Solar contribution evaluation for building attached sunspace in the Mediterranean climate

G. Oliveti, M. De Simone and S. Ruffolo
Mechanical Engineering Department, University of Calabria, Italy

ABSTRACT

A glazed space adjacent to an air-conditioned room is an innovative architectural solution to use the energy contribution of solar radiation in the winter and in the intermediate months, whereas in the summer adequate shading systems are needed. The sunspace is separated from the said room by a wall, generally in part opaque in part glazed, which acts as a collection system and directly removes the solar energy to the internal room through the glazed surface, and indirectly through the opaque surfaces.

Some models are available in literature for the evaluations of the solar gain for some types of sunspace-building with performance evaluations relative to Northern European climatic conditions and to the heating season (Wall, 1995).

This paper, with reference to the most simple geometry made up of a glazed box fronting on a room, reports the solar contribution for a locality in the Mediterranean area. A parametric analysis has been developed that points out the dependence of the solar contribution on the glass surfaces composing the box, on the glass surface-opaque surface ratio of the intercepting wall, glass type, optical properties of the opaque surfaces and on the orientation. For some geometries the monthly variability of the solar contributions has also been pointed out. The evaluations were carried out with the dynamic simulation program DEROB-LTH, which models the optical and thermal behaviour of the glass surfaces with great accuracy, evaluating the angular aspects of the incident solar radiation and the radiative field of the solar and infrared band (Arumi-Noè, 1979).

The aim is to verify, for the Mediterranean climate, the collecting capacity of this collection system in comparison with an ordinary opaque wall provided with windows.

1. INTRODUCTION

The use of large glazed surfaces is increasingly widespread in modern architecture. Glazed surfaces are effective aesthetic elements and can contribute to energy saving in buildings by optimising the collection of solar radiation. The importance of evaluating the energy really collected through the transparent surfaces is evident, with the aim of calculating correctly the energy load of the building both during the heating and the cooling season. The calculation procedures applied by the standard (Cardinale and Ruggiero, 2000; Oliveti et al., 2004; UNI EN 832, 2001) and those implemented in the majority of simulation programs (Wall, 1997), evaluate the solar radiation fraction effectively collected by glazed systems in a simplified way. These procedures do not consider that, when the glazed surfaces of the building are quite large compared to ordinary windows, multiple reflectance phenomena have to be taken into account which determine the loss of a non-negligible portion of radiation to the outside. The phenomenon is evident in attached sunspaces, generally made up of several glazed surfaces. The solar energy effectively collected by these systems influences the energy balance of the room with which the sunspace communicates. Solar radiation absorbed by a space depends on its geometry, on the optical properties of the glazed and opaque surfaces. The absorptance is also connected to the angular aspects of the solar radiation which becomes evident at variation of the exposition of the collecting surfaces and of the period of the year. To evaluate the absorption capacity of a space the absorption coefficient α is introduced, defined as the ratio of solar energy absorbed by the space and that entering through the glazed surfaces that separate them from the outside.

The calculation of these energies was carried out using the dynamic simulation program DEROB-LTH (Dynamic Energy Response of Buildings) (Arumi-Noè, 1979). The DEROB code was originally developed at the Numerical Simulation Laboratory of the School of Architecture of the University of Texas at Austin and further developed at the Department of Building Science at Lund Institute of Technology, Sweden with the name of DEROB-LTH. The program requires some input data of the geometric description of the building, the thermal and optical properties of the opaque walls and of the transparent surfaces, the climatic data regarding the locality under consideration. DEROB-LTH calculates the solar energy absorbed by a space for every hour of the specified simulation period. The evaluations are obtained starting from the normal direct radiation I_N and from the diffuse component on the horizontal plane I_{DH}. The model takes into account the position of the sun, which the portion of the effectively lit collecting surfaces depends on, and of the presence of any shading.

Direct radiation interacts with the frontal wall and is reflected as diffuse radiation from the opaque surfaces, while one of its components is transmitted as direct from transparent surfaces. Diffuse radiation I_{DH} is considered isotropic and transmitted through the windows as diffused (Kallblad, 1998). The redistribution of solar radiation among the surfaces of the volume that are not originally struck by the radiation is carried out by the calculation of the illumination tensors J. The illumination factor J_{ij} represents the fraction of radiation arrives at surface i from surface j, taking all the reflections into account.

