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Solar heat gains and operative temperature in attached sunspaces

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ABSTRACT

Solar heat gains obtainable from attached sunspaces to air-conditioned rooms are evaluated by means of the solution to the optical problem of incident solar radiation absorption through the windows and of the temperature field in the shell separating the sunspace from outdoors and adjacent spaces. The effective absorption coefficient of the sunspace was used for these evaluations as well as the ratio of the absorbed energy of the internal surfaces to the solar energy entering, and the utilization factor of the solar contributions that represent the fraction of the absorbed energy supplied to the indoor air. With reference to a pre-established geometry and to a system of windows made up of clear double-glazing, the solar gains of the sunspace and the adjacent spaces are calculated for some Italian localities at variation of exposure, optical properties and thermal capacity of the opaque surfaces, the amount of ventilation and of the shading device. Finally, the operative temperature was determined for an estimate of comfort acceptability conditions in the sunspace.

1. Introduction

Sunspaces are a very interesting architectonic solution from an energy point of view since by means of the use of solar radiation they allow energy benefits to be obtained for adjacent spaces in terms of the reduction of winter energy demand and the extension of usable space in conditions of acceptable thermal comfort for the occupants [1]. These types of sunspace are delimited by opaque walls, all or partly belonging to an adjacent building, and by windows which can be considered without thermal inertia, subject to the radiant solar load, to atmospheric infrared radiation and to the temperature variations of the outdoor air [2]. These forcing agents make the microclimate inside the sunspace greatly dependent on that outdoors. In most cases the sunspace constitutes a passive non-air-conditioned solar system, that is there are no energy contributions from the plant. The sunspace can be subject to ventilation flows and it is configured as an open thermodynamic system that has energy and mass exchanges with the outdoor surroundings and the adjacent spaces. The control of mass and energy flows through the building shell, obtained by adequate ventilation and radiation shading strategies [3], allows the optimization of the solar contributions, reducing the energy demands of the adjacent building and at the same time creates acceptable thermal conditions inside the sunspace. In this regard, it should be pointed out that the sunspace cannot be evaluated from the point of view of thermal comfort with the same criteria as an internal space, in accordance with the provisions of UNI EN ISO 7730 [4], but as a space in which the temperature is not constant but variable in an acceptable interval centred around the building reference temperature and of changeable range on a monthly basis.

The determination of both the climatic conditions inside the sunspace and the energy gains for the adjoining rooms requires the evaluation of the solar gains in the sunspace, which is a purely optical problem, and of the thermal exchanges through the envelope elements in dynamic regime.

The solar radiation transmitted through the glazed shell is partly absorbed by the opaque and glazed walls, some is lost to the outside through the same glass and a part is transmitted to the adjacent rooms through the glazed separation elements.

To determine the radiative field in the sunspace, it is necessary to consider separately the direct and diffuse radiation transmitted. The absorption of diffuse radiation is evaluated by solving a system of equations obtained by directly applying the definition of radiance, being able to consider the surfaces to be uniformly diffusing, or in an approximate mode by determining the solid angle between the glazed surfaces and internal surfaces, or by distributing the incoming radiation in proportion to the area of internal surfaces for their absorption coefficients [5].

The absorption of direct radiation requires a more accurate model to determine the areas that are directly illuminated, which act as directional sources of reflected radiation. The latter aspect is difficult to model because it requires knowledge of the optical

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directional properties of the reflecting surfaces, which are generally not known. For this reason, the reflected radiation is treated as an isotropic diffuse radiation.

In addition to the optical field in the solar band, to determine the solar gain in sunspaces and adjacent rooms the dynamic thermal field in the walls of the sunspace shell should be resolved and the energy imparted to the internal air should be evaluated. The resolution of the thermal field requires the definition of the convective and far infrared radiative boundary conditions.

In literature there are contributions in which the optical or thermal aspects are developed by adopting simplifying assumptions. In some the directional effects of the direct incoming radiation are not considered, in others the energy absorbed by the walls of the sunspace is considered completely ceded to the internal air. In general, the analysis is not accompanied by assessments on the comfort conditions when using the sunspace.

A presentation of the most widespread models for calculating the optical behavior of the sunspaces and a comparison between the energy solar fractions absorbed, transmitted to the adjacent room and lost to the outside, is given in Ref. [6]. The article highlighted the effects produced by different evaluations of the absorbed energy provided by the models on the air temperature in the sunspace and on the energy demand for summer cooling and winter heating in the case of an air-conditioned sunspace. The latter estimates are obtained considering the solar energy absorbed as completely transferred to the internal air of the sunspace.

A case study aimed to investigate the effects of an attached sunspace on a building with no air-conditioning, in different climatic conditions, is given in Ref. [2]. The effects of the sunspace presence on the air temperature of the adjacent building are evaluated by a dynamic code that does not consider the directional aspects of the incoming radiation.

