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The use of sunspaces in Portugal

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Abstract

In this paper, a study related to the use of sunspaces within five Portuguese locations (Porto, Bragança, Lisboa, Évora and Faro) is presented [1]. A sunspace model was developed by using the ESP-r (Environmental System Performance-research) simulation program [2] and it was therefore possible to relate the sunspaces envelope features to the energy consumption and thermal comfort conditions inside adjacent rooms. In winter, the attachment of sunspaces may reduce significantly energy consumption and lead to increasing thermal comfort, as long as the tilt and orientation of the sunspace glazing become optimised. The best tilt for Portuguese climate revealed to be between 50 and 70° for south oriented glazing. It was impossible to distinguish the glazing tilt according to latitude. Concerning sunspace to living room volumetric ratio, it is possible to built between 1:5 (Bragança) and 1:13 (Faro), in order to ensure thermal comfort inside adjacent room. During summertime, the application of shading and ventilation strategies to sunspaces pointed out to be peremptory, for the establishment of thermal comfort conditions inside adjacent spaces. The cooling strategy that has lead to larger maximal temperature reductions was the shading of non ventilated sunspaces (approximately 3.8°C). Nevertheless, the most efficient cooling strategy is the simultaneous application of shading and natural ventilation (with maximal temperature reductions of 4-5°C).

INTRODUCTION

Architecture of Transparency: Sunspaces Over the Centuries

During centuries, sunspaces have been a fundamental indoor space, allowing transition between the inside and the outside. Although its undeniable importance in providing good shelter for plants and leading to the growth of fruits outside of its natural environment, only in our days, architects and engineers began to associate sunspaces with energy savings and thermal comfort. Thus, the sunspace's appearance was a fundamental consequence of the energetic crises that took place in 1970 [3].

The first sunspace sketch, namely the *lapis specularis* stoves began to be built during the roman empire and were associated to fruits conservation in a distinct environment [4]. The "greenhouse effect" was already known and used by Romans as a supplementary heating source for the *caldarium* [5]. However, it was not until the Renaissance, that the original ancestor of the sunspace finally emerged. The *Botanical Garden*, that appeared for the first time in Pisa, in 1543 [4] soon become spread all over Europe. The huge and magnificent botanical gardens exhibit unusual exotic plants and were adopted by public institutions and private owners. Purchasing a private sunspace was an attribute of aristocratical extravagance, a necessary good for the social integration of important individuals. Decay of sunspaces along history was almost always associated with bankruptcy of families that owned them.

During the Industrial Revolution, the development of glass and iron industries convey to a widespread of sunspaces across the UK and among all people, disregarding their social background. Furthermore during this period, in France, the idea of a common residence for people and plants was the result of a profound cult and admiring of Nature, relying on a Romantic essence.

The XX[th] Century Expressionists argued, that the transparency of Architecture should be a mirror of social thought's transparency. Therefore, everything ought to be built with a high grade of physical transparency: people believed in the extermination of evil by means of contemplating the beauty of transparency.

Nowadays, sunspaces became not only a useful shelter for plants, but are also important living spaces, allowing comfort and well-being to owners and plants.

Sunspaces in Portugal

Sunspaces have not been largely integrated in Portuguese Architectural Design. Only a few examples of these systems can be found among all the passive solar houses built in the past few years. The reason for this tendency is quite obvious: summer in Portugal is extremely warm.

Some sunspace buildings have been identified and studied during a project denominated *Thermal Characterisation of Passive Solar Construction in Portugal* [6]. All the identified sunspaces have following common features: single south oriented glazing and high glazing to floor surface ratio (between 60% and 250%).

METHODOLOGY

Sunspace Thermal Model

The thermal behaviour of a building with an attached sunspace has been numerically simulated using Esp-r program (fig.1). An attached sunspace is characterised by having only the north wall in common with the remaining building zones [7]. The only sunspace glazed surface of the thermal model is south oriented, whilst the volume ratio between sunspace and living room was assumed to be 1:5.

