Thermal human body behavior analyze during cycling movements

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Abstract: - This paper presents some considerations about thermal behavior for human body during working cycling movements and evaluation analyze of these implications in working abilities for different people. In the first part of the paper it is presented a dynamic model predicting human thermal responses in cold, cool, neutral, worm and hot environment conditions to understand the influences of these perceptions in different parts of human body. The methodology and the investigations procedure are presented in the second part of the paper and in the final part it is presented the results and the conclusions of this work.

Key-Words: - Thermal behavior, movement, human body, force plate.

1 Introduction

In the past time a lot of multi-segmental mathematical models of human thermo-regulation systems have been developed and they became an important mechanism in the design of different working places or automotive seats, or only to understand the thermal regulatory processes of human body in environment. These models allow to only predicting the abilities, the limited range of applicability and the modeling the heat exchange between human body and the inside or outside environment.

Analyzing the human body from mathematical point of view it can establish there are two systems, interacting in thermo-regulation process: active system and passive system, both of them controlled by the central neuro-motor unit. Each of these systems are simulated by different models but the final answers are interconnected and allow to control and to improve the heat transfer between human body and the environment.

There are some cybernetic models predicting the regulatory responses that allow simulating the active system and also there are different phenomena for heat-transfer modeling the physical human body interfaces with the environmental conditions.

In complete analyzes of human body heat transfer it is very important to use both actions: active and passive systems because only in these assembly it will be possible to optimize the comfort and the thermal behavior to obtain maximum responses from human body.

2 Thermal human body behavior analyze

Compare the human bipedal position with a quadruped animal it can be possible to understand the thermal adaptation phenomena like a possibility to regulate the temperature inside the human body, because an upright posture has 40% less body surface exposed to heat from the sun than an animal with four legs and also the same upright body puts its head in cooler air or in a position with more air movements.

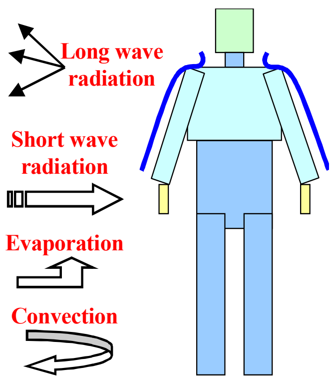

Fig.1.

The regulatory process is affected by the skin thickness (dead skin cells on the skin surface in different positions), the number and distribution of the specific thermal receptors, but also by the body heat flow and human body radiation, convection, conduction, evaporation. In the same time a big contribution in thermo regulatory system of human body have the sweat glands with the sweating

process, in hot environment and also the shivering process for cold environment.
The metabolic heat is produced in the human body, distributed by conduction and carried by blood in sanguine vessel to the body surface.
In this way the heat is isolated by clothing and is lost by convection, radiation, respiration or evaporation.
In this moment it is necessary to know the properties of tissue materials, the physiological parameters of the people and also it takes in account the anthropometric and anatomic characteristics of human body.

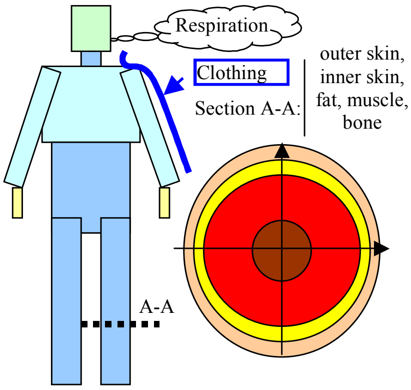

Fig.2.

