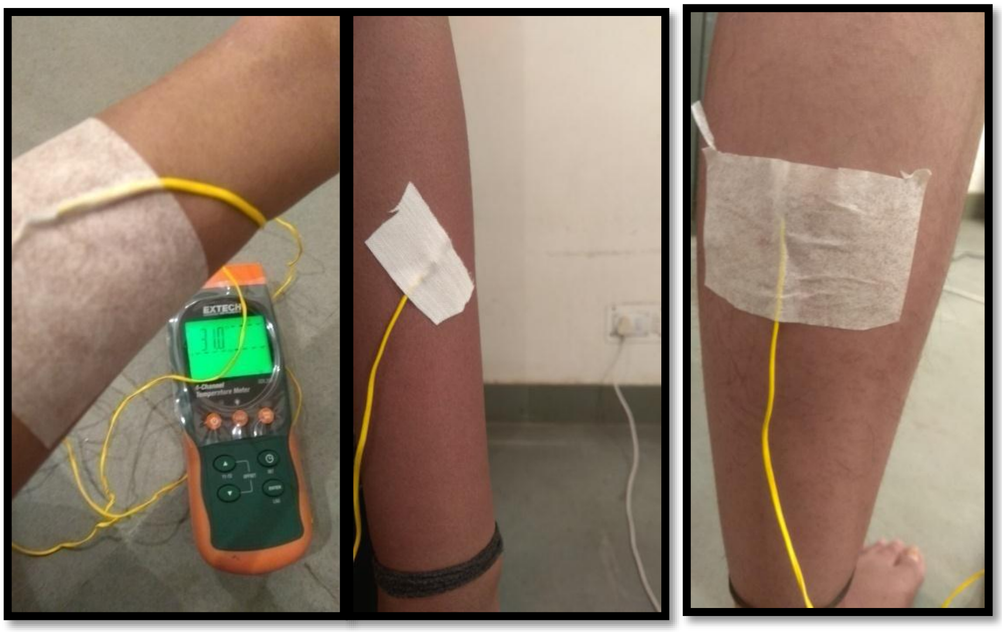


Figure 3.14 Skin temperature measurements at different body sites

3.6Evaluation of Selected Existing Mean Skin Temperature Model in Indian Conditions.

Evaluation of selected existing Mean skin temperature was carried out in environmental chamber. Mean skin temperature was calculated by eight different selected existing mean skin temperature models for different simulated WBGT temperature range. Details of the selected existing mean skin temperature models were described in section 3.2. Reference mean skin temperature was calculated by area weighted fifteen point mean skin temperature model (T_{ref}) given by Winslow, *et al*, 1936. The best weighted mean skin temperature was derived by measuring the temperature at a large number of sites and determining the area represented by the each temperature. The number of sites for the measurement of mean skin temperature was restricted to fifteen due to some factors as time and obstruction caused by wiring. Fifteen sites area weighted as recommended by Winslow, *et al* (1936) was the best way of applying a weighted method to estimate the mean skin temperature and regarded as an “optimal method” and used as a reference mean skin temperature method in many studies, as method estimates the skin temperature of maximum body points. Selected mean skin temperature models were evaluated statistically. Evaluation of selected existing mean skin temperature models were performed to find the suitability of selected existing models in the Indian conditions and to recommend the best fit model for Indian conditions. Twelve female subjects were selected for the study. The experimental protocol was followed and described in section 3.5.1.Statistical analysis was performed on the T_{sk} and T_{ref} data to find out the suitability of existing mean skin temperature model.

3.6.1 Data Analysis

Data recorded for mean skin temperature by eight selected existing mean skin temperature models and fifteen point area weighted reference mean skin temperature model were analysed statistically. Data analysis was carried out to find out which mean skin temperature model fits to Indian conditions and which gave the true mean skin temperature among the selected existing mean skin temperature models. Data analysis was performed using the R software and SPSS software. Data analysis was performed on the mean skin temperature data which was calculated by the different selected existing mean skin temperature models (T_{sk}). Reference mean skin temperature was calculated by the area weighted fifteen point mean skin temperature model (T_{ref}). All these formulas claim to calculate a T_{sk}which should be approximately equal to $T_{ref,}$ thus they should all fit the equation X = Y, where X is T_{ref} and Y is the calculated T_{sk}concerned. The stepwise regression was carried out using "step AIC" method which chooses the best model by AIC. AIC stands for "Akaike's Information criterion" compares the quality of set of statistical models to each other, AIC estimates the quality of each model, relative to each of the other models.AIC method was used for finding the suitability of model for Indian conditions.

3.7Development of Mean Skin Temperature Model for Indian Farm Women

Development of mean skin temperature model was carried out on the basis of weighting coefficients and the required body sites which get affected while performing the agricultural activities were identified. Aim of the study was to develop the mean skin temperature model with fewer points which gave the accurate estimation of mean skin temperature.Developed model based on the weighting coefficients which were calculated for Indian farm women by different body segments.

For the development of the new mean skin temperature model weighting coefficient was calculated using the surface area ratio.

Skin surface area ratio was calculated using the following formula

$$\text{Skin surface area ratio} = \frac{\text{Segmental body surface area (m}^2\text{)}}{\text{Total body surface area (m}^2\text{)}} \ldots\ldots (3.1)$$

Segmental body surface area was calculated by the formula given by the Meeh (1879), is given below:

$$\text{Segmental body surface area in } m^2 = 0.1053 * (W)^{2/3} \qquad \text{........ (3.2)}$$

Where, W= Weight of the individual body part in kg.

Total body surface area was estimated by using the DuBois formula given below: (DuBois,1915)

$$\text{Total body surface area } (m^2) = 0.20247 * \text{height } (m)^{0.725} * \text{Weight } (kg)^{0.425} \qquad \text{......... (3.3)}$$

Where, W= Weight of the subjects in kg

H= Height of the subjects in m

Site selection, segmental body surface area calculation, total body surface area calculation and area ratio calculation was finalised for the development of the model.

3.7.1 Site Selection

Site selection criteria for development of the mean skin temperature model was based on the two main factors:

1. Body sites selection by considering the weightages
2. Based on the prone body parts to sun while performing the agricultural activities.

The body parts having higher percentage of total body weight were consider while developing the mean skin temperature model. Sen, *et al* (1976) studied the relationship between the segmental and whole body weights of Indian subjects, and presented the data for segmental weight of the human body for Indian subjects. Average segmental weight in percent for Indian subjects is given in table 3.6

Table 3.6Average weights of the body segments expressed as a percentages of total body weight

S. No	Segments (Body parts)	Percentages (%)
1	Head	9
2	Trunk	58.2
3	Total right arm	4.3
4	Upper arm	2.1

5	Forearm and palm	2.2
6	Forearm	1.4
7	Palm	0.8
8	Total left arm	3.9
9	Total right leg including thigh	12.2
10	Thigh	6.8
11	Leg and foot	5.4
12	Leg	3.5
13	Foot	1.9
14	Total left leg including thigh	12.2
Total		**100**

Source: Sen, *et al.* (1976).

Relationship between segmental and whole body weights of Indian subjects.

For Indian subjects trunk, head, and thigh weights higher i.e. 58.2,9 and, 6.8 per cent (Sen et al. 1976). So these body parts were considered while developing the model.

Body sites selection based on the prone body parts to sun while performing the agricultural activities

Body sites forearm and right anterior calf were selected on the basis of the exposure to the sun while performing the agricultural activities. As WBGT 28˚C and above falls under the heat stress conditions. Long term exposure to the sun while performing the agricultural activities causes heat rashes, sun burn and most dangerously increases the risk of skin cancer. Body parts like face, hands, forearms and ears, legs (calf) remain open during agricultural operations. (Kashyap, et al., 2017). Most farming operations which are performed in hot sunny days or in high temperature, female farm workers use different personal protective gadgets for the protection of the body. Head, hands and legs were the parts found most susceptible to the exposure of the sun. Suitable hand guards, protective clothing for legs were developed for the female agricultural workers to provide the protection from the sun as they remain uncovered while performing the agricultural activities. By considering the above factors the body sites right forearm and right anterior thigh were selected for the development of the mean skin temperature model having the fractioned weightages of 1.4 and 3.5 per cent.

Segmental body surface area:

Segmental body surface area was calculated by the formula given by the Meeh (1879) given in equation (3.2). Before calculation of the segmental body surface area, segmental weight (kg) of the selected body sites were calculated. Segmental weight (kg) of the selected body part was calculated by the regression equation given by the Sen et al. (1976). Segmental weight of the selected body parts for the Indian subjects for development of the model is given in table: 3.7

Table 3.7 Segmental weights of the selected body parts for the Indian subjects

S. No.	Selected body parts	Segmental weight of the body part (kg)
1	Left upper chest	18.23
2	Right Anterior thigh	4.21
3	Forehead	3.91
4	Right Anterior Calf	1.60
5	Right forearm	1.24

Segmental body surface area (m^2) is calculated from the Meeh (1879) formula as discussed earlier. The segmental surface area (m^2) for the Indian subjects is as given in table 3.8

Table 3.8 Segmental surface area (m^2) for the Indian subjects

S.No.	Selected body parts	Segmental body surface area (m^2)
1	Left upper chest	0.736
2	Right Anterior thigh	0.27
3	Forehead	0.262
4	Right Anterior Calf	0.14
5	Right forearm	0.12

Table (3.8) shows the segmental body surface area of selected sites considered for development of the mean skin temperature model. From the surface area ratio the weighting coefficients for Indian farm women was calculated for the development of the mean skin temperature model.

3.8Validation of Developed Mean Skin Temperature Model in Controlled Conditions.

Validation of newly developed mean skin temperature model was carried out in environmental chamber at different WBGT conditions. WBGT of 24˚C,26˚C,28˚C,30˚C and 32˚C as previously mentioned were simulated for the study. Ten female subjects were selected for the validation of developed mean skin temperature model. Subject's height, weight, body surface area, body mass index, blood pressure, core temperature and heart rate were recorded. The developed mean skin temperature model was validated with area weighted 15 point model given by Winslow et al., (1936). The 15 point model was used as reference mean skin temperature model for calculation of mean skin temperature ($T_{ref.}$). The details of the model was discussed in section 3.2. Proper experimental protocol was followed as described in section 3.5.1.Developed model was claimed to calculate mean skin temperature approximately equal to reference temperature ($T_{ref.}$). Statistical analysis was performed on the data by comparing the developed mean skin temperature model and reference mean skin temperature model. Correlation analysis was performed on the data to find out the correlation between the developed mean skin temperature and the reference mean skin temperature model.

3.9 Evaluation of Developed Mean Skin Temperature Model in Open Field Conditions.

The developed and validated mean skin temperature model was evaluated in open field conditions in the month of March 2021. Eight female subjects were selected for the study. Subject's height, weight, body surface area, body mass index, blood pressure, core temperature and heart rate were recorded. Details of core temperature, blood pressure and heart are given in Appendix-G and Appendix-H. Developed MST model was evaluated in the open field, while the subject was performing farm operations i.e. harvesting of carrots and harvesting of green peas.

Figure 3.15 Evaluation of developed mean skin temperature model in open field conditions while performing field operation.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter presents the results of the work undertaken for assessment of environmental heat on human skin temperature, evaluation of selected existing mean skin temperature models, development of mean skin temperature model for Indian farm women, validation of developed mean skin temperature model in controlled conditions and evaluation of developed mean skin temperature model in open field conditions. The results of validation and field evaluation of mean skin temperature model are also given. The results of the studies related to these aspects and their discussions are presented in this chapter under following headings.

1. Assessment of environmental heat on human skin temperature.
2. Evaluation of selected existing mean skin temperature model for Indian farm women.
3. Development of mean skin temperature model for Indian farm women.
4. Validation of developed mean skin temperature model in controlled conditions.
5. Evaluation of developed model in open field conditions.

4.1 Assessment of Environmental Heat on Human Skin Temperature

Assessment of environmental heat on human skin temperature was carried out in controlled environmental chamber, the details of chamber was discussed in section3.3.Effects of environmental heat on the human skin temperature were assessed by measuring the skin temperature at simulated WBGT conditions 24˚C, 26˚C, 28˚C, 30˚C and 32˚C. The response of body site temperature to the increasing WBGT was observed. Wet Bulb Globe Temperature (WBGT) was recorded with the Quest Temp 36 Heat stress monitor. The measurement of skin temperature was carried out by using Thermocouple SDL-200 as discussed in section 3.4.7.

The experiment was conducted in controlled WBGT conditions in the environment chamber. Effect of environmental heat was observed by measuring the skin temperature for thirtytwo sites selected according to the existing mean skin temperature models. Skin temperature for body sites like forehead, left and right upper chest, left and right anterior calf, left and right abdomen, left chest, left and right upper arm, left hand, left foot, left and right anterior thigh, right shin, neck, lower leg, occiput, left and right shoulder, back of the trunk, left and right forearm, left and right back of the hand, left and right posterior thigh, left and right dorsal foot, right interior mid inner thigh and left and right lumbar were measured.

Experiments were carried out in controlled environmental chamber with twelve female subjects.

4.1.1 Subject Details

Twelve female subjects in the age group of 21 to 35 years were selected for the study. Their average weight, height, body mass index and body surface area, were 55.66 kg, 156 cm, 22.65 kg/m^2 and 1.53m^2 respectively. Subjects under study were covered by all the three categories of BMI. Informed consent was taken from every individual which was approved by the ethical committee of the University. The details of twelve subject participated in the study are shown in table 4.1

Table 4.1Details of twelve subjects participated in measurement of skin temperature

S. No.	Subject code	Weight, kg	Height, m	BMI kg/m	Body surface area, m^2	BMI Category
1	S1	61	1.7	21.1	1.7	Normal
2	S2	65	1.65	23.87	1.71	Normal
3	S3	39	1.47	18.01	1.27	Underweight
4	S4	53	1.49	23.87	1.46	Normal
5	S5	66	1.53	28.19	1.63	Overweight
6	S6	46	1.52	19.9	1.39	Normal
7	S7	47	1.53	20.07	1.41	Normal
8	S8	74	1.62	28.19	1.78	Overweight
9	S9	62	1.62	23.62	1.65	Normal
10	S10	46	1.42	22.81	1.32	Normal
11	S11	52	1.65	19.1	1.56	Normal
12	S12	57	1.57	23.12	1.56	Normal
Average		**55**	**1.56**	**22.65**	**1.53**	**--**

Detailed assessment of environmental heat on human skin temperature and the respective response of skin sites to the changing temperature at different WBGT are given below:

4.1.2 Assessment of Environmental Heat on Human Body at WBGT 24˚C

The assessment of environmental heat on human skin temperature at WBGT 24˚C were carried out in a controlled environmental chamber. Skin temperature measurement were taken according the body sites of selected existing mean skin temperature models and fifteen point reference mean skin temperature model in a controlled conditions of temperature and humidity. The details of selected existing mean skin temperature models and reference mean skin temperature models as discussed in section 3.2. Effect of environmental heat on human skin temperature was observed for thirty two body sites. Skin temperature for body sites like forehead, left and right upper chest, left and right anterior calf, left and right abdomen, left chest, left and right upper arm, left hand, left foot, left and right anterior thigh, right shin, neck, lower leg, occiput, left and right shoulder, back of the trunk, left and right forearm, left and right back of the hand, left and right posterior thigh, left and right dorsal foot, right interior mid inner thigh and left and right lumbar were measured. Skin temperature for thirty two body sites measured at WBGT 24˚C is given in table 4.2

Table 4.2 Measured skin temperature at WBGT 24˚C.

S. No.	Body sites	Skin temperature at WBGT 24˚C
1	Forehead	32.57
2	**Chest**	
	Left upper chest	31.45
	Right upper chest	31.71
3	**Calf**	
	Left anterior calf	31.40
	Right anterior calf	31.35
4	**Abdomen**	
	Left abdomen	32.62
	Right abdomen	31.98
5	Left cheek	32.17
6	**Upper arm**	
	Left upper arm	30.65
	Right upper arm	30.59
7	Left hand	30.61
8	Left foot	29.75
9	**Anterior thigh**	
	Left anterior thigh	31.76
	Right anterior thigh	31.89
10	Right shin	31.21
11	Neck	32.24
12	Lower leg	29.35
13	Occiput	31.73
14	**Shoulder**	
	Left shoulder	32.34
	Right shoulder	32.10

15	Back of trunk	32.67
16	**Forearm**	
	Left forearm	31.20
	Right forearm	31.42
17	**Back of hand**	
	Left hand	30.61
	Right hand	29.9
18	**Posterior thigh**	
	Left posterior thigh	31.61
	Right posterior thigh	31.82
19	**Dorsal foot**	
	Left dorsal foot	28.27
	Right dorsal foot	28.54
20	Right interior mid inner thigh	31.92
21	**Lumbar**	
	Left lumbar	31.80
	Right lumbar	31.56

From the table it is observed that, body sites forehead, left abdomen, left cheek, neck, left and right shoulder and back of the trunk showed higher skin temperature while body sites left hand, left foot, lower leg, back of the right hand, left and right dorsal foot showed lower skin temperature at WBGT 24˚C. Back of the trunk showed the maximum skin temperature of 32.67˚C at WBGT 24˚C, while skin site left dorsal foot showed the minimum skin temperature of 28.27˚C at WBGT 24˚C. No sweating or discomfort was observed at WBGT 24˚C.

4.1.3 Assessment of Environmental Heat on Human Body at WBGT 26˚C

The assessment of environmental heat on human skin temperature at WBGT 26˚C were carried out in controlled environmental chamber. Measurement of skin temperature was carried out for selected subject by using the Thermocouple SDL-200. Skin temperature measurement were taken according the body sites of existing mean skin temperature models and fifteen point reference mean skin temperature model in a controlled environmental conditions of temperature and humidity. Effect of environmental heat on human skin temperature was observed for thirty two body sites as mentioned in section 3.2. Skin temperature for twenty one body sites measured at WBGT 26˚C is given in table 4.3

Table 4.3 Measured skin temperature at WBGT 26˚C.