The ratio between sunspace single glazing and living room floor area is 23%. Building envelope is characterised by the following heat transmission coefficients (U-values):

Table 1. Building Envelope U-values

Building Element	Description	U (W/m²K)
Ext. walls	double brick (11+15 cm)	0.6
Ceiling	insulated concrete (16 cm)	0.3
Floor	insulated concrete (20 cm)	0.4
Int. wall	concrete (30 cm)	2.7

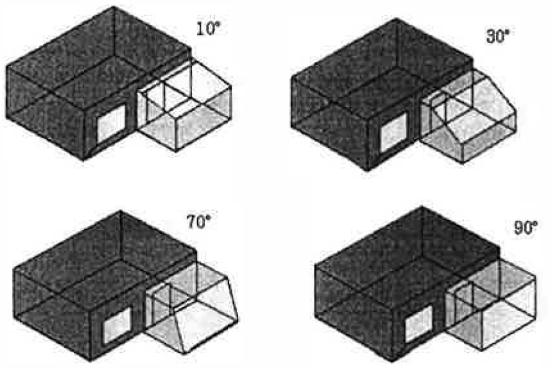

Figure 1. Winter sunspace model

The sunspace model was based on a calibration study undertaken by comparing measurements and predicted simulation results in *Vale Rosal* [1].

Living room and attached sunspace were assumed unoccupied during the whole year and with ventilation and infiltration schedules stated in fig.2.

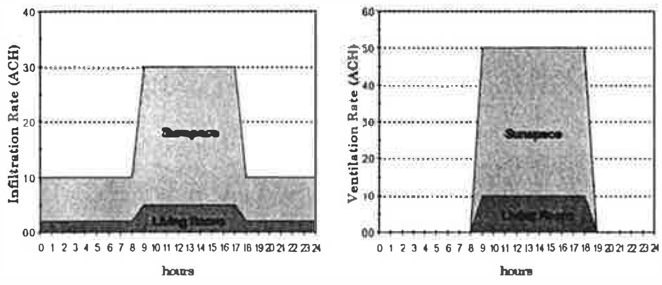

Figure 2. Infiltration and ventilation rate profile (ACH)

In winter, the months of November to March have been chosen as reference months, while, in summertime, June to September period has been selected. Numerical simulation has been carried out using, as input data, the Reference Year [8] for Lisbon, measured hourly values of external air temperature, solar radiation, relative humidity and wind speed for Évora and hourly generated data using a library of Markov Transition Matrices [9] for the remaining locations. Climatic data (mean monthly temperature and mean radiation for the whole winter) are shown in fig.6.

In summer, simulation conditions included the closing of living room external blinds and the activation of sunspace openings, promoting natural cooling. Therefore, a stratified sunspace model was introduced (fig.3) and the mass flow module (mfs) of ESP-r Program used to simulate natural ventilation. The mfs is based upon the *Zonal Method* [10], which consists in associating a node to each building zone. A non-linear equation set for mass conservation at each internal node is solved, in order to obtain pressure inside all building zones, by the Newton-Raphson Technique [11].

Summer protection was modelled considering a material with thermal and optical properties of vegetation coupled with glazing, as propose by Krause [12].

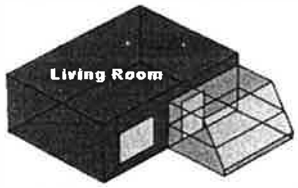

Figure 3. Summer sunspace model

Simulation Methodology

In order to study only the influence of different glazing tilts in winter, volumetries of both, sunspace and living room, were held constant, while varying tilt. Therefore, since wall areas also vary, a conservative hypothesis has been made by assuming equal heat fluxes crossing the sunspace and adjacent room boundaries in and out. Only the sunspace glazing and living room ceiling and south wall were influenced by climatic data, since its surface does not vary.

Simulations were performed, considering a constant sunspace volume, while the one of the living room was varying, in order to obtain different sunspace to living room volume ratios. Since infiltration and ventilation rates, as well as direct gain to floor area ratios become different across the simulations, these parameters were set to zero. So, it is possible to isolate only the influence of volumetry.

