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Experimental and Analytical Investigation of Solar Radiant Flux Distribution on Interior Surfaces of A Sunspace

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Prepared for
Solar Buildings Technology Division
Office of Solar Heat Technologies
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EXPERIMENTAL AND ANALYTICAL INVESTIGATION OF SOLAR RADIANT FLUX DISTRIBUTION ON INTERIOR SURFACES OF A SUNSPACE

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

PREFACE

SOLAR BUILDINGS RESEARCH AND DEVELOPMENT PROGRAM

In keeping with the national energy policy goal of fostering an adequate supply of energy at a reasonable cost, the United States Department of Energy (DOE) supports a variety of programs to promote a balanced and mixed energy resource system. The mission of the DOE Solar Buildings Research and Development Program is to support this goal, by providing for the development of solar technology alternatives for the buildings sector. It is the goal of the Program to establish a proven technology base to allow industry to develop solar products and designs for buildings which are economically competitive and can contribute significantly to building energy supplies nationally. Toward this end, the program sponsors research activities related to increasing the efficiency, reducing the cost, and improving the long term durability of passive and active solar systems for building water and space heating, cooling, and daylighting applications. These activities are conducted in four major areas: Advanced Passive Solar Materials Research, Collector Technology Research, Cooling Systems Research, and Systems Analysis and Applications Research.

Advanced Passive Solar Materials Research - This activity area includes work on new aperture materials for controlling solar heat gains, and for enhancing the use of daylight for building interior lighting purposes. It also encompasses work on low-cost thermal storage materials that have high thermal storage capacity and can be integrated with conventional building elements, and work on materials and methods to transport thermal energy efficiently between any building exterior surface and the building interior by non-mechanical means.

Collector Technology Research - This activity area encompasses work on advanced low to medium temperature (up to 180°F useful operating temperature) flat plate collectors for water and space heating applications, and medium to high temperature (up to 400°F useful operating temperature) evacuated tube/concentrating collectors for space heating and cooling applications. The focus is on design innovations using new materials and fabrication techniques.

Cooling Systems Research - This activity area involves research on high performance dehumidifiers and chillers that can operate efficiently with the variable thermal outputs and delivery temperatures associated with solar collectors. It also includes work on advanced passive cooling techniques.

Systems Analysis and Applications Research - This activity area encompasses experimental testing, analysis, and evaluation of solar heating, cooling, and daylighting systems for residential and nonresidential buildings. This involves system integration studies, the development of design and analysis tools, and the establishment of overall cost, performance, and durability targets for various technology or system options.

This report is an account of research conducted in the Systems Analysis and Applications Research area concerning the distribution of solar radiative flux inside a partially transparent passive solar structure and the validation of a design and analysis tool that can be used for a parametric study of those flux distributions.

ABSTRACT

The short wave solar radiant flux distribution inside a sun-space model with a large south opening was studied experimentally under clear sky conditions. Miniature photovoltaic pyranometer sensors responsive to short wave radiation were mounted at various locations on the interior surfaces of the enclosure. It was found that solar flux distribution on an interior surface not in direct sunlight varies approximately in a linear fashion from the south opening, so that a limited number of sensors are adequate for the determination of the flux distribution in an enclosure. A highly reflective floor or wall surface not under direct irradiation from the sun tends to distribute the incoming solar flux evenly over all indirectly irradiated interior surfaces having the same solar reflectivity. The flux values vary only as a function of the distance from the solar opening. The multiple reflected solar flux within the enclosure increases the amount of solar energy falling on an area under direct sunlight to a value significantly greater than would be measured outside of the enclosure. An NBS developed solar flux distribution program was tested against the experimental results and was found to give good agreement. The computer program can be used as a design tool for the evaluation of thermal storage location and solar physical properties of floor and walls in a passive solar structure.

Key words: Computer program; partially transparent enclosures; passive solar structure; solar flux measurement; solar radiation; sun-space model

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1. INTRODUCTION

Fundamental to the prediction of the heating and cooling loads in the design of passive solar buildings is the spatial distribution of the solar energy flux among the various interior surfaces of a highly solar-driven zone such as the direct gain sunspace or atrium. Radiant solar energy transmitted through the large fenestration in a typical sunspace design undergoes a process of multiple reflections and absorptions. Part of the entering short-wave solar flux is retransmitted out of the space through the glazings. The solar energy absorbed and stored at any location on the interior surfaces and the surface temperature distribution depends on the amount of the solar radiant flux incident on and absorbed by the surfaces at that particular location. Currently, none of the existing energy analysis programs provide for detailed treatment with regard to internal multiple reflections and re-transmissions out of the space.

McCabe and Van Migom [1,2] reviewed the recent development of the enclosure theories for specular and diffuse radiative energy transfer among semi-gray, opaque surfaces [3] and for diffuse radiative energy transfer in partially transparent enclosures [4,5], and presented a general formulation for partially transparent enclosures involving both the beam and the diffuse solar energy transfer through multiple transparent surfaces. In their development, the shortwave irradiance and radiosity at each surface in the enclosure are formulated for the diffuse and the beam component separately. Diffuse reflection of both the beam and the diffuse irradiance is assumed. The effect of view (angle) factors on diffuse reflection among the surfaces are considered, and the shading effect of opaque enclosure surfaces on others for incident beam radiation is also taken into consideration. The resulting equations for all the surfaces are presented in matrix form and techniques for matrix manipulation are used to simplify and solve the equations. Details of the formulation are described in [1,2].

On the basis of the analytical formulation described above, a computer code, "SUNFLUX," was developed at the National Bureau of Standards (NBS) that models the admission, multiple reflection, and absorption of the solar radiant flux in partially transparent enclosures. At the same time, an experimental study sponsored by the Department of Energy (DOE) was undertaken to make actual measurements of the distribution of radiant solar flux incident on the interior surfaces of a direct gain structure. This paper presents the findings of the experimental investigation and a comparison of the measured results with the analytical prediction obtained from the computer code. The test facility, instrumentation, and data acquisition are described, and samples of the experimental results are presented. The test and results are compared with the analytical predictions produced by the NBS developed computer program "SUNFLUX". Reasonably close agreement is shown to validate the computer program for use as a research and design tool in passive solar research and applications.