S. No.	Body sites	Skin temperature at WBGT 26˚C
1	Forehead	33.77
2	**Chest**	
	Left upper chest	32.66
	Right upper chest	32.45
3	**Calf**	
	Left anterior calf	32.54
	Right anterior calf	32.24
4	**Abdomen**	
	Left abdomen	33.85
	Right abdomen	33.74
5	Left cheek	33.41
6	**Upper arm**	
	Left upper arm	32.82
	Right upper arm	32.87
7	Left hand	32.33
8	Left foot	30.53
9	**Anterior thigh**	
	Left anterior thigh	33.36
	Right anterior thigh	33.21
10	Right shin	32.40
11	Neck	33.35
12	Lower leg	30.38
13	Occiput	32.73
14	**Shoulder**	
	Left shoulder	33.35
	Right shoulder	33.14
15	Back of trunk	33.70
16	**Forearm**	
	Left forearm	32.74

	Right forearm	32.75
17	**Back of hand**	
	Left hand	33.20
	Right hand	33.12
18	**Posterior thigh**	
	Left posterior thigh	32.89
	Right posterior thigh	32.54
19	**Dorsal foot**	
	Left dorsal foot	28.44
	Right dorsal foot	28.75
20	Right interior mid inner thigh	32.85
21	**Lumbar**	
	Left lumbar	32.73
	Right lumbar	32.45

From the table: it is observed that, body sites forehead, left abdomen, right abdomen, left cheek, left and right anterior thigh, neck, left and right shoulder, back of the trunk, left and right hand showed higher skin temperature, while body sites left foot, lower leg, left and right dorsal foot showed lower skin temperature. Left abdomen showed the maximum skin temperature of 33.85 ˚C at WBGT 26˚C, while skin site left dorsal foot showed the minimum skin temperature of 28.44˚C at WBGT 26˚C.As WBGT increases from WBGT 24˚C to WBGT 26˚C there was increase in skin temperature. No sweating and discomfort was experienced while increase in temperature from WBGT 24˚C to WBGT 26˚C.

4.1.4 Assessment of Environmental Heat on Human Body at WBGT 28˚C

The controlled environmental chamber was simulated for WBGT 28˚C to assess the environmental heat on human skin temperature. Skin temperature measurement were taken according the body sites of existing mean skin temperature models and fifteen point reference mean skin temperature model in a controlled environmental conditions of temperature and humidity for selected subject by using the Thermocouple SDL-200.Skin temperature for thirty two body sites measured at WBGT 28˚C is given in table 4.4

Table 4.4 Measured skin temperature at WBGT 28 ˚C

S. No.	Body sites	Skin temperature at WBGT 28˚C
1	Forehead	33.60
2	**Chest**	
	Left upper chest	34.27
	Right upper chest	34.12
3	**Calf**	
	Left anterior calf	34.23
	Right anterior calf	34.32
4	**Abdomen**	
	Left abdomen	33.81
	Right abdomen	33.80
5	Left cheek	34.46
6	**Upper arm**	
	Left upper arm	34.05
	Right upper arm	34.12
7	Left hand	34.03
8	Left foot	32.21
9	**Thighs**	
	Left anterior thigh	33.85
	Right anterior thigh	33.91
10	Right shin	33.85
11	Neck	33.75
12	Lower leg	31.99
13	Occiput	34.2
14	**Shoulder**	
	Left shoulder	34.05
	Right shoulder	34.10
15	Back of trunk	34.24
16	**Forearm**	
	Left forearm	34.21

	Right forearm	34.15
17	**Back of hand**	
	Left hand	33.8
	Right hand	33.21
18	**Posterior thigh**	
	Left posterior thigh	34.10
	Right posterior thigh	34.12
19	**Dorsal foot**	
	Left dorsal foot	32.05
	Right dorsal foot	32.14
20	Right interior mid inner thigh	32.98
21	**Lumbar**	
	Left lumbar	34.16
	Right lumbar	34.01

From the table 4.4, it is observed that, body sites left and right upper chest, left and right calf, left cheek, left and right upper arm, left hand, left and right anterior thigh, occiput, left and right shoulder, back of the trunk, right and left forearm, left and right posterior thigh, and left and right lumbar showed higher skin temperature, while body sites lower leg, right and left dorsal foot showed lower skin temperature. Left cheek showed the maximum skin temperature of 34.46 ˚C at WBGT 28˚C, while skin site left dorsal foot showed the minimum skin temperature of 32.05˚C at WBGT 28˚C. Forehead, right and left abdomen, right and left anterior thighs showed lower skin temperature. As the WBGT increases from WBGT 26˚C to WBGT 28˚C subject experienced the discomfort. Sweating was observed at forehead, right and left abdomen and right and left anterior thighs due to which lower skin temperature were recorded. Maximum skin sites showed higher skin temperature at WBGT 28˚C. Subjects were slightly uncomfortable with WBGT 28˚C, as the WBGT 28 ˚C falls under the heat stress conditions according to ACGIH.

4.1.5 Assessment of Environmental Heat on Human Body at WBGT 30˚C

As discussed above, for measurement of skin temperature, the controlled environmental chamber was simulated at WBGT 30˚C. Measurement of skin temperature was carried out for selected subject by using the Thermocouple SDL-200 and measurements were taken according the body sites of existing mean skin temperature models and fifteen point reference mean skin temperature model in a controlled conditions of temperature, humidity and air velocity. Effect of environmental heat on human skin temperature was observed for thirty two body sites as discussed in section 3.2. Skin temperature for thirty two body sites measured at WBGT 30˚C is given in table 4.5

Table 4.5 Measured skin temperature at WBGT 30˚C.

SI. No.	Body sites	Skin temperature at WBGT 30˚C
1	Forehead	33.57
2	**Chest**	
	Left upper chest	35.31
	Right upper chest	35.20
3	**Calf**	
	Left anterior calf	35.06
	Right anterior calf	35.12
4	**Abdomen**	
	Left abdomen	33.93
	Right abdomen	33.91
5	Left cheek	34.95
6	**Upper arm**	
	Left upper arm	35.25
	Right upper arm	35.65
7	Left hand	35.08
8	Left foot	33.88
9	**Thighs**	
	Left anterior thigh	33.95
	Right anterior thigh	33.52
10	Right shin	34.90
11	Neck	34.96
12	Lower leg	34
13	Occiput	35.28
14	**Shoulder**	
	Left shoulder	35.1
	Right shoulder	35.12
15	Back of trunk	35.8

16	**Forearm**	
	Left forearm	35.23
	Right forearm	35.21
17	**Back of hand**	
	Left hand	35.59
	Right hand	35.24
18	**Posterior thigh**	
	Left posterior thigh	34.56
	Right posterior thigh	34.87
19	**Dorsal foot**	
	Left dorsal foot	33.65
	Right dorsal foot	33.21
20	Right interior mid inner thigh	32.96
21	**Lumbar**	
	Left lumbar	35.23
	Right lumbar	35.45

From the table: it is observed that, body sites left and right upper chest, left and right calf, left cheek, left and right upper arm, left hand, occiput, left and right shoulder, back of the trunk, right and left forearm, left and right back of the hand and left and right lumbar showed higher skin temperature, while body sites left foot, right and left dorsal foot showed lower skin temperature. Right upper arm showed the maximum skin temperature of 35.65 ˚C at WBGT 30˚C, while skin site right anterior mid inner thigh showed the minimum skin temperature of 32.96˚C at WBGT 30˚C.Forehead, abdomen, and thighs showed lower skin temperature. Sweating was observed at forehead, abdomen and thighs due to which lower skin temperature was observed. Subjects felt heat and were uncomfortable while measurement of skin temperature.

4.1.6 Assessment of Environmental Heat on Human Body at WBGT 32˚C

As discussed above, same procedure was followed for assessing the environmental heat on human body at WBGT 32˚C. Skin temperature measured at WBGT 32˚C is given in table 4.6

Table 4.6 Measured skin temperature at WBGT 32˚C.

S. No.	Body sites	Skin temperature at WBGT 32˚C
1	Forehead	33.60
2	**Chest**	
	Left upper chest	36.17
	Right upper chest	36.10
3	**Calf**	
	Left anterior calf	36.16
	Right anterior calf	36.41
4	**Abdomen**	
	Left abdomen	34.02
	Right abdomen	34.00
5	Left cheek	36.20
6	**Upper arm**	
	Left upper arm	36.3
	Right upper arm	36.21
7	Left hand	35.41
8	Left foot	33.95
9	**Thighs**	
	Left anterior thigh	34.33
	Right anterior thigh	34.21
10	Right shin	35.09
11	Neck	35.17
12	Lower leg	35.47
13	Occiput	36.06
14	**Shoulder**	
	Left shoulder	35.82
	Right shoulder	35.45
15	Back of trunk	36.27
16	**Forearm**	
	Left forearm	36.25

	Right forearm	36.21
17	**Back of hand**	
	Left hand	36
	Right hand	36.2
18	**Posterior thigh**	
	Left posterior thigh	34.93
	Right posterior thigh	34.65
19	**Dorsal foot**	
	Left dorsal foot	34.72
	Right dorsal foot	34.21
20	Right interior mid inner thigh	32.69
21	**Lumbar**	
	Left lumbar	35.23
	Right lumbar	35.14

From the table: it is observed that, body sites left and right upper chest, left and right calf, left cheek, left and right upper arm, left hand, left and right anterior thigh, occiput, left and right shoulder, left and right back of hand, back of the trunk, right and left forearm, showed higher skin temperature, while body sites forehead, left foot, lower leg, right anterior mid inner thigh and left dorsal foot showed lower skin temperature. Right anterior calf showed the maximum skin temperature of 36.41 ˚C at WBGT 32˚C, while skin site right anterior mid inner thigh showed the minimum skin temperature of 32.69˚C at WBGT 32˚C. Forehead, abdomen and thighs showed lower skin temperature. Sweating was observed at forehead, abdomen and thighs due to which lower skin temperature was observed.

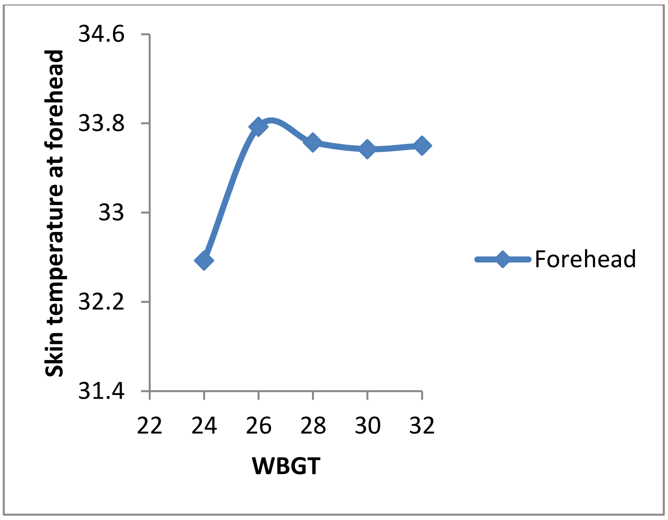


Figure 4.1 Effect of WBGT on forehead temperature

Figure4.1 shows the effect of environmental heat on forehead skin temperature at different simulated WBGT. At WBGT 24˚C forehead showed the lower temperature, as the WBGT increases from 28˚C to 32˚C the drop in forehead temperature was recorded and sweating was observed at forehead. At WBGT 24°C, forehead showed skin temperature of 32.57°C as WBGT increases to 32°C, it showed 33.60°C. Decrease in temperature may be because of condensation effect. In the heat, increased conductance below the skin surface, due to increase blood flow facilitates heat transfer from body interior to the skin.

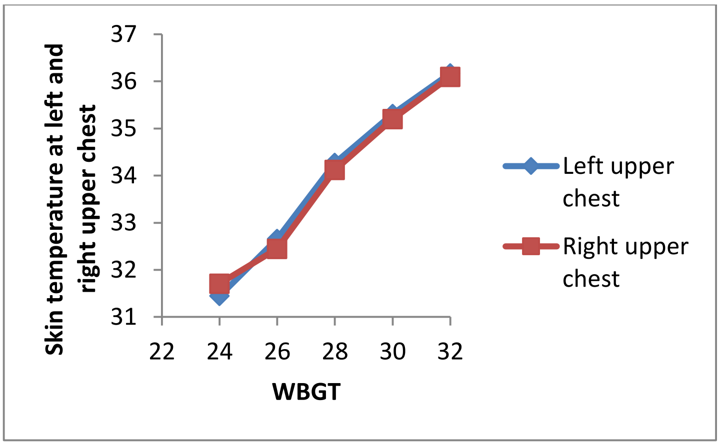


Figure 4.2 Effect of WBGT on left and right upper chest temperature

Figure 4.2 shows the effect of environmental heat on left and right upper chest at different simulated WBGT. Effects of environmental heat on left and right upper chest was observed at different simulated WBGT to find out the response of left and right chest skin temperature with increase in WBGT. In figure 4.2 left and right upper chest skin temperature is observed to increase with an increase in WBGT. At WBGT 24˚C left and right upper chest showed the lowest skin temperature of 31.45˚C and 31.71˚C, while at WBGT 32˚C, left and right upper chest showed the highest skin temperature of 36.17˚C and 36.10˚C. No drop of skin temperature was observed at left and right upper chest with increasing WBGT. Increase in skin temperature at left and right upper chest may be because of lower fat content. Chest found the relatively flat body part, and the fat thickness of the chest found lower than the abdomen, due to which chest showing the higher skin temperature.(LecBlank, 1954).

Effect of environmental heat on body sites left and right anterior calf at different created WBGT shown in figure 4.3.

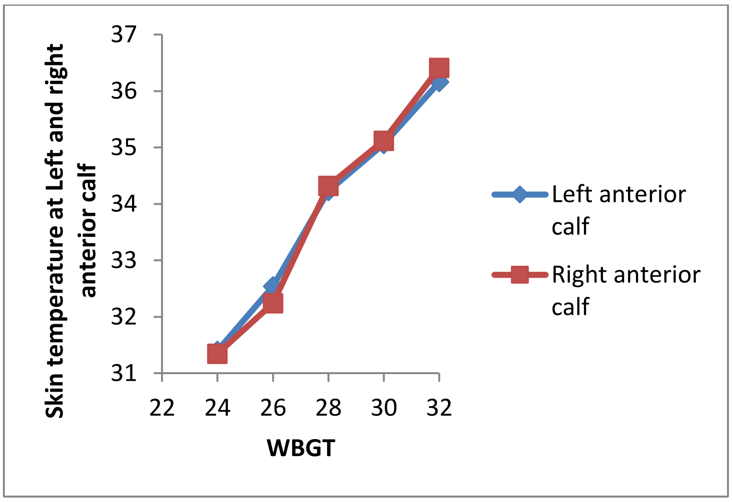


Figure 4.3 Effect of WBGT on left and right anterior calf

Skin temperature at left and right calf was recorded at different simulated WBGT. The response of skin temperature is observed at left and right anterior calf, and it is observed that, both the left and right anterior calf showed the increasing skin temperature with increase in WBGT. At WBGT 24˚C, left and right anterior calf showed the skin temperature of 31.4˚C and 31.35˚C, while skin temperature of 36.16˚C and 36.41˚C showed by the left and right anterior calf at WBGT 32˚C.

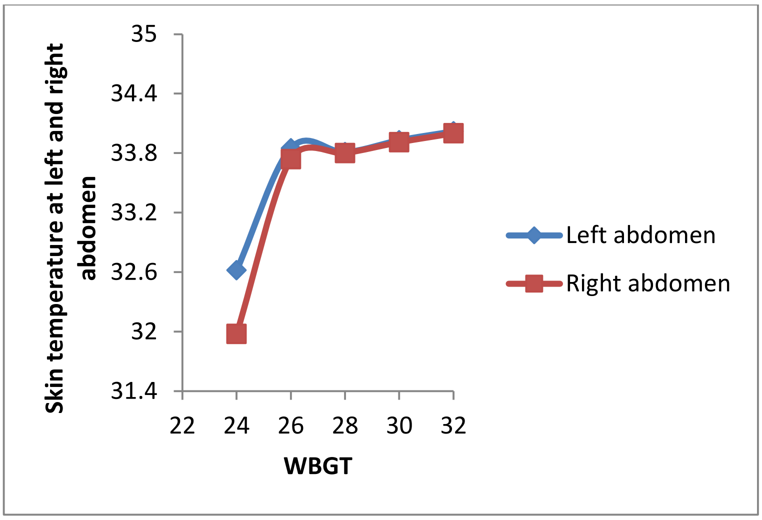


Figure 4.4 Effect of WBGT on left and right abdomen temperature

Figure4.4 shows the effect of environmental heat on left and right abdomen at different simulated WBGT. Effects of environmental heat on left and right abdomen is observed at different simulated WBGT to find out the response of left and right abdomen skin temperature with increase in WBGT. At WBGT 24˚C left abdomen showed skin temperature of 32.62˚C, while skin temperature of 34.02˚C at WBGT 32˚C. Right abdomen showed skin temperature of 31.98˚C at WBGT 24˚C, while at WBGT 32˚C, it showed skin temperature of 34.00˚C.As the temperature increases from WBGT 26˚C to WBGT 30˚C there was no increase in skin temperature. At WBGT 32˚C , increase in skin temperature was observed. The drop in skin temperature at left and right abdomen may be because of the more the body fat. Fat content is the important parameter while considering the skin temperature distribution over the human body. Insulation of the fat layer increases as the environmental temperature is lowered. The variations in fat thickness explain not only the differences in the average skin temperature of different persons, but also, to a certain extent, the regional variations of the skin temperatures observed over the body. With increase in WBGT, left and right abdomen skin temperature showed the drop in skin temperature due to fat content. Due to presence of number adipose tissues at the thigh region, fat content of the thigh is more, and it is well established that, adipose tissue has insulating properties, which affects the thermal conductivity.(Cooper and Trezek,1971).

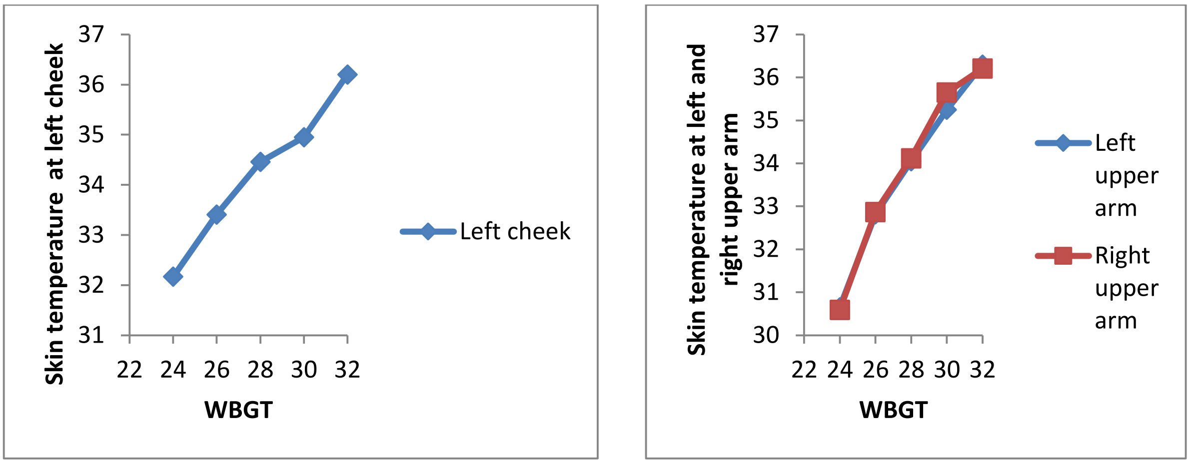


Figure 4.5 Effect of WBGT on left cheek and left and right upper arm temperature

Skin temperature of body sites left cheek, left and right upper arm showed the increasing skin temperature with increasing WBGT. No sweating was observed at the left cheek and left and right upper arm. The left cheek showed 32.17˚C at WBGT 24˚C, while 36.20˚C at WBGT 32˚C. Left and right upper arm showed skin temperature of 30.65˚C and 30.59˚C at WBGT 24˚C while skin temperature of 36.30˚C and 36.21˚C at WBGT 32˚C.

