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SIMULATION OF THERMAL RADIATION DISTRIBUTIONS IN CLASSROOMS OCCUPIED BY STUDENTS

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ABSTRACT

The thermal radiation distributions in several types of classrooms occupied by students were simulated using the VLITE algorithm(1) and a newly proposed "weighted absorption factor (WAF)" that determines the effects of a particular primary surface on seated students.

We determined (1) the WAFs for each body surface of a student, (2) the distribution of WAFs for each student, and (3) variations in WAFs due to student occupancy, seating orientation, addition of an adjacent open space, and use of personal partitions. In addition, the resultant distributions of mean radiant temperature(MRT) were evaluated for four cases in which the primary surface was heated. The floor and personal partitions were found to have the greatest influence on the majority of students, while walls most strongly affected students seated nearby them, i.e., those in the perimeter zone of the classroom.

INTRODUCTION

The thermal radiation environment in most classrooms is generally nonuniform and asymmetric due to the presence of windows, walls, desks, and many other obstructions. As such, analytical evaluation of this environment has presented researchers with a problem, i.e., it is difficult to determine view factors for the presence of obstructions. However, application of the VLITE algorithm developed by Walton (1993) enables these factors to be accurately calculated with relative ease; an advancement leading to the present study which utilizes VLITE to investigate which surfaces in typical classroom types have the strongest influence on occupying students.

METHODS

Fig. 1 shows the box model to represent a student's body, being comprised of seven surfaces, as the front surface of a body consists of upper and lower surfaces. To represent a standard classroom, we used a simple rectangular box model comprising various primary surfaces, considering it to be occupied by 40 students (Fig. 2).

A block diagram of our analysis procedure is presented in Fig. 3, where absorption factors are calculated using resultant view factors obtained by VLITE. The respective effects of the primary surfaces on students are then obtained using newly proposed weighted absorption factors (WAFs) that are based on weighted factors previously proposed by Nakamura (1987)(2).

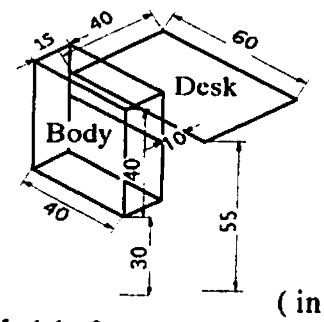
To determine the effect of a primary surface g on a particular student, his or her weighted MRT is first determined by summing the MRT for each body surface (e = 1~7), i.e.,

$$Weighted\ MRT = \sum_{e=1}^{7} w_e \sum_{j}^{N} B_{ej}\theta_j = \sum_{e=1}^{7} w_e \sum_{j \neq g}^{N} B_{ej}\theta_j + \theta_g \sum_{e=1}^{7} w_e B_{eg} . \qquad \ldots (1)$$

where w is the weighted factor of the body surface, B its absorption factor, θ its surface temperature, and N the number of primary surfaces (j = 1~N). The WAF of surface g is expressed as

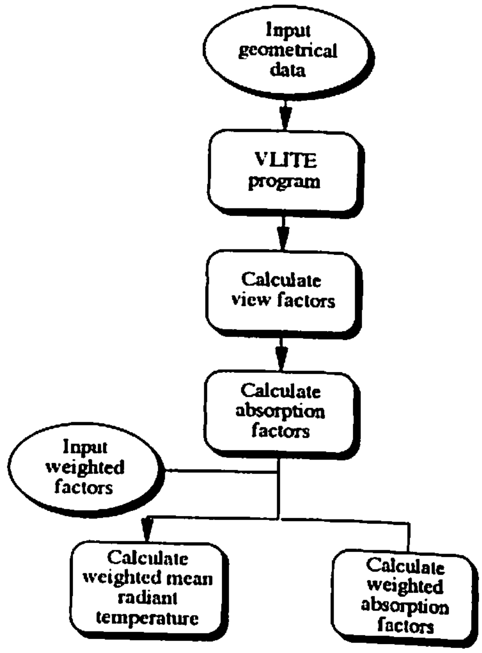
$$\sum_{e=1}^{7} w_e B_{eg} \quad \cdots(2)$$

In addition, we evaluate the distributions of thermal radiation by calculating distributions of MRT using four cases in which the surface showing the greatest WAF was heated.