In the analysis the energy contributions are not highlighted directly in winter and in summer the problem of overheating is examined by several passive techniques.

The optical aspects related to the absorption of solar radiation are treated in Ref. [7]. The optical and geometrical variables which determine the phenomenon of absorption are highlighted by a detailed parametrical study. This analysis is used for the formulation of certain correlations for calculating the effective absorption coefficient of the incoming solar radiation. The correlations allow monthly evaluations of solar energy absorbed by the walls of the sunspace with different geometry, exposure and optical properties of opaque and glazed surfaces, in the study thermal behavior has not been investigated.

In other theoretical and experimental studies simulation models of the thermal behaviour of attached sunspaces have been proposed and validated. In particular in Ref. [8] radiative exchanges in the long infrared and the distribution of solar radiation in the sunspace have been considered while in Ref. [9], by means of a sensitivity analysis, the parameters which mainly influence the thermal behaviour of the sunspace have been considered.

This article addressed the problem of the energy performances evaluation of sunspaces with reference to a non-air-conditioned sunspace bordered by two rooms, one adjacent and another below, both air-conditioned. In the optical analysis the effective absorption coefficient α_e has been used to assess the solar energy absorbed by the internal surfaces of the sunspace, determined considering the directional aspects of the incoming radiation.

The analysis of heat transfer through the envelope led to the introduction of some performance parameters relevant to the assessment of the energy in the sunspace and in the adjacent rooms.

With reference to the absorbed solar energy, the following have been defined: the solar energy utilization factor η_u, to assess the fraction transferred by convection to the air of the sunspace; the utilization factor $\eta_{u,v}$ to evaluate the energy fraction removed by the ventilation flow rate; and the effective utilization factor $\eta_{u,v}^{\text{eff}}$ associated to the ventilation to determine the energy fraction usable for the winter heating of the adjacent rooms.

The schematization used to describe the behavior of the sunspace consents the evaluation of the energy absorbed from the internal surfaces, the energy transferred to the sunspace air in absence and in presence of ventilation and the contribution to the energy requirement reduction of the bordering rooms if using the ventilation flow rate coming from the sunspace from the entering energy.

2. Methodology

This paper evaluates the behaviour of sunspaces in free evolution conditions, that is without the thermal contribution of plants, by means of the solar radiation transmission coefficient through the glazed surfaces, the effective absorption coefficient which qualifies the collection capacity of entering solar radiation [7] and the utilization coefficient that supplies the absorbed energy fraction of the walls given to the indoor air of the sunspace owing to convection. Moreover, the solar contributions to the adjacent spaces through the opaque partition walls are evaluated and the energy contribution obtainable from the ventilation flow rate that heats the sunspace when crossing it. In calculating the solar contributions it is supposed that the reduction coefficients due to shading, curtains and frames are unitary [10]. With the purpose of thermal comfort in the sunspace reference is made to the operative temperature that is the parameter used in the theory of "adaptive comfort" of Dear and Brager [11].

For these evaluations the dynamic simulation programme DEROB-LTH (Dynamic Energy Response of Buildings) [12] was used, originally developed at the Numerical Simulation Laboratory of the Architecture School of the University of Texas at Austin [13] and successively perfected by the Technology Institute of Lund in Sweden (DEROB-LTH v1.0, 2004) [14]. It is to be highlighted that the results obtained by the DEROB-LTH code, concerning the thermal behavior of sunspaces, were subjected to experimental verification [15].

The simulation code DEROB-LTH solves the problem of solar radiation transmission through the glazed shell by applying the Fresnel formalism [16]; the absorption of the entering radiation in the sunspace is evaluated taking into account directional aspects of the beam radiation, and the temperature field in the opaque and glass walls is obtained by integrating the conduction equation with the relative boundary conditions using the finite difference method. To this aim the adjoining spaces, one adjacent to the vertical wall and the other below the floor, are considered air-conditioned and provided with a control system that intervenes when the indoor air temperature is less than 20 °C in winter heating, and more than 26 °C in summer cooling.

Reference is made to the geometry of Fig. 1 with the glass system made up of a glazed space with 4 mm clear double-glazing and 12 mm air gap, the vertical wall is 32 cm thick and has two layers of brick separated by an air cavity filled with 3 cm insulation, it has a thermal transmittance $U_w = 0.553$ W/m^2 K and a heat capacity $C_w = 241.7$ kJ/m^2 K. The floor slab made of brick-cement is also 32 cm thick, it has 4 cm of insulation laid under the block in contact with the floor and a thermal transmittance $U_f = 0.573$ W/m^2 K and a heat capacity $C_f = 185$ kJ/m^2 K.

The thermal behaviour of the sunspace was simulated for a whole year, data for normal direct solar radiation, of the diffuse radiation on the horizontal plane and the external air temperature were obtained through a generation procedure contained in Type