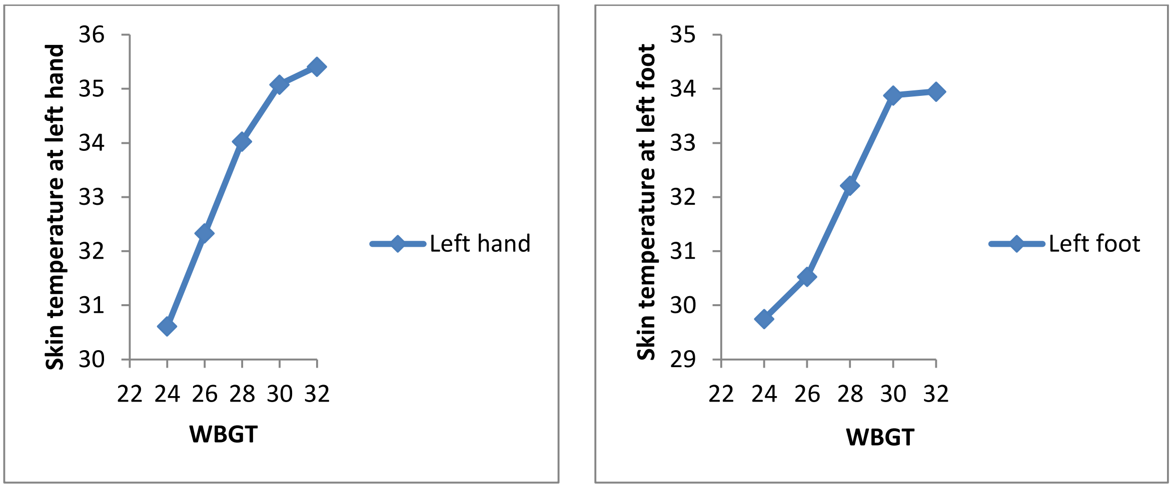


Figure 4.6 Effect of WBGT on left hand and left foot

Effects of environmental heat on left hand and left foot was observed, and it was concluded that, with increase in WBGT, body sites left hand and left foot showed the increasing temperature. Left hand showed 30.61˚C at WBGT 24˚C, while 35.41˚C at WBGT 32˚C. Left foot showed 29.75˚C at WBGT 24˚C, while 33.95 at WBGT 32˚C.

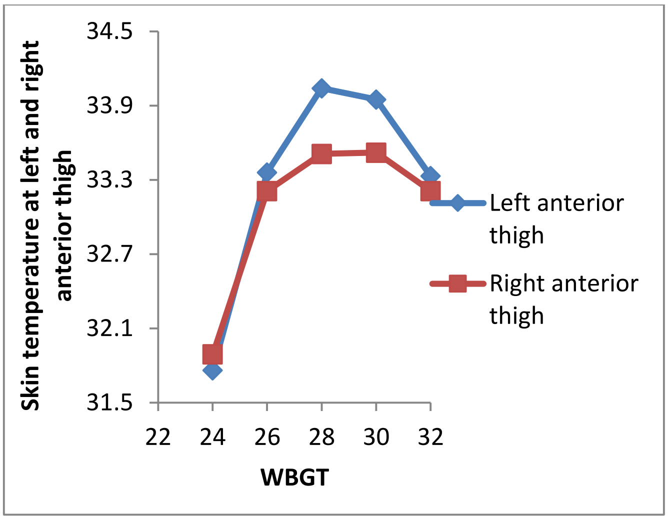


Figure 4.7 Effect of WBGT on left and right anterior thigh

Figure 4.7 shows the effect of environmental heat on left and right anterior thigh at different created WBGT. Effects of environmental heat on left and right anterior thigh was observed at different created WBGT to find out the response of left and right anterior thigh temperature with increase in WBGT. In figure 4.7 left and right anterior thigh skin temperature was observed to decrease with an increase in WBGT. Left and right thigh showed higher temperature at WBGT 24˚C and 26˚C, as the temperature increases from 28˚C to 32 ˚C the drop in WBGT was observed. Sweating was observed with the increasing WBGT, the reason may be because of females have a high concentration of apocrine glands around the thighs region. Therefore, some degree of inner thigh sweating is occurs (The medical news today, 2015).

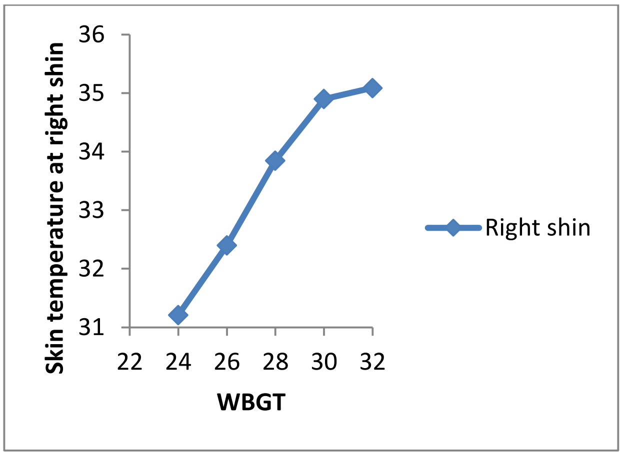


Figure 4.8Effect of WBGT on right shin temperature

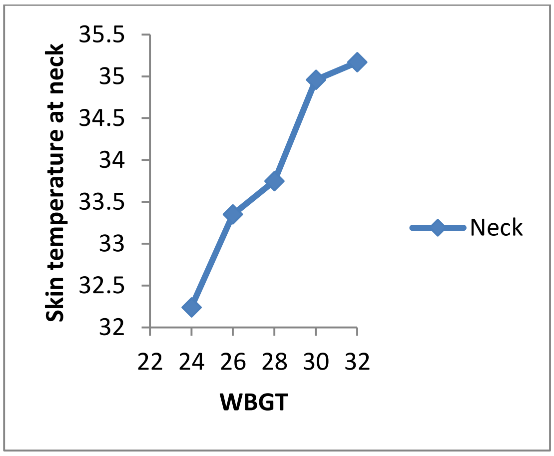


Figure 4.9Effect of WBGT neck on temperature

Figure4.8 and 4.9shows the increasing trend of skin temperature, with an increase of WBGT. With increasing WBGT from 24˚C to 32˚C body sites right shin and neck showed the increase in skin temperature. No sweating was observed at both skin sites. At 24˚C right shin showed the 31.21˚C, while 35.09˚C at WBGT 32˚C. Neck showed 32.24˚C at WBGT 24˚C, while 35.17˚C at WBGT 32˚C.

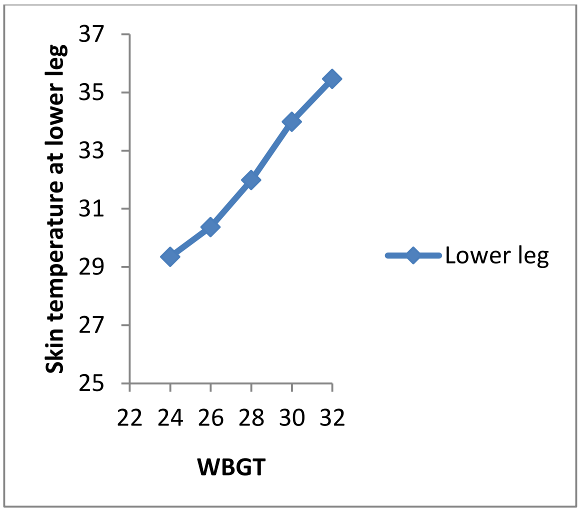


Figure 4.10Effect of WBGT on lower leg temperature

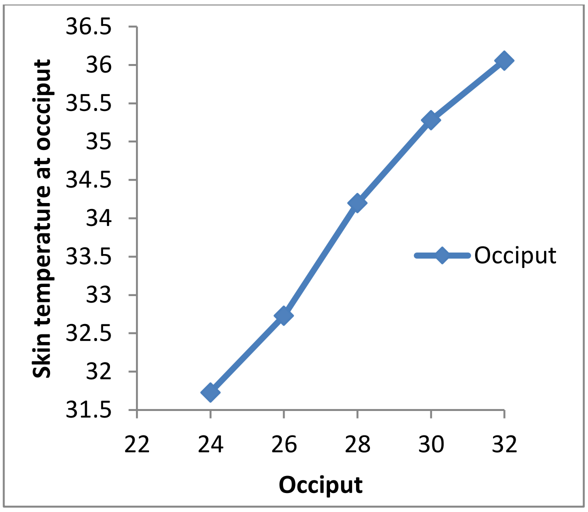


Figure 4.11Effect of WBGT on occiput temperature

With the increase in WBGT from 24˚C to 32 ˚C, body sites lower leg and occiput showed the increase in skin temperature. Lower leg showed 29.35 ˚C at WBGT 24 ˚C, while 35.47 ˚C at WBGT 32 ˚C, whereas, skin site occiput showed 31.73 ˚C at WBGT 24 ˚C and 36.06 ˚C at WBGT 32 ˚C. No sweating was observed with increase in WBGT.

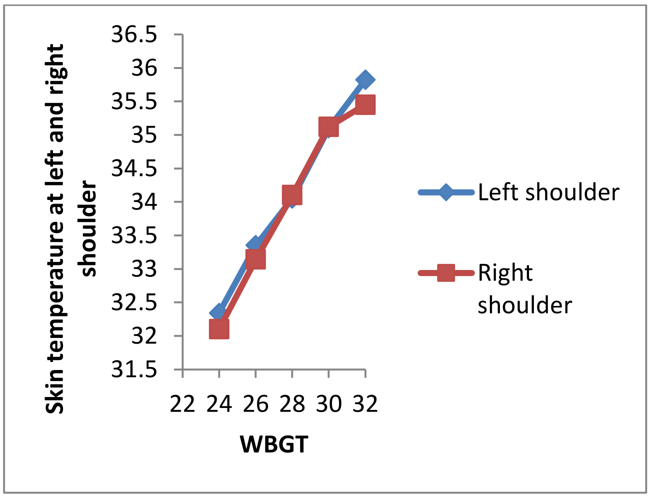


Figure 4.12Effect of WBGT on left and right shoulder temperature

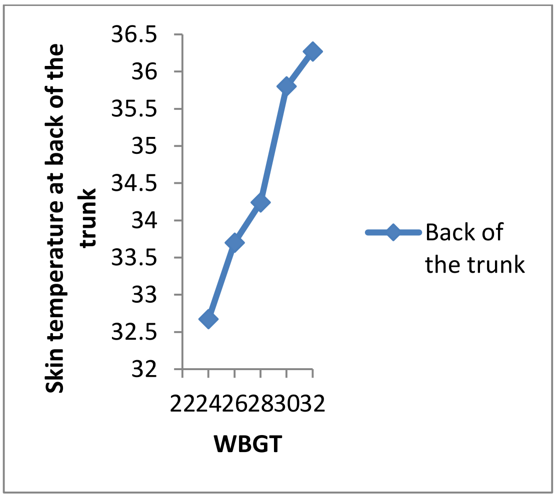


Figure 4.13Effect of WBGT on back of the trunk temperature

With the increase in WBGT from 24˚C to 32 ˚C, body sites lower leg and left and right shoulder and back of the trunk showed the increase in skin temperature. At WBGT 24˚C left and right shoulder showed skin temperature of 32.34˚C and 32.10˚C, and at WBGT 32˚C, left and right shoulder showed the 35.82˚C and 35.45˚C. Back of the trunk showed skin temperature of 32.67˚C at WBGT 24˚C, while 36.27˚C at WBGT 32˚C. Back of the trunk skin temperature includes the upper back temperature and lower back temperature. Distribution of fat on the back of the trunk influence the skin temperature, as the fat thickness was found lower at the back of the trunk.

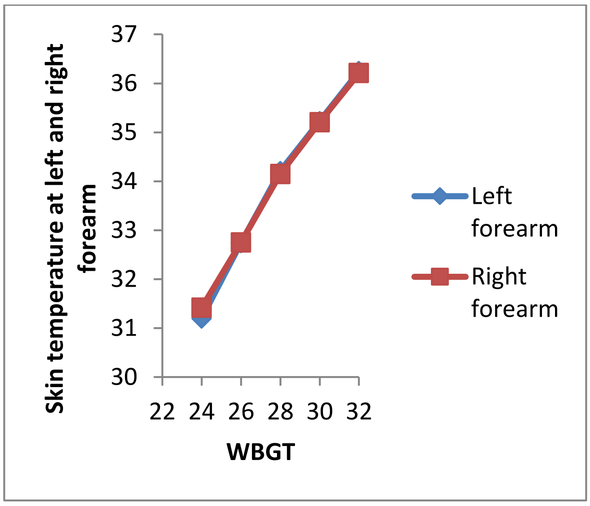


Figure 4.14Effect of WBGT on left and right forearm temperature

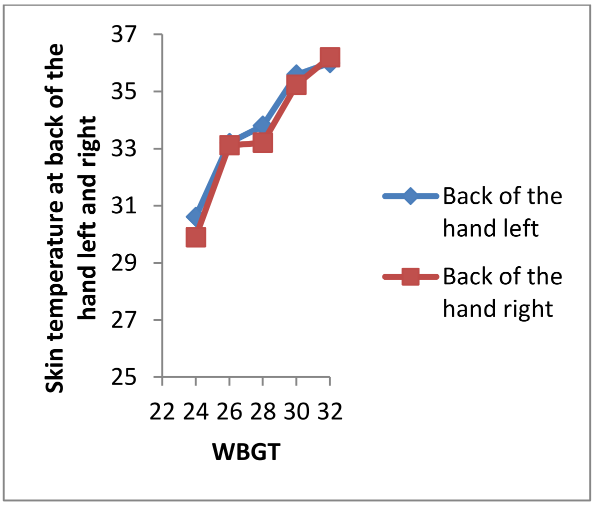


Figure 4.15Effect of WBGT on left and right back of the hand temperature

With the increase in WBGT from 24˚C to 32 ˚C, body sites left and right forearm and left and right back of the hand showed the increase in skin temperature. Left and right forearm showed 31.20˚C and 31.42˚C skin temperature at WBGT 24˚C, while skin temperature of 36.25˚C and 36.21˚C at WBGT 32˚C.

Body sites left and right back of the hand showed 30.61˚C and 29.9˚C skin temperature at WBGT 24˚C, while skin temperature of 36.00˚C and 36.20˚C at WBGT 32˚C.

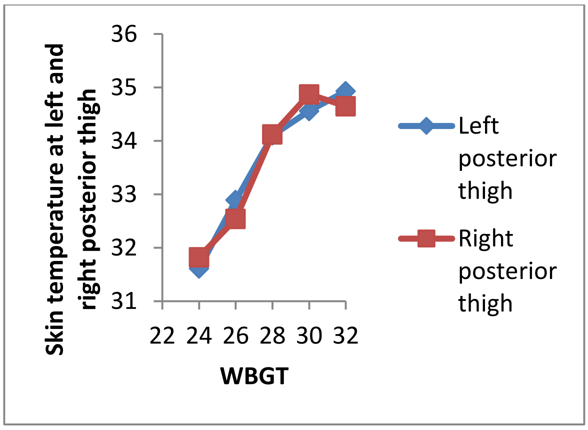


Figure 4.16Effect of WBGT on left and right posterior thigh temperature

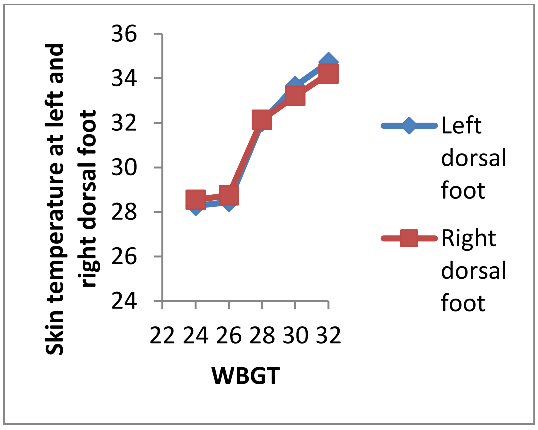


Figure 4.17Effect of WBGT on left and right dorsal foot temperature

With the increase in WBGT from 24˚C to 32 ˚C, body sites left and right posterior thigh and left and right dorsal foot showed the increase in skin temperature. Left and right posterior thigh showed 31.61˚C and 31.82˚C skin temperature at WBGT 24˚C, while skin temperature of 34.93 ˚C and 34.65˚C at WBGT 32˚C.

Body sites left and right dorsal foot showed 28.27˚C and 28.54˚C skin temperature at WBGT 24˚C, while skin temperature of 34.72˚C and 34.21˚C at WBGT 32.