(in cm)

Fig. 1 Model of a student's body surfaces when seated by a desk.



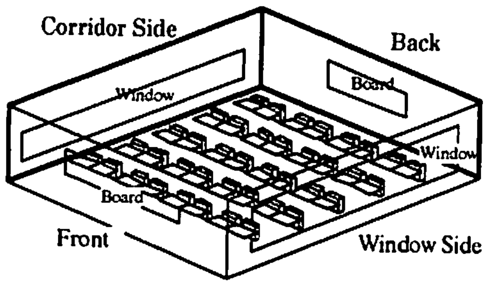


Fig. 2 Model of a standard classroom.

Fig. 3 Block diagram of analysis procedure.

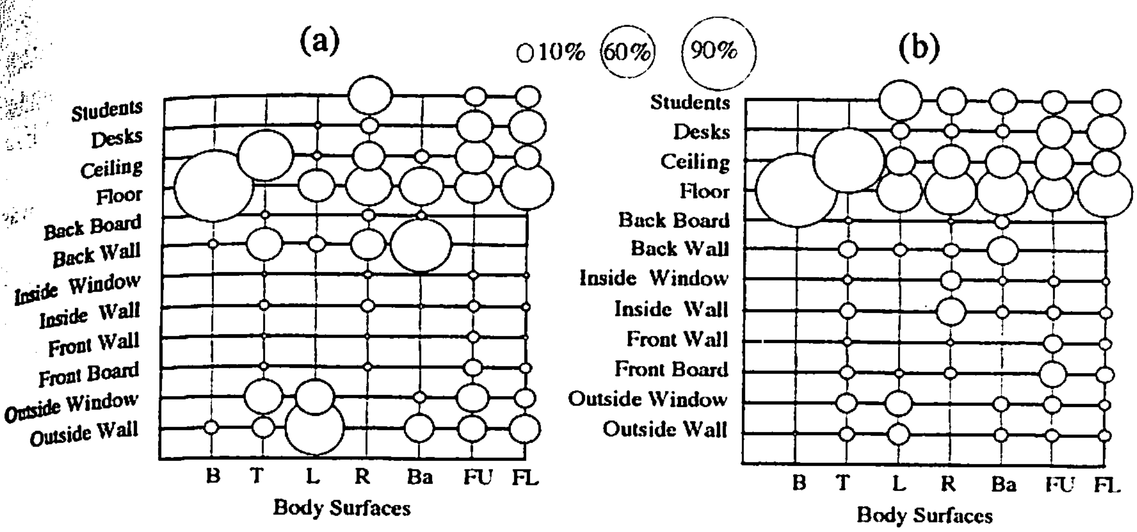
RESULTS

Weighted absorption factors for a student's body surfaces

Fig. 4 shows resultant WAFs for each body surface of a student seated at the center and at the back/window side of a standard classroom, where 12 primary surfaces are considered: various walls (8), ceiling, floor, desks, and students. The WAF of students represents the thermal radiation on a student from other students. Note that (i) the floor generally has the greatest influence on all body surfaces except the top surface, being due to the fact that it is the closest primary surface and has such a large surface area, and (ii) the WAFs of students are relatively greater at the center.

Distribution of WAFs for each student

Fig. 5 shows the distribution of WAFs calculated for each student seated in a standard classroom, where values were found to range as follows: floor, 33~36%; walls, 23~43%; ceiling, 17~22%; desks, 3~7%; and students, 2~11%. Note that the walls have the greatest influence on students seated in the perimeter zone (30~37%), especially on those in the corners (40~43%).



(B: Bottom, T: Top, L: Left side, R: Right side, Ba: Back, FU: Front upper, FL: Front lower)

Fig. 4 WAFs (circles) for body surfaces of a student seated at the (a) center and (b) back/window side of a standard classroom.