A part of the redistributed radiation escapes from the volume to the outside through the transparent surfaces (Arumi-Noè, 1979).

The transmittance coefficient of solar radiation is calculated by applying the Fresnel equations and the Snell laws, the thickness of each glazed element, the refraction index and the extinction coefficient all being known.

In literature there are methodologies available aimed at evaluating the energy convenience of sunspaces in areas of North Europe with the aim of maximising the solar radiation absorbed, since it is scarce. These studies have pointed out the importance of the geometry of the sunspace-building system, of the type of glazing and of the absorptance of the opaque surfaces of the volumes (Wall, 1995).

With the aim of obtaining evaluations relative to the Mediterranean climate, the analysis illustrated in this paper was conducted for the town of Cosenza (South Italy, Latitude 39°18', Longitude 16°15') whose climatic data, normal direct solar radiation I_N and diffuse radiation on the horizontal plane I_{DH}, were obtained by using a generation procedure contained in Type 54 of the TRNSYS code, which generates hourly data starting from mean monthly values (UNI 10349, 1994). The data obtained in this way has statistical values approximately the same as the long-term statistical values of the place under consideration (TRNSYS 15.0, 1996). The collection properties of a single box were studied varying the size of the glazing on the frontal wall from 20% to 100% and the number of glazed surfaces. Successively the sunspace-room was considered.

The reference building typology consists of a communicating room, through a glazed surface of variable size, with a glazed space whose transparent surfaces can be laid out in different ways and with varied orientation. The geometry of the sunspace-building system is shown in Figure 1.

2. THE GLAZED BOX

The 10 configurations analysed are shown in Figure 2.

All the evaluations were conducted considering a single clear glass with a thickness of 4 mm, successively an analysis was carried out using double-pane window with two clear glass.

The glazed-space was oriented to the South, East and North. The western exposition is equivalent to the eastern. A simulation period of a year was considered, starting from hourly values of the absorption coefficient α the mean monthly values were obtained. The evaluations

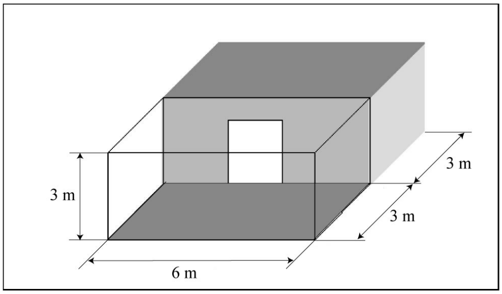

Figure 1: Sunspace-room system.

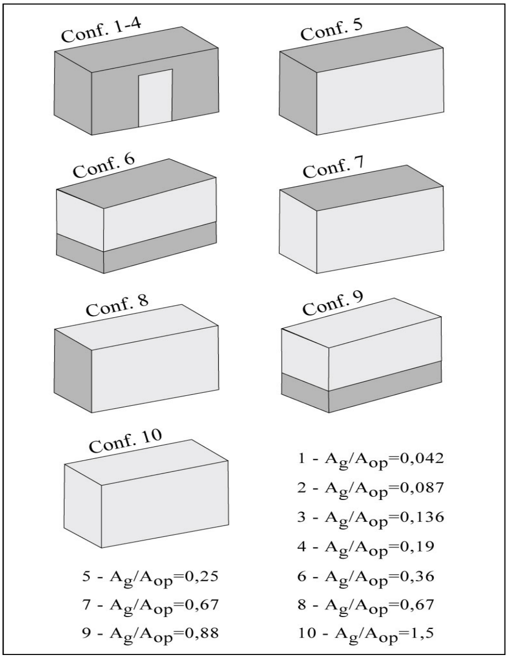

Figure 2: Configurations of the glazed box considered and values of the glass surface-opaque surface ratio A_g/A_{op}.

were achieved by considering the different absorption coefficients of the opaque surfaces. Specifically, 16 different combinations were studied, obtained by coupling variable values between 0,2 and 0,5 of the absorption coefficient of the vertical walls α_w and of the floor α_f.

2.1 Monthly variability of the absorption index

For the southerly exposition a considerable monthly variability of the absorption coefficient was not recorded for configurations 1-8 shown in Figure 2. This consideration is not valid for configurations 9 and 10 which have glazed surfaces on the three differently orientated sides and on the roof. For the latter a monthly variability of the absorption coefficient can be observed with a minimum value in June and a maximum in December. This deviation, equal to α_f, becomes more evident at an increase of the absorption coefficient of the vertical walls as shown in Figure 3.