During Summer, it is important to deactivate the sunspace. Hence, four cooling strategies were performed:
1. Ventilation of non-shaded sunspaces;
2. Ventilation of shaded sunspaces;
3. Shading of non-ventilated sunspaces;
4. Shading of ventilated sunspaces

The main conclusions are drawn and discussed assuming three variables: internal temperatures (mean and mean daily maximal and minimal), energy consumption and degree day of discomfort [13].

In order to compare heating demands among the five locations, energy consumption was obtain by imposing a constant temperature control, considering a reference comfort level temperature for unoccupied zones kept at 15°C, as given by Portuguese Standards - RCCTE [14].

Degree Day of Discomfort (DDD) was calculated according to Oliveira and Maldonado [13]

$$DDD=\int_{\Delta t}(T_{comf,min}-T)dt$$

for the whole heating season, considering as reference level the neutral temperature given by Humphreys correlation for free running buildings, under unsteady conditions [15, 16], for each month and according to location:

$$T_{comf} = 0.53T_m + 11.9 \qquad (R^2=0.95)$$

where T_m represents the mean external temperature of each month.

Results were obtained for the living room; thermal comfort inside sunspace was considered to be a secondary issue, since occupation of the space is assumed transient.

RESULTS

WINTER PERFORMANCE

Sunspace Glazing Tilt

As can be seen from the underlying graphs, in Portugal, south oriented glazing should have a tilt between 50 and 70°, in order to minimise heating demands, while increasing simultaneously inside thermal comfort. However, one may adopt a tilt of 90° without inducing a considerable increase in energy consumption or decrease in inside temperature.

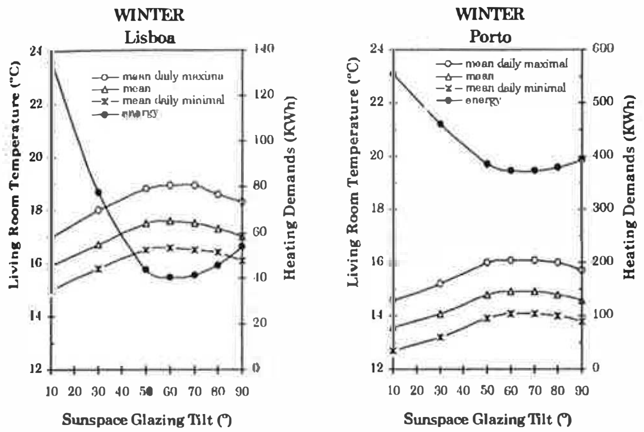

Figure 4. Sunspace glazing tilt variation (Lisboa, Porto)

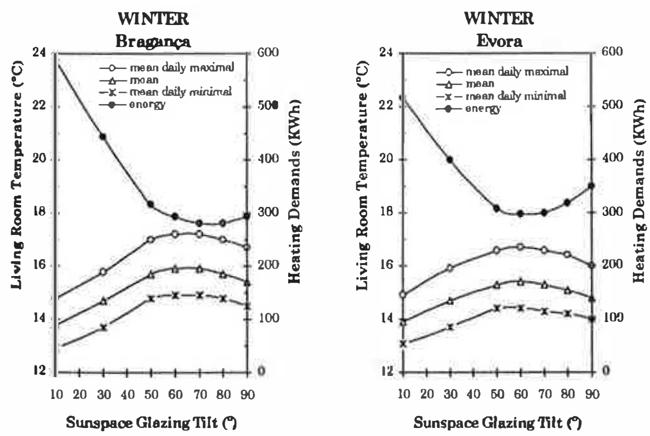

Figure 5. Sunspace glazing tilt variation (Bragança, Évora)