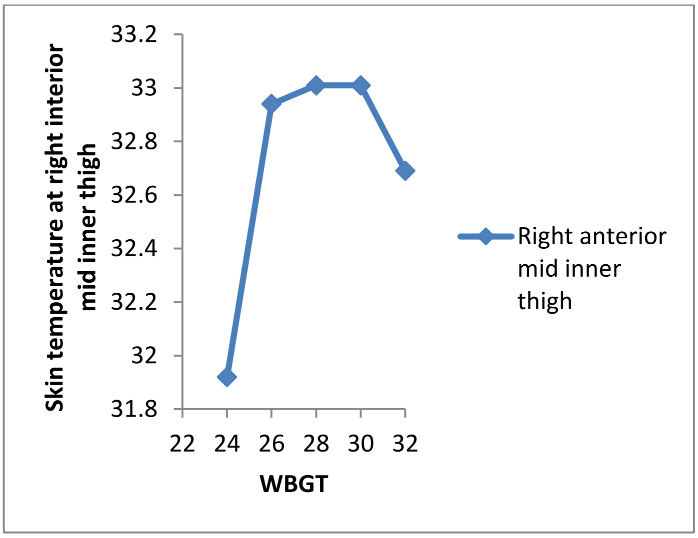


Figure 4.18Effect of WBGT on right anterior mid inner thigh temperature

Figure 4.18 shows the effect of environmental heat on right anterior mid inner thigh at different simulated WBGT. Effects of environmental heat right anterior mid inner thigh was observed at different simulated WBGT to find out the response of right anterior mid inner thigh skin temperature with increase in WBGT. In figure 4.18 right anterior mid inner thigh skin temperature was observed to decrease with an increase in WBGT. Sweating was observed at the mid inner thigh, which provides cooling effect due to which fall in skin temperature was observed from WBGT 26˚C to WBGT 32˚C .At WBGT 24˚C, right anterior mid inner thigh showed skin temperature of 31.92˚C, while skin temperature of 32.69˚C at WBGT 32˚C. Fat content affects the skin temperature of mid inner thigh.

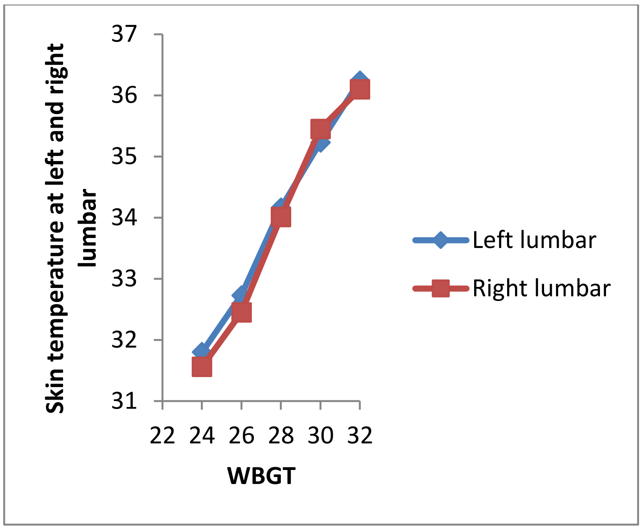


Figure 4.19Effect of WBGT on left and right lumbar temperature

With the increase in WBGT from 24˚C to 32˚C, left and right lumbar showed the increase in skin temperature. Left and right lumbar showed skin temperature of 31.80˚C and 31.56˚C at WBGT 24˚C, while skin temperature of 35.23˚C and 35.14˚C were observed at WBGT 32˚C.

Assessment of environmental heat on human skin temperature was observed by measuring the skin temperature of thirty two skin sites. The sites were selected according to the eight selected existing mean skin temperature models and fifteen point reference mean skin temperature model. The response of skin sites with increase in WBGT was observed. Some skin sites like thigh and abdomen showed the drop in skin temperature with the increase in WBGT. The higher fat content of the thigh and abdomen provides the cooling effect by sweating with increase in WBGT. Forehead showed the drop in skin temperature with the increase in WBGT.

The factors that influence skin temperature distribution are core temperature, blood flow, thickness of the insulating shell, thermal conductivity of the tissues, metabolic rate of the tissues shell, evaporative heat loss, etc. Since chest and back are relatively flat body parts, the influence of the heat stream according to the body posture and curvatures would be negligible. Instead, the variation in skin temperatures would be attributed to the difference in the thermal conductivity or the metabolic rate of the tissues of the chest, abdomen, and back regions. Effective thermal conductivity is governed by physical heat conduction and skin blood flow (Ohara, 1960). Physical thermal conductivity of the tissues is associated with fat content (Ohara, 1960).Skin temperature depends upon both the rate of heat supply to the skin and the rate of heat removal i.e. upon the temperature and flow rate of the blood, and the insulation and temperature difference between skin and environment (Fetcher *et al*, 1949).

Body sites left and right chest, left and right anterior calf, left and right upper arm, left hand, left foot, right shin, neck, lower leg, occiput, left and right shoulder, back of the trunk, left and right forearm, left and right back of the hand, left and right dorsal foot and left and right lumbar showed increase in the skin temperature with the increase in WBGT. No sweating was observed on above selected sites and all those body sites having the relatively flat body surfaces. Flat body surfaces showed the lower fat content and lower cooling effect with increase in temperature. The skin fold thickness (fat content) influences the skin temperature distribution. With increase in temperature, certain body sites of human body like thigh, abdomen and forehead allows sweating to maintain the proper thermoregulation of the human body.

4.2 Evaluation of Selected Existing Mean Skin Temperature Model in Indian Conditions

Evaluation of selected existing mean skin temperature models in Indian conditions were carried out in controlled environmental conditions of temperature and humidity. Eight existing mean skin temperature models were selected for the study. Various methods for estimation of mean skin temperature were employed since 1935 (e.g. simple average, one point, skin surface area ratio, skin surface area ratio and sensitivity of the skin, skin surface area ratio and heat transfer coefficient ratio, etc.) among these methods mean skin temperature based on the skin surface area ratio to the total body surface area has been the most widely accepted and this method more faithfully represents the definition of mean skin temperature. (Lee. *et al*, 2010). Due to which selected existing mean skin temperature model based on the surface area ratio of human body i.e. ratio of segmental body surface area to the total body surface area of human body were selected for the study. Mean skin temperature were calculated from the following selected existing mean skin temperature models Burton; 1934, Teichner; 1958, Hardy and DuBois; 1938, Palmes and Park; 1947, Ramananthan; 1964, ISO; 2004, Newburgh and Spealman; 1943, and Nadel; 1971, and 15 point area weighted reference mean skin temperature model given by Winslow, et.al. (1936) for which weighting coefficients was based on the surface area ratio. Selected models having body sites ranges from minimum three to maximum seven body sites. Selected existing mean skin temperature models were evaluated statistically to find out the best fit model for Indian conditions. Eight existing models with corresponding weighting coefficients were selected as discussed in section 3.2. The models were evaluated statistically. Mean skin temperature were calculated from eight selected existing mean skin temperature models and were compared with an area weighted 15 point model used as reference mean skin temperature model. Reference mean skin temperature was calculated by area weighted fifteen point mean skin temperature model (T_{ref}) given by Winslow. *et al*, (1936). The best weighted mean skin temperature was derived by measuring the temperature at a large number of sites and determining the area represented by the each temperature. The number of sites for the measurement of mean skin temperature was restricted to fifteen due to factors as time and obstruction caused by wiring. Fifteen sites area weighted recommended by Winslow, *et al* (1936) was the best way of applying a weighted method to estimate the mean skin temperature and regarded as an "optimal method" and used as a reference mean skin temperature method in many studies, as method estimates the skin temperature of maximum body points. Mean skin temperature calculated by the selected mean skin temperature models and the reference mean skin temperature models at created WBGT i.e. 24˚C, 26˚C, 28˚C, 30˚C and 32˚C is represented in following tables. Mean skin temperature at WBGT 24˚C by selected existing mean skin temperature models and reference mean skin temperature model is given in table 4.7

Table 4.7 Mean skin temperature at WBGT 24˚C

S. No.	Selected existing mean skin temperature models	Mean skin temperature, ˚C	Mean skin temperature Reference 15 point model, ˚C
1	Burton	31.40	31.47
2	Teichner	31.71	31.47
3	Hardy and DuBois	31.77	31.47
4	Palmes and park	31.66	31.47
5	Ramananthan	31.36	31.47
6	ISO 4	31.58	31.47
7	Nadel	31.32	31.47
8	Newburgh and Spealman	31.11	31.47

At WBGT 24˚C, mean skin temperature was calculated and Hardy and DuBois formula showed the highest mean skin temperature, while Newburgh and Spealman showed lower mean skin temperature.

Table 4.8 Mean skin temperature at WBGT 26˚C

S. No.	Selected existing mean skin temperature models	Mean skin temperature, ˚C	Mean skin temperature Reference 15 point model, ˚C
1	Burton	32.63	32.67
2	Teichner	32.99	32.67
3	Hardy and DuBois	33.07	32.67
4	Palmes and park	33.01	32.67

5	Ramananthan	33.83	32.67
6	ISO 4	32.90	32.67
7	Nadel	32.74	32.67
8	Newburgh and Spealman	32.38	32.67

Mean skin temperature were recorded for selected existing mean skin temperature models at 26˚C, and it was observed that, Ramanathan four point model showed the higher mean skin temperature at WBGT 26˚C, while Palmes and Park showed the lower mean skin temperature at WBGT 26˚C.

Table 4.9Mean skin temperature at WBGT 28˚C

S. No.	Selected existing mean skin temperature models	Mean skin temperature, ˚C	Mean skin temperature Reference 15 point model, ˚C
1	Burton	34.25	33.83
2	Teichner	34.12	33.83
3	Hardy and DuBois	33.82	33.83
4	Palmes and park	34.19	33.83
5	Ramananthan	34.14	33.83
6	ISO 4	33.90	33.83
7	Nadel	33.71	33.83
8	Newburgh and Spealman	33.63	33.83

Burton three point mean skin temperature model showed the higher skin temperature at WBGT 28 ˚C, while Newburgh and Spealman four point model showed the lower mean skin temperature at WBGT 28˚C.

Table 4.10 Mean skin temperature at WBGT 30˚C

S. No.	Selected existing mean skin temperature models	Mean skin temperature, ˚C	Mean skin temperature Reference 15 point model, ˚C
1	Burton	35.22	34.88
2	Teichner	34.75	34.88
3	Hardy and DuBois	34.30	34.88
4	Palmes and park	34.76	34.88
5	Ramananthan	34.98	34.88
6	ISO 4	34.96	34.88
7	Nadel	34.55	34.88
8	Newburgh and Spealman	34.68	34.88

Burton three point model showed the higher mean skin temperature at WBGT 30˚C, while Hardy and DuBois seven point model showed the lower skin temperature at WBGT 30˚C.

Table 4.11Mean skin temperature at WBGT 32˚C

S. No.	Selected existing mean skin temperature models	Mean skin temperature, ˚C	Mean skin temperature Reference 15 point model, ˚C
1	Burton	36.20	35.49
2	Teichner	35.63	35.49
3	Hardy and DuBois	34.72	35.49
4	Palmes and park	35.63	35.49
5	Ramananthan	35.91	35.49
6	ISO 4	35.27	35.49
7	Nadel	35.28	35.49
8	Newburgh and Spealman	35.60	35.49

At WBGT 32˚C, Burton three point model showed the higher mean skin temperature, while Hardy and DuBois seven point model showed the lower skin temperature at WBGT 32˚C.

Statistical analysis was carried out by using the “R software” and SPSS software. The stepwise regression was carried out using “step AIC” method which chooses the best model by AIC. AIC stands for “Akaike’s Information criterion” compares the quality of set of statistical model to each other, AIC estimates the quality of each model, relative to each of the other models. Thus, AIC provides a means for model selection. By calculating and comparing the AIC scores of several possible models, one can choose the best fit for the data. Mean and standard deviation of selected existing mean skin temperature models at created WBGT 24˚C, 26˚C,28˚C,30˚Cand 32˚C is given in table 4.12

Table 4.12Mean and standard deviation

Selected models	WBGT 24 ˚C		WBGT 26 ˚C		WBGT 28 ˚C		WBGT 30 ˚C		WBGT 32 ˚C	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Burton	31.40	0.11	32.63	0.16	34.25	0.16	35.22	0.18	36.20	0.11
Teichner	31.71	0.12	32.99	0.09	34.12	0.15	34.75	0.09	35.63	0.06
Hardy& DuBois	31.77	0.12	33.07	0.15	33.82	0.15	34.30	0.10	34.72	0.10
Palmes and park	31.66	0.12	33.01	0.16	34.19	0.15	34.76	0.14	35.63	0.06
Ramananthan	31.36	0.17	32.83	0.10	34.14	0.08	34.98	0.10	35.91	0.07
ISO 4	31.58	0.19	32.90	0.20	33.90	0.13	34.96	0.12	35.27	0.34
Nadel	31.32	0.13	32.74	0.08	33.71	0.13	34.55	0.12	35.28	0.12
Newburgh	31.11	0.12	32.38	0.14	33.63	0.14	34.68	0.13	35.60	0.10
Reference	31.47	0.08	32.67	0.13	33.83	0.09	34.88	0.11	35.49	0.08

By applying the “Akaike’s Information criterion (AIC)” on eight selected existing mean skin temperature models, six models fits the “AIC” criteria. The details of the retained models by step AIC given below:

Table 4.13Retained mean skin temperature models after Step AIC models

Models	Regression Coefficient	Std. Error	t value	P Value (>|t|)	Interpretation
(Intercept)	0.85466	0.76853	1.112	0.27113	Non-Significant
Burton	0.14843	0.06662	2.228	0.03015	Significant
Teichner	0.2492	0.15003	1.661	0.10261	Non-significant
`Hardy &DuBois`	0.16591	0.07707	2.153	0.03591	Significant
`Palmes and park`	-0.33237	0.14468	-2.297	0.02558	Significant
`ISO 4`	-0.1782	0.04962	3.591	0.00072	Significant
Newburgh	0.56804	0.08342	6.809	0.125	Non-Significant

The above retained models (i.e. Burton, Hardy and DuBois, Palmes and Park and ISO 4) were significant as P< 0.05 with Adjusted R-squared 0.996, indicating that these four models can determine the reference score up to 99% level when considered all data. Some of the coefficient are non- significant (P-value > 0.05) but are retained with minimum Akaike’s Information criterion (AIC). From the above data, it was observed that, the mean skin temperature model Hardy and DuBois and Burton having P- value 0.035 and 0.030 (P- Value < 0.05) and Regression coefficient 0.169 and 0.148 fits the best criteria of less p value and higher regression coefficients. But the Hardy and DuBois mean skin temperature model having slightly higher coefficient of regression than Burton mean skin temperature model, therefore the Hardy and DuBois seven point model was considered as a best fit model for Indian conditions. Mean skin temperature calculated from the Hardy Dubois formula gives the true estimation of mean skin temperature for Indian conditions. Therefore, the Hardy and DuBois seven point model is recommended for Indian conditions or for Indian farm women. Existing Hardy and DuBois mean skin temperature seven point model is as follow:

T_{sk} (Hardy and DuBois)= 0.07 T_{sk} Forehead + 0.14 T_{sk} Left forearm + 0.05 T_{sk} Left hand + 0.07 T_{sk} Left foot + 0.13 T_{sk} Left anterior calf + 0.19 T_{sk} Left anterior thigh + 0.35 T_{sk} Left abdomen.

These findings agree with the observations taken by Lee, et al. 2010. That Hardy and DuBois seven point weighted model to determine the mean skin temperature has remained the authority in respect of its historical importance and contributions to human thermal environmental research. Hardy and DuBois seven point model has been the most commonly used model due to its balanced choice of segments and reliable weighted coefficients, along with its historical contributions. Ramanathan, (1964). conducted the study on a new weighting system for mean surface temperature of the human body. He has selected the Hardy and DuBois seven point model and Burton three point model due to its more or less generally accepted form to compare the result of his newly developed four point model. Olesen, (1984), studied on how many sites are necessary to estimate a mean skin temperature. He evaluated the eight mean skin temperature models statistically by stepwise regression analysis and found good correlation among the selected mean skin temperature model.

4.3 Development of Mean Skin Temperature Model for Indian Farm Women

Mean skin temperature model was developed for Indian farm women. On evaluation of the selected existing mean skin temperature models statistically, it was found that four models i.e. Burton three point model, Hardy and DuBois seven point model, Palmes and Park six point model and ISO four point model fits best to the Indian conditions. From the evaluation of selected mean skin temperature models in Indian conditions it was concluded that, with the fewer body sites Burton model showed the significant results by satisfying the criteria of best fit model according to step AIC method. By keeping this in view the new mean skin temperature model for Indian farm women was developed with fewer body sites. Mean skin temperature model with a five point or five body sites was developed for Indian farm women.

Developed mean skin temperature model was designed based on two main criteria:

1. Body sites selection by considering the weightages and agricultural activities.
2. Calculation of weighting coefficients for Indian farm women.

Body sites for the development of the mean skin temperature model were selected on the basis of weightages i.e. the body site having higher percentages of total body weight for Indian subjects trunk, head, and thigh weights higher i.e 58.2 per cent, 9 per cent and 6.8 per cent (Sen, et al. 1976). So these body parts were considered while developing the model.

Another criterion based on the agricultural activities, i.e. body sites which are prone to environmental heat while performing the agricultural activities. Based on the agricultural activities body sites forearm and calf were considered while developing the mean skin temperature model having average segmental weight 1.4 per cent and 3.5 percent. Therefore the body sites viz; Forehead, Left upper chest, right anterior thigh; right forearm and right calf were selected for the development of the mean skin temperature model. Body sites right upper chest, forehead and right anterior thigh contained higher percentages total body weight, and were considered for the model development. Body sites right forearm and right anterior calf were selected on the basis of agricultural activities, as these body sites remained uncovered while performing the agricultural activities.

The second criterion to develop the mean skin temperature model was to calculate the weighting coefficients for the Indian farm women. The weighting coefficients for the developed model based on the surface area ratio were calculated. Segmental weight of the body sites were calculated by using the regression equations given by the (Sen, et al., 1976) for the Indian subjects. Segmental body surface area was calculated by Meeh constant (1879) as discussed in equation 3.2. Based on the segmental body surface area and total body surface area of the Indian subjects weighting coefficients were calculated for the Indian subjects. As discussed in the equation 3.1.

For the Indian subjects, while considering the percentage weightings of the body parts the focus was given on the right side of the body than the left because the parts like right arm, calf showed the higher weightages than left side (Sen *et al*, 1976). By considering the above factors the body sites left upper chest, forehead, right anterior thigh, right forearm, and right calf were selected for the development of the mean skin temperature model. Instead of taking whole trunk i.e. chest, abdomen or back weightages, the focus was given on the anterior side of the trunk for development of the mean skin temperature model, as the chest and abdomen are more actively respond to the changes in temperature than the posterior parts like upper back and lower back of the human body. In the majority of the formulae, torso (trunk) is assigned with a greater weighting factor than other body surface areas ranging from 0.50 in Burton (1934) three point formula to 0.35 Hardy and DuBois (1938) seven point formula. Because of great percentage of trunk part, whether the chest or abdomen or back was chosen may have significance influence on determination of mean skin temperature. (Lee, *et al*, 2010). The front torso (trunk) sites (chest and abdomen) normally used for the determination of mean skin temperature were cooler than the surrounding regions on the frontal trunk when examined through infrared thermography. (Livingstone et al., 1987). In majority of the models trunk has assigned with the greater weighting factors because of the higher percentages the trunk. The findings support the calculation taken by the Clauser, et al (1969). Estimated 50.7 per cent for the trunk area, Fujikawa (1963). Found 53.6 per cent for trunk. Mori and Yamamoto, (1959). Found 53.5 percent for trunk of the human.