This variability can not be found in the case in which $\alpha_f = \alpha_w$ (Fig. 4), while the inverse situation is found if $\alpha_f > \alpha_w$.

For geometries 9 and 10 the monthly variability depends on the height of the solar trajectory in the different months, which determines the incident energy directly on the floor and on the walls. In the case of $\alpha_f < \alpha_w$ the maximum deviation is obtained for the combination α_f = 0,2 and α_w = 0,5: for configuration 9 α_{June} = 0,5 was obtained and $\alpha_{December}$ = 0,56, while for configuration 10 α_{June} = 0,38 and $\alpha_{December}$ = 0,46. In the case in which $\alpha_f > \alpha_w$ the maximum deviation is obtained for the combination α_f = 0,3 and α_w = 0,2: for configuration 9 α_{June} = 0,41 and $\alpha_{December}$ = 0,36; for configuration 10 previous values become α_{June}= 0,34 and $\alpha_{December}$ = 0,30. These deviations are contained and therefore the absorption capacity of the box can be characterised through the mean monthly year values. The results obtained for all the configurations at

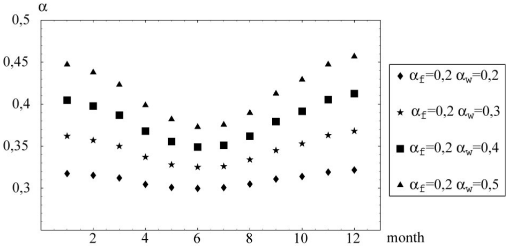

Figure 3: South exposition. Monthly variability of the absorption coefficient of the volume for the configuration 10 (α_f = 0,2 and variable α_w).

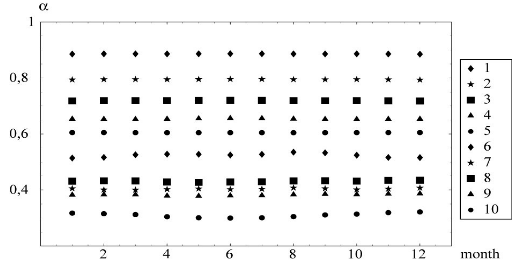

Figure 4: South exposition. Monthly variability of the absorption coefficient for the 10 geometric configurations considered (α_f = 0,2 and α_w = 0,2).

variation of α_f and α_w are shown in Table 1.

2.2 Influence of the geometry

For each geometric configuration the ratio was defined of the glazed to opaque surface area A_g/A_{op}. The values obtained are shown in Figure 2. The dependence of the absorption coefficient of the volume on this parameter is pointed out in Figure 5. At an increase in the ratio A_g/A_{op} the absorption coefficient of the volume decreases, because the dispersing surface increases.

Table 1: South exposition. Mean monthly year values of the absorption coefficient for all the configurations at variation of α_f and α_w.

α_f	α_w	Conf. 1	Conf. 2	Conf. 3	Conf. 4	Conf. 5
0,2	0,2	0,89	0,79	0,72	0,65	0,60
	0,3	0,92	0,84	0,78	0,72	0,68
	0,4	0,94	0,88	0,82	0,77	0,74
	0,5	0,95	0,90	0,86	0,81	0,79
0,3	0,2	0,91	0,82	0,75	0,69	0,64
	0,3	0,93	0,86	0,81	0,75	0,71
	0,4	0,94	0,89	0,84	0,80	0,77
	0,5	0,95	0,91	0,87	0,83	0,81
0,4	0,2	0,92	0,85	0,79	0,73	0,69
	0,3	0,94	0,88	0,83	0,78	0,75
	0,4	0,95	0,91	0,86	0,82	0,79
	0,5	0,96	0,92	0,89	0,85	0,83
0,5	0,2	0,93	0,87	0,82	0,77	0,72
	0,3	0,95	0,90	0,85	0,81	0,77
	0,4	0,96	0,92	0,88	0,85	0,82
	0,5	0,97	0,93	0,90	0,87	0,85

