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# Calculation of the distribution of incoming solar radiation in enclosures

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ABSTRACT

Solar heat gains are an important factor in the calculation of cooling loads for buildings. This paper aims at introducing an improved methodology to calculate the distribution of incoming solar energy on the internal surfaces of closed spaces with multiple openings. The independent numerical methodology is based on the view factor theory and in order to justify and prove its functionality, it has been linked to the commercial software of TRNSYS, which normally uses a surface area ratio based algorithm for the same process. For the simplified building structures that have been examined, there are noticeable differences in the spatial and temporal distribution of the absorbed solar energy. The proposed approach is indeed an improvement over the surface area ratio method, having a strong physical basis with relatively little extra computational effort.



## 1. Introduction

The need for accurate simulation models, concerning the distribution of solar energy entering domestic buildings has become the main subject of many research efforts in the last few decades. Improved accuracy of the distribution algorithm will lead to more accurate prediction of the energy requirements of the simulated building and therefore valid conclusions regarding energy efficiency and indoor thermal comfort conditions [1].

Calculation of the distribution of incoming solar energy in enclosed spaces can be accomplished through a number of different approaches with increasing levels of complexity, computational effort and accuracy. Wall [2] has presented an interesting study comparing four such approaches for solar radiation distribution in a room and concluded that a geometrical description of the enclosed space is important and transmission through windows, reflection and absorption must be accurately taken into account. Perhaps the simplest approach is that of an area weighted distribution whereby only the area of each surface (i.e. walls) is used in the distribution algorithm. This is the approach currently applied by the commercial software TRNSYS [3], with a surface absorptance factor also being taken into account but no other geometrical relations between the enclosure surfaces, e.g. view factors. The more accurate approach is that of the exact calculation of ‘sun patches’ that are formed as direct solar radiation passes through windows. However, this requires detailed geometrical information with regard to internal surfaces, the borders of the enclosure’s openings and the time varying position of the sun. Athienitis and Stylianou [4] and Cucumo et al. [5], presented analysis for estimating the solar absorptance of a room, based on the radiosity-irradiation method (RIM) algorithm that was developed by Sparrow and Cess [6]. The above mentioned algorithm (RIM) uses the view factor theory and leads to an $N^{*}N$ system of equations, where $N$ refers to the number of elements that the larger wall surface is divided into. Later on, Wen and Smith [7] developed a model which describes the dynamic thermal behavior of a building, considering its inner space to be surrounded by a number of elemental areas including interior and exterior windows. The radiosity-irradiation method (RIM) was also used in this case in order to compute the illumination (irradiation) of each area. Both Wen and Smith [7] and Cucumo et al. [5] also calculated the redistribution of solar energy inside a building’s rooms and the room’s effective solar absorptance, a concept which was initially introduced by Duffie and Beckman [8]. Trombe et al. [9] proceeded to implement a similar procedure for calculating ‘sun patch’ location in a complex enclosure including an occupant. The procedure was implemented in a zone thermal simulation model within the TRNSYS simulation program basically focusing on the thermal comfort of the occupant. The importance of the highest achievable accuracy in solar radiation distribution usually becomes evident inside highly-glazed spaces, i.e. greenhouses, sunspaces, etc. Mottard and Fissore [10], showed that the view factor weighted approach is not sufficient for highly-glazed spaces, from which a large portion of the incoming solar radiation finally escapes. In these configurations, insolation and shading become increasingly important as shown by Pieters and Deltour [11], who used a semi one-dimensional climate model to investigate the relative importance of the constructional parameters that

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**Nomenclature**

*Latin symbols*

| | |
|---|---|
| $A_s$ | area of surface $s$, $m^2$ |
| $a$ | solar altitude angle, deg |
| $F_{i\to j}$ | view factor for surfaces $i$ and $j$ |
| $f_{d,s,s}$ | fraction of diffuse or reflected solar radiation leaving any surface $s$ and absorbed by any other surface $s$ |
| $G(x, y, \xi, \eta)$ | view factor parameter in Eqs. (2) and (3) |
| $GS_i$ | fractions of the total incoming solar radiation absorbed by surface $i$ |
| $Q$ | solar radiation, $W/m^2$ |
| $Q_{th}$ | thermal load, kW h |
| $U$ | thermal transmittance, $W/m^2$ K |
| $x_i$ | coordinate $i$ on $x$ axis |
| $y_i$ | coordinate $i$ on $y$ axis |
| $z$ | distance between two parallel rectangular surfaces |