Puhakka, K., 1994 selected forehead area as a body site while development of the mean skin temperature model because of the larger proportionality of head area, also he quoted that, forehead area seems to be a thermally stable area.

All Mean skin temperature models based on the surface area ratio preferred the chest as a trunk than abdomen and back (Kuwabara*et al*, 2006). The formula developed by the Hardy and DuBois has been most commonly used due to its balanced choice of segments and reliable weighting coefficients, along with its historical contributions. While Hardy and Dubois seven points weighted formula to determine mean skin temperature has remained the authority in the respect of its historical importance and contributions to human thermal environmental research. The original draft of Hardy and DuBois formula presented the trunk as a body site in the seven point mean skin temperature model and did not stipulate any specified trunk parts. Because of the greater percentage of trunk site, whether the chest, abdomen and back is chosen may have a significance influence on the determination of mean skin temperature. The issue on the choice of the optimum site on the trunk has been somewhat neglected. A group of studies have used the abdomen as the trunk region in Hardy and DuBois seven point formula in their reviewed tables Houdas and Ring, (1982); Kuwabara, *et al.* (2006), Mitchell and Windham, (1969), Nielson and Nielson, (1984), Parsons, (2003), while another group of studies marked the chest Choi *et al.* (1997), Teichner(1958), Ramanathan (1984). (Lee, *et al*, 2010).

Weighting coefficients were calculated using skin surface area ratio as discussed in equation 3.1. Selected body sites and their corresponding weighting coefficients in developed mean skin temperature model are given in table 4.14.

Table 4.14Selected body parts and their corresponding weighting coefficient

S. No.	Selected body parts	Weighting coefficients
1	Left upper chest	0.481
2	Right Anterior thigh	0.176
3	Forehead	0.169
4	Right Anterior Calf	0.091
5	Right forearm	0.078
Average		**0.995≈1**

From the above data new mean skin temperature model was developed for Indian farm women. The developed model is given as follow:

T_{sk} = 0.481 T_{sk} (Left upper chest) +0.169 T_{sk} (Forehead) + 0.091 T_{sk}(Right anterior calf) + 0.078 T_{sk} (Right forearm) + 0.176 T_{sk} (Right anterior thigh)

4.4 Validation of Developed Mean Skin Temperature Model in Controlled Conditions.

Model validation is defined as “the set of processes and activities intended to verify that models are performing as expected, in line with their design objectives.” It also identifies “potential limitations and assumptions, and assesses their possible impact.” Validation of developed mean skin temperature was carried out in controlled environmental chamber. Developed model was validated at different simulated WBGT as 24˚C, 26˚C, 28˚C, 30˚C and 32˚. Developed model was validated with the area weighted fifteen point reference mean skin temperature model as a reference mean skin temperature model. 15 point area weighted reference mean skin temperature model regarded as a “optimal method (model)” (Liu, et al.,2011) and this model was used in many studies as reference mean skin temperature model. 15 point reference mean skin temperature model more faithfully represents true mean skin temperature as the number of body sites are more. As, greater the number of skin temperature measurements, the greater the accuracy of the estimation. (Lee, *et al.*, 2010), by considering the above factors 15 point reference mean skin temperature model was used as a reference mean skin temperature model during the validation of developed mean skin temperature model. Ten female subjects were selected for the study having age group of 21 to 35. Average weight, height, body surface area and body mass index of the selected subjects were 56.6 kg, 158cm, 1.57m^2 and 22.59 kg/m respectively. Body mass index (BMI) of subjects falls under normal category. Core temperature, blood pressure and heart rate of the selected subjects were also measured. Duly signed informed consent was taken from the subject which was approved by the ethical committee of MPUAT University. Details of the ten selected subjects for the validation of developed model are given in table 4.15

Table 4.15Details of ten subjects participated in validation of developed mean skin temperature model

S. No.	Subject Code	Weight, kg	Height, m	BMI kg/m	Body surface area, m^2	BMI Category
1	S1	61	1.7	21.1	1.7	Normal
2	S2	65	1.65	23.87	1.71	Normal
3	S3	39	1.47	18.01	1.27	Underweight
4	S4	66	1.53	28.19	1.63	Overweight
5	S5	46	1.52	19.9	1.39	Normal
6	S6	74	1.62	28.19	1.78	Overweight
7	S7	46	1.42	22.81	1.32	Normal
8	S8	57	1.57	23.12	1.56	Normal
9	S9	52	1.69	18.2	1.63	Underweight
10	S10	60	1.63	22.6	1.73	Normal
Average		56.6	1.58	22.59	1.57	--

Table 4.15 shows the details of the selected subjects for the study. Informed consent was taken from the subject which was approved by the ethical committee of the university. Duly signed informed consent is given in Appendix-A.

Validation of developed mean skin temperature model was carried out in controlled environmental chamber at created WBGT i.e. 24˚C, 26˚C, 28˚C, 30˚Cand 32˚C. The developed mean skin temperature model was validated with the reference mean skin temperature model. Calculated mean skin temperature data by the developed mean skin model and reference mean skin temperature model is represented in the following tables.

Mean skin temperature calculated by the developed mean skin temperature model and reference mean skin temperature for the validation at WBGT 24˚C is given in table 4.16

Table 4.16Mean skin temperature by developed and reference mean skin temperature model at WBGT 24 ˚C

S.No	**Mean skin temperature by developed model,** ˚C		**Mean skin temperature by reference mean skin temperature model,** ˚C
	Subject Code	**Mean skin temperature**	**Mean skin temperature**
1	S1	31.32	31.55
2	S2	31.29	31.52
3	S3	31.16	31.52
4	S4	31.20	31.49
5	S5	31.50	31.52
6	S6	31.49	31.54
7	S7	31.33	31.42
8	S8	31.36	31.44
9	S9	31.39	31.51
10	S10	31.39	31.51
Average		**31.34**	**31.51**

Mean skin temperature of 31.34 and 31.50˚C for developed mean skin temperature models and reference mean skin temperature was recorded at WBGT 24˚C.

Mean skin temperature calculated by the developed mean skin temperature model and reference mean skin temperature for the validation at WBGT 26˚C is given in table 4.17

Table 4.17Mean skin temperature by developed and reference mean skin temperature model at WBGT 26 ˚C

S.No	Mean skin temperature by developed model, ˚C		Mean skin temperature by reference mean skin temperature model, ˚C
	Subject Code	**Mean skin temperature**	**Mean skin temperature**
1	S1	32.61	32.77
2	S2	32.59	32.71
3	S3	32.48	32.65
4	S4	32.47	32.70
5	S5	32.75	32.71
6	S6	32.44	32.55
7	S7	32.56	32.58
8	S8	32.39	32.57
9	S9	32.52	32.62
10	S10	32.45	32.54
Average		**32.53**	**32.64**

Mean skin temperature of 32.53 and 32.64˚C for developed mean skin temperature models and reference mean skin temperature was recorded at WBGT 26˚C.

Mean skin temperature calculated by the developed mean skin temperature model and reference mean skin temperature for the validation at WBGT 28˚C is given in table 4.18

Table4.18Mean skin temperature by developed and reference mean skin temperature model at WBGT 28 ˚C.

S.No.	Mean skin temperature by developed model, ˚C		Mean skin temperature by reference mean skin temperature model, ˚C
	Subject Code	**Mean skin temperature**	**Mean skin temperature**
1	S1	33.54	33.68
2	S2	33.59	33.68
3	S3	33.60	33.64
4	S4	33.71	33.73
5	S5	33.77	33.76
6	S6	33.50	33.69

7	S7	33.35	33.71
8	S8	33.78	33.62
9	S9	33.68	33.69
10	S10	33.66	33.70
Average		**33.62**	**33.70**

Mean skin temperature of 33.62 and 33.69 ˚C for developed mean skin temperature models and reference mean skin temperature was recorded at WBGT 28˚C.

Mean skin temperature calculated by the developed mean skin temperature model and reference mean skin temperature for the validation at WBGT 30˚C is given in table 4.19

Table 4.19Mean skin temperature by developed and reference mean skin temperature model at WBGT 30˚C.

S.No	**Mean skin temperature by developed model,** ˚C		**Mean skin temperature by reference mean skin temperature model,** ˚C
	Subject Code	**Mean skin temperature**	**Mean skin temperature**
1	S1	34.48	34.65
2	S2	34.46	34.72
3	S3	34.53	34.78
4	S4	34.53	34.67
5	S5	34.58	34.77
6	S6	34.69	34.76
7	S7	34.53	34.75
8	S8	34.51	34.66
9	S9	34.77	34.78
10	S10	34.63	34.76
Average		**34.58**	**34.73**

Mean skin temperature of 34.575 and 34.734 ˚C for developed mean skin temperature models and reference mean skin temperature was recorded at WBGT 30˚C.

Mean skin temperature calculated by the developed mean skin temperature model and reference mean skin temperature for the validation at WBGT 32˚C is given in table 4.20

Table 4.20Meanskin temperature by developed and reference mean skin temperature model at WBGT 32˚C.

S. No	Mean skin temperature by developed model, ˚C		Mean skin temperature by reference mean skin temperature model, ˚C
	Subject Code	**Mean skin temperature**	**Mean skin temperature**
1	S1	35.06	35.45
2	S2	35.21	35.44
3	S3	35.14	35.44
4	S4	35.00	35.38
5	S5	35.14	35.41
6	S6	35.11	35.44
7	S7	35.16	35.39
8	S8	35.10	35.46
9	S9	35.18	35.45
10	S10	35.21	35.52
Average		**35.14**	**35.44**

Mean skin temperature of 35.136 and 35.442 ˚C for developed mean skin temperature models and reference mean skin temperature was recorded at WBGT 32˚C.

Statistical analysis was carried out for the validation of developed mean skin temperature model. The data for mean skin temperature calculated from the developed mean skin temperature model and reference mean skin temperature model firstly distributed. The test of normality was carried out on developed mean skin temperature and reference mean skin temperature data. The results of test of normality are shown in table 4.21

Table 4.21Test of normality

Groups	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	SD	Df	Sig.	SD	Df	Sig.
24	0.214	10	0.200	0.925	10	0.397
26	0.196	10	0.200	0.942	10	0.578
28	0.176	10	0.200	0.946	10	0.620
30	0.180	10	0.200	0.941	10	0.564
32	0.121	10	0.200	0.935	10	0.500
All Data	0.071	50	0.200	0.983	50	0.697

The above table 4.21 presents the results from two well-known tests of normality, namely the Kolmogorov-Smirnov Test and the Shapiro-Wilk Test. The Shapiro-Wilk Test is more appropriate for small sample sizes (< 50 samples), but can also handle sample sizes as large as 2000. For this reason, Shapiro-Wilk test was used as a numerical means for assessing the normality.

From the K-S and S-W test it was interpreted that, since p-value for the K-S and S-W test is greater than that of 0.05 indicates that data is distributed normally. Therefore, we can apply paired t test to compare the significance of difference between the average score of developed mean skin temperature model and Reference mean skin temperature model.

The Shapiro–Wilk test is a test of normality in statistics while performing the paired t-test. The null-hypothesis of this test is that the population is normally distributed. Thus, if the *p* value is less than the chosen alpha level, then the null hypothesis is rejected and there is evidence that the data tested are not normally distributed. On the other hand, if the p value is greater than the chosen alpha level, then the null hypothesis (that the data came from a normally distributed population) cannot be rejected. Here from the table: it was observed that the null hypothesis for the test is accepted and the data is distributed normally.

Table 4.22 Interpretation of paired t- test

Selected WBGT	SD	t value	df	p value	Interpretation
24	0.10	-4.92	9	0.001	Significant
26	0.07	-4.54	9	0.001	Significant
28	0.13	-1.68	9	0.128	Non-significant
30	0.08	-6.41	9	0.000	Significant
32	0.06	-16.33	9	0.000	Significant
Average	**0.12**	**-9.50**	**49**	**0.000**	**Significant**

From the above table 4.22 it is interpreted that, the p value of the result is less than 0.05 indicates the significance of difference among the data calculated from the developed mean skin temperature model and reference mean skin temperature model. Hence, the developed model is validated with the reference mean skin temperature model.

Correlation among the developed mean skin temperature model and the reference fifteen point mean skin temperature was observed. Mean skin temperature calculated from the reference mean skin temperature model plotted against the developed mean skin temperature model at all selected WBGT levels.Mean skin temperature calculated from the developed mean skin temperature models plotted against the reference mean skin temperature model is shown in figure 4.20

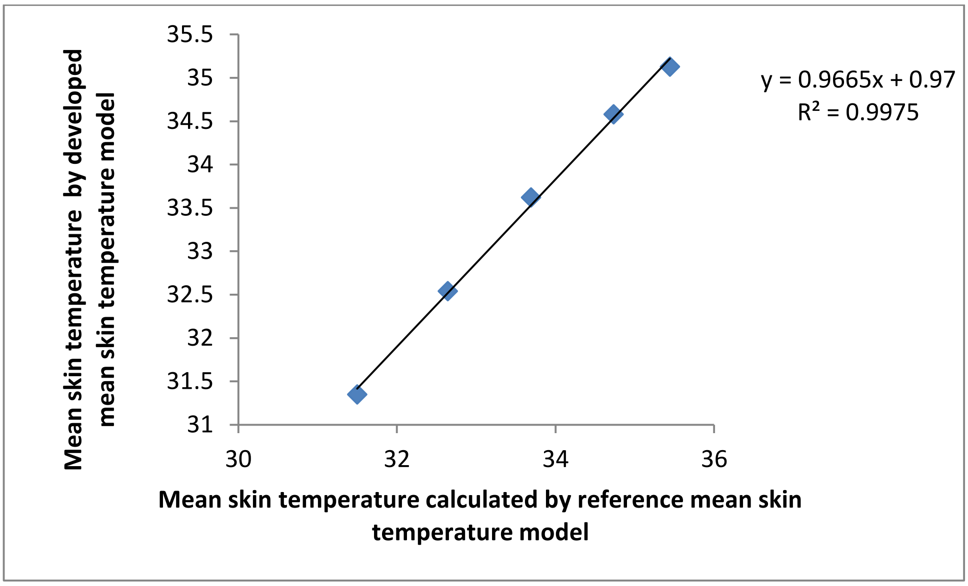


Figure 4.20 Mean skin temperature by reference model versus developed model

There was a linear relationship between the developed mean skin temperature model and reference mean skin temperature model and R^2 value were high 0.997. The best fitting linear regression is indicated shown in figure 20 with higher correlation among the reference mean skin temperature and developed mean skin temperature data.

Correlation among the developed mean skin temperature model and the models which fits best to the Indian conditions was observed. Among the selected existing mean skin temperature models after evaluating the models for Indian conditions statistically, four models i.e. Burton three point model, Hardy and DuBois seven point model, palmes and park six point model and ISO four point model shows significant results. Mean skin temperature calculated from the Burton three point model, Hardy and DuBois seven point model and palmes park six point models, and ISO four point model was plotted against the developed mean skin temperature model. The best fitting linear regression is indicated as shown in following figures and higher correlation was observed among the selected existing mean skin temperature models and developed mean skin temperature model data. Mean skin temperature calculated from the developed mean skin temperature models plotted against the Burton's three point mean skin temperature model is shown in figure4.21.

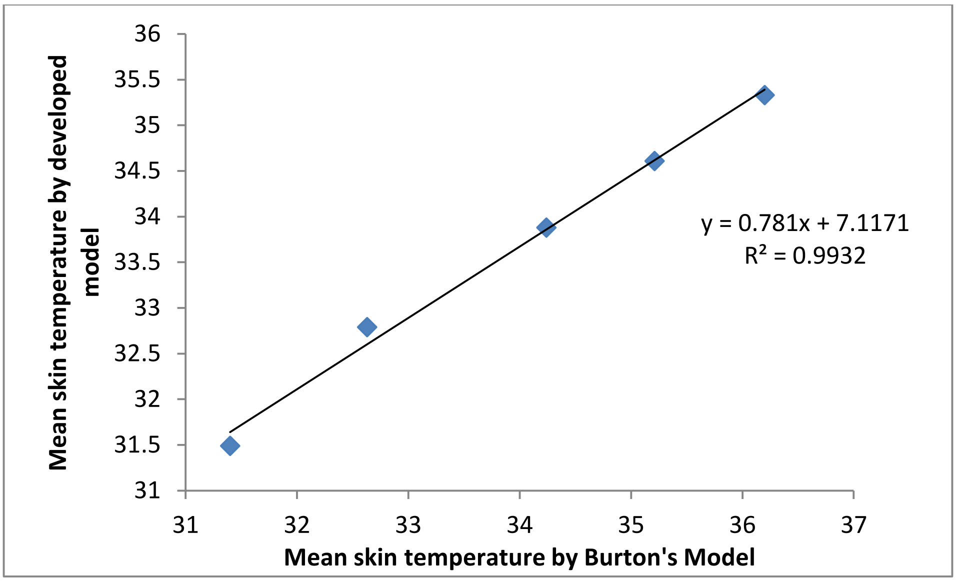


Figure 4.21Mean skin temperature by the developed model versus Burton three point model.

There was a linear relationship between the developed mean skin temperature model and Burton three point mean skin temperature model and R^2 value was 0.993.

Mean skin temperature calculated from the Hardy and DuBois seven point model was plotted against the developed mean skin temperature model. The best fitting linear regression is indicated as shown in figure 22 and higher correlation was observed in between the Hardy and DuBois seven point mean skin temperature model and developed mean skin temperature model data.