α_f	α_w	Conf. 6	Conf. 7	Conf. 8	Conf. 9	Conf.10
0,2	0,2	0,52	0,40	0,43	0,38	0,31
	0,3	0,59	0,46	0,50	0,44	0,35
	0,4	0,65	0,50	0,56	0,49	0,38
	0,5	0,70	0,55	0,62	0,53	0,41
0,3	0,2	0,55	0,44	0,44	0,39	0,32
	0,3	0,62	0,50	0,54	0,47	0,38
	0,4	0,67	0,54	0,59	0,51	0,41
	0,5	0,71	0,58	0,64	0,55	0,45
0,4	0,2	0,59	0,49	0,51	0,45	0,39
	0,3	0,65	0,53	0,57	0,49	0,42
	0,4	0,69	0,57	0,62	0,54	0,45
	0,5	0,73	0,61	0,67	0,57	0,48
0,5	0,2	0,62	0,53	0,55	0,48	0,42
	0,3	0,67	0,57	0,60	0,52	0,45
	0,4	0,71	0,61	0,65	0,56	0,48
	0,5	0,74	0,64	0,69	0,59	0,51

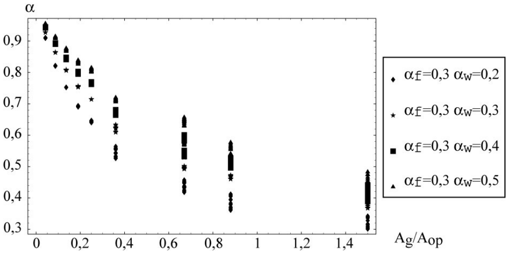

Figure 5: South exposition. Variability of the absorption coefficient of the volume with the ratio of the glazed to opaque area A_g/A_{op} ($\alpha_f = 0,3$ and variable α_w).

2.2.1 Presence of just one glazed wall

The effect attributable to the increase of window size is evident when the opaque surfaces are only slightly absorbent. Increasing the glazed area on the frontal wall (configurations 1-5) determines a decrease in α, maximum when the percentage of transparent surface goes from 20% to 40%. This difference decreases with the increase in the percentage of the glass surface (Fig. 4). On average with an increase of the percentage of glazed area by 20% there is a corresponding decrease of 9% in the absorption coefficient of the volume.

2.2.2 Presence of more glazed surfaces

Doubling the A_g/A_{op} ratio (as in cases 6 and 7) α decreases to a maximum of 23% (Fig. 4). A similar situation is occurs for configurations 7 and 10. Configurations 7 and 8 reveal the same A_g/A_{op} ratio but in the second case higher values of α can be observed (Table 1) since the presence of the transparent side surfaces facilitates energy loss to the outside.

2.3 Influence of the exposition

In cases in which the glazed surface is only located on the frontal wall (configurations 1-5) a substantial variation of the absorption coefficient is not observed at variation of the exposition, since the angular aspects of solar radiation are not recordable because of the small size of the glazed area compared to the opaque surfaces. Also for the East and North expositions the absorption coefficient of the volume remains constant at variation of the month. Orientating configurations 6-10 to the East, a decrease in α is obtained, compared to the values obtained for orientation to the South, only for the cases where there is a transparent roof (Figs. 4 and 6).

For exposition to the East the monthly variability is evident only for configurations 9 and 10. In the summer months higher values of α are recorded compared to the winter period, independently of the $\alpha_f - \alpha_w$ combination. The maximum deviation is on average 11%. For exposition to the North the values of α found are on average lower than 15% compared to those relative to a South exposition. The monthly variability becomes evident for all the configurations with more than one transparent surface and the maximum value for α is always found for the month of June.

2.4 Influence of the type of glass

The use of double pane window with two clear glass determines an increase in the absorption coefficient of the volume for all the configurations and expositions considered. This increase is evident for the configurations characterised by a high A_g/A_{op} ratio as shown in Figure 7.

3. THE GLAZED BOX AND THE ADJACENT ROOM

The geometries analysed are obtained by coupling configurations 6-10 of the glazed box in front of a room communicating with the glazed area by means of a variably-sized glazed surface (Fig. 8).