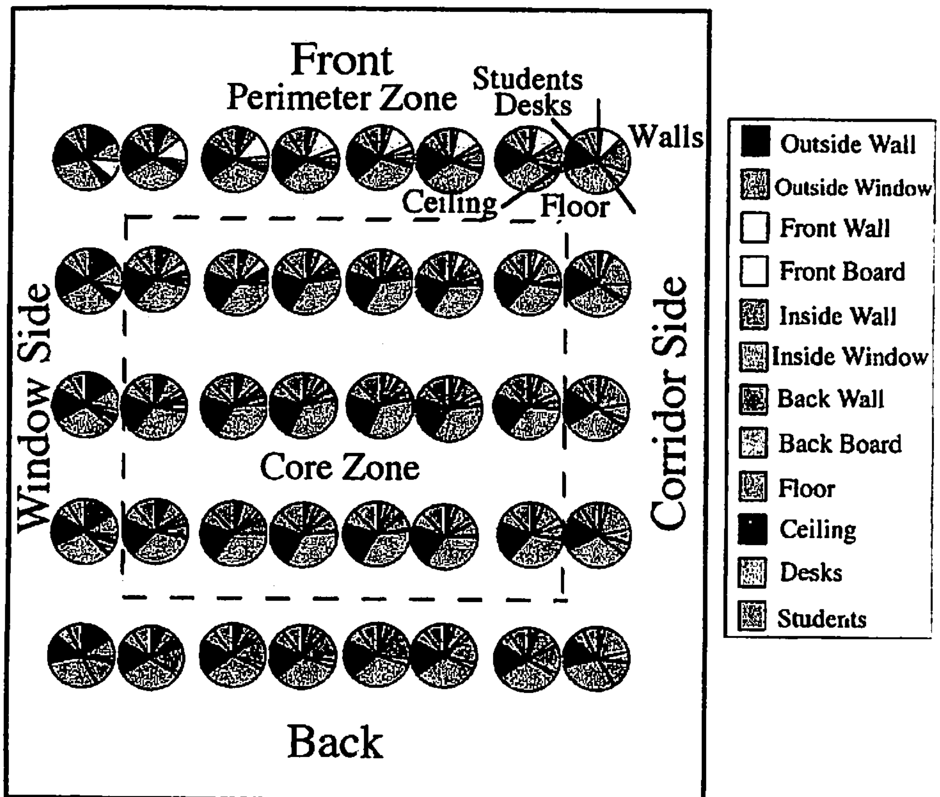
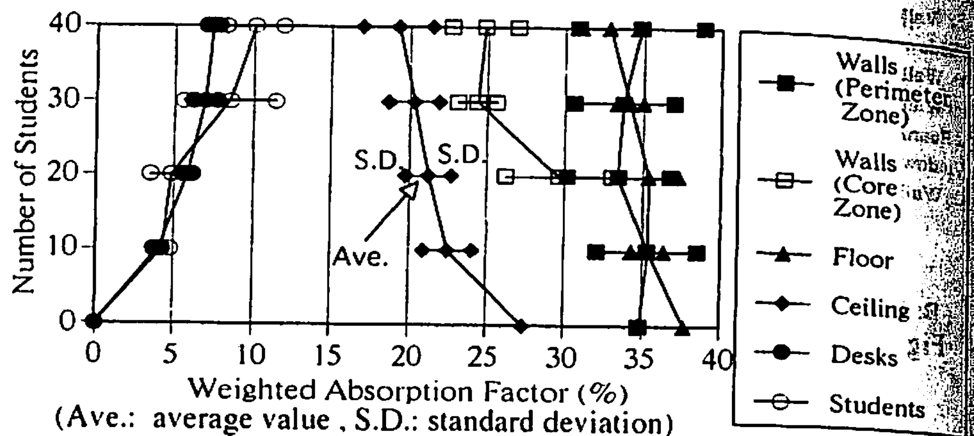


Fig. 5 Distribution of WAFs for each student in a standard classroom.

Variations in WAFs due to student occupancy

To determine how student occupancy affects the thermal radiation environment, we varied the number of students occupying a standard classroom (0 to 40) and calculated the respective WAF distributions in each case. Figure 6 shows this relationship by plotting resultant averages and standard deviations in WAFs of primary surfaces, where the WAFs of walls corresponding to the perimeter and core zones are separately treated. For the case in which no students occupy the classroom, WAFs were calculated for 1 cm^3 cube whose bottom side was situated 56 cm above the floor. Increasing the number of students from 0 to 40 results in decreasing the WAF of walls in the core zone by about 5% and the corresponding value in the perimeter zone by about 2%, while the WAFs of the ceiling and floor also decrease by about 5~8%. The WAF of students, however, naturally increases, reaching about 7~10%.

