Numerical calculation of angle factor and effective radiation area for humans and animals using hemi-cube method

Shinsuke Watanabe*, Shin-ichi Tanabe

Department of Architecture, Waseda University, Japan

ABSTRACT

Angle factor and effective radiation area are significant for knowing the radiation heat exchange between the occupant and the surrounding planes of the room. Angle factor calculation program of hemi-cube method using 3-dimentional surface data of the object was developed. By comparing the calculation results with the results of previous studies using a numerical integration method, the division number of hemi-cube was determined in a short time with sufficient accuracy. Calculating angle factors using the determined division number of hemi-cube, the errors were almost under 2%, but the errors for the sides closer to the object were somewhat larger. This program using hemi-cube method was applied to 3-dimentional surface data of a horse model.

INDEX TERMS

Angle factor; Effective radiation area; Radiant heat; Hemi-cube method; Animal's model

INTRODUCTION

Angle factor for human body have been studied by various researchers in the past. When calculating the radiant heat exchange between the object and surrounding surfaces, it is necessary to read the value of the angle factor from the diagrams drawn for different rectangular sizes and distances from the object. Recently, not only the photograph method (Fanger *et al.*, 1970), but also computer calculations of various methods using 3-dimensional surface data were utilized for evaluation of angle factors. In this paper, angle factor calculation program using hemi-cube method is developed. It aimed to calculate angle factors for surrounding planes in a short time, with sufficient accuracy. The calculation condition for the hemi-cube method was determined by comparing the calculation results with numerical integration method. This program is able to calculate angle factor for any object with 3-dimensional surface data. The method was applied to animals, which is quite difficult to measure in real life.

ANGLE FACTOR CALCULATION PROGRAM

Angle factors can be generally calculated by a numerical integration method, Monte Carlo method, hemi-sphere method, or hemi-cube method. The algorithm of hemi-cube method is simple for programming, and uses the analytical solutions (not approximated ones) in the code. In this paper, angle factor calculation program was developed using the hemi-cube method. The outline of the hemi-cube method is described in Figure 1.

Calculation Flow

The program uses 3-dimensional surface data of the object divided into a triangular mesh. An imaginary hemi-cube is constructed around the median point of each triangular plane. The hemi-cube is divided with square mesh. The division number of hemi-cube is defined as the division number of vertical axis, and expressed as 'hemi5' when division number is 5 as in Figure 1. Angle factor between the centre point at the bottom of hemi-cube, which corresponds to the median point of triangular plane of the object, and each square plane on hemi-cube surface is calculated in advance. The ray is irradiated from the median point of the triangular plane on the object, to median point of each square plane on hemi-cube surface. If the ray through a square plane of hemi-cube surface reached a surrounding plane, a value is added to individual variable assigned to each surrounding plane. The value corresponds to angle factor between median point of triangular plane and the square

* Corresponding author. E-mail: watanabe@tanabe.arch.waseda.ac.jp

plane multiplied by the area of the triangular plane. For each triangular plane of the object, the ray for each square plane of hemi-cube surface is solved. The sum total of the variables for all surrounding planes enclosing the objects is considered to be the effective radiation area of the object. The angle factor between the object and each surrounding plane is derived by the variable for each surrounding plane by the effective radiation area.