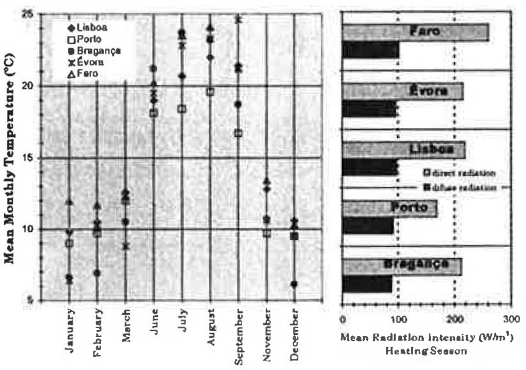

Figure 6. Climatic Data (Mean Radiation and Temperature)

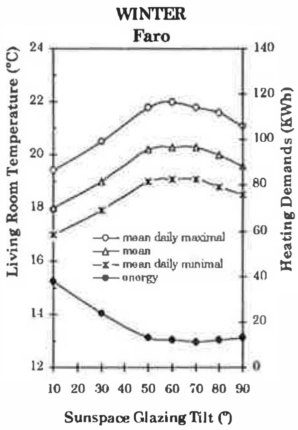

Figure 7. Sunspace glazing tilt variation (Faro)

For the five locations, the attachment of sunspaces lead, in the adjacent room, to the following heating energy savings:

1. Lisboa: 149 kWh
2. Porto: 121 kWh
3. Bragança: 210 kWh
4. Évora: 217 kWh
5. Faro: 37 kWh

Degree Day of Discomfort analysis shows the same evolution tendency for tilt values as before. An additional study announces, that the integration of sunspaces in buildings (considering the exposed simulation conditions) is always of advantage, since it decreases discomfort.

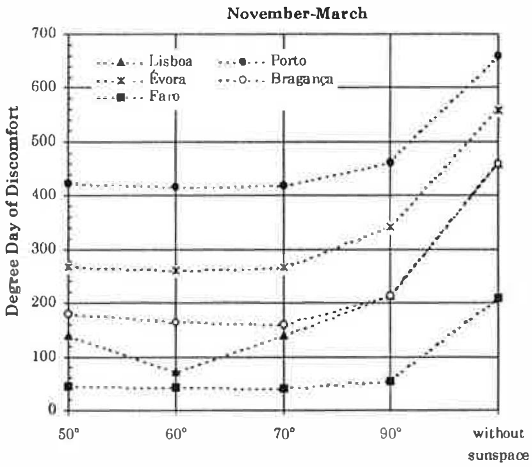

Figure 8.Sunspace tilt and Degree Day of Discomfort

Sunspace to Living Room Volumetric Ratios

Results presented refer to extreme Portuguese locations (Bragança and Faro) and state that, in order to ensure inside 15°C temperature, it is possible to built until sunspace to living room ratios of 1:13 in Faro and 1:5 in Bragança.

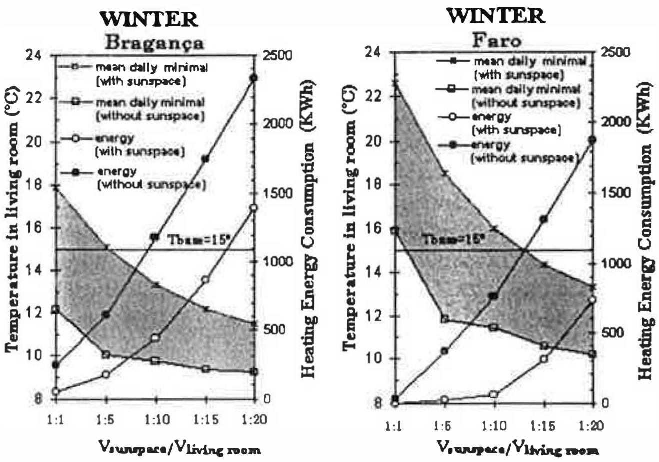

Figure 9. Temperature and energy consumption inside living room

SUMMER PERFORMANCE

Ventilation rates inside sunspace and adjacent room, as given by mass flow simulation module, are stated bellow in tables 1 and 2. Comparing the obtain values, it is possible to realise that they do not vary significantly for the five locations.

Table 2. Mean Ventilation Rates inside Sunspace (ACH).