Using a 120-MHz PC compatible microcomputer, a computation time of 54 min was required for VLITE to obtain view factors of 374 surfaces.



(Ave.: average value, S.D.: standard deviation)

Fig. 6 Variations in WAFs of primary surfaces due to student occupancy.

Variations in WAFs due to seating orientation

As the seating orientation of a classroom can be altered in open-schools, we investigated how this affects the thermal radiation environment, using increments of 45°, i.e., we varied "seat facing angles" over 360° (Fig. 7). We compared differences following subtraction of values obtained at 0°. Resultant differences are shown in Fig. 8 for a student seated at the center and at the back/window side, where those for the later case are larger due to the strong effect of nearby walls. Note that in both cases the differences are less than 3% for each primary surface.

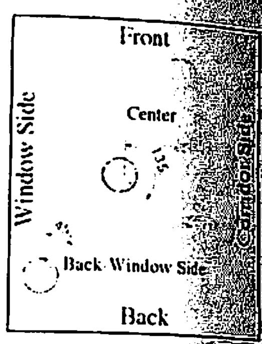


Fig. 7 Reference diagram of seat facing angles

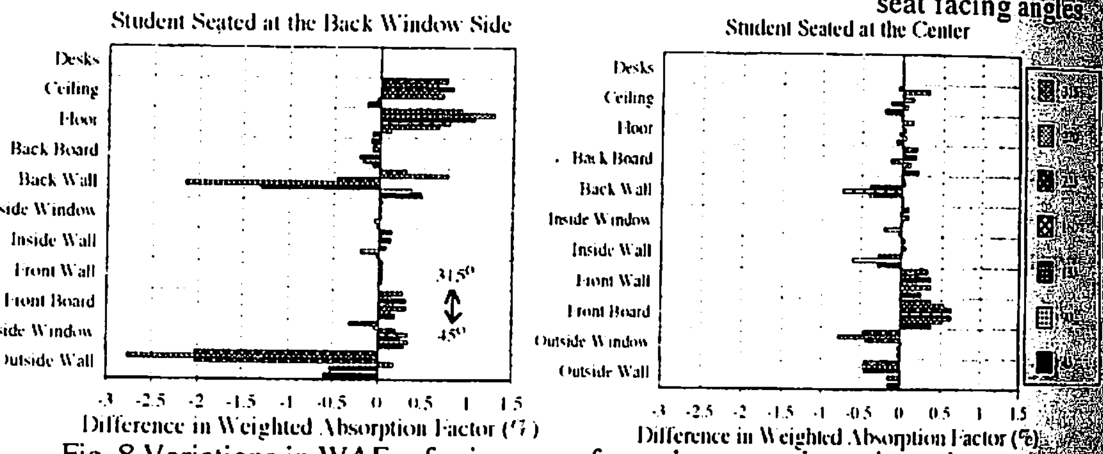


Fig. 8 Variations in WAFs of primary surfaces due to seating orientation.

Variations in WAFs due to space addition

As open-school classrooms sometimes have an open space on one side (Fig. 9), we investigated how this adjacent space affects the thermal radiation environment, i.e., we calculated WAF distributions for a standard classroom with and without an inside wall, and plotted the difference for each seat (Fig. 9). Results are shown in Fig. 10, where differences in ceiling WAFs for each row markedly increase towards the open space, reaching about 8% at row 8. In contrast, corresponding values of the inside wall decrease, reaching about -12%.

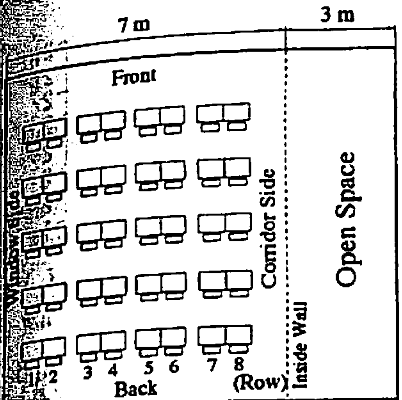


Fig. 9 Model of an open-school classroom.