2. "SUNFLUX" - THE SOLAR FLUX DISTRIBUTION COMPUTER PROGRAM

The computer program named "SUNFLUX" is a computer model developed by NBS for the prediction of the amount of short wave solar radiation absorbed by each of the interior surfaces in a highly solar driven, partially transparent enclosure such as a sunspace or an atrium. The computer program consists of two parts. The first part generates the geometrical view (angle) factors and shadow factors due to solar beam radiation among all the interior surfaces or subsurfaces. It is a simplified version of the "CONSHAD" subroutine used in the "Simplified Shuttle Payload Thermal Analyzer Program" (SSPTA) developed by Arthur D. Little, Inc. for the Goddard Space Flight Center of the National Aeronautics and Space Administration [6]. The second part of the program uses the algorithm described in [1] and computes the solar radiant flux distribution and absorption at the interior surfaces for any time of the day. The program can handle up to 100 interior surfaces or sub-surfaces in an enclosure of arbitrary shape, including internally blocking surfaces and multiple transparent surfaces. The program is developed for use as a design tool for the evaluation of solar driven passive solar design. It can also be incorporated into larger general energy analysis programs.

3. EXPERIMENTAL TEST FACILITY

The test facility consists of a one-sixth (1/6) scale model of the direct-gain room of the NBS/DoE Passive Test Facility [7]. The model, as shown in Figure 1, is a rectangular shaped cell with a 610 mm wide by 1380 mm deep floor and a 380 mm high ceiling. The fenestration opening at the south end has a dimension of 610 mm wide by 320 mm high, measured from the floor up. The model is made of plywood and lined with gypsum wallboard for all interior opaque surfaces. The surface of the wall is painted latex flat white color. The measured reflectivity of the painted surface in the solar wave-length spectrum varies from 0.92 at 500 nm to 0.75 at 2100 nm, with an average weighted solar reflectivity of 0.88. This highly reflective surface paint was chosen for all surfaces including the floor to give the maximum possible values of solar radiant flux measured by the pyranometer sensors located away from the direct beam radiation. No glass cover was used in the south end opening for the same reason.

The scale model is mounted on a wheeled table top on a wood framed base. The model can be tilted upward at the south end to a maximum of 30° from the horizontal to artificially change the solar altitude angle. The ability to vary the altitude angle permitted testing throughout the year.

4. INSTRUMENTATION AND DATA ACQUISITION

Twelve (12) miniature silicon photovoltaic (PV) type pyranometers were used to measure the incident solar radiant flux on the interior opaque surfaces of the model at selected locations. This type of sensor responds to the solar radiation in the wave length spectrum of 400 to 1100 nm. The sensors were factory calibrated against a first class thermopile type precision spectral pyranometer (PSP) under natural daylight conditions with an absolute error of $\pm 5\%$ maximum over the solar spectrum. The sensor is mounted in a fully cosine-corrected miniature head, and according to the manufacturer can be installed in any plane without affecting its performance.

In addition to the 12 PV sensors, a thermopile type precision spectral pyranometer and a normal incidence pyrheliometer (NIP) mounted on a tracker, away from the scale model, were used to measure the total horizontal and the normal beam solar radiations, respectively. Before the test was started, the silicon PV sensors were calibrated against the PSP under various daylight conditions ranging from clear sky to total cloud cover and during different times of the day. The PV sensors performed according to the manufacturer's specification as described in the last paragraph. Figure 2 shows a typical calibration of one silicon PV sensor against the PSP. The measurements were taken at one minute intervals under various sky conditions. Because of the differences in time response (very small for the PV sensor while over 20 seconds for the PSP), some data scattering during intermittent cloudy weather showing large discrepancies was expected and should be ignored. A linear least square fit of the data was made for each of the PV sensors. All data taken in the subsequent measurements are corrected accordingly using these calibration curves.

A microcomputer based data acquisition system is used to collect the 14 channels of data at one minute intervals and the data are stored on floppy diskette. The data logger has a scanner with an integrated digital voltmeter having one (1) microvolt resolution.

5. TEST RESULTS AND DISCUSSIONS

5.1 Solar Flux Distribution on An Interior Surface

Because of the limited number of the silicon PV sensors that can be installed on each surface within the scale model it is necessary to select optimum location. Therefore, preliminary tests were conducted to determine the pattern of the solar flux distribution along the centerline of an interior surface under clear sky conditions. Figure 3 shows the results of tests for the flux distribution on the floor of the model. For these tests, the south to north centerline along the floor was divided into eight (8) equally spaced segments starting from the south side and seven (7) sensors were installed at the locations $X/L = 1/8, 1/4, 3/8, 1/2, 5/8, 3/4,$ and $7/8$, where L is the length of the floor and X is the distance measured from the south opening. Figure 3 shows the incident solar flux in the areas not under direct beam radiation. Only data from 5 out of the 7 sensors are shown since the other two are in the direct sunlit area. It is interesting to note that solar flux distribution varies almost linearly with respect to the distance from the sunlit area, under both clear and hazy sky conditions. This phenomenon also holds true for the other surfaces as shown in Figures 4 and 5 for the east surface and the ceiling, respectively. It is also interesting to note that while the sun's ray changed from the west surface in the morning to the east surface in the afternoon, the flux distributions on the shaded portion of the east surface under clear sky condition are almost the same. This showed the effect of multiple reflections of the solar radiant energy among the interior surfaces.

5.2 Solar Flux Distributions Inside an Enclosure

Based on the flux distribution measurement on the individual surfaces, it is seen that two sensors on a surface not in direct sunlight is sufficient to determine the flux distribution on that surface. The locations for the sensors were therefore decided to be that shown in Figure 6. The criteria for these selections was to have one sensor at each sunlit surface area and to have two sensors on each shaded surface area to give an average reading on each half (south and north) of the surface. Throughout the daytime hours, portions of the floor, east surface, and west surface, will be in direct sunlight. In Figure 6, the sensors labelled 1, 4, and 5 will be in direct sunlight in certain times of the day. The rest of the sensors will be receiving only reflected solar flux. A sample of the test results is shown in Figure 6. The values beneath the sensors (represented by the black circles) are the incident solar fluxes measured on a clear day averaged over a ten minute period near solar noon. Comparing sensors 1 and 2, it is seen that there is nearly 3 to 1 difference in the magnitude of the solar fluxes, where sensor 1 is in the sun and sensor 2 is in the shade but near the edge of the sunlit area. It is interesting to note that, while the total horizontal solar radiation measured by the PSP outside the test model was 559 W/m^2, the solar flux on the horizontal floor of the model in the sunlit region as measured by sensor No. 1 (Figure 6) was much higher (810 W/m^2). Further examination showed that the difference (251 W/m^2) was caused almost completely by the difference in the amount of diffuse solar radiation received by the two sensors (PSP and sensor No. 1). While the sky diffuse solar radiation to the PSP was computed to be 51 W/m^2 the solar diffuse radiation as measured by sensor No. 2 which is located close to sensor No. 1 was 287 W/m^2, with a difference of 236 W/m^2. It is obvious that this difference is significant when the floor material is used as a thermal storage medium in passive solar design. Of course, the difference is expected to become smaller if the solar reflectivity of the floor and/or wall surfaces is decreased.