In this model of the thermal human body analyze it was establishing the initial conditions about skin temperature distribution, body heat flow, warm/cold spot distribution thermal sensation, thermal adaptation, heat balance and loss mechanism, human body radiation by different processes, sweating and shivering mechanism etc.
For a person standing 30 minutes in a cold room at 11^0C, the skin temperature distribution is measured and observed that the warmest surfaces are on the head-face, abdomen and spine.
In the same time, by body heat flow, the human body loss 30% of heat through the head and highest heat flow is in the neck in contrary with the lowest heat flow which is in the feet.
The distribution of thermal sensation depends on skin adaptation, surface, rate of temperature changes and thermal conductivity of the epidermis and skin wetness.
The heat production in the human body depends upon the metabolic rate, muscles produce up to 30% of body heat and some times when the activities are very strong and long duration, the heat output from muscles increase 40 times that from other tissues.
Because there are equilibrium between productions and losing the heat from human body it can be write a heat balance equation:

$$M - W = R + C + E + L + K + S \qquad (1)$$

where: **M** is total energy production rate, calculated from oxygen consumption; **W** is the external work rate; **R** is loss by radiation; **C** is loss by convection (air movement over the body); **E** is loss by evaporation; **L** is warming and wetting of air during inhalation/exhalation; **K** is loss by conduction through skin to surfaces, clothes, chairs,, floor etc.; **S** is the heat storage in the human body
To modeling the human body thermal behavior and to analyze the influences of different working activities on the human body heat radiation it was establishing a simplified equation which calculate the radiant energy gained or lost by the human body:

$$Q_r = aS\left(dT_0^4 - eT^4\right) \qquad (2)$$

where: **a** is a parameter constant of radiation; **S** is the body surface area; **d** is absorption coefficient (dark or light skin); $\mathbf{T_o}$ is temperature of opposing surface; **e** is emission coefficient; **T** is the body surface temperature.
Thermoregulation mechanisms are determined by the thermal indices (up then 30) which are categorized into 3 groups: *direct indices* – based on direct measurements; *rational indices* – based on human responses at thermoregulatory processes and *empirical indices* – based on empirical research results [2].

2.1 Human body thermoregulatory model

In different representations and for analyze the thermal human body behavior it was establish a simplified configuration using simple shape for body parts.
Head is like a sphere, face is like a cylinder, also neck, shoulders, thorax, abdomen, arms, hands, legs, feet are cylinders and blood are fluid into a very long and thin vessel.
At these shapes are attached materials with strength characteristics to obtain a model close to the real configuration – human body.
The heat transport mechanisms occurring in the living tissue have been formulated by *Pennes* [1] in the so-called "bio-heat equation". This differential equation describes the heat dissipation in a homogenous, infinite tissue volume:

$$k\left(\frac{\partial^2 T}{\partial r^2} + \frac{\omega}{r}\frac{\partial T}{\partial r}\right) + q_m + \rho_{bl} w_{bl} c_{bl}\left(T_{art\text{-}bl} - T\right) = \rho c \frac{\partial T}{\partial t} \qquad (3)$$

where: **k** is the tissue conductivity; **T** is the tissue temperature; **r** is radius; **w** is a geometry parameter; $\mathbf{q_m}$ is overlayed by metabolism, $\boldsymbol{\rho_{bl}}$ is density of the blood; $\mathbf{w_{bl}}$ is blood perfusion rate, $\mathbf{T_{art\text{-}bl}}$ is arterial blood temperature and $\mathbf{c_{bl}}$ is the heat capacity of blood; **t** is time, **ρ** is tissue density and **c** is tissue capacity to heat.

With this model and using a simplified human body model it can obtain the configuration of the exchanges between human body heat and environment in thermoregulatory system to assure a comfort of working activities.

2.2 Method and setup configuration

To study the thermal human behavior in cycling movements it was necessary to establish a methodology for investigation and a stable setup configuration also the environmental parameters and information acquisitions.
In the first step was very important to have and to keep a stable environment during the experiments.
To appreciate the way in which the factors of the interior microclimate contribute at the thermal comfort it was necessary to establish the sensorial temperature according with all parameters. In the next equation it is presented an empirical relation used in these experiments to evaluate the sensorial temperature develop into human body:

$$t_{sz} = 0,431 \cdot t_i + 0,408 \cdot t_{mr} + 136,5 \cdot \varphi_i \cdot p_i - 0,328 - 0,141 \cdot (37,8 - t_i) \cdot \sqrt{w} \quad (4)$$

The experimental setup it is presented in the next figures and it contains: a thermovision videocam, a Kistler force plate, computer, ergometer to induce a measured effort state.