*Greek symbols*

| | |
|---|---|
| $\alpha_s$ | solar absorptance of surface $s$ |
| $\gamma$ | solar azimuth angle, deg |
| $\eta_i$ | alternative Cartesian coordinate used in Fig. 1 |
| $\xi_i$ | alternative Cartesian coordinate used in Fig. 1 |
| $\rho$ | solar reflectance |
| $\tau$ | solar transmittance |

*Subscripts*

| | |
|---|---|
| area | result obtained by using the absorptance-weighted area ratio method for the distribution of total incoming direct solar radiation |
| d | diffuse solar radiation |
| dir | direct solar radiation |
| s | surface |
| sum | summer day (June 2nd) |
| tot | total |
| v.f. | result obtained by using the view factor method for the distribution of total incoming direct solar radiation |
| wi | winter day (January 2nd) |

influence the solar energy collecting efficiency of greenhouses under Western European conditions. Increased computational effort is needed in the approach of Hiller et al. [12], who developed an algorithm for shading and insolation calculations focusing mainly on surface shapes, interactions and shading, but including the effects of internal non-opaque surfaces.

The improved accuracy of the previous methodologies comes at the cost of computational complexity and effort. It is interesting to note that another commercial software targeting building thermal simulation [13] includes both a simpler form of view factor weighted methodology and a more complex beam tracking one as options.

The purpose of this paper is to present a simple and computationally efficient methodology that distributes the total incoming solar radiation in enclosures of parallelepiped shape, taking into account enclosure geometry, view factor theory and the position of the sun throughout the day. The total incoming solar radiation from multiple openings is distributed among the enclosure surfaces with the use of simple distribution factors, without the need to separately trace each opening's beam radiation incidence on other surfaces. Analytical expressions are used for the view factors in parallelepiped geometry, this being the most common representative geometry in the majority of buildings: i.e. a typical building consists of surfaces that are either perpendicular or parallel. In order for the algorithm to be tested and verified, it was linked to the commercial simulation software TRNSYS and the results were compared to the absorptance-weighted area ratio distribution algorithm [3] that the software already uses. As previously mentioned, more accurate distribution algorithms including multiple and/or specular reflections may be applied but the motivation for the present methodology is (a) to provide improved accuracy and physical basis compared to the absorptance-weighted area ratio method, (b) to include geometrical characteristics of the enclosure walls and openings such as area, relative position and distance, (c) to account for the incident solar radiation on each of the multiple openings, as a function of geographical location of the building and the opening's orientation relative to the diurnally varying position of the sun and (d) to retain simplicity in form, implementation and computational effort.

In the next section, the proposed numerical methodology is described, followed by information concerning the test case building configuration and the whole simulation process. Results and comparison of the two approaches are presented for two different

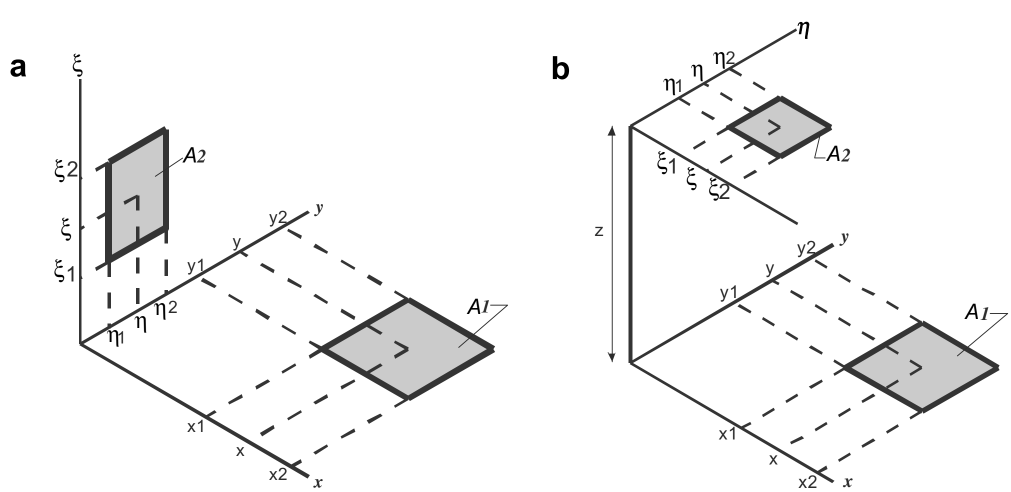


**Fig. 1.** Schematic diagram of perpendicular (a) and parallel (b) rectangular surfaces.