In Figure 6, it is also interesting to see that, near the north end, the flux distributions on all 4 surfaces (sensors 3, 7, 9, and 11) at equal distance from the south opening are almost of equal magnitude regardless of the surface orientation. Data at other times of the day showed the same type of variation. This shows that the highly reflective interior surfaces tend to distribute the solar flux evenly. This phenomenon should be noted in determining the location of thermal storage material in passive solar designs.

6. ANALYTICAL PREDICTIONS AND COMPARISONS

As stated in the beginning of this report, the purpose of the experimental tests previously described was to provide measured data to validate the computer program "SUNFLUX" developed on the basis of the theoretical analysis in [1]. To this end the experimental scale model was used to test the computer algorithm and codes. On the basis of sun-lit area patterns observed during the tests, and from the measured solar flux distribution data, the interior surfaces of the scale model was sub-divided into 13 surfaces as shown in Figure 7. The centers of the subsurfaces correspond mostly to the locations of sensors shown in Figure 6. The slight variations were in the floor which was divided into four parts instead of three, and in the east and west surfaces which were divided into two equal parts each instead of three unequal parts. Experimentally measured normal beam radiation (by the NIP) and the total horizontal radiation (by the PSP) outside the scale model at solar noon and at 3:00 p.m. solar time were used as input to the computer program. The ground reflectivity was assumed to be 0.20 on the basis of prior measurement. The resulting predicted solar flux distribution on the various surfaces are discussed below.

6.1 COMPARISON OF PREDICTED AND MEASURED FLUX DISTRIBUTION

Table 1 shows the results of the predicted solar flux distribution on the various interior surfaces of the model together with the test results measured at the same locations under clear sky conditions at the two time periods of the day. It is seen that the results compare well (within 10 percent of each other) for most of the interior surface locations. The major discrepancy between the predicted and the measured results are at the locations near the south opening, where the measured values are 15 to 23 percent higher. This difference is considered to be the result of two factors. The first factor is the possible small misalignment of the sensors' head with respect to the surface, causing errors in measured data. The second factor concerns the assumption of diffuse reflection in the theoretical analysis [1]. In the analysis, it was assumed that the solar fluxes reflected from all the surfaces are diffuse without any specular reflection. In the experimental study, it is possible that some specular reflections occurred both at the ground around the scale model and at the model interior surfaces near the south opening where the solar beam radiation first strikes on the surfaces. This would increase the amount of radiant energy incident on surfaces near the south opening. This second factor is considered to be the main factor causing the discrepancy in the comparison.

Even with the discrepancy in the comparison just discussed, it is seen from Table 1 that the analytical model is in good agreement with the experimental data. Thus, the algorithm and codes can be used as a design tool in the design of passive solar structures such as in the selections of thermal storage locations and floor covering materials.

6.2 APPLICATION OF THE SOLAR FLUX DISTRIBUTION PROGRAM

As an example of the application of the solar flux distribution program, the program is used to evaluate the effects of the solar reflectivity of the floor on the sunspace's energy collection efficiency. The program was run on the same scale model as before, except that the floor's solar reflectivity is changed from 0.88 to 0.50. The results are shown on Table 2 at a solar time of 3:00 p.m. on November 14. Table 2 gives a comparison of the solar flux incident on each opaque surface inside the enclosure for the two values of solar reflectivity, as well as the percentage absorbed solar energy by the surfaces. Table 2 also gives the total amount of absorbed solar radiation by the sunspace as a percentage of the total solar energy entering through the south opening. It is seen that the net effect of a highly reflective floor surface (r=0.88) is to redistribute the incoming solar flux to other surfaces. The net absorbed solar flux by the total floor area was much smaller for the high reflectivity case than the lower reflectivity case (17.4% at r=0.88 vs. 52.9% at r=0.50), however, the total percentage of absorbed solar energy for the enclosure decreased by only 16 percentage points, from 76% at r=0.50 to 60% for r=0.88. In both cases, a significant portion of the incoming solar flux was retransmitted out of the south opening.

As described previously in Section 5.2 of this report, the incident solar fluxes on the north side of the surfaces have almost equal magnitude regardless of the surface orientation. Table 2 shows that this phenomenon is true even for surfaces with unequal values of solar reflectivity as indicated by the incident flux values in the 4th column of Table 2 for a floor solar reflectivity of r = 0.50. It is seen in Table 2 that even though the floor's solar reflectivity is only a little over one-half the value for the rest of the surfaces (which is 0.88), the incident fluxes for the north half of the surfaces including the floor (No. 1, 2, 8, 9, 10 and 12) vary only from 51 to 60 W/m^2.

As described previously in the experimental part of this study (section 5.2), the effect of the surface reflectivity is to increase the amount of diffuse solar flux incident on the sunlit area of the floor above those measured on a horizontal surface outside the enclosure. Table 3 shows such effects by using the computer program for a floor reflectivity of 0.88 and 0.50, while the reflectivity of the walls are kept at 0.88 for both cases. It is seen that, as in the case of the experimental study, the total solar fluxes on the floor in the sunlit area are augmented by the reflected solar fluxes to values much higher than those measured outside the enclosure.

7. CONCLUSIONS

Based on the experimental and analytical study on the solar radiant flux distribution inside a sunspace enclosure, the following conclusions can be drawn:

1. The solar flux distribution on any surfaces not in direct sunlit area can be approximated in a linear fashion from the solar opening, so that the distribution can be determined with a limited number of sensors installed at the right locations.

2. A highly reflective wall surface such as white painted gypsum wallboard tends to reflect and distribute the solar radiant energy evenly over all indirectly irradiated internal surfaces having equal distance to the south opening.