Fig.3.

With this configuration of apparatus were simulated different situations to analyze the thermal human body behavior in cycling movements of the hands and legs.
In first stage of the experiments was established and kept the parameters of the laboratory environment. Temperature into laboratory was 25^{0}C, air humidity 80% and atmospheric pressure 755 mmHg.
In the second stage were measured the physiological parameters of the human subjects (weight, high, age, pulse, blood pressure) in relaxed shape, without any health problems, at 9 o'clock in the morning and with a good metabolism (example: blood pressure 155/82 mmHg, pulse 91, face temperature 36,7^{0}C, high 175 cm, weight 80 kg)

All these parameters are necessary to establish a common modeling base to measure and to evaluate the human body thermoregulatory system.

3 Results

In the next figures are presented the recordings of the temperature gradient on the surface of human body wearing cotton coats.

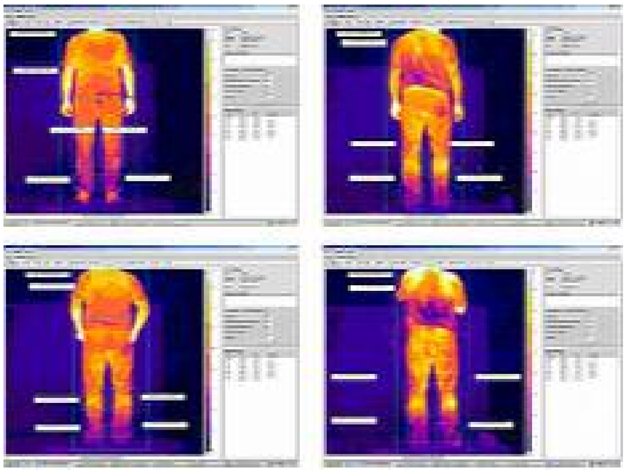

Fig.4.

In these four situations the human subject, wearing cotton coats, have different physiological behavior: relaxed, after a moderate effort (top) and after a great effort in long time and in short time (bottom).
The effort was measured by calorie consumption, from 20 kcal to 80 kcal in the last experiments.
In the same time was measured the temperature in different parts of the feet and the results are presented in the following diagram.

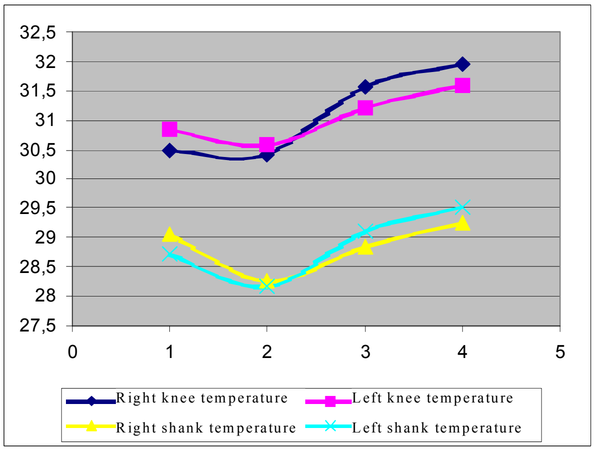

Fig.5.

Analyzing the results of temperature measurements it can be seen that the temperature in relaxed state was bigger then the temperature measured in the moderate effort, because the sweat in this case is bigger that in first moment and the humidity of the coat increase during the effort allowing to the human body to decrease the temperature by thermoregulatory system.

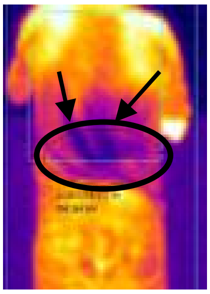

Fig.6.