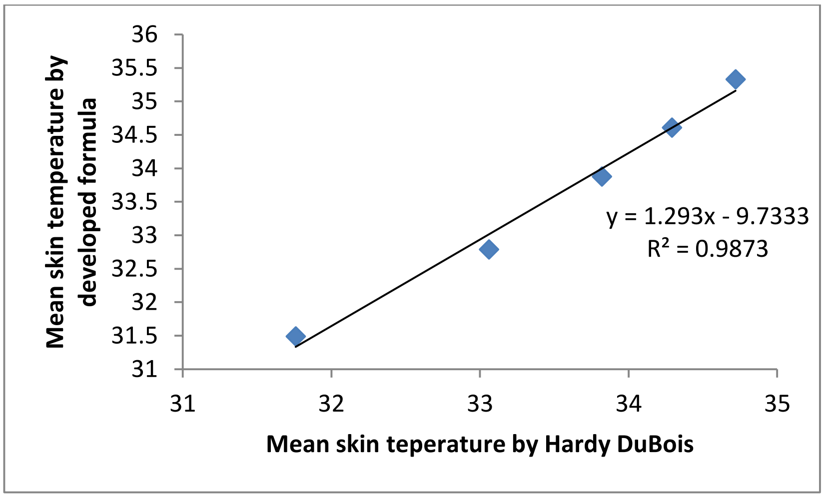


Figure 4.22Mean skin temperature by the developed model versus Hardy and DuBois seven point model.

There was a linear relationship between the developed mean skin temperature model and Hardy and DuBois seven point mean skin temperature model and R^2 value was 0.987.

Mean skin temperature calculated from the Palmes and Park six point model was plotted against the developed mean skin temperature model. The best fitting linear regression is indicated as shown in figure 23 and higher correlation was observed in between the Palmes and Park six point mean skin temperature model and developed mean skin temperature model data.

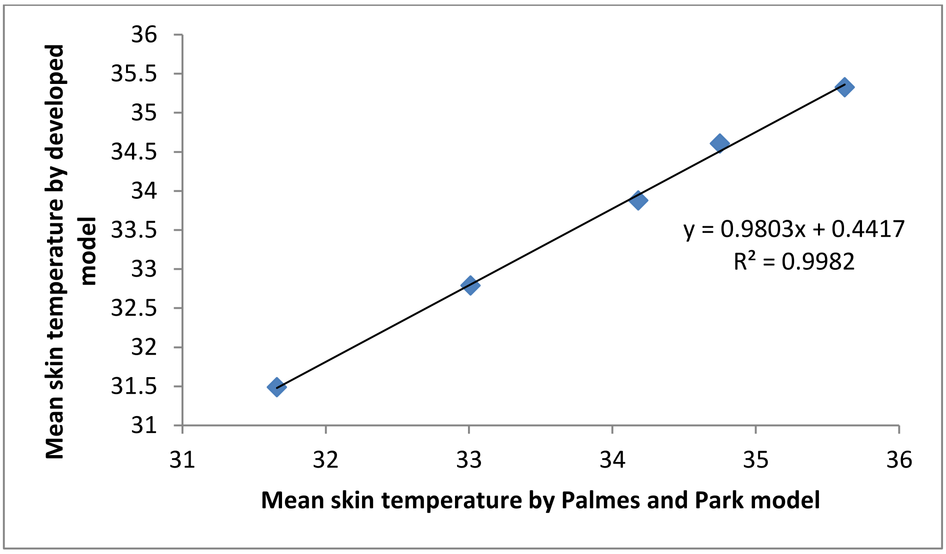


Figure 4.23 Mean skin temperature by the developed model versus Palmes and Park six point model.

There was a linear relationship between the developed mean skin temperature model and Palmes and Park six point mean skin temperature model and R^2 value was 0.998.

Mean skin temperature calculated from the ISO four point model was plotted against the developed mean skin temperature model. The best fitting linear regression is indicated as shown in figure 4.24 and higher correlation was observed in between the ISO four point mean skin temperature model and developed mean skin temperature model data.

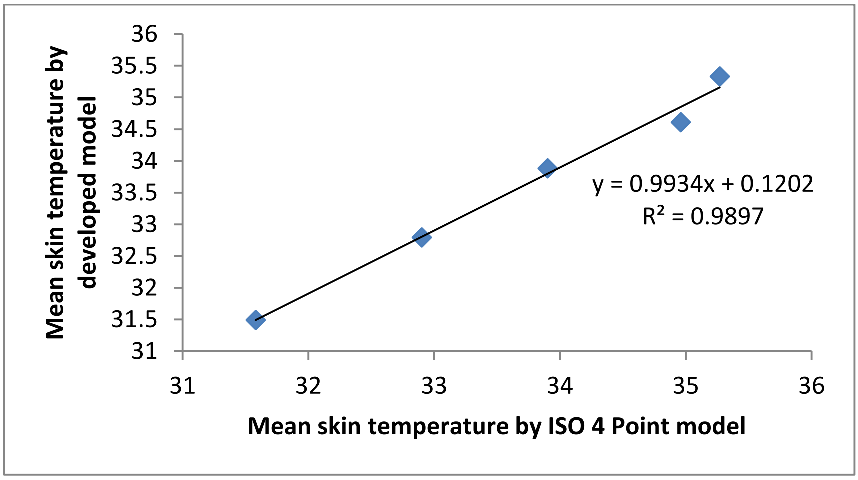


Figure 4.24Mean skin temperature by the developed model versus ISO four point model.

There was a linear relationship between the developed mean skin temperature model and ISO four point mean skin temperature model and R^2 value was 0.989.

4.5 Evaluation of Mean Skin Temperature Model in Open Field Conditions

Developed mean skin temperature model was evaluated in open field conditions.

Developed mean skin temperature model was evaluated for WBGT 22-32˚C. The evaluation was carried out in between 9:00 a.m. to 3:00 p.m. Details of the environmental parameters recorded while evaluating the developed mean skin temperature model in open field conditions is given in table 4.23

Table 4.23 Recorded WBGT parameters while evaluation of mean skin temperature model in open field conditions

S. No.	Time	WB	DB	GT	WBGT˚C Outdoor	RH	Humidex	Flow
1	9:10 a.m.	20.1	30.5	31.6	22.6	28	31	0.4
2	9:40 a.m.	21.7	32.5	32.5	24.8	29	35	0.4
3	10:30 a.m.	22.1	32.3	32.6	25.1	29	34	0.4
4	10:45 a.m.	22.4	33.6	33.8	25.8	27	36	0.4
5	11.15 a.m.	22.5	34.8	34.6	26.1	23	34	0.3
6	11:45 a.m.	23.5	34.6	46.2	29.8	25	35	0.3
7	12:30 a.m.	22.8	38.4	49.6	30.4	19	32	0.4
8	2.45 p.m.	28.2	33.1	52.3	31.9	15	39	0.3

4.5.1 Subject Details

Eight female subjects were selected for the study. Average weight, height, body surface area, and body mass index of the subjects was 51.37 kg, 154 cm, 1.62 m^2, and 21.55 kg/m, respectively. Average body mass index falls under normal category. Subjects core body temperature, blood pressure and heart rate was also measured. Details of the subjects selected for the evaluation of developed mean skin temperature model is as shown in table 4.24

Table 4.24 Details of eight subjects participated in evaluation of developed mean skin temperature model

S. No.	Subject Code	Weight, kg	Height, m	BMI kg/m	Body surface area, m^2	BMI Category
1	S1	45	1.54	19	1.53	Normal
2	S2	54	1.49	24.3	1.66	Normal
3	S3	46	1.52	19.9	1.55	Normal
4	S4	55	1.53	23.5	1.67	Normal

5	S5	52	1.56	21.4	1.63	Normal
6	S6	61	1.6	23.8	1.75	Normal
7	S7	53	1.59	21	1.64	Normal
8	S8	45	1.52	19.5	1.53	Normal
Average		**51.54**	**1.54**	**21.55**	**1.62**	**Normal**

Evaluation of developed mean skin temperature model was carried out in open field conditions while subject performing the farm operations. The study was carried out in CTAE instructional farm in the month of March 2021. The ongoing farm operations i.e. harvesting of green peas and the harvesting of carrot were selected for the evaluation of developed mean skin temperature model.

4.5.2Evaluation of Developed Mean Skin Temperature Model

Measurement of skin temperature was carried out by using the thermocouple SDL-200. Mean skin temperature was calculated by the developed mean skin temperature model as given:

Tsk (Developed MST model) = 0.481 T_{sk} (Left upper chest) +0.169 T_{sk} (Forehead) + 0.091 T_{sk}(Right anterior calf) + 0.078 T_{sk} (Right forearm) + 0.176 T_{sk} (Right anterior thigh)

The skin temperature was recorded for the skin sites Forehead, Right thigh, Right forearm, and left upper chest by the selected sites from developed mean skin temperature model. Calculated mean skin temperature by the developed mean skin temperature model is shown in table4.25

Table 4.25 Mean skin temperature measured at field while subject performing the field operations.

S. No.	**Subject Code**	**Measured Mean skin temperature by developed mean skin temperature model, ˚C.**
1	S1	33.10
2	S2	33.12
3	S3	33.81
4	S4	34.07
5	S5	33.54
6	S6	34.4
7	S7	33.3
8	S8	34.36

Mean skin temperature were recorded for the subjects while subjects performing the harvesting of green peas and harvesting of carrots at CTAE farm.

Skin temperature behaviour varies according to the type of exercise, intensity, duration, muscle mass and subcutaneous fat layer. As, in the present study, while evaluating the developed mean skin temperature model in the open field conditions, the observations were taken in heat stress conditions. According to the ACGIH WBGT 28˚C falls under heat stress conditions. Many complex factors are related to the heat exchange phenomena between human body and environment. Nag et al. 1980 studied on effective heat load in agricultural workers in summer. They calculated the mean skin temperature for the rest, light and moderate type of work for the WBGT 30˚ and 31˚C and quoted the mean skin temperature for rest, light and moderate type of work were 33.2˚, 33.2˚ and 33.9˚C respectively. i.e. skin temperature was more or less constant.

CHAPTER V

SUMMARY AND CONCLUSION

Skin temperature is said to be one of the indices useful for estimating thermal environments. The skin temperature, which is closely related to the thermal sensation, is a physiological value regulated by both the conditions of man and his work environment. Mean skin temperature is a physiological parameter of interest for the evaluation of thermal comfort and heat stress in working human being. Human thermal comfort is defined as being "that condition of mind in which satisfaction is expressed with the thermal environment".

Many methods and calculation formulae for calculating mean skin temperature have been developed incorporating body points from one to fifteen local skin temperatures. Values of mean skin temperature are obtained by summing the products of local skin temperatures and the corresponding weighting factors. Up to now, many mean skin temperature calculation methods have been formulated from the field of physiology, which are separated by the number of skin temperature sites and weighting factors. The true mean skin temperature (T_{sk}) will be measured only by obtaining an infinite number of measuring sites of temperature on the skin. However, it is virtually impossible to determine the skin temperatures over the entire surface of the body. Therefore, T_{sk} estimates are generally limited to a finite number of skin temperatures and their corresponding weighting factors. The T_{sk} can be estimated by the following general formula: $T_{sk} = f1 \cdot T1 + f2 \cdot T2 + \ldots + fn \cdot Tn$, where $T1$, $T2$, …, Tn are local skin temperatures, and $f1$, $f2$, …, fn are corresponding weighting factors. Since the 1930s many formulae with various numbers of skin temperature sites have been proposed, (Burton 1934; Crawshaw et al. 1975; Gagge and Nishi 1977; Hardy and DuBois 1938; Mitchell and Wyndham 1969; Nadel et al. 1973; Ramanathan 1964; Teichner 1958; and Winslow et al.1936).

Agriculture is of paramount importance in most developing countries because of large proportion of the population's dependence and concern of national food security. This is of particular relevance because many agricultural tasks in developing countries demand high levels of labour input. Even with mechanization in developing country like India there is still need of human workforce for agricultural activity.Women workers contribute significantly in agricultural activity as compared to men. Besides their household work they are also involved in agricultural activity like weeding, transplanting, harvesting and threshing. There is significant role of farm workers in the country's agriculture and due attention needs to be given to their capabilities and limitations during design and operation of various farm equipment so as to get higher productivity, enhanced comfort and better safety.

For India, very few researchers have developed the mean skin temperature calculation model for Indian subjects, for general population, there is no specific mean skin temperature model available for farm workers or no model is available from the field of agriculture. There is no specific mean skin temperature model is available for Indian farm women, however they play a major role in Indian agriculture. As mean skin temperature is the key parameter while measuring the heat stress while working in the agricultural field, the mean skin temperature model development is necessary for Indian farm women while assessing the heat stress. Keeping this in view the research work is conducted on Indian farm women workers to develop the mean skin temperature model by considering the Indian physiological data. Aim of the study was to develop the mean skin temperature model for Indian farm women. The attempt was made to develop the mean skin temperature model with fewer points which gives the best estimation of mean skin temperature.

Before conducting the study, selection of subjects and the selection of models were done. Measurement of skin temperature was carried out in controlled environmental chamber. The assessment of environmental heat on human skin temperature was carried out in controlled environmental chamber. Twelve female subjects and the thirty three skin temperature measurement sites were selected. Body sites were selected on the basis of eight selected existing mean skin temperature model and fifteen point area weighted reference mean skin temperature model.

Initially, controlled environmental chamber for measurement of skin temperature was prepared. Windows and doors of the controlled environmental chamber were sealed in such way that no direct sunlight, air entered in it. Temperature, humidity and radiations were regulated inside the controlled environmental chamber by using the oil based heat convector, room humidifier, room dehumidifier and by using the incandescent lamp. Measurement of skin temperature was carried out inside the controlled environmental chamber. WBGT conditions of24˚C, 26˚C, 28˚C, 30˚C and 32˚C were simulated for the study inside the controlled environmental chamber simulation of temperature, humidity and radiations were carried out for regulating the required WBGT temperature inside the controlled environmental chamber at least for one hour.

Assessment of environmental heat on human skin temperature was carried out inside the controlled chamber with simulated WBGT conditions 24˚C, 26˚C, 28˚C, 30˚C and 32˚C. Twelve female subjects were selected for the study. Each subject's data was recorded. Response of skin temperature due to the increase in WBGT was observed at each WBGT. From the above study it was found that, the active body parts of human like muscles, chest, abdomen showed slightly higher temperature at WBGT 24˚C, and 26˚C, while the protruding parts like legs, forearm, fingers shows the lower temperature at WBGT 24˚C, and 26˚C. For WBGT 24˚C, and 26˚C, forehead temperature showed higher temperature. At the selected WBGT 28˚C, 30˚C and 32˚C falls under heat stress conditions (ACGIH,) and due to the increase in WBGT the human body parts like forehead, thighs and abdomen showed the decrease in temperature through the sweating while protruding parts like forearm, legs showed higher temperature. From the above study it was observed that, the body regulates its own temperature due to the thermoregulatory system of the body. Human body has its tendency to maintain the thermal comfort. When the environmental heat increases, sweating takes place to maintain the body temperature, while environmental heat decreases shivering takes place by human body to regulate the temperature.

After assessment of environmental heat on human skin temperature, evaluation of selected existing mean skin temperature models in Indian conditions were carried out. Twelve female subjects were selected for the study. The evaluation of existing mean skin temperature model was carried out to find the suitability of existing mean skin temperature model for Indian conditions. From the study, it was concluded that, the existing seven point Hardy and DuBois model was found suitable for Indian conditions and recommended as a best fit existing mean skin temperature model among the eight selected existing mean skin temperature models.

Further, development of mean skin temperature model for Indian farm women was carried out. Mean skin temperature model with five point was developed for the Indian farm women. Selection of human body parts in the development of mean skin temperature model was based on the two main criteria, first on the basis of higher weightages of human body parts, secondly the body parts which were highly susceptible while performing the agricultural operations were considerated. The weighting coefficients for the developed model based on the surface area ratio were calculated. Segmental weight of the body sites were calculated using regression equations given by the (Sen, et al., 1976) for the Indian subjects. Segmental body surface area was calculated by Meeh constant (1879). Based on the segmental body surface area and total body surface area of the Indian subjects weighting coefficients were calculated for the Indian subjects. For Indian subjects trunk, head, and thigh weights higher i.e 58.2 per cent, 9 per cent and 6.8 per cent (Sen, et al. 1976). So these body parts were considered while developing the model. Weighting coefficients were calculated and new model was developed for the Indian farm women given below

T_{sk} = 0.481 T_{sk} (Left upper chest) +0.169 T_{sk} (Forehead) + 0.091 T_{sk}(Right anterior calf) + 0.078 T_{sk} (Right forearm) + 0.176 T_{sk} (Right anterior thigh).

After the development of the mean skin temperature model for the Indian farm women, validation of developed model was carried out in controlled chamber for all selected WBGT with ten female subjects. The developed model was validated with the fifteen point reference mean skin temperature model. The statistical significance between the developed and reference mean skin temperature model showed that the developed model validated successfully.

Field evaluation of developed mean skin temperature was also carried out at CTAE Udaipur farm. Mean skin temperature was recorded with eight female subject while performing the agricultural activities i.e. harvesting of carrots and harvesting of green peas.

The results obtained at various stages of the investigation are summarised as follows:

1) Assessment of environmental heat on human skin temperature at different simulated WBGT it was observed that, few body sites like forehead, thigh, and abdomen showed the decrease in skin temperature with the increase in WBGT, while other showed the increase in skin temperature with increase in WBGT.
2) Amongst the selected existing mean skin temperature model for Indian farm women, it was concluded that Hardy and DuBois seven point mean skin temperature model was best fit for Indian farm women and recommended for Indian farm women.
3) Based on the body weightages and thermo susceptible body parts five point mean skin temperature model was developed for Indian farm women.

4) Linear correlation was found between the developed mean skin temperature model and reference mean skin temperature model with a higher degree of correlation.
5) Developed mean skin temperature model was validated with the Burton's three point model, Palmes and park six point model, Hardy and DuBois seven point model and ISO four point model and linear correlation was found between all of them with the higher degree of R^2 value 0.993,0.987,0.989 and 0.998.
6) Developed and validated mean skin temperature model was evaluated in open field conditions and recorded the mean skin temperature.

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ABSTRACT

Skin temperature is said to be one of the indices useful for estimating thermal environments. The skin temperature, which is closely related to the thermal sensation, is a physiological value regulated by both the conditions of man and his working environment. Mean skin temperature is an important physiological parameter reflecting the human response to heat. For India, very few researchers have developed the mean skin temperature calculation model for Indian subjects, and they have developed the model for general population. There is no specific mean skin temperature model available for farm workers in general and farm women in particular though play the major role in Indian agriculture. The mean skin temperature is the key parameter for measuring the heat stress while working in the agricultural field. The mean skin temperature model development is necessary for Indian farm women for assessing the heat stress. Keeping this in view the research work was conducted on Indian farm women workers to develop the mean skin temperature model by considering the Indian farm women data. The attempt was made to develop the mean skin temperature model with fewer points which gives the best estimation of mean skin temperature. Environmental chamber was prepared for measurement of skin temperature in controlled environmental condition. Twelve female subjects and the thirty two skin temperature measurement sites were selected for assessment of environmental heat on skin temperature.

