PERGAMON

Renewable Energy 19 (2000) 39–45

RENEWABLE ENERGY

www.elsevier.com/locate/renene

Experimental study of passive systems thermal performance

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Abstract

In geographical zones with a continental Mediterranean climate, the convenience of passive systems becomes doubtful, when one takes into account real thermal performance throughout the different seasons of the year. It is assumed that these systems stay shut down during summer thus avoiding undesirable solar gains. This study contributes answers to some questions about this topic by means of a comparative experimental analysis on the thermal performance of three passive systems (Massive/Trombe Wall, Direct Gain and Sunspace) and two traditional constructive systems (with/without low energy measures) for various situations (with/without night/day protection and ventilation) and climatic seasons (winter, summer and one neutral-times of spring and autumn). The measured variables are solar irradiance, outdoor temperature and indoor temperature taken from different points of the physical models. The applied procedures, technics and instruments are explained and some conclusions are drawn based on the obtained results.

Keywords: Passive systems; Experimental study; Thermal performance

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0960-1481/00/$ - see front matter
PII: S0960-1481(99)00013-0

1. Introduction

The developments in the application of principles corresponding to the so called 'low-energy' architecture have been worldwide spread, which is highly positive since they contribute to improve not only the environment but also the living quality of human beings. Nevertheless, these revised concepts relating to architecture are not free from exaggeration and error due to the scarcity of systematic studies of different statements that have been accepted [1]. The work presented here, faced in San Juan, Argentina aims to:

1. contribute on this research field according to principles stated by European scientists [2];
2. count, with measured values of passive and traditional systems, real thermal performance;
3. prove some constructive design improvements.

The zone has a continental Mediterranean climate, with short (2–3 months), moderate winter-time (average temperature between 8°C and 14°C) and long (4–5 months), hot summer-time (average temperature between 23°C and 32°C), which determines the need to carry out systems measurements throughout the seasons of the year, to compare their different thermal performance.

2. Physical models

Two identical physical units were built to carry out the experiment. Each one was a scale box with paralelepiped shape containing the volume unit, whose height was the greater dimension. The boxes' walls counted a high thermal insulation (U = 0.63 W/m^2 °C). The experiment comprised a vertical closure of a unitary brick surface facing north, measuring 18 × 30 × 7 cm (U = 2.58 W/m^2 °C), plastered on both sides for the Massive/Trombe Wall and Conventional studies, and having a transparent cover of 4 mm common glass (U = 5.80 W/m^2 °C) for the study of Direct Gain. Its interior and cut faces were thermally insulated from external conditions, exposing only one face to the outside and enclosing a unitary volume of air, which could gain or lose heat only through the experimental element. The Sunspace study was pasted to the massive north-facing wall.

In all the cases the box contained a wall and floor, as heat storage (20 cm thick and 3 m^2 surface area), made from the same material as the experimental element. The frames were built with metal sheeting, coated with anticorrosive paint and coloured white (U = 5.93 W/m^2 °C). They were designed in minimizing sections, so as to produce the least possible shading effect to the collection areas, including the ventilation and protection systems, and introducing constructive innovations in the experiment, possibly leading to a standardization of their application. The protection system consisted of a reinforced PVC rolling curtain (U = 1.42 W/m^2 °C), with manual control.

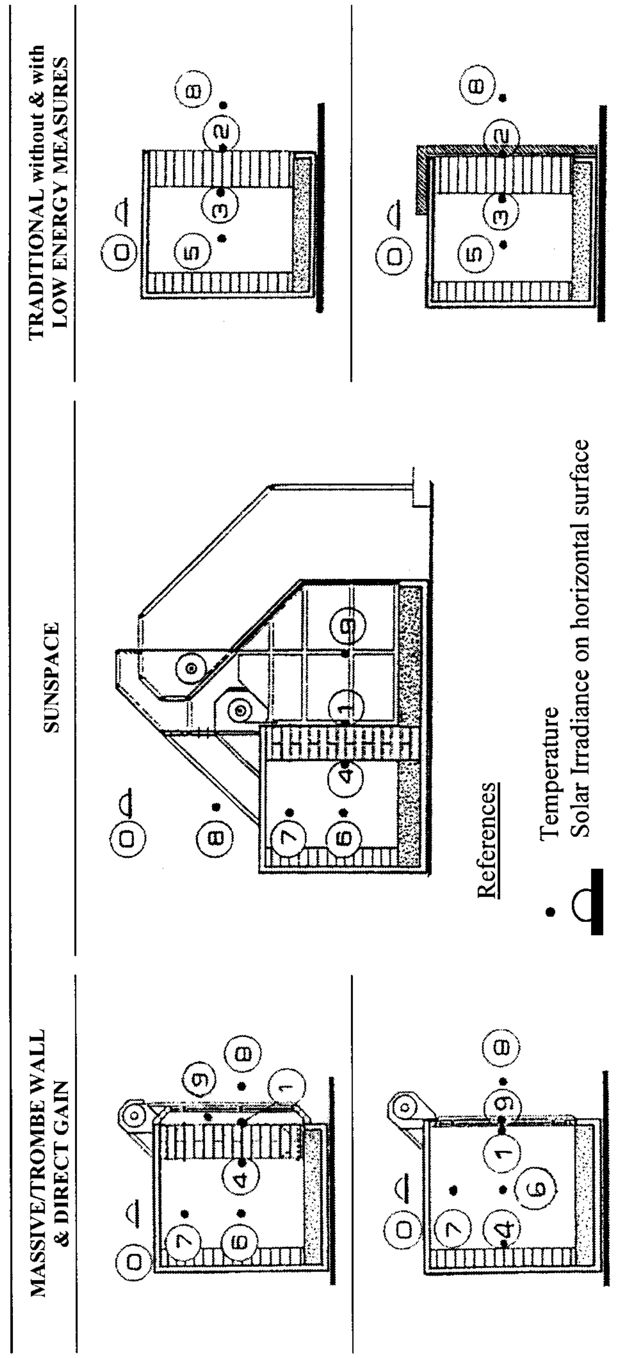

Fig. 1. Location and designation of sensors in each system.

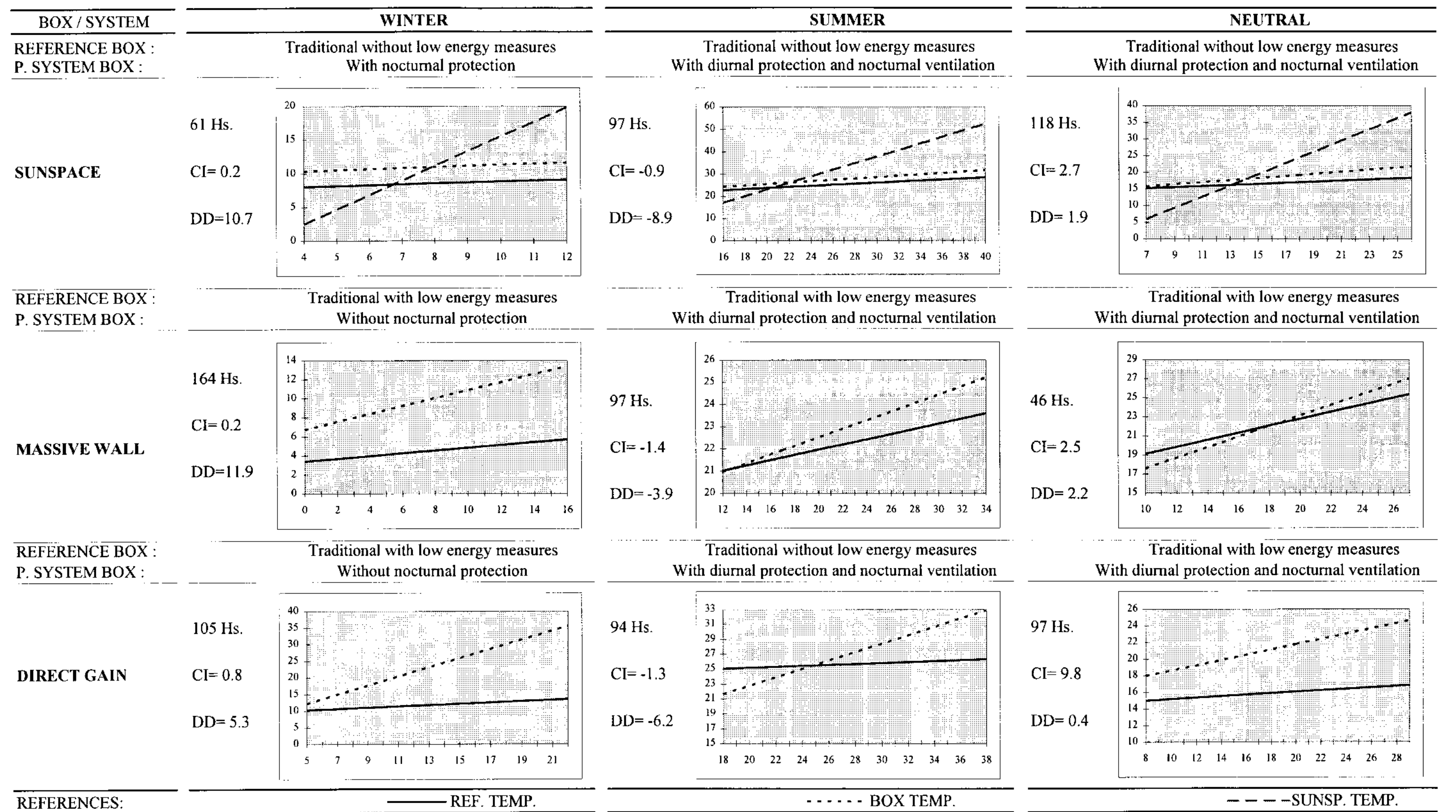

Fig. 2. Regression lines for one situation per analysed period and passive system. It is drawn indoor temperature (y) vs outdoor temperature (x). SUNSP = Sunspace System Box, P. SYSTEM = Passive System, REF. = Reference System, BOX = Passive System Box, TEMP. = Temperature [°C]; DD = Degrees-Day [°C day] and CI = Climatic Index [kWh/m^2 °C]. The CI is the rate of daily averages of the accumulated solar irradiance and the DD for the monitored period, so as to count with a referential value of the weather conditions.

3. Measurement procedures, technics and instruments

The analysis situations emerged from combining the respective seasonal periods (winter, summer and neutral-times), with the daily ones (diurnal and nocturnal) and its operational strategies (with/without protections and ventilations) with the contrasted systems (traditional systems with/without thermal insulation) [3]. Each system was tested for nine different situations, during periods from 25 to 265 hours, conditioned by the seasons of the year. The procedure used consisted of simultaneously monitoring one passive system and one reference system for each study situation. In order to analyse the comparative performance under identical external conditions, a mechanical record of the measured parameters of solar irradiance, outdoor temperature and indoor temperature was taken from different points of the boxes. The location and designation of sensors in each system are shown in Fig. 1.

Thermocouple Measuring Junctions Type K (a chromel and alumel alloy, through point electric welding) were selected for measuring temperatures, and a Kipp & Zonen solarimeter Type CM6B for measuring solar irradiance. These measurements were carried out systematically, in a permanent and simultaneous way, through hourly average records of registers which were recorded every 30 s by a 20 channels datalogger FLUKE. The obtained data was processed through statistical technics, such as regression analysis of outdoor and indoor temperatures, temporal analysis of temperatures and seasonal average calculations of solar irradiance together with outdoor and indoor temperatures.

4. Results

Fig. 2 summarizes the regression lines for one situation per analysed period and passive system. The data correspond to 879 hours, selected from a total of 5000 hours of measurements. It shows the continuous measurement time for each situation and their respective daily calculated indexes.

The regression equation $Ti = a + bTe$, where Ti and Te are respectively indoor and outdoor temperature, permits the respective empirical constants (a and b) of the studied systems to be obtained. The obtained correlation coefficients indicate that there is a good adjustment of data to the regression straight line. The confidential interval was calculated to obtain an indicative value of the dispersion

Table 1
Percentual varying ranges of passive systems indoor average temperatures with respect to the traditional ones

System state	Winter	Summer	Neutral
Logg on	(+)10–(+)117%	(+)3–(+)10%	(−)1–(+)20%
Logg off	(+)7–(+)76%	(+)4–(+)10%	(+)1–(+)30%

grade of indoor temperatures obtained in each sample. Those systems obtaining great amplitudes of daily thermal oscillations show values of more than the unit (up to 3.5 for a mean of 34.9) and those remaining steady show values of less than the unit, making the corresponding mean more representative. Table 1 shows the percentual varying ranges of passive systems indoor average temperatures (*Pas.Ti*) with respect to the traditional ones (*Ref.Ti*) for each season, calculated as: $(Ref.Ti - Pas.Ti) \div Ref.Ti$. At logg on state, the value of the detected differences is greatly conditioned by the applied strategy. The differences at logg off state prove that the type of protection used was inefficient and that they would reduce if an additional protection, which may avoid the direct exposure to the sky (green shield, sunshade, etc.), had been used.

The analysis of results shows that all passive systems presented solar gains throughout all the seasons of the year, even in situations where performance should have been more favourable. The Massive Wall and box joined to the Sunspace gave the best results, compensating widely for the small gain in summer with the great solar contribution in winter. In neutral periods passive systems with diurnal protection and nocturnal ventilation had almost the same gain levels as the traditional ones. The situations mentioned are ones that are most similar to the performance of the Traditional Wall with low energy measures. As Direct Gain systems are generally associated with the spaces needing daylight, the resulting values were discussed and thought acceptable when the more convenient diurnal and nocturnal protection and ventilation strategies are adopted. The Sunspace box had excessive heat gain in all seasons, especially in summer, even when adopting the appropriate strategies, being preferable to the Traditional Wall without low energy measures. Therefore it is not advisable to use the Sunspace box as habitable space.

5. Conclusions

The applied procedures were the appropiated ones for the aims of this study, even though not all the range of desirable situation cases could be covered, due to a range of inconveniences. The resulting values determined the importance of considering passive systems thermal performance throughout all the seasons of the year, before making decisions over the technical and economic convenience of its application in climatic zones as considered in this case. The appropriate functioning strategies affect the quality of results, therefore it is advisable to give special care to the implementation of ventilation and to the incorporation of efficient protection. The empirical constants deduced have not been contrasted for spaces of greater scale, nevertheless, they can be used to calculate an approximation of those indoor temperatures which would be obtained in similar systems to those studied in regions with similar weather. Comparative relative values offer greater accuracy, since they damp the scale effect. It will be interesting to carry out experiments with protection shields, to prove the intensity of the possible effect. Due to lack of space, not all the data is presented in this paper but are available in electronic sheets (EXCEL V6.0) and include other parameters of analysis like correlated damp values and delay times of the temperature waves for each measured system point. The elaborated data bank is useful for comparisons with other regions and/or constructive systems and to validate analytical methods.

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