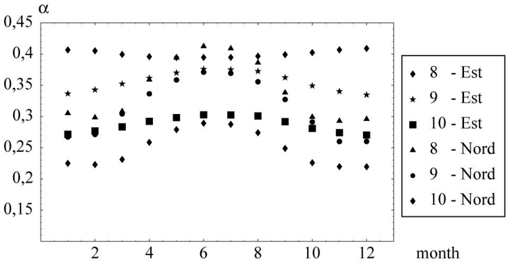

Figure 6: East and North exposition. Monthly variability of the absorption index for configurations 8-10 ($\alpha_f = 0,2$ e $\alpha_w = 0,2$).

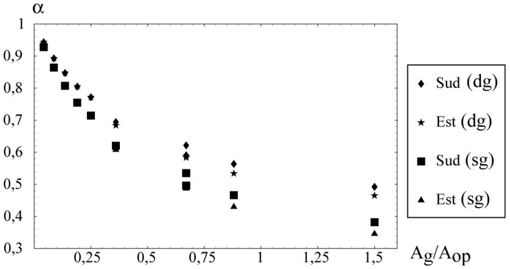

Figure 7: South and East exposition. Mean monthly year values of the absorption coefficient of the volume for the single (sg) and double (dg) glazing as a function of the Ag/Aop ratio ($\alpha_f = 0,3$ e $\alpha_w = 0,3$).

Simple clear glass was used both for the glazed surfaces of the sunspace and for the dividing wall.

The absorption coefficient of the glazed box α_b and that of the adjacent room α_r was calculated with the relations:

$$\alpha_b = \frac{\text{Energy absorbed by the box}}{\text{Energy entering the box}} \quad (1)$$

$$\alpha_r = \frac{\text{Energy absorbed by the room}}{\text{Energy entering the box}} \quad (2)$$

Their sum supplies the absorption coefficient of the sunspace-room system $\alpha_{b\text{-}r}$ which can be used for a comparison of the solar gain between a volume provided with traditional windowing (configurations 1-5 of the box) and the sunspace-building system.

The sunspace-building system was orientated to the South and the East, the North exposition was not considered, because it is not commonly used.

Considering all the configurations of the box, when the percentage of glazing on the dividing wall goes from 20% to 100% the absorption coefficient of the glazed box α_b decreases, on average, by 30%. The monthly variability is evident for all the combinations, in particular for the geometry (5+6) and (5+9) there is a monthly deviation of 28%. The monthly variability is evident also for the room, as shown in Figure 9. For the sunspace-room system the variability is more contained (Fig. 10). The overall absorption coefficient $\alpha_{b\text{-}r}$ is shown in Figure 10 for exposition to the South. The configuration (5+8) is that which gives the greatest monthly variability.

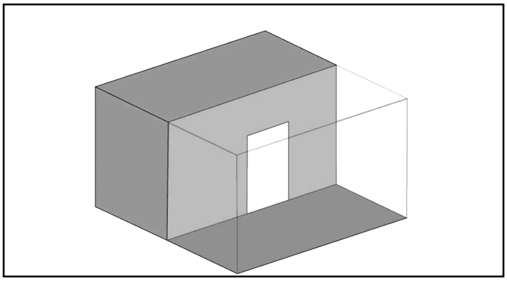

Figure 8: Sunspace-room system. Geometry (5+10).

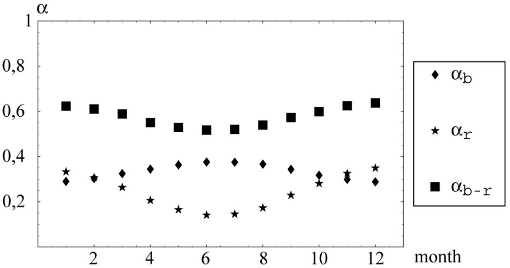

Figure 9: South exposition. Monthly variability of the absorption coefficient of the sunspace, the room, and of the sunspace-room system for the configuration 10 ($\alpha_f = 0,5$ e $\alpha_w = 0,5$).

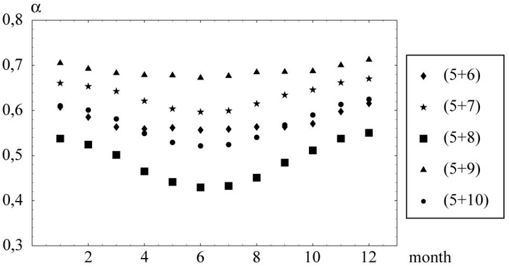

Figure 10: South exposition. Monthly variability of the absorption coefficient of the sunspace-building system for all the configurations ($\alpha_f = 0,3$ e $\alpha_w = 0,3$).