The response of skin temperature site with increase in WBGT was observed. Some skin sites like thigh and abdomen showed the drop in skin temperature with the increase in WBGT. The higher fat content of the thigh and abdomen provides the cooling effect by sweating with increase in WBGT. Forehead showed the drop in skin temperature with the increase in WBGT. Flat body surfaces showed the lower fat content and lower cooling effect with increase in temperature. With increase in temperature, certain body sites of human body like thigh, abdomen and forehead allows sweating to maintain the proper thermoregulation of the human body.

Evaluation of selected eight existing mean skin temperature models in Indian conditions were carried out in controlled environmental conditions of temperature and humidity. The selected models were evaluated statistically. The Hardy DuBois seven point model was found best for the Indian farm women.

Body sites for the development of the mean skin temperature model were selected on the basis of weightages i.e. the body site having higher percentages of total body weight and

thermal susceptibility. Body sites of left upper chest, forehead, right anterior calf, right forearm, and right posterior thigh were selected for the development of mean skin temperature model.

Validation of developed mean skin temperature model was carried out in controlled environmental chamber at simulated WBGT conditions. The developed mean skin temperature model was validated with the reference mean skin temperature model. By analyzing the data statistically, significant results were obtained between the developed and reference mean skin temperature model. Linear regression was observed with higher degree of R^2 between the developed mean skin temperature model and reference mean skin temperature model.

Evaluation of developed mean skin temperature model was carried out in open field conditions while subject performing the farm operations. Mean skin temperature was calculated by the developed five point mean skin temperature model. The skin temperature was recorded for the skin sites forehead, right anterior thigh, right forearm, and left upper chest by the selected sites from developed mean skin temperature model. Eight female subjects were selected for the study. Mean skin temperature was recorded for the subjects while subjects performing the field operations like harvesting of green peas and harvesting of carrots at CTAE farm**.**

अनुक्षेपण

त्वचा का तापमान तापीय वातावरण का आंकलन करने के लिये उपयोगी सूचकांकों में से एक है। त्वचा का तापमान, जिसका सनसनी से निकट से सम्बन्ध है, एक शारीरिक मूल्य है जो मनुष्य और उसके काम के माहौल दोनों की स्थितियों से नियंत्रित होता है। त्वचा का ओसत तापमान एक महत्वपूर्ण शारीरिक पैरामीटर है जो ताप के प्रति मानवीय प्रतिक्रिया को दर्शाने के लिये है। भारत के लिए, बहुत कम शोधकर्ताओं ने भारतीय विषयों के लिए औसत त्वचा तापमान गणना प्रतिरूपण विकसित किया गया है, जिसके सामान्य जनसंख्या के लिए प्रतिरूपण विकसित किया है। सामान्य रूप से कृषि श्रमिकों और विशेष रूप से खेतिहर महिलाओं के लिए कोई विशिष्ट औसत त्वचा तापमान प्रतिरूपण उपलब्ध नहीं है, हालांकि उनकी भारतीय कृषि में प्रमुख भूमिका हैं।

कृषि क्षेत्र में काम करते समय तापीय तनाव को मापने के लिए औसत त्वचा का तापमान प्रमुख पैरामीटर है। गर्मी के तनाव का आकलन करने के लिए भारतीय कृषि महिलाओं के लिए औसत त्वचा तापमान प्रतिरूपण का विकास आवश्यक है। इसे ध्यान में रखते हुए, भारतीय कृषि महिला श्रमिकों के आंकड़ों पर विचार करके औसत त्वचा तापमान प्रतिरूपण विकसित करने के लिए भारतीय कृषि महिला श्रमिकों पर शोध कार्य किया गया। औसत त्वचा तापमान प्रतिरूपण को कम बिंदुओं के साथ विकसित करने का प्रयास किया गया जो औसत त्वचा तापमान का सबसे अच्छा अनुमान देता है। नियंत्रित पर्यावरणीय स्थिति में त्वचा के तापमान को मापने के लिए पर्यावरण कक्ष तैयार किया गया था। त्वचा के तापमान पर पर्यावरणीय ताप के आकलन के लिए बारह महिलाओं और बत्तीस त्वचा तापमान माप स्थलों का चयन किया गया था।

डब्ल्यू. बी. जी. टी. में वृद्धि के साथ त्वचा के तापमान स्थल की प्रतिक्रिया देखी गई। जांघ और पेट जैसी कुछ त्वचा स्थलों ने डब्ल्यू. बी. जी. टी. में वृद्धि के साथ त्वचा के तापमान में गिरावट दिखाई। डब्ल्यूबीजीटी में वृद्धि के साथ जांघ और पेट की उच्च वसा सामग्री पसीने से शीतलन प्रभाव प्रदान करती है। डब्ल्यू. बी. जी. टी. में वृद्धि के साथ ललाट ने त्वचा के तापमान में गिरावट दिखाई। सपाट शरीर की सतहों ने तापमान में वृद्धि के साथ वसा की कम मात्रा और कम शीतलन प्रभाव दिखाया। तापमान में वृद्धि के साथ, मानव शरीर के कुछ शरीर स्थल जैसे

जांघ, पेट और ललाट मानव शरीर के उचित तापमान को बनाए रखने के लिए पसीने निकालते हैं।

भारतीय स्थितियों में चयनित आठ मौजूदा औसत त्वचा तापमान प्रतिरूपण का मूल्यांकन तापमान और आर्द्रता की नियंत्रित पर्यावरणीय परिस्थितियों में किया गया था। चयनित मॉडलों का सांख्यिकीय रूप से मूल्यांकन किया गया था। हार्डी डुबोइस सात बिंदु प्रतिरूपण को भारतीय कृषि महिलाओं के लिए सबसे अच्छा पाया गया।

औसत त्वचा तापमान प्रतिरूपण के विकास के लिए शारीरिक स्थलों का चयन महत्त्व के आधार पर किया गया था, यानी कुल शरीर के वजन और थर्मल संवेदनशीलता के उच्च प्रतिशत वाले शरीर स्थल। औसत त्वचा तापमान प्रतिरूपण के विकास के लिए बाएं ऊपरी छाती, ललाट, दाहिनी पूर्वकाल पिंडली, दाहिनी बांह की कलाई और दाहिनी पिछली जांघ शारीरिक स्थलों का चयन किया गया।

बनावटी डब्ल्यू. बी. जी. टी. स्थितियों में नियंत्रित पर्यावरण कक्ष में विकसित औसत त्वचा तापमान प्रतिरूपण का सत्यापन किया गया। विकसित औसत त्वचा तापमान प्रतिरूपण को संदर्भ माध्य त्वचा तापमान प्रतिरूपण के साथ मान्य किया गया। सांख्यिकीय रूप से डेटा का विश्लेषण करके, विकसित और संदर्भ माध्य त्वचा तापमान प्रतिरूपण के बीच महत्वपूर्ण परिणाम प्राप्त किए गए। विकसित औसत त्वचा तापमान प्रतिरूपण और संदर्भ औसत त्वचा तापमान प्रतिरूपण के बीच उच्च डिग्री के साथ रैखिक प्रतिगमन देखा गया।

विकसित औसत त्वचा तापमान प्रतिरुपण का मूल्यांकन खुले प्रक्षेत्र की स्थितियों में किया गया था, जबकी विषय प्रक्षेत्र कार्य कर रहा था। विकसित पांच बिन्दु औसत त्वचा तापमान प्रतिरुपण द्वारा औसत त्वचा तापमान की गई। त्वचा के तापमान को विकसित औसत त्वचा तापमान प्रतिरूपण से चयनित स्थलों द्वारा ललाट, दाहिनी जांघ, दाहिनी बांह की कलाई और बाएं ऊपरी छाती के लिए दर्ज किया गया था। अध्ययन के लिए आठ महिला विषयों का चयन किया गया। सी.टी.ए.ई. फार्म में हरी मटर की कटाई और गाजर उन्मूलन जैसे क्षेत्र संचालन करते समय विषयों के लिए औसत त्वचा का तापमान दर्ज किया गया।

APPENDIX-A

INSTITUTIONAL ETHICAL COMMITTEE FOR HUMAN RESEARCH

Maharana Pratap University of Agriculture and Technology

Udaipur, Rajasthan

Ref. No. CCAS/AICRP/FN/2020/10-13 Date: 07:03:2020

ETHICAL COMMITTEE CERTIFICATE

TO WHOM IT MAY CONCERN

This is to certify that a clinical trial entitled "DEVELOPMENT OF MEAN SKIN TEMPERATURE MODEL FOR INDIAN FARM WOMEN" is going to be started in this institution by Miss Kavitkar Chhaya Ragho, Ph.D. Research Scholar, Department of Farm Machinery and Power Engineering, College of Technology and Engineering. This project was presented before the Institutional Ethical Committee for Human Research and there is no objection to conduct this work. The project is approved by the committee.

Dr. Vishakha Singh
Member Secretary
MPUAT, Udaipur, Rajasthan

Dr. S. K. Sharma
Chairman
MPUAT, Udaipur, Rajasthan

APPENDIX-B

Mean skin temperature by selected existing mean skin temperature models at WBGT 24 ˚C

B1 Mean skin temperature by Burton three Point model and Reference 15 point mean skin temperature model

Burton three Point model		**Reference 15 point mean skin temperature model**	
Subject Code	**Mean skin temperature, ˚C**	**Subject Code**	**Mean skin temperature, ˚C**
S1	31.47	S1	31.40
S2	31.57	S2	31.50
S3	31.18	S3	31.24
S4	31.35	S4	31.48
S5	31.51	S5	31.47
S6	31.39	S6	31.46
S7	31.52	S7	31.49
S8	31.37	S8	31.50
S9	31.24	S9	31.46
S10	31.33	S10	31.49
S11	31.43	S11	31.52
S12	31.40	S12	31.55
Average	**31.40**		**31.47**

B2 Mean skin temperature by Teichner six point model and Reference 15 point mean skin temperature model

Teichner six point model		**Reference fifteen point mean skin temperature model**	
Subject code	**Mean skin temperature ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	31.81	S1	31.40
S2	31.71	S2	31.50
S3	31.79	S3	31.24
S4	31.59	S4	31.48
S5	31.55	S5	31.47
S6	31.85	S6	31.46
S7	31.58	S7	31.49
S8	31.55	S8	31.50
S9	31.81	S9	31.46
S10	31.81	S10	31.49
S11	31.77	S11	31.52
S12	31.59	S12	31.55
Average	**31.71**		**31.47**

B3 Mean skin temperature by Hardy and DuBois Seven point model and Reference 15 point mean skin temperature model

Hardy and DuBois Seven point model		**Reference fifteen point mean skin temperature model**	
Subject code	**Mean skin temperature ˚C**	**Subject code**	**Mean skin temperature ˚C**
S1	31.62	S1	31.40
S2	31.89	S2	31.50
S3	31.64	S3	31.24
S4	31.75	S4	31.48
S5	32.02	S5	31.47
S6	31.69	S6	31.46
S7	31.94	S7	31.49
S8	31.77	S8	31.50
S9	31.65	S9	31.46
S10	31.69	S10	31.49
S11	31.75	S11	31.52
S12	31.75	S12	31.55
Average	**31.77**		**31.47**

B4 Mean skin temperature by Palmes and Park six point model and Reference 15 point mean skin temperature model

Palmes and Park six point model		**Reference fifteen point mean skin temperature model**	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	31.75	S1	31.40
S2	31.77	S2	31.50
S3	31.78	S3	31.24
S4	31.49	S4	31.48
S5	31.64	S5	31.47
S6	31.84	S6	31.46
S7	31.55	S7	31.49
S8	31.50	S8	31.50
S9	31.59	S9	31.46
S10	31.77	S10	31.49
S11	31.71	S11	31.52
S12	31.52	S12	31.55
Average	**31.66**		**31.47**

B5Mean skin temperature by Ramanathan four point model and Reference 15 point mean skin temperature model

Ramanathan four point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	31.61	S1	31.40
S2	31.3	S2	31.50
S3	31.24	S3	31.24
S4	31.22	S4	31.48
S5	31.72	S5	31.47
S6	31.58	S6	31.46
S7	31.27	S7	31.49
S8	31.19	S8	31.50
S9	31.27	S9	31.46
S10	31.3	S10	31.49
S11	31.39	S11	31.52
S12	31.28	S12	31.55
Average	**31.36**		**31.47**

B6 Mean skin temperature by ISO four point model and Reference 15 point mean skin temperature model

ISO four point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skint temperature, ˚C**
S1	31.31	S1	31.40
S2	31.58	S2	31.50
S3	31.32	S3	31.24
S4	31.74	S4	31.48
S5	31.88	S5	31.47
S6	31.23	S6	31.46
S7	31.65	S7	31.49
S8	31.67	S8	31.50
S9	31.62	S9	31.46
S10	31.66	S10	31.49
S11	31.62	S11	31.52
S12	31.66	S12	31.55
Average	**31.58**		**31.47**

B7 Mean skin temperature by Nadel seven point model and Reference 15 point mean skin temperature model

Nadel seven point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	31.11	S1	31.40
S2	31.51	S2	31.50
S3	31.08	S3	31.24
S4	31.22	S4	31.48
S5	31.41	S5	31.47
S6	31.33	S6	31.46
S7	31.47	S7	31.49
S8	31.32	S8	31.50
S9	31.21	S9	31.46
S10	31.35	S10	31.49
S11	31.38	S11	31.52
S12	31.35	S12	31.55
Average	**31.32**		**31.47**

B8 Mean skin temperature by Newburgh and Spealman-4 Point model and Reference 15 point mean skin temperature model

Newburgh and Spealman-4 Point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	31.09	S1	31.40
S2	31.24	S2	31.50
S3	30.89	S3	31.24
S4	30.98	S4	31.48
S5	31.17	S5	31.47
S6	31.19	S6	31.46
S7	31.08	S7	31.49
S8	31.03	S8	31.50
S9	31.05	S9	31.46
S10	31.27	S10	31.49
S11	31.26	S11	31.52
S12	31.03	S12	31.55
Average	**31.11**		**31.47**

APPENDIX-C

Mean skin temperature by selected existing mean skin temperature models at WBGT 26˚C

C1 Mean skin temperature by Burton three Point model and Reference 15 point mean skin temperature model

Burton three Point model		**Reference 15 point mean skin temperature model**	
Subject Code	**Mean skin temperature, ˚C**	**Subject Code**	**Mean skin temperature, ˚C**
S1	32.35	S1	32.35
S2	32.47	S2	32.63
S3	32.60	S3	32.69
S4	32.85	S4	32.78
S5	32.76	S5	32.72
S6	32.59	S6	32.59
S7	32.82	S7	32.80
S8	32.62	S8	32.67
S9	32.5	S9	32.68
S10	32.81	S10	32.83
S11	32.70	S11	32.64
S12	32.50	S12	32.55
Average	**32.63**		**32.67**

C2 Mean skin temperature by Teichner six point model and Reference 15 point mean skin temperature model

Teichner six point model		**Reference fifteen point mean skin temperature model**	
Subject code	**Mean skin temperature ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	32.78	S1	32.35
S2	32.89	S2	32.63
S3	33.00	S3	32.69
S4	32.97	S4	32.78
S5	33.02	S5	32.72
S6	32.99	S6	32.59
S7	33.11	S7	32.80
S8	33.11	S8	32.79
S9	32.98	S9	32.68
S10	33.06	S10	32.83
S11	32.94	S11	32.64
S12	32.92	S12	32.55
Average	**32.99**		**32.67**

C3 Mean skin temperature by Hardy Dubois Seven point model and Reference 15 point mean skin temperature model

Hardy Dubois Seven point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature ˚C**	**Subject code**	**Mean skin temperature ˚C**
S1	32.77	S1	32.35
S2	32.82	S2	32.63
S3	33.19	S3	32.69
S4	33.13	S4	32.78
S5	33.22	S5	32.72
S6	32.97	S6	32.59
S7	33.2	S7	32.80
S8	33.22	S8	32.79
S9	33.10	S9	32.68
S10	33.12	S10	32.83
S11	32.95	S11	32.64
S12	33.06	S12	32.55
Average	**33.07**		**32.67**

C4 Mean skin temperature by Palmes and Park six point model and Reference 15 point mean skin temperature model

Palmes and Park six point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	32.65	S1	32.35
S2	32.79	S2	32.63
S3	33.06	S3	32.69
S4	33	S4	32.78
S5	33.1	S5	32.72
S6	33.22	S6	32.59
S7	33.11	S7	32.80
S8	33.17	S8	32.79
S9	32.97	S9	32.68
S10	33.15	S10	32.83
S11	32.98	S11	32.64
S12	32.93	S12	32.55
Average	**33.01**		**32.67**

C5 Mean skin temperature by Ramanathan four point model and Reference 15 point mean skin temperature model

Ramanathan four point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	32.62	S1	32.35
S2	32.74	S2	32.63
S3	32.85	S3	32.69
S4	32.85	S4	32.78
S5	32.97	S5	32.72
S6	32.86	S6	32.59
S7	32.95	S7	32.80
S8	32.84	S8	32.79
S9	32.79	S9	32.68
S10	32.9	S10	32.83
S11	32.82	S11	32.64
S12	32.74	S12	32.55
Average	**32.83**		**32.67**

C6 Mean skin temperature by ISO four point model and Reference 15 point mean skin temperature model

ISO four point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skint temperature, ˚C**
S1	32.52	S1	32.35
S2	32.55	S2	32.63
S3	33.22	S3	32.69
S4	32.88	S4	32.78
S5	32.92	S5	32.72
S6	32.96	S6	32.59
S7	33.04	S7	32.80
S8	33.03	S8	32.79
S9	32.96	S9	32.68
S10	32.88	S10	32.83
S11	33.08	S11	32.64
S12	32.76	S12	32.55
Average	**32.90**		**32.67**

C7 Mean skin temperature by Nadel seven point model and Reference 15 point mean skin temperature model

Nadel seven point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	32.60	S1	32.35
S2	32.60	S2	32.63
S3	32.77	S3	32.69
S4	32.77	S4	32.78
S5	32.79	S5	32.72
S6	32.75	S6	32.59
S7	32.81	S7	32.80
S8	32.86	S8	32.79
S9	32.65	S9	32.68
S10	32.74	S10	32.83
S11	32.76	S11	32.64
S12	32.69	S12	32.55
Average	**32.74**	**Average**	**32.67**