Month	Porto	Bragança	Lisboa	Évora	Faro
June	4.5	4.3	4.7	5.4	4.2
July	4.5	4.3	4.8	6.3	4.1
August	5.0	4.8	5.1	5.8	4.7
September	5.7	5.2	5.3	5.3	5.5

Table 3. Mean Ventilation Rates inside Living Room (ACH).

Month	Porto	Bragança	Lisboa	Évora	Faro
June	1.5	1.6	1.2	1.6	1.6
July	1.4	1.5	1.4	1.5	1.5
August	1.4	1.5	1.6	1.5	1.5
September	1.3	1.3	1.7	1.6	1.3

Without any cooling strategy, mean daily maximal temperatures obtained inside of the living room are 25°C for Porto, 27°C in Lisboa and 28°C in Bragança, Évora and Faro. Therefore, vegetation cover and natural ventilation of sunspace were introduced, in order to improve summer performance of this building. Results of four cooling strategies related to a base case, where no strategy is applied, are presented in table 3 for the living room. An aperture control was established between sunspace and living room. This way, the door that connects them will open only if temperature inside sunspace is lower than the one inside living room, in order to improve cooling process.

As can be seen, shading of non-ventilated sunspaces is the cooling strategy that most decreases maximal temperature (3.8°C). Ventilation alone leads mostly to a decrease of minimal temperature (2.1°C), while maximal temperature assumes the mean value of 1.6°C. If sunspaces are already shaded, ventilation has little effect on temperature value, leading to a mean daily maximal temperature decrease of 0.7°C.

CONCLUSIONS

From the results above, it is possible to draw the following conclusions:

1. The existence of sunspace represents always a thermal benefit. Energy savings in winter are more important in colder locations, such as Évora and Bragança.
2. The ideal tilt for a south oriented sunspace glazing is between 50 and 70°. Nevertheless, architects may adopt a 90° glazing tilt without relevant increasing in energy consumption or thermal discomfort. It turned out to be impossible to differentiate glazing tilt according to latitude, since this interval reveals to be short for Portugal.
3. The variation of sunspace to living room ratio for two Portuguese extreme locations showed, that a minimal standard comfort temperature may be ensured, provided that the mentioned ratios lie between 1:13 in Faro and 1:5 in Bragança.
4. In summer, ventilation strategies alone are not very efficient in reducing maximal temperatures in Portuguese climate. This is due to the little effect of night ventilation. Thus, it is always necessary to avoid the entrance of direct radiation inside the sunspace, using an appropriate solar protection, such as vegetation cover.

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Table 4. Cooling Strategies and Temperature (°C) Evaluation inside Living Room

	Ventilation of non-shaded sunspaces			Ventilation of shaded sunspaces			Shading of non-ventilated sunspaces			Shading of ventilated sunspaces		
Location	$\Delta\bar{T}_{max}$	$\Delta\bar{T}_{med}$	$\Delta\bar{T}_{min}$	$\Delta\bar{T}_{max}$	$\Delta\bar{T}_{med}$	$\Delta\bar{T}_{min}$	$\Delta\bar{T}_{max}$	$\Delta\bar{T}_{med}$	$\Delta\bar{T}_{min}$	$\Delta\bar{T}_{max}$	$\Delta\bar{T}_{med}$	$\Delta\bar{T}_{min}$
Lisboa	1.6	1.8	2.2	0.5	0.7	1.0	3.9	3.8	3.9	2.8	2.7	2.6
Porto	1.7	2.0	2.3	0.7	0.8	1.2	3.9	3.8	3.7	2.8	2.7	2.6
Faro	1.4	1.7	2.1	0.5	0.7	1.0	3.6	3.6	3.6	2.7	2.6	2.5
Bragança	1.5	1.8	2.0	0.5	0.7	1.0	3.7	3.7	3.5	2.7	2.6	2.5
Évora	1.6	1.7	2.0	0.5	0.7	1.0	3.8	3.7	3.6	2.7	2.7	2.6