The passive solar system Barra-Costantini: performance and applications

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Sunto. Si descrive il sistema solare passivo, sviluppato in Italia e denominato Sistema Barra-Costantini, dal nome di Barra che ne ha concepito la fluidodinamica e da Costantini che ne ha concepito la parte meccanica ed applicato come prototipo sperimentale alla sua casa di Salisano (Rieti). Il sistema costituisce un avanzamento del sistema Trombe-Michel del quale risolve tutti le criticità, sia migliorandone le prestazioni per il riscaldamento degli ambienti sia permettendo anche il raffrescamento degli stessi.

Parole Chiave: Bioclimatica, Sistema solare passivo integrato, Termoventilazione solare passiva

Abstract. It describes the passive solar system, developed in Italy and called Barra-Costantini System, from the name of Barra who conceived the fluid dynamics and from Costantini who conceived the mechanical part and applied it as an experimental prototype to his house in Salisano (Rieti). The system constitutes an advancement of the Trombe-Michel system, which solves all the critical issues, both improving the performance for heating the rooms and also allowing the cooling of the same.

Keyword: Bioclimatic, Integrated Passive Solar System, Solar Passive Thermoventilation

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1. Introduction

It is a passive solar system that uses air as a heat transfer fluid and is based on the principle of natural convection (Izard, 1982). The system constitutes an advancement of the Trombe-Michel system, which solves all the critical issues, both improving the performance for heating the rooms and also allowing the cooling of the same. In fact, Orazio A. Barra, analyzing the below mentioned critical issues of the Trombe-Michel system, not only solves them but also considerably broadens their performance, conceiving one of the most preforming passive solar systems.

The triple function of the absorber, accumulator and heat transmitter attributed to the south wall of the Trombe-Michel system sometimes leads to serious difficulties essentially summarized in three points:

1. the hot south wall causes significant thermal losses to the outside during the day and high at night, except for difficult and expensive nocturnal mobile insulation;
2. the thermocirculation and the energy yielded from the wall to the habitat affect only the areas of the habitat close to the south wall, making it impossible to air-condition double or triple-body buildings;
3. the export of heat from the wall (resulting in the subtraction of energy available for the initiation of natural convection) and the fluid-dynamic simplicity of the path profile make the phenomenon of natural convection low, which leads to moderate ventilation summer; nevertheless, since the hot air is directly introduced into the environment, there is the risk of overheating even in outdoor winter conditions with the waste of energy, which in such cases must necessarily be rejected outside by opening the windows (Barra, 1981).

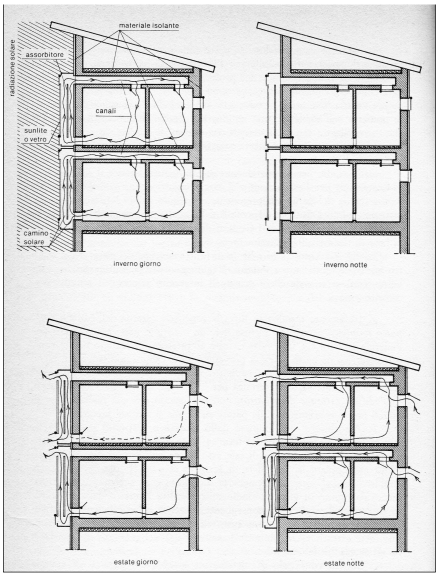
The "Barra-Costantini" system, the first prototype of a passive solar system with solar collectors applied on the façade, is born from the study to overcome these difficulties.

2. Description and operation of the system

You can distinguish different system configurations that depend on the seasonal operating period. It consists of specific technical-architectural components with the function of solar collectors, leaning against and integrated with the external wall of the building most exposed to the amount of sunshine.

The collected solar radiation is absorbed by the collector and converted into thermal energy, as well as subsequently distributed in the environment in the form of hot air flows and, in part, by re-heating by a specific thermal mass integrated into the floors, able to absorb and re-irradiate part of the heat absorbed by the heated air flows.

The main components of the system are:- The thermal insulation on the entire external surface of the building (thermal coat), including the south wall, such as to constitute a real trap for the thermal energy that once entered the building for convective transport by the air coming from the chimneys does not find easy way out; the thermal coat also makes it possible to consider the entire mass of the building (distributed storage) as the heat capacity for the accumulation of energy, no longer obliging the construction of large masses concentrated in the south wall like the Trombe-Michel system.- The absorber, decoupled from the storage, consists of a thin metal plate with a small thermal capacity placed in the gap between the glass and the south wall; the introduction of this absorber in the path allows to double the air-absorber exchange surface (since the air laps the plate on both sides) and, if suitably shaped from the point of view of fluid dynamic, facilitates the start of air turbulence in the chimney with consequent increase of the convective exchange coefficient: all this translates macroscopically into a strong extraction of heat by the air of the chimney and in a good efficiency of the system.



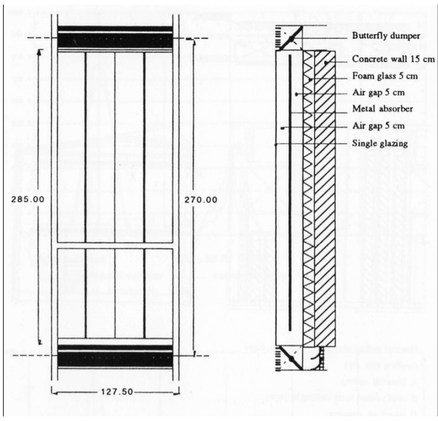


Fig. 1 Functional schemes of the system. Fig. 2 Front view and section of the solar chimney.

The system operates as follows: on winter day, the air heated in the solar panels rises and enters ducts in the concrete ceiling. The hot air warms the concrete structure and becomes cooler before entering the room. Here it mixes with the room air and returns to the panel through the low opening. At night, a backdraft damper closes the return, preventing reverse air circulation. The return air openings were reduced to one per solar panel, allowing greater freedom in furnishing the living space. The heat stored during the day is radiated from the ceiling to the room. During the summer, upper and lower seasonal butterfly dampers are manually shifted to vent the hot air to the ambient.

The collector is a thermo-circulating solar air panel integrated into the south facade; this consists of single panel of glass, an air space, a dark coloured aluminium sheet, a second air space in front of 60 mm. insulation and the load-bearing wall. The net collector area is 16.5 m^2 and the yearly solar contribution is 100 kWh/m^2. The air flow is 30 m^3/h for square meter of air panel. Dimensions are based on a module 30 cm wide and a floor to ceiling height of 270 cm; the collector depth is 18 cm. Dimensions can be easily modified on demand.

The storage is a passive charging and discharging thermal ceiling. It is a modification of traditional prefabricated concrete slab. Galvanized steel duct are substituted for polystyrene forms. The typical dimensions of the thermal ceiling are 120x30x70 cm; ducts dimensions are 40x16 cm. The thermal capacity of the ceiling is 4.17 kWh/K or 0.25 kWh/K m^2 net collector area. A special connection was designed to minimised the resistance to the air flow from the vertical collector to the horizontal ceiling ducts.

The distribution follows the following loop: through the thermal-ceiling inlet into the room, mix with room air, return via the opening in the solar air panel. Efficiency of distribution depends on the friction of the loop. It is advisable to have, as far possible, constant cross-section for the air ducts, the vent section and all chimney section.

In the winter-night set-up the communication channels of the ceiling-path (upper) and interior-path (lower) are closed and the warm ceiling acts as a large radiator for the interiors. The summer-daytime configuration benefits from ventilation and insulation of the south wall, which reduces the entry of energy and thus reduces the summer heat load, ventilating the rooms with the outside. Finally, the characteristic of the present system is the summer-night configuration, in which an inverse circulation is activated between path, channels and internal environment, obtaining a night thermal decay of the structure, which appears "cold" the following morning, opposing its thermal capacity, in addition to thermal resistance due to general insulation, to overheating of internal environments (Lepore, 2016).

Regarding the detected air velocity profiles inside the chimneys, in various geometric configurations of the chimney itself and particularly for non-high insolations: the configuration that provides a double air gap of 4.5 cm (glass-absorber, absorber-wall) is preferable and the presence of the desired turbulent regime of air motion can be supported by the following arguments: a) the velocity profiles, although in natural convection and with asymmetrical boundary conditions, are similar to the profiles valid for turbulent regimes in forced convection and symmetrical boundary conditions; b) the calculable values of the Reynolds number are in the range 2000/4000, which in natural convection means almost safe turbulence; c) it has been shown that the laminar regime may be established by air recirculation and, from the results, no evidence of such recirculation appears.

About the efficiency of the paths in relation to the insolation and the glass-absorber-wall distances: the results show that, in a climate with frequent and long-lasting low insolation levels, longer distances give better results due to lower losses of load presented by the chimney, where higher absolute values of efficiency are obtained for shorter distances, if the insolation levels are sufficiently high (Barra, 1981).

About the analysis on the dependence of the performance of the path from the type of absorber; four absorbers were tested, consisting respectively of: a) flat iron plate with density 2.35 Kg/m^2; b) flat aluminum sheet with a density of 0.53 Kg/m^2; c) corrugated aluminum sheet with a density of 0.67 Kg/m^2; d) aluminum venetian blind with a density of 0.49 Kg/m^2. The results were recorded on the Salisano house, considering the increase and decrease in temperature that the air undergoes passing respectively in the solar chimney and in the storage channels in the ceilings, the average air speed in the solar chimney, the efficiency of storage, that is the relationship between the energy released by the air to the ceiling as it passes through the channels and the solar energy incident on the floor of the chimneys. It is seen that the chimneys performance appears generally good with any absorber, and a qualitative classification of the absorbers appears dependent on insolation and specific design requirements. Thus, for example, the aluminum flat absorber is capable of reaching the highest peak efficiency value, but with medium insolation the venetian blind appears preferable. On the contrary, the corrugated aluminum sheet shows the highest accumulation efficiency probably due to the lower values of the air outlet velocity from the chimneys.

The figure 3 shows instead the importance of the external thermal coat for the Barra-Costantini system, as in

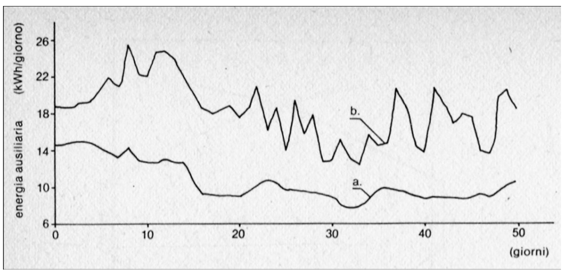