3. The amount of solar radiation incident on a sunlit floor surface near the solar opening can be much higher than those measured on a horizontal surface outside the enclosure under identical conditions (attenuation by glazing material, for example), especially if the floor and wall surfaces are highly reflective. This surface reflected solar radiant flux should be taken into consideration by designers when the sunlit floor is used as thermal storage medium.

4. The NBS developed solar flux distribution program gives a reasonable estimate of the flux distribution inside an enclosure, and can be used as a valuable design tool in the design of

passive solar structures. It can also be incorporated into other general energy analysis programs to give a better estimate of the solar flux distribution on internal surfaces in the overall energy balance computations of those surfaces.

Finally, it should be emphasized that the experiment and the analytical model deal only with the reflection and absorption of the shortwave solar radiation in an enclosure. The exchange of long wave infrared radiation emitted by the interior surfaces, and convective heat transfer from the surfaces to the air, are not considered. The analytical model is therefore not a complete building energy analysis model. Rather, it is a model to be used to determine the distribution of shortwave solar radiation which is affected by the solar radiation properties of the surfaces, by the solar properties of the glazing material, and by the size and location of the solar openings. However, neglecting the convection and infrared radiation exchanges do not limit the usefulness of the model for passive solar study since the shortwave solar energy exchanges do not depend on the surface or air temperature as long as the solar properties of the surfaces remain constant over the temperature range normally encountered in a passive solar enclosure.

8. ACKNOWLEDGMENTS

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Table 1

Comparison of Measured and Predicted Solar Radiant Flux Distribution Incident on Surfaces Inside A Sunspace Enclosure

Surface		Solar Time of Day					
No.	Location	12.00 noon			3:00 p.m.		
		Test	Predict	% Diff.	Test	Predict	% Diff.
1+2	FL., N. Half	185	179	3.2	123	126	-2.4
3	FL., S. Mid.	542	495	8.7	238	195	18.1
4	FL., S. End	808	739	8.5	400	369	7.8
7	E. Wall, S. Half	365	309	15.3	510	413	19.0
8	E. Wall, N. Half	191	182	4.7	124	122	1.6
9	N. Wall	186	172	7.5	123	119	3.3
10	W. Wall, N. Half	188	182	3.2	133	131	1.5
11	W. Wall, S. Half	370	309	16.5	231	209	9.5
12	CL, N. Half	193	191	1.0	128	128	0.0
13	CL, S. Half	433	335	22.6	267	221	17.2

Notes:
1. All fluxes in unit of W/m^2.
2. Surface NO. in accordance to Figure 7.
3. Clear day on Nov. 14, 1984 at 39° N. latitude.

Table 2

Effects of Different Floor Solar Reflectivity on the Surface Solar Radiant Energy Flux Distribution Inside an Enclosure

Surface		Incident Flux (W/m^2)		% Net Absorbed Energy	
No.	Location	r=0.88	r=0.50	r=0.88	r=0.50
1+2	FL, N. Half	126	60	5.35	10.70
3	FL, S. Mid.	195	164	4.17	14.66
4	FL, S. End	369	309	7.91	27.57
7	E. Wall, S. Half	413	326	11.21	8.84
8	E. Wall, N. Half	122	51	3.30	1.38
9	N. Wall	119	51	2.81	1.20
10	W. Wall, N. Half	131	59	3.55	1.60
11	W. Wall, S. Half	209	122	5.67	3.30
12	CL, N. Half	128	53	5.50	2.28
13	CL, S. Half	221	127	9.46	3.91
5	Header, S. Open.	221	131	0.79	0.47
			TOTAL ABSORBED	59.72	75.91

Notes:
1. Data are for 3:00 p.m. solar time.
2. Surface No. in accordance to Figure 7.
3. Solar reflectivity on surfaces other than floor is r=0.88.
4. Clear day on Nov. 14, 1984 at 39° N. latitude.

Table 3

Augmentation of Solar Flux on Sunlit Floor Area
Due to Surface Solar Reflectivity

Solar Time (11/14)	Outside of the Enclosure			Floor Inside the South Opening, Sunlit			
	Normal Beam	Horizontal Total	Horizontal Diffuse	Horizontal Total		Horizontal Diffuse	
				r=0.88	r=0.50	r=0.88	r=0.50
Noon	956	559	51	739	623	231	115
3:00 pm	825	301	41	445	385	184	124

Notes:
1. All fluxes in unit of W/m^2.
2. Solar reflectivity on surfaces other than floor is r=0.88.
3. 39°N latitude, on Nov. 14.

