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Effect of posture on the heat transfer areas of the human body

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Abstract

The purpose of this paper is to measure the heat transfer areas of the human body and to examine the effect of posture on these values, which is necessary data for calculating heat exchange between the human body and its environment. The total surface area of a subject's body was measured directly. Then, the convective heat transfer area, radiative heat transfer area and conductive heat transfer area were measured for the same subject in 9 postures: standing, chair sitting, seiza sitting, cross-legged sitting, sideways sitting, both-knees-erect sitting, legs-out sitting, lateral position and supine. The ratios of the radiative heat transfer area, convective heat transfer area ratio and conductive heat transfer area to body surface area were as follows: Standing, 0.942, 0.773, 0.013; chair sitting, 0.910, 0.732, 0.008; seiza sitting, 0.853, 0.621, 0.013; cross-legged sitting, 0.843, 0.606, 0.029; sideways sitting, 0.877, 0.634, 0.030; both-knees-erect sitting, 0.865, 0.609, 0.023; legs-out sitting, 0.878, 0.686, 0.038; lateral position, 0.879, 0.712, 0.039; and supine, 0.811, 0.708, 0.100. Posture was shown to have a noticeable effect on the heat transfer areas of the human body.

Keywords: Heat transfer area; Posture; Heat exchange; Convection; Radiation; Conduction

1. Introduction

To date, existing research into the effects of the thermal environment on the human body has mainly examined light work performed in an office environment. Most of that research is concerned with the appropriate settings for office air conditioning systems; inevitably, these impose a large number of conditions, including assumptions on the postures adopted by the occupants. In contrast to the passive environment in a laboratory space, however, an active living space environment has a much higher number of degrees of freedom. This means that the inhabitants must use behavioral thermoregulation, which itself can affect the environment. One aspect of this is the variation in rate of heat exchange between the body and the environment when a person changes his posture. In other words, as a matter of course, people in a living space adopt quite a range of postures. The heat exchange conditions posed by different postures needs to be investigated in order to account for postures in the design of living spaces.

The development of computers has enabled designers to move experiments from the realm of actual living spaces to virtual living spaces. However, few virtual space experiments have incorporated the density of postures, or of other variables, that are possible in actual environments. Another desirable and essential development is to express the temperature in terms of the perceived temperature, as well as in terms of the air temperature. However, there are very few simulations, which address perceived temperature with respect to the subject's posture. Perceived temperature is a function of many elements of the thermal environment. That function is based on the heat balance equation, which expresses the heat balance between the human body and

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the surrounding environment. The heat balance equation for the human body is known as the law of heat transfer, but many of the engineering data of the human body included in this law remain to be determined. Experiments with a large number of subjects should be conducted to calculate these thermal quantities. One piece of engineering data that is not incorporated in the design of living spaces is the heat transfer area of the human body. This quantity is affected by the total surface area of the body, the convective heat transfer area, the radiative heat transfer area and the conductive heat transfer area. Usually, the heat quantity used in the heat balance of the human body has been normalized to the total body surface area.

Studies of the total surface area of the human body are divided into actual measurements and calculations. The former make up only a small fraction of the studies.

Many studies have been conducted since Funke's [1] measurements of surface area. Dubois' [2] expression for calculating body surface area has been widely employed. However, Dubois only used 12 subjects for his expression [3,4]. He assumed left-right symmetry and measured only half the body area of some subjects; in others, he compared his results only to measurements of certain body parts.

Fujimoto and Watanabe's [5] equation for calculation of total body surface area has been widely used in Japan. The shape, height and weight of the Japanese body has changed substantially, however, due to changes in eating habits and living situation, and the data on which they based their expression are quite obsolete. Kurazumi et al. [6] compared the results of Dubois' [2] equation for body area with those of Fujimoto et al. [5], those of the expression developed by Kurazumi himself [7], and actual measurements of Japanese people's body areas. They showed that Kurazumi's expression was the most accurate for estimating the changing Japanese body area.

Heat exchange due to conduction comprises a small proportion of the total heat balance of the human body, and so little research has addressed this area.

In contrast to their behavior in office spaces, people often sit or lie in direct contact with the floor in living spaces. Previous research has neglected this contact area between the human body and the floor, assuming it to be a negligibly small fraction of the body surface area and approximating it as radiative heat transfer according to the law of solid angle projection. It has been shown [8,9], however, that heat transfer due to conduction cannot be neglected for certain postures.

Kurazumi et al. [9–15] and Miyamoto et al. [16] published results for the conductive heat transfer area between the floor and the human body. Kurazumi et al. defined the postures (standing, chair sitting, seiza sitting, cross-legged sitting, sideway sitting, both-knees-erect sitting, legs-out sitting, lateral and supine) commonly adopted in living spaces and measured their conductive areas. Miyamoto et al. took measurements for other postures, but did not actually define postures.

There have been very few studies on the convective heat transfer area of the human body, since it is assumed that the entire body must be exposed to air currents and because measurements are difficult. Büttner [17] and Kurazumi et al. [13,14] have suggested specific values.

Büttner [17] estimated a value of 0.80 for the convective heat transfer area ratio (convective heat transfer area/total body surface area) in the supine position. Kurazumi et al. [13,14] defined an effective thermal convection area factor for the heat transfer area ratio, and measured values for this factor for each of the following: standing, chair sitting, seiza sitting, cross-legged sitting, sideways sitting, both-knees-erect sitting, legs-out sitting, lateral position and supine.

Formerly, it was assumed that the entire body is exposed to air currents, but measurements have shown that even in standing or chair sitting postures, much of the area of the body is sheltered from currents.

Research into the radiative heat transfer area of the human body has focused on the effective thermal radiation area.

Bohnencamp and Pasquary's [18] leading study on the effective thermal radiation area of a naked body in standing position is widely cited. However, all these studies combine the heat conducted through the feet into the effective 'radiation' area.

Guilbert and Taylor [19] were the first to study the effective thermal radiation area of the naked human body in a sitting position, and have been referenced by many other researchers. As in the standing case mentioned above, however, contacts with the floor and seat surfaces were handled in terms of the effective thermal radiation area.

Other postures have partly been quantified. Effective thermal radiation areas for the naked body have been found for the seiza sitting position by Kurazumi et al. [11], for the cross-legged sitting position by Miyamoto et al. [20], for the sideways sitting position by Kurazumi et al. [15], for the standing and both-knees-erect sitting positions by Miyamoto et al. [20], for the legs-out sitting position by Kurazumi et al. [15], for the lateral position by Miyamoto et al. [20] and Kurazumi et al. [15], and for the supine position by Kurazumi et al. [15]. However, there were some differences in handling of the heat transfer for contact with the floor, assuming radiation or conduction.

Thus, the heat transfer area of the human body has been investigated through various transfer pathways, but aside from the radiative heat transfer areas proposed for the standing and sitting positions, there has been extremely little research into other postures and heat transfer pathways. In addition, none of the reports provide measurements of the same person in different positions. In order to compare between builds and body types, it is necessary to establish a standard value for the heat transfer area of the human body, but very few studies have made the necessary measurements to quantify this. None have addressed the radiative heat transfer area of the body.