In the same time was very important to establish a correlation between these relaxed/effort state and thermoregulatory system with stability of human body before, in time and after cycling movements.
For that was made, in the same time with measurement of temperature gradient, recordings with human subject performing cycling movements (10 sec.) using right hand and a weight of two kilos.

Fig.7.

The stability of human body was recorded with a Kistler force plate, a signal amplifier and a computer with two acquisition cards. The human subject standing (small-fig.8. or big-fig.9. support base) on the force plate moves the right hand with a two kilos weight in cycling movements from vertical until horizontal position during 10 sec.

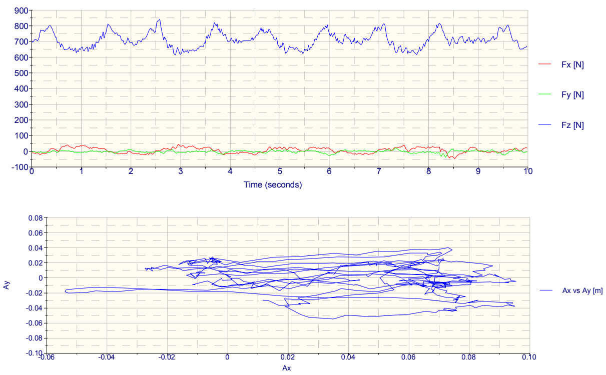

Fig.8.

The force measured on the Oz direction can be analyzed in concordance with the "behavior" of the stability surface - the surface of COM projection on the force plate - during the movements and the position of the feet.

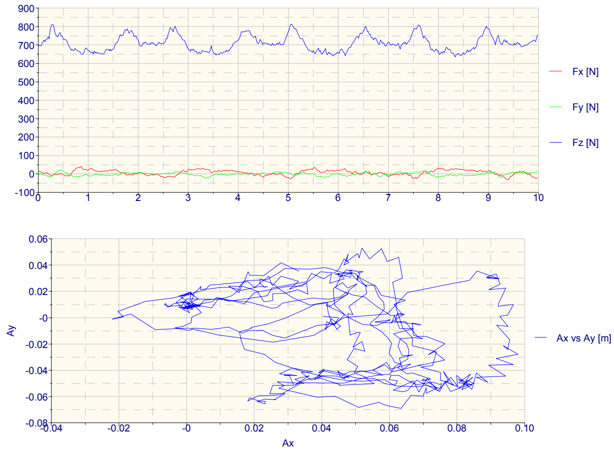

Fig.9.

4 Conclusion

In the graph from following figure are presented the evolution of parameters during these investigations. It can observe that the values of them increase with intensification of physical activities and after the effort finishing the parameters tend to return to normal values.

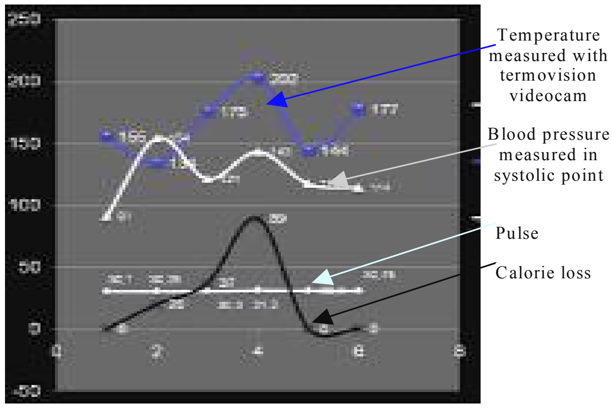

Fig.10.

Also it can observe a total heating of a human body from 27,3 to 27,9^{0}C; at the knee level temperature varies from 30,05 to 31,95^{0}C; at the shank level from 28,27 to 29,22^{0}C. These values confirm the fact that during physical activities the muscles produce 80% of human body heat. Also the shape and the size of stability surface are affected by the temperature gradient in the human body.

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