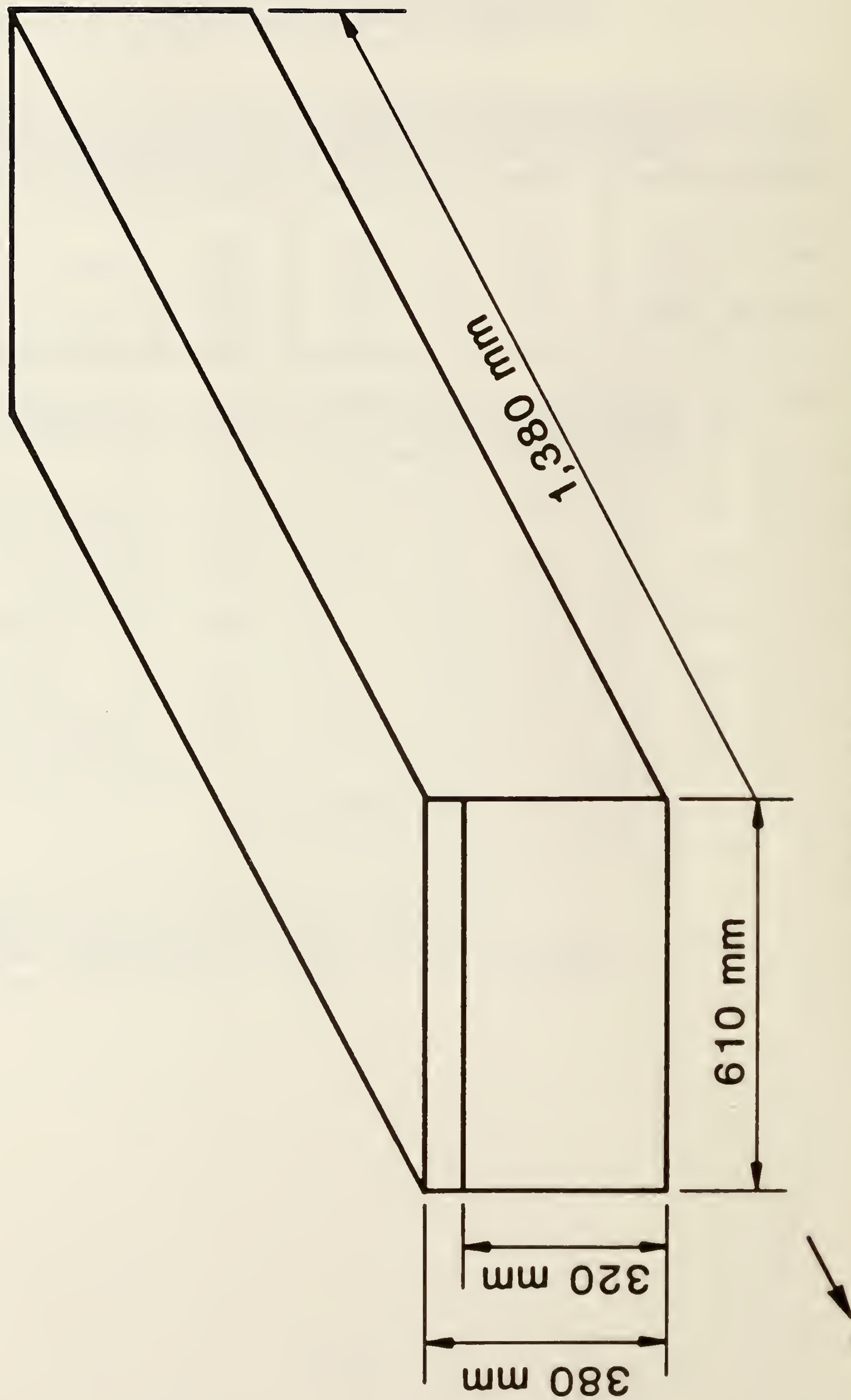

Fig. 1 The direct-gain model

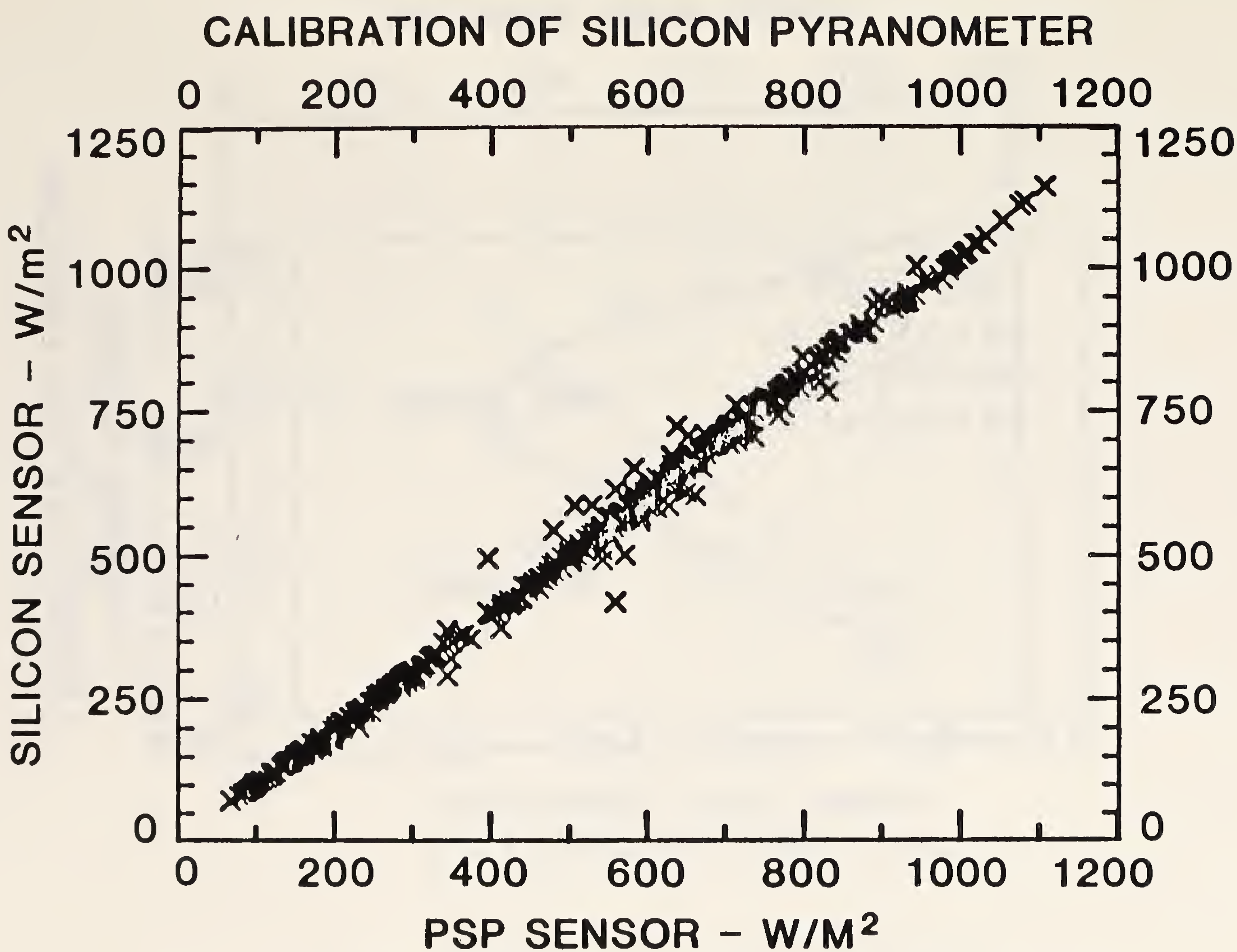

Fig. 2 Calibration of silicon PV sensor vs PSP sensor