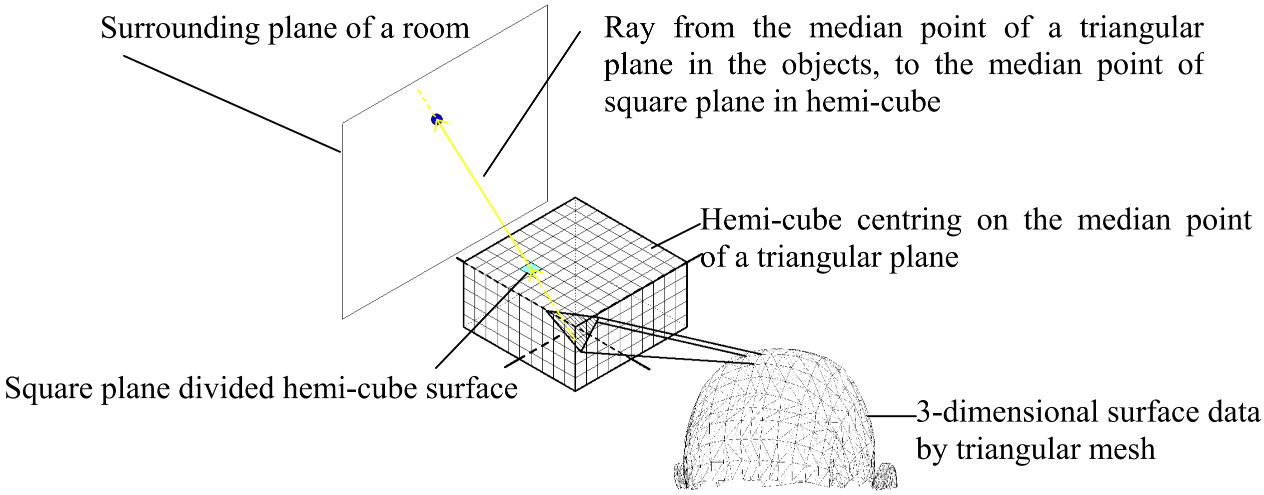


Figure 1 Hemi-cube method.

COMPARISON BY HUMAN BODY MODEL

Method

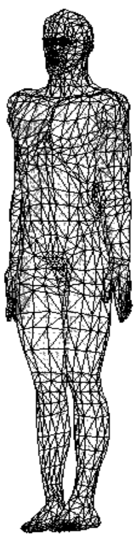
In order to determine the division number of hemi-cube required for sufficient accuracy, the calculation results in various division number of hemi-cube by this program were compared with results of the previous studies using a numerical integration method (Ozeki *et al.*, 1999). The same room condition and 3-dimensional surface data of standing/seated human body model were used. Calculation conditions of six different types of rooms and the object's position are presented in Table 1. Standing and seated human body models are described in Figure 2.

Table 1 Case of room for calculation

Case	Room size(m)			Object position(m)	
	X	Y	Z	X	Y
1	28	28	28	Center	Center
2	14	14	14	Center	Center
3	3.3	3.3	2.5	Center	Center
4	3.3	3.3	2.5	Center	0.6 from front side
5	3.3	3.3	2.5	Center	0.6 from back side
6	3.3	3.3	2.5	0.6 from left side	Center

Standing human body

4396 triangular planes
Height: 1.75m



Seated human body

4396 triangular planes
Height: 1.32m

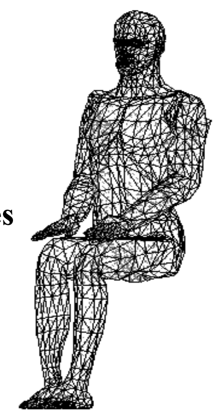


Figure 2 Human body model.

Results

Angle factors for each condition were calculated between standing/seating human body model and Rear/Right/Front/Left/Floor/Ceiling side of the room, with different division number of hemi-cube. The results of the present method for each model and type showed the same tendency as the results by Ozeki *et al.* The comparison of angle factors between the model and each side for standing human body model and Case 3 is described in Figure 3. The division number of hemi-cube was determined to be over 3. Assuming the results of Ozeki et al. as the benchmark, errors for each side were derived in Figure 4. Errors for Rear/Right/Front/Left sides were almost under 2%, and those in Floor/Ceiling side were almost under 4%. When the objects were near to a side, errors tended to be larger.

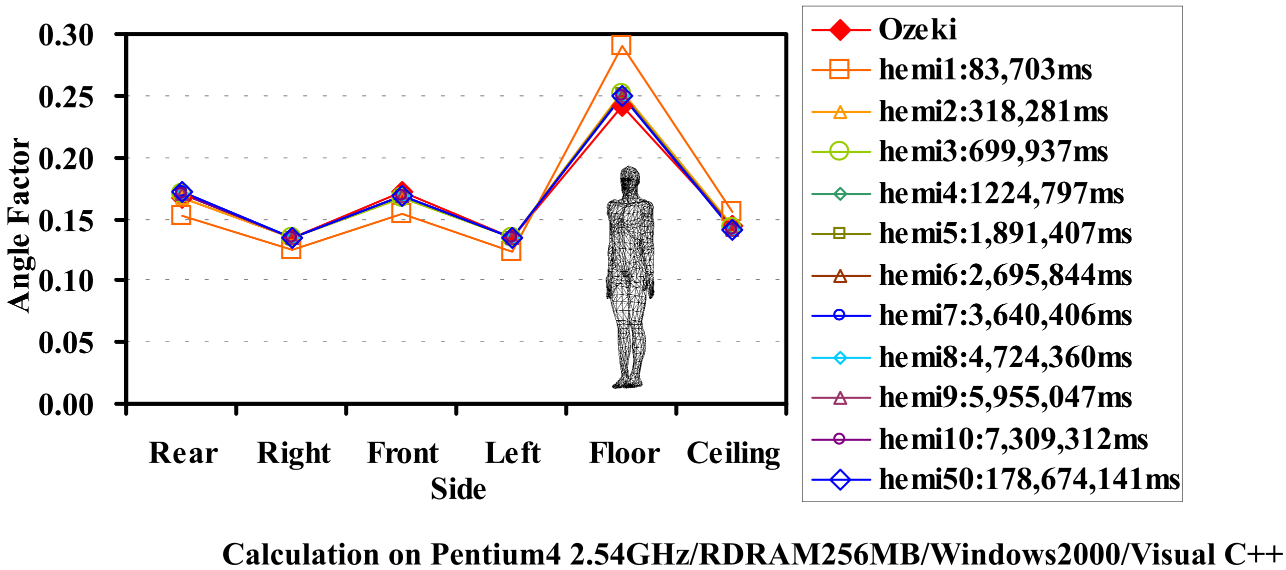


Figure 3 Comparison of angle factor by standing human body model.

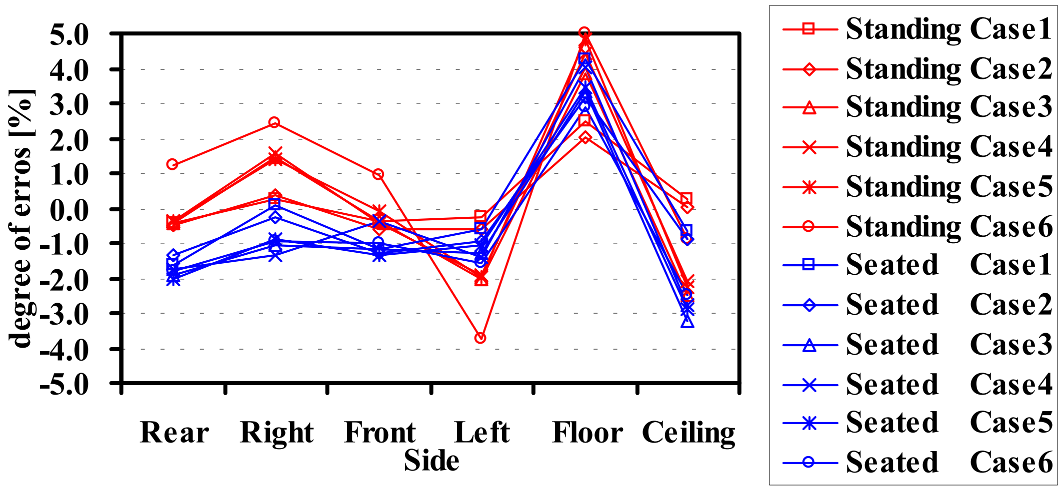


Figure 4 Degree of errors in 'hemi5'.

ANGLE FACTOR CALCULATION USING ANIMAL MODEL

Method

Angle factors of 3-dimensional surface data of a horse model were calculated using division the number of 'hemi5'.

Standing horse body

9608 triangular planes
Height: 2.13m

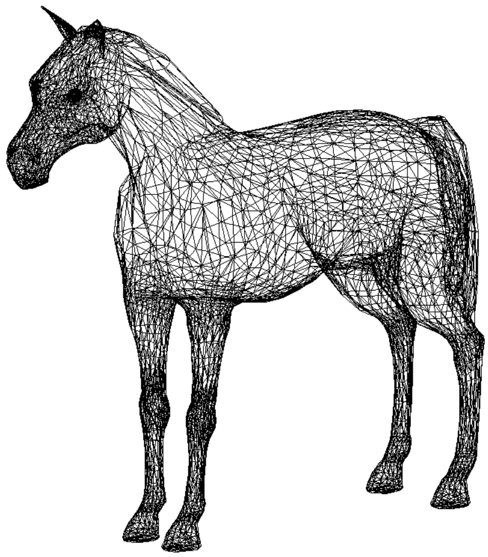


Figure 5 Horse model.

Results

In Figure 6, the calculation results of angle factors between a horse model and each side in Case 1 and 2 is described. The results of a horse model were compared with those of the human body models. The information for horse, standing human body, and seated human body model is presented in Table 2. Angle factors between a horse model and Rear/Right/Front/Left side in Case 1 was larger than that in Case 2 as for human body models. Angle factors between a horse model and Right/Left side were larger than those for Rear/Front side. On the other hand, angle factors for Rear/Front side were larger than that for Right/Left side. The effective radiation area factor of a horse model was larger than that of human body models.

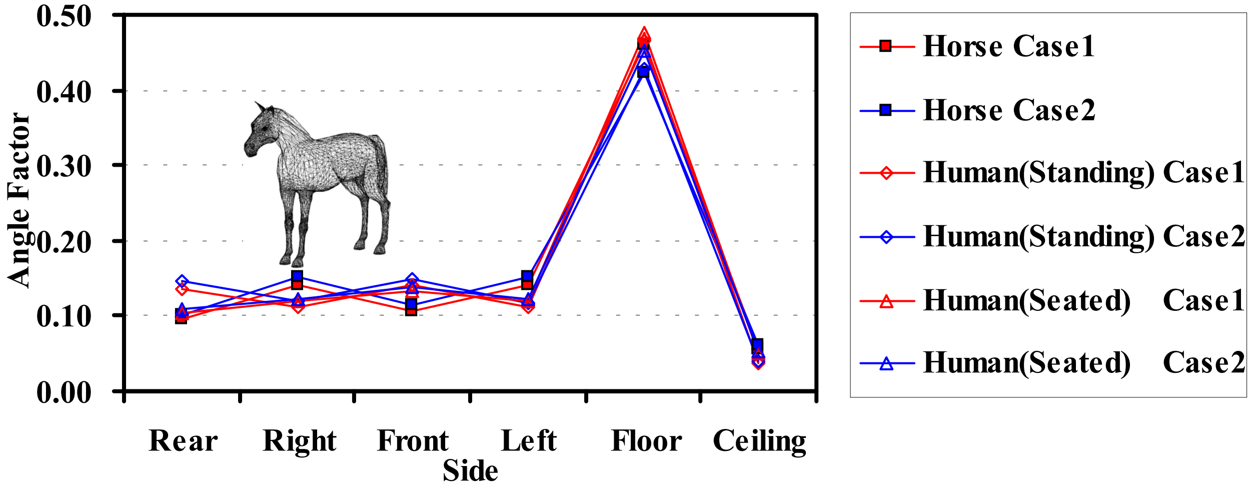


Figure 6 Angle factor by horse model(compared with standing/seating human body).

Table 2 Information of models

	Horse	Human body	
		Standing	Seated
Mesh number	9608	4396	4396
Height(m)	2.13	1.75	1.32
Surface area(m^2)	5.85	1.71	1.70
Effective radiation area(m^2)	5.22	1.29	1.20
Effective radiation area factor	0.89	0.75	0.71

DISCUSSION
The present program using hemi-cube method could calculate angle factors in a short time with sufficient accuracy, over division number of 'hemi3'. When the object and the side were closer, the differences between the calculated results and those of previous studies tended to be large, but the errors were under 4%. Larger division number of hemi-cube is required when the distance between the object and the side is short.

CONCLUSION
An angle factor calculation program was developed using the hemi-cube method. By comparing with the results of the previous studies, the division number of hemi-cube in this program was calculated in a short time with sufficient accuracy. This program was able to calculate angle factor for any object with 3-dimensional surface data. Angle factors between a horse model and Right/Left side were larger than those for Rear/Front side.

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