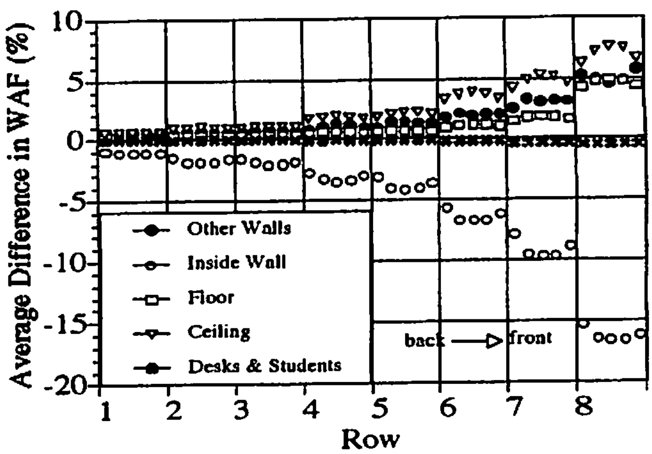


Fig. 10 Variations in WAFs due to space addition.

Variations in WAFs due to personal partitions

As there are some language laboratories having "personal partitions" for each student (Fig. 11), we simulated how these partitions affect the thermal radiation environment by varing their height from 65 to 80 cm in 5-cm increments and evaluating resultant variations in WAFs. Fig. 12 shows the average WAFs of the considered surfaces, where the WAF of partitions is significantly greater than the WAFs of all other primary surfaces. Note that from 70 to 80 cm the WAFs of the partition increase from 37 to 43%, whereas those of the ceiling, floor, and walls instead decrease from 19 to 16%.

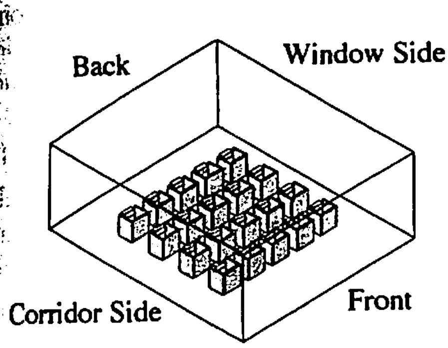


Fig. 11 Model of a language laboratory classroom.

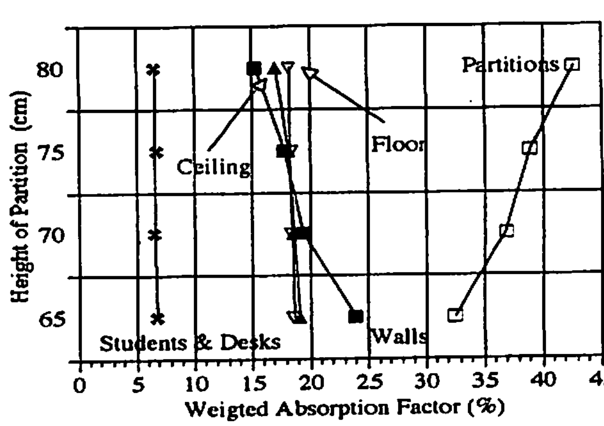
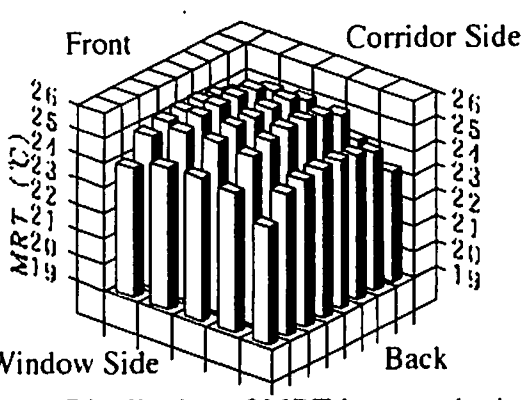


Fig. 12 Variations in WAFs due to personal partitions.