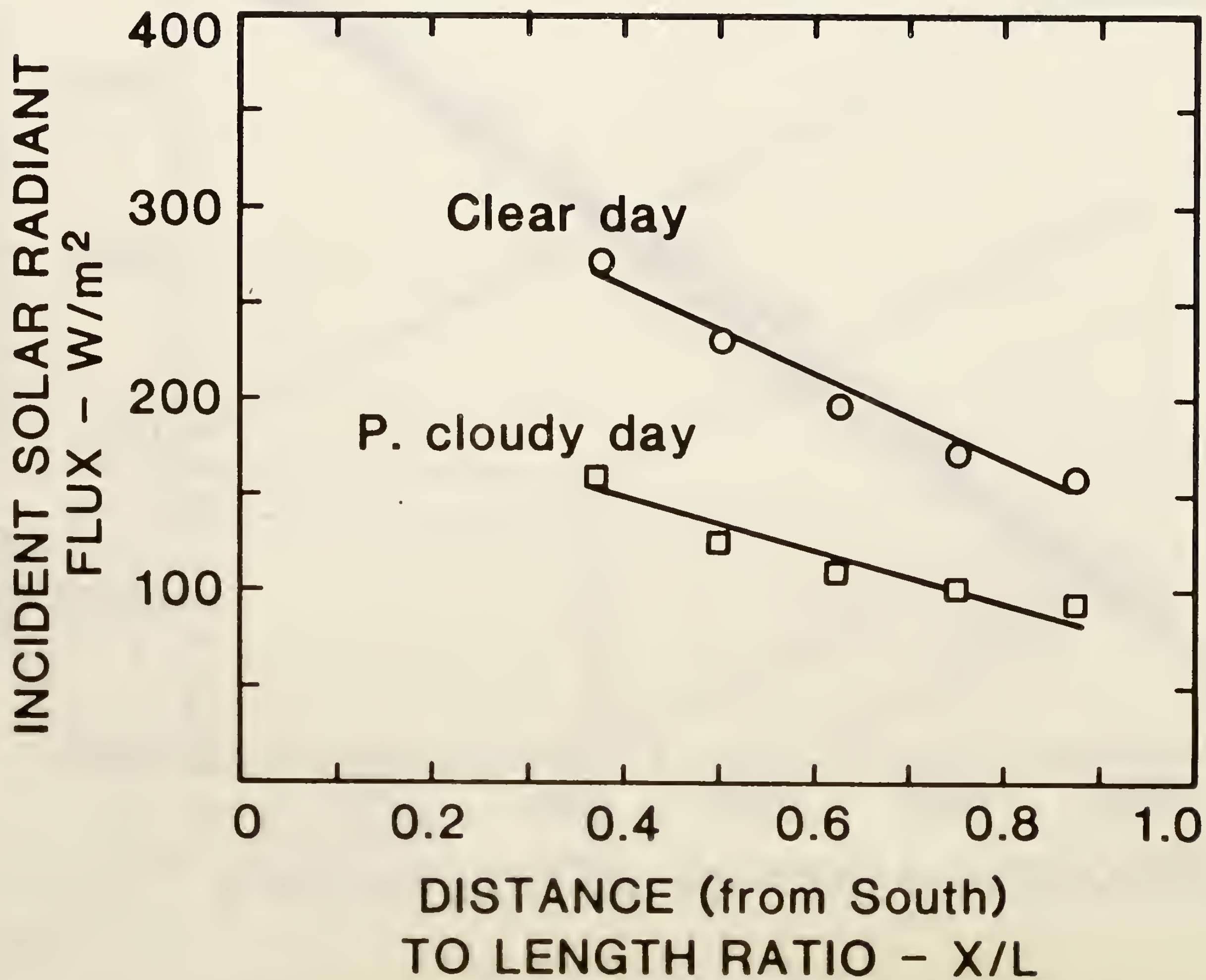

Fig. 3 Radiant flux distribution along centerline of floor (solar noon)

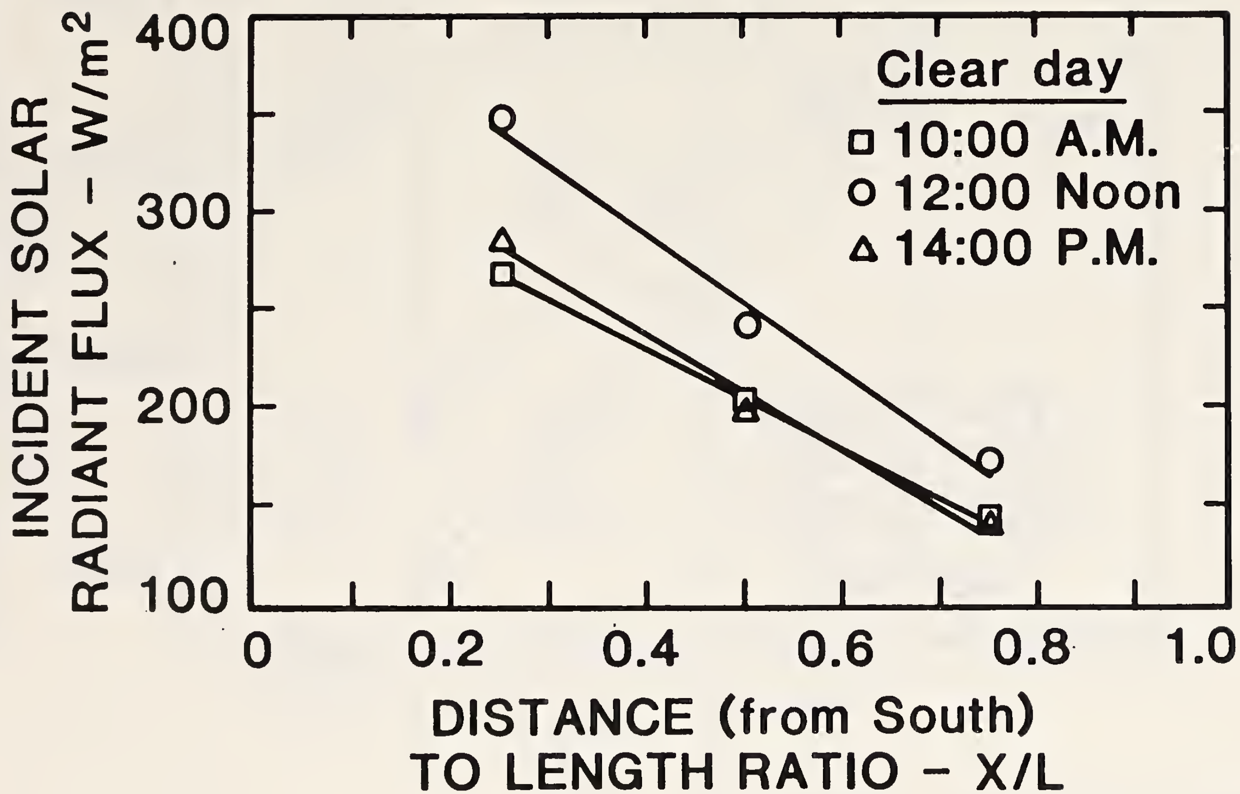

Fig. 4 Radiant flux along east wall (mid-height)