C8 Mean skin temperature by Newburgh and Spealman-4 Point model and Reference 15 point mean skin temperature model

Newburgh and Spealman-4 Point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	32.12	S1	32.35
S2	32.27	S2	32.63
S3	32.28	S3	32.69
S4	32.45	S4	32.78
S5	32.48	S5	32.72
S6	32.39	S6	32.59
S7	32.55	S7	32.80
S8	32.47	S8	32.79
S9	32.27	S9	32.68
S10	32.60	S10	32.83
S11	32.41	S11	32.64
S12	32.27	S12	32.55
Average	**32.18**	**Average**	**32.67**

APPENDIX-D

Mean skin temperature by selected existing mean skin temperature models at WBGT 28˚C

D1 Mean skin temperature by Burton three Point model and Reference 15 point mean skin temperature model

Burton three Point model		Reference 15 point mean skin temperature model	
Subject Code	**Mean skin temperature, ˚C**	**Subject Code**	**Mean skin temperature, ˚C**
S1	34.11	S1	33.70
S2	34.15	S2	33.80
S3	34.21	S3	33.79
S4	34.04	S4	33.71
S5	34.45	S5	33.73
S6	34.30	S6	34.00
S7	34.06	S7	33.90
S8	34.10	S8	33.87
S9	34.17	S9	33.85
S10	34.4	S10	33.95
S11	34.39	S11	33.80
S12	34.52	S12	33.76
Average	**34.25**		**33.83**

D2 Mean skin temperature by Teichner six point model and Reference 15 point mean skin temperature model

Teichner six point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	34.02	S1	33.70
S2	34.23	S2	33.80
S3	34.13	S3	33.79
S4	34.00	S4	33.71
S5	34.13	S5	33.73
S6	34.51	S6	34.00
S7	34.01	S7	33.90
S8	34.04	S8	33.87
S9	34.22	S9	33.85
S10	33.98	S10	33.95
S11	34.05	S11	33.80
S12	34.07	S12	33.76
Average	**34.12**		**33.83**

D3 Mean skin temperature by Hardy and DuBois Seven point model and Reference 15 point mean skin temperature model

Hardy and DuBois Seven point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature ˚C**	**Subject code**	**Mean skin temperature ˚C**
S1	33.86	S1	33.70
S2	33.98	S2	33.80
S3	33.73	S3	33.79
S4	33.53	S4	33.71
S5	33.67	S5	33.73
S6	34.03	S6	34.00
S7	33.94	S7	33.90
S8	33.94	S8	33.87
S9	33.73	S9	33.85
S10	33.88	S10	33.95
S11	33.78	S11	33.80
S12	33.76	S12	33.76
Average	**33.82**		**33.83**

D4 Mean skin temperature by Palmes and Park six point model and Reference 15 point mean skin temperature model

Palmes and Park six point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	34.04	S1	33.70
S2	34.27	S2	33.80
S3	34.14	S3	33.79
S4	34.13	S4	33.71
S5	34.30	S5	33.73
S6	34.55	S6	34.00
S7	34.30	S7	33.90
S8	34.09	S8	33.87
S9	34.14	S9	33.85
S10	34.11	S10	33.95
S11	34.12	S11	33.80
S12	33.99	S12	33.76
Average	**34.19**		**33.83**

D5 Mean skin temperature by Ramanathan four point model and Reference 15 point mean skin temperature model

Ramanathan four point model		**Reference fifteen point mean skin temperature model**	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	34.02	S1	33.70
S2	34.08	S2	33.80
S3	34.22	S3	33.79
S4	34.03	S4	33.71
S5	34.14	S5	33.73
S6	34.3	S6	34.00
S7	34.18	S7	33.90
S8	34.14	S8	33.87
S9	34.06	S9	33.85
S10	34.18	S10	33.95
S11	34.16	S11	33.80
S12	34.17	S12	33.76
Average	**34.14**		**33.83**

D6 Mean skin temperature by ISO four point model and Reference 15 point mean skin temperature model

ISO four point model		**Reference fifteen point mean skin temperature model**	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skint temperature, ˚C**
S1	33.66	S1	33.70
S2	33.90	S2	33.80
S3	33.88	S3	33.79
S4	33.97	S4	33.71
S5	33.76	S5	33.73
S6	34.04	S6	34.00
S7	33.89	S7	33.90
S8	33.84	S8	33.87
S9	34	S9	33.85
S10	34.12	S10	33.95
S11	33.97	S11	33.80
S12	33.76	S12	33.76
Average	**33.90**		**33.83**

D7 Mean skin temperature by Nadel seven point model and Reference 15 point mean skin temperature model

Nadel seven point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	33.77	S1	33.70
S2	33.84	S2	33.80
S3	33.85	S3	33.79
S4	33.38	S4	33.71
S5	33.64	S5	33.73
S6	33.84	S6	34.00
S7	33.76	S7	33.90
S8	33.76	S8	33.87
S9	33.61	S9	33.85
S10	33.74	S10	33.95
S11	33.66	S11	33.80
S12	33.60	S12	33.76
Average	**33.71**		**33.83**

D8 Mean skin temperature by Newburgh and Spealman-4 Point model and Reference 15 point mean skin temperature model

Newburgh and Spealman-4 Point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	33.45	S1	33.70
S2	33.50	S2	33.80
S3	33.71	S3	33.79
S4	33.67	S4	33.71
S5	33.55	S5	33.73
S6	33.63	S6	34.00
S7	33.82	S7	33.90
S8	33.88	S8	33.87
S9	33.51	S9	33.85
S10	33.68	S10	33.95
S11	33.59	S11	33.80
S12	33.45	S12	33.76
Average	**33.63**		**33.83**

APPENDIX-E

Mean skin temperature by selected existing mean skin temperature models at WBGT 30˚C

E1 Mean skin temperature by Burton three Point model and Reference 15 point mean skin temperature model

Burton three Point model		**Reference 15 point mean skin temperature model**	
Subject Code	**Mean skin temperature, ˚C**	**Subject Code**	**Mean skin temperature, ˚C**
S1	35.01	S1	34.69
S2	35.15	S2	34.87
S3	35.27	S3	34.88
S4	35.20	S4	34.81
S5	35.24	S5	34.81
S6	35	S6	34.76
S7	35.57	S7	35.01
S8	35.44	S8	35.01
S9	34.97	S9	35.01
S10	35.35	S10	34.94
S11	35.19	S11	34.77
S12	35.13	S12	34.97
Average	**35.22**		**34.88**

E2 Mean skin temperature by Teichner six point model and Reference 15 point mean skin temperature model

Teichner six point model		**Reference fifteen point mean skin temperature model**	
Subject code	**Mean skin temperature ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	34.72	S1	34.69
S2	34.87	S2	34.87
S3	34.69	S3	34.88
S4	34.68	S4	34.81
S5	34.66	S5	34.81
S6	34.79	S6	34.76
S7	34.74	S7	35.01
S8	34.71	S8	35.01
S9	34.72	S9	35.01
S10	34.70	S10	34.94
S11	34.75	S11	34.77
S12	34.96	S12	34.97
Average	**34.75**	**Average**	**34.88**

E3 Mean skin temperature by Hardy and DuBois Seven point model and Reference 15 point mean skin temperature model

Hardy Dubois Seven point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature ˚C**	**Subject code**	**Mean skin temperature ˚C**
S1	34.25	S1	34.69
S2	34.40	S2	34.87
S3	34.29	S3	34.88
S4	34.14	S4	34.81
S5	34.27	S5	34.81
S6	34.25	S6	34.76
S7	34.50	S7	35.01
S8	34.37	S8	35.01
S9	34.19	S9	35.01
S10	34.24	S10	34.94
S11	34.23	S11	34.77
S12	34.41	S12	34.97
Average	**34.30**		**34.88**

E4 Mean skin temperature by Palmes and Park six point model and Reference 15 point mean skin temperature model

Palmes and Park six point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	34.73	S1	34.69
S2	34.95	S2	34.87
S3	34.75	S3	34.88
S4	34.74	S4	34.81
S5	34.83	S5	34.81
S6	34.66	S6	34.76
S7	34.67	S7	35.01
S8	34.68	S8	35.01
S9	34.68	S9	35.01
S10	34.55	S10	34.94
S11	34.69	S11	34.77
S12	35.07	S12	34.97
Average	**34.76**		**34.88**

E5 Mean skin temperature by Ramanathan four point model and Reference 15 point mean skin temperature model

Ramanathan four point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	34.77	S1	34.69
S2	34.96	S2	34.87
S3	34.97	S3	34.88
S4	34.94	S4	34.81
S5	34.93	S5	34.81
S6	34.85	S6	34.76
S7	35.12	S7	35.01
S8	35.06	S8	35.01
S9	35.04	S9	35.01
S10	35.05	S10	34.94
S11	34.94	S11	34.77
S12	35.11	S12	34.97
Average	**34.98**		**34.88**

E6 Mean skin temperature by ISO four point model and Reference 15 point mean skin temperature model

ISO four point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skint temperature, ˚C**
S1	34.82	S1	34.69
S2	35.04	S2	34.87
S3	34.86	S3	34.88
S4	34.91	S4	34.81
S5	34.86	S5	34.81
S6	35.06	S6	34.76
S7	35.06	S7	35.01
S8	35.15	S8	35.01
S9	34.86	S9	35.01
S10	35.07	S10	34.94
S11	35.01	S11	34.77
S12	34.82	S12	34.97
Average	**34.96**		**34.88**

E7 Mean skin temperature by Nadel seven point model and Reference 15 point mean skin temperature model

Nadel seven point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	34.40	S1	34.69
S2	34.56	S2	34.87
S3	34.51	S3	34.88
S4	34.48	S4	34.81
S5	34.58	S5	34.81
S6	34.41	S6	34.76
S7	34.82	S7	35.01
S8	34.63	S8	35.01
S9	34.66	S9	35.01
S10	34.48	S10	34.94
S11	34.45	S11	34.77
S12	34.51	S12	34.97
Average	**34.55**		**34.88**

E8 Mean skin temperature Newburgh and Spealman-4 Point model and Reference 15 point mean skin temperature model

Newburgh and Spealman-4 Point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	34.56	S1	34.69
S2	34.73	S2	34.87
S3	34.57	S3	34.88
S4	34.58	S4	34.81
S5	34.71	S5	34.81
S6	34.43	S6	34.76
S7	34.84	S7	35.01
S8	34.82	S8	35.01
S9	34.76	S9	35.01
S10	34.64	S10	34.94
S11	34.59	S11	34.77
S12	34.84	S12	34.97
Average	**34.68**		**34.88**

APPENDIX-F

Mean skin temperature by selected existing mean skin temperature models at 32˚C

F1 Mean skin temperature by Burton three Point model and Reference 15 point mean skin temperature model

Burton three Point model		**Reference 15 point mean skin temperature model**	
Subject Code	**Mean skin temperature, ˚C**	**Subject Code**	**Mean skin temperature, ˚C**
S1	36.02	S1	35.46
S2	36.21	S2	35.61
S3	36.42	S3	35.54
S4	36.11	S4	35.45
S5	36.11	S5	35.47
S6	36.26	S6	35.40
S7	36.17	S7	35.53
S8	36.26	S8	35.47
S9	36.28	S9	35.41
S10	36.29	S10	35.47
S11	36.04	S11	35.62
S12	36.24	S12	35.38
Average	**36.20**		**35.49**

F2 Mean skin temperature by Teichner six point model and Reference 15 point mean skin temperature model

Teichner six point model		**Reference fifteen point mean skin temperature model**	
Subject code	**Mean skin temperature ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	35.56	S1	35.46
S2	35.68	S2	35.61
S3	35.69	S3	35.54
S4	35.71	S4	35.45
S5	35.67	S5	35.47
S6	35.68	S6	35.40
S7	35.64	S7	35.53
S8	35.56	S8	35.47
S9	35.64	S9	35.41
S10	35.60	S10	35.47
S11	35.57	S11	35.62
S12	35.55	S12	35.38
Average	**35.63**		**35.49**

F3 Mean skin temperature by Hardy and DuBois Seven point model and Reference 15 point mean skin temperature model

Hardy Dubois Seven point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature ˚C**	**Subject code**	**Mean skin temperature ˚C**
S1	34.82	S1	35.46
S2	34.68	S2	35.61
S3	34.80	S3	35.54
S4	34.82	S4	35.45
S5	34.69	S5	35.47
S6	34.62	S6	35.40
S7	34.85	S7	35.53
S8	34.81	S8	35.47
S9	34.64	S9	35.41
S10	34.65	S10	35.47
S11	34.55	S11	35.62
S12	34.67	S12	35.38
Average	**34.72**		**35.49**

F4 Mean skin temperature by Palmes and Park six point model and Reference 15 point mean skin temperature model

Palmes and Park six point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	35.59	S1	35.46
S2	35.65	S2	35.61
S3	35.67	S3	35.54
S4	35.71	S4	35.45
S5	35.66	S5	35.47
S6	35.65	S6	35.40
S7	35.70	S7	35.53
S8	35.54	S8	35.47
S9	35.54	S9	35.41
S10	35.61	S10	35.47
S11	35.60	S11	35.62
S12	35.53	S12	35.38
Average	**35.63**		**35.49**

F5 Mean skin temperature by Ramanathan four point model and Reference 15 point mean skin temperature model

Ramanathan four point model		**Reference fifteen point mean skin temperature model**	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	35.83	S1	35.46
S2	35.94	S2	35.61
S3	36.05	S3	35.54
S4	35.91	S4	35.45
S5	35.92	S5	35.47
S6	35.94	S6	35.40
S7	35.89	S7	35.53
S8	35.94	S8	35.47
S9	35.86	S9	35.41
S10	35.96	S10	35.47
S11	35.8	S11	35.62
S12	35.83	S12	35.38
Average	**35.91**		**35.49**

F6 Mean skin temperature by ISO four point model and Reference 15 point mean skin temperature model

ISO four point model		**Reference fifteen point mean skin temperature model**	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	35.53	S1	35.53
S2	34.99	S2	34.99
S3	35.16	S3	35.16
S4	35.28	S4	35.28
S5	35.74	S5	35.74
S6	35.24	S6	35.24
S7	35.34	S7	35.34
S8	34.87	S8	34.87
S9	35.96	S9	35.96
S10	35.14	S10	35.14
S11	35.18	S11	35.18
S12	34.79	S12	34.79
Average	**35.27**		**35.49**

F7 Mean skin temperature by Nadel seven point model and Reference 15 point mean skin temperature model

Nadel seven point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	35.17	S1	35.46
S2	35.24	S2	35.61
S3	35.43	S3	35.54
S4	35.22	S4	35.45
S5	35.18	S5	35.47
S6	35.37	S6	35.40
S7	35.45	S7	35.53
S8	35.38	S8	35.47
S9	35.17	S9	35.41
S10	35.37	S10	35.47
S11	35.12	S11	35.62
S12	35.20	S12	35.38
Average	**35.28**		**35.49**

F8 Mean skin temperature by Newburgh and Spealman-4 Point model and Reference 15 point mean skin temperature model

Newburgh and Spealman-4 Point model		Reference fifteen point mean skin temperature model	
Subject code	**Mean skin temperature, ˚C**	**Subject code**	**Mean skin temperature, ˚C**
S1	35.59	S1	35.46
S2	35.67	S2	35.61
S3	35.80	S3	35.54
S4	35.52	S4	35.45
S5	35.70	S5	35.47
S6	35.54	S6	35.40
S7	35.58	S7	35.53
S8	35.57	S8	35.47
S9	35.50	S9	35.41
S10	35.61	S10	35.47
S11	35.60	S11	35.62
S12	35.44	S12	35.38
Average	**35.60**		**35.49**

Appendix- G

G1 Core body temperature of subject while performing field operations.

S. No.	Subject code	Core body temperature, ˚F
1	S1	95.6
2	S2	94.6
3	S3	97.4
4	S4	95.8
5	S5	96.1
6	S6	96.3
7	S7	96.7
8	S8	95.3
Average		**95.97**

G2 Blood pressure of subject while performing field operations.

S. No.	Subject code	Systolic blood pressure	Diastolic blood pressure
1	S1	130	70
2	S2	120	80
3	S3	98	70
4	S4	110	80
5	S5	130	70
6	S6	120	80
7	S7	120	80
8	S8	100	80
Average		**116**	**76.25**

Appendix-H

H1 Subject's heart rate during the evaluation of developed mean skin temperature model

S.No	Time	S1	S2	S3	S4	S5	S6	S7	S8
1	0:00:00	81	71	92	76	78	82	75	79
2	0:01:00	79	71	92	73	76	79	73	76
3	0:02:00	82	83	93	77	74	83	72	73
4	0:03:00	86	74	84	76	76	85	74	71
5	0:04:00	83	78	78	74	73	79	76	76
6	0:05:00	81	84	76	73	78	78	78	78
7	0:06:00	85	77	74	72	73	76	86	76
8	0:07:00	90	78	76	74	75	73	85	71
9	0:08:00	96	82	88	71	76	78	79	73
10	0:09:00	88	77	85	75	79	83	83	75
11	0:10:00	90	79	88	78	82	86	86	81
12	0:11:00	94	81	90	79	86	87	95	87
13	0:12:00	98	87	92	85	88	89	98	89
14	0:13:00	101	89	95	82	92	92	101	95
15	0:14:00	109	95	98	84	94	95	105	99
16	0:15:00	111	99	101	88	98	98	111	112
17	0:16:00	116	112	105	91	101	101	112	116
18	0:17:00	118	116	110	95	105	106	117	113
19	0:18:00	110	119	112	99	109	111	116	112
20	0:19:00	101	112	119	100	112	109	109	105
21	0:20:00	98	109	116	106	116	105	102	103
22	0:21:00	92	99	111	109	119	100	95	100
23	0:22:00	95	101	102	110	117	98	91	96
24	0:23:00	92	100	105	106	112	96	96	93
25	0:24:00	96	98	101	109	109	93	93	89
26	0:25:00	91	96	98	103	104	91	88	91
27	0:26:00	83	90	96	100	98	96	84	90
28	0:27:00	84	88	94	99	95	90	83	88
29	0:28:00	83	87	93	95	93	88	81	83
30	0:29:00	81	86	89	96	89	83	76	81
31	0:30:00	78	84	88	95	86	81	74	79
32	0:31:00	74	80	82	90	83	79	73	78
Working HR		**100.86**	**98.333**	**101.93**	**92.46**	**100.66**	**97.06**	**101.13**	**98.4**
Resting HR		**84.26**	**83.09**	**88.14**	**86.18**	**85.03**	**83.42**	**79.52**	**79.82**