For exposition to the East the monthly variability is reduced and for the configuration (5+9) is 10% for the box, 19% for the room and 15% for the box-room.

In the parametric analysis the effects attributable to the absorptance of the opaque walls were also considered. Reference was also made to the most important geometry (5+10) made up of a completely glazed box separated from the volume by a transparent wall (Fig. 8).

The monthly variability for the box is contained for both expositions and, at parity of α_f it increases with the absorption coefficient of the vertical walls. For the room the monthly variability is accentuated, for $\alpha_f = 0,5$ and $\alpha_w = 0,5$ is of 60%. The optical properties of the opaque walls for the box have little importance compared to the room since they are small.

The monthly variability for the sunspace-building system is of 27% to the South in the case of $\alpha_f = 0,2$ and $\alpha_w = 0,5$, while for the East with $\alpha_f = 0,5$ and $\alpha_w = 0,5$ it is 15%.

4. CONCLUSIONS

The values of the absorption index of solar radiation were found for a single glazed box and for the compound box-room system, at variation of the layout and orientation of the sunspace, of the absorptance of the opaque walls, considering the glazed system composed either of a single clear pane or of a double pane.

10 configurations of the simple box and 25 configurations of the compound system were considered.

Analysis pointed out that the collecting capacity of solar energy of a volume depends mostly on the configuration through the ratio of the glazed to opaque area and on the optical properties of the surfaces. The absorption coefficient is only slightly influenced by exposition and by the month in the cases in which the glazed to opaque surface ratio is contained (configurations 1-5).

The angular characteristics of solar radiation for the other configurations create a monthly variability of the absorption coefficient that depends on the exposition, on the values that the absorption coefficient of the floor and of the opaque walls assume.

The variability field is wide and for the single box orientated to the South and East it is contained between 0,97, obtained for configuration 1 and for $\alpha_f = 0,5$ and $\alpha_w = 0,5$, and 0,31 for configuration 10 with $\alpha_f = 0,2$ and $\alpha_w = 0,2$. For exposition to the North the minimum value is reduced to 0,22.

On average, the effect of the double glazing provides and increase in the absorption coefficient of 10%.

For the combined box-room system orientated to the South the overall absorption coefficient, the sum of the absorption coefficient of the box and the room, does not exceed the value of 0,64 for the configuration (5+10) and with $\alpha_f = 0,5$ and $\alpha_w = 0,5$. For the exposition to the East it becomes 0,55.

From the results it emerges that the calculation of the solar contribution, in the energy analysis of buildings, must be carried out taking into account, in a suitable way, the typology and configuration of the glazed elements.

REFERENCES

Arumi-Noè, F., 1979. The DEROB System, Volume II, Explanatory Notes and Theory. Numerical Simulation Laboratoty, School of Architecture, University of

Texas Austin.

Cardinale, N. and F. Ruggiero, 2000. Energetic Aspects of bioclimatic buildings in the Mediterranean area: a comparison between two different computation methods. Energy and Buildings n° 31 pp. 55-63.

Oliveti, G., N. Arcuri, M. De Simone and S. Ruffolo, 2004. A calculation method of energy contributions in glazed systems in the air conditioning of buildings. International Conference AICARR 2004, Milan, March 3-4, pp. 961-979.

Kallblad, K., 1998. DEROB-LTH, Shading of Diffuse Radiation, Theoretical background. Department of Building Science, Lund Institute of Technology, University of Lund, Sweden.

Kallblad, K., 1998. DEROB-LTH, Thermal Model of Windows, Theoretical background. Department of Building Science, Lund Institute of Technology, University of Lund, Sweden.

TRNSYS 15.0, 1996. Reference Manual. University of Wisconsin-Madison.

UNI 10349, 1994. Heating and cooling of buildings. Climatic data.

UNI EN 832, 2001. Thermal performance of buildings. Calculation of energy use for heating. Residential buildings.

Wall, M., 1995. A Design tool for glazed spaces – Part I: Description. ASHRAE Transaction 101(1995) 1261.

Wall, M., 1997. Distribution of solar radiation in glazed spaces and adjacent buildings. A comparison of simulation programs. Energy and Buildings n° 26 pp. 129-135.