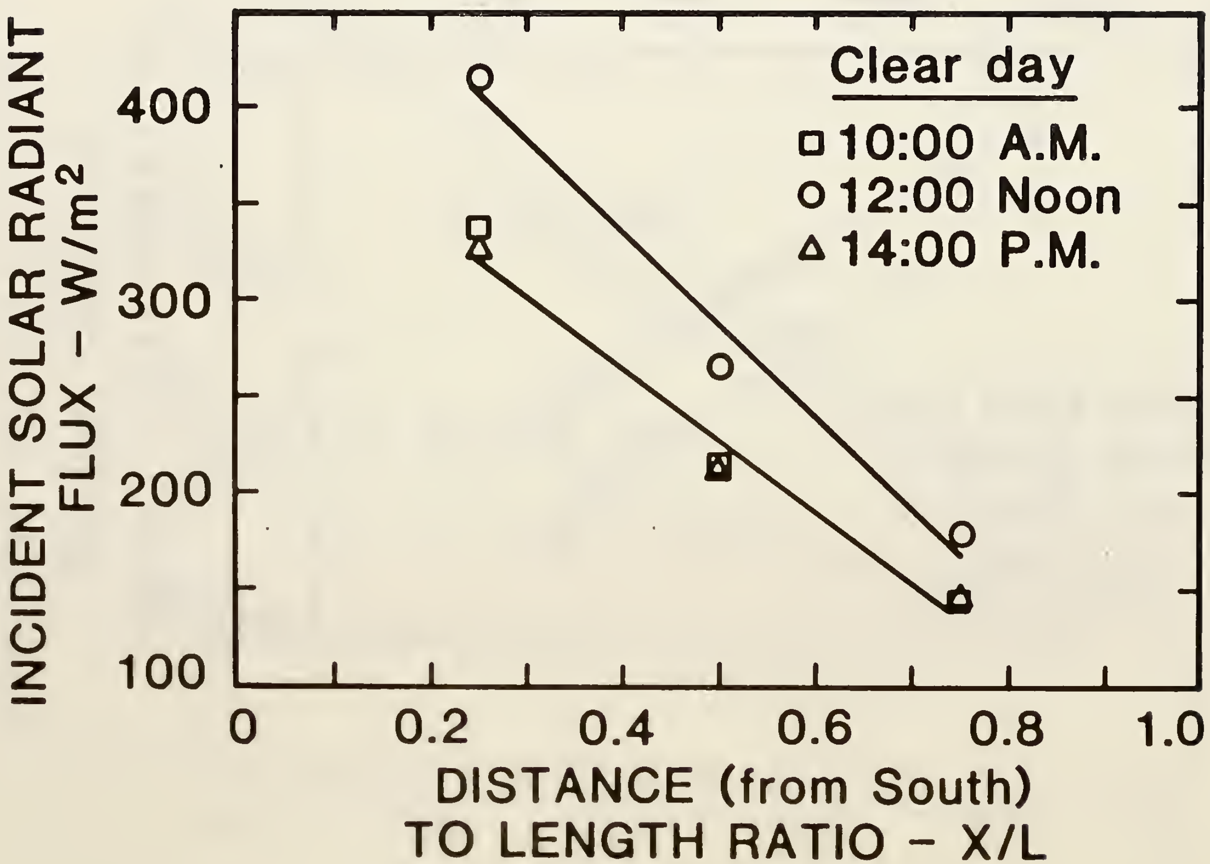

Fig. 5 Radiant flux along centerline of ceiling

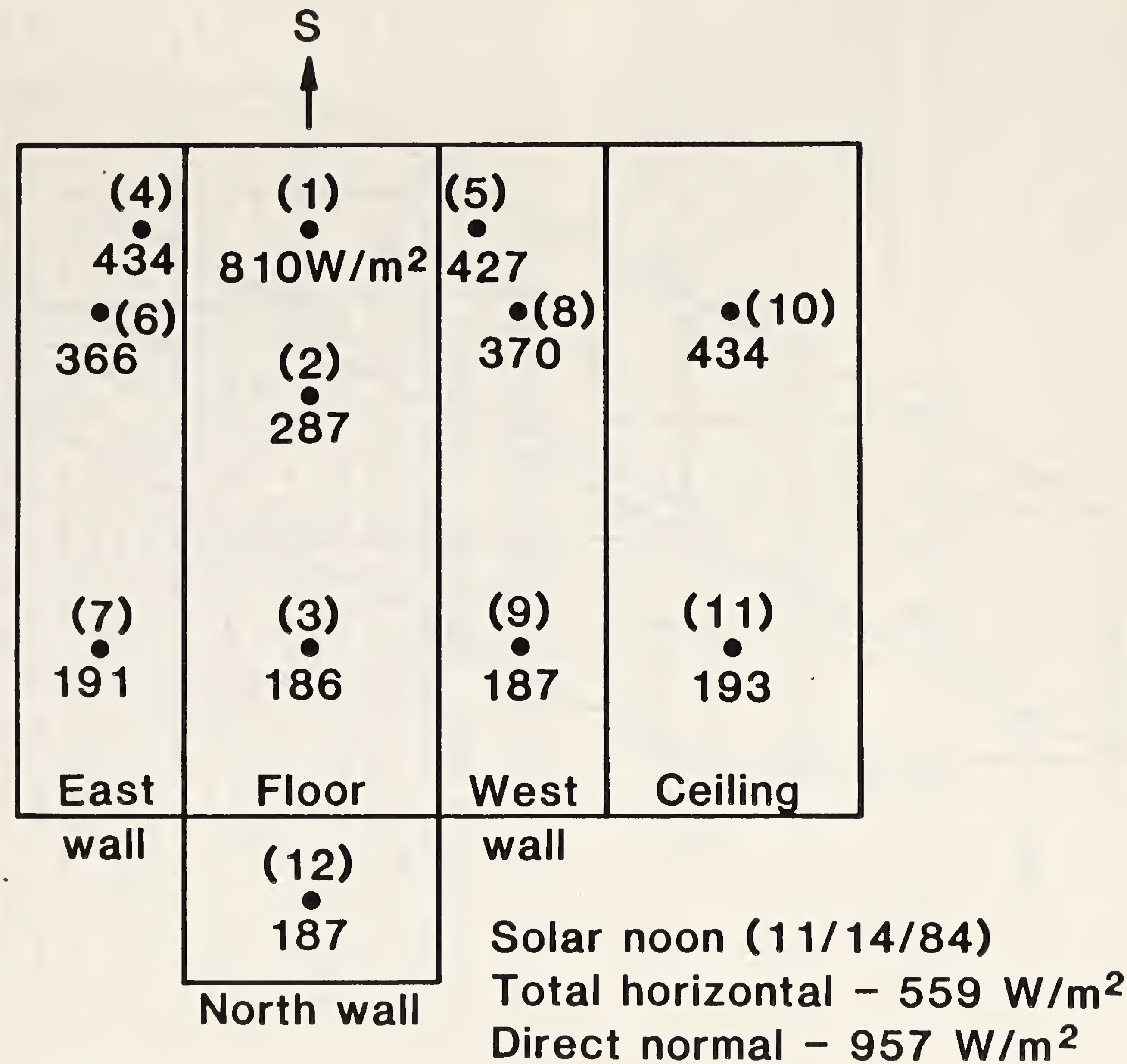

Fig. 6 Location of PV sensors on interior surfaces

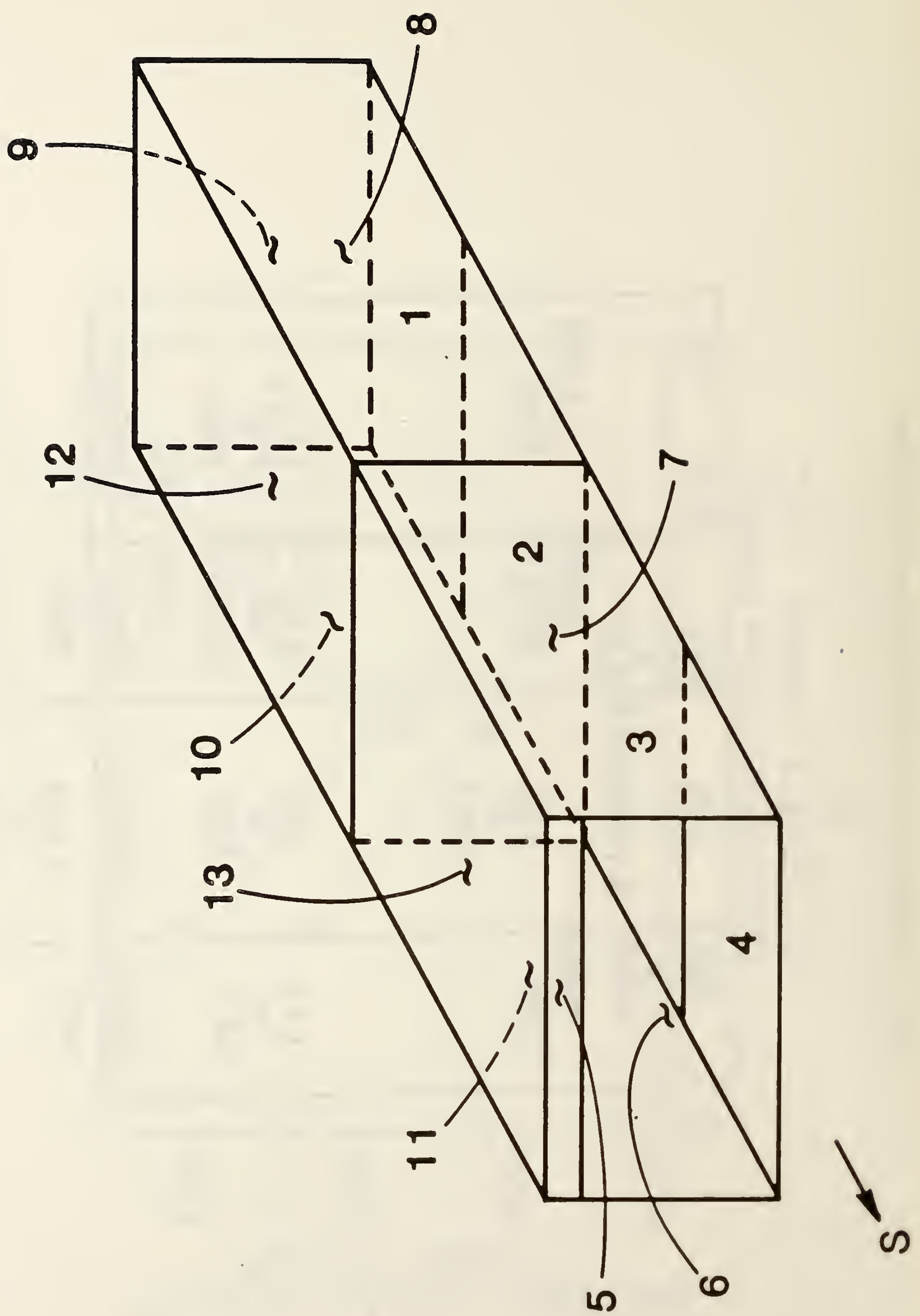

Fig. 7 Sub-division of Sunspace Interior Surfaces for Computer Modelling

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Solar Buildings Technology Division
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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

The short wave solar radiant flux distribution inside a sun-space model with a large south opening was studied experimentally under clear sky conditions. Miniature photovoltaic pyranometer sensors responsive to short wave radiation were mounted at various locations on the interior surfaces of the enclosure. It was found that solar flux distribution on an interior surface not in direct sunlight varies approximately in a linear fashion from the south opening, so that a limited number of sensors are adequate for the determination of the flux distribution in an enclosure. A highly reflective floor or wall surface not under direct irradiation from the sun tends to distribute the incoming solar flux evenly over all indirectly irradiated interior surfaces having the same solar reflectivity. The flux values vary only as a function of the distance from the solar opening. The multiple reflected solar flux within the enclosure increases the amount of solar energy falling on an area under direct sunlight to a value significantly greater than would be measured outside of the enclosure. An NBS developed solar flux distribution program was tested against the experimental results and was found to give good agreement. The computer program can be used as a design tool for the evaluation of thermal storage location and solar physical properties of floor and walls in a passive solar structure.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Key words: Computer program; partially transparent enclosures; passive solar structure; solar flux measurement; solar radiation; sun-space model

13. AVAILABILITY

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