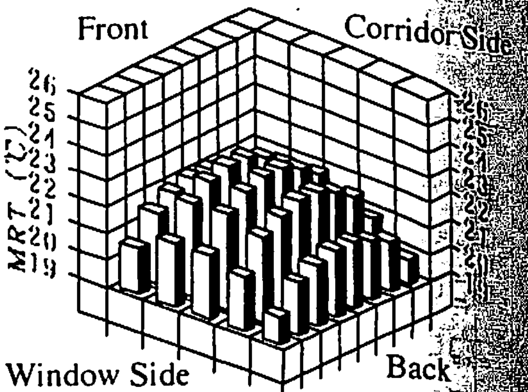
Distribution of MRT with a heated surface

To simulate how heating one primary surface affects the thermal radiation environment, we calculated the distributions of MRT for the following four cases: heating of (1) floor or (2) ceiling in a standard classroom, and (3) floor or (4) partitions in a language laboratory. We assumed the temperature of the heated surface, surrounding air, and students to remain constant at 40, 15, and 35℃, respectively. Fig. 13 presents the results for each case, where cases (1) and (4), which use floor and partition heating respectively, show the highest MRT values, as cases (2) and (3) show lower MRT values and have lower WAFs as well.

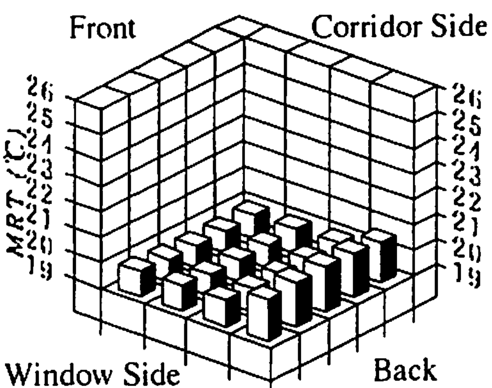
This indicates that a classroom radiant heating system should be installed on a primary surface having a high WAF value. Also of interest, the MRT values in the perimeter zone are lower than those in the core zone, being due to the WAFs of walls being high.



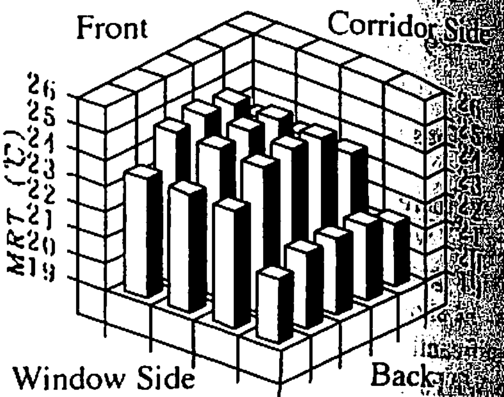
Case(1) Distribution of MRT in a standard classroom with heated floor



Case(2)Distribution of MRT in a standard classroom with heated ceiling



Case(3) Distribution of MRT in a language laboratory with heated floor



Case(4) Distribution of MRT in a language laboratory with heated partitions

Fig. 13 Distributions of MRT for cases (1)-(4) in which one primary surface is heated.

CONCLUSIONS

By the combined application of the VLITE algorithm and newly proposed "weighted absorption factors (WAFs)" of primary surfaces, we simulated the thermal radiation distributions in several types of classrooms occupied by students. In addition, the distributions of mean radiant temperature (MRT) were obtained for standard and language laboratory classroom in which one primary surface was heated. Major results are as follows:

(1) As the floor in a standard classroom and the personal partitions in a language laboratory showed the highest WAFs, i.e., 33~36% and 33~43% respectively, these primary surfaces have the greatest effect on seated students in such classrooms. However, nearby walls were found to have the greatest effect for students seated in the perimeter zone of a classroom.

(2) Based on evaluations of resultant MRT distributions, heating the classroom primary surface with the largest WAF was shown to give the highest MRT values, although, those in the perimeter zone were still comparatively small due to the strong effect of the nearby walls.

REFERENCES

1. Walton G. N.; 1993. Computer Programs for Simulation of Lighting/HVAC Interactions. *NISTIR*

2. Nakamura Y.; 1987. Expression Method of the Radiant Field on a Human Body in Buildings and Urban Spaces. *Journal of Architecture Planning Eng., AIJ*, No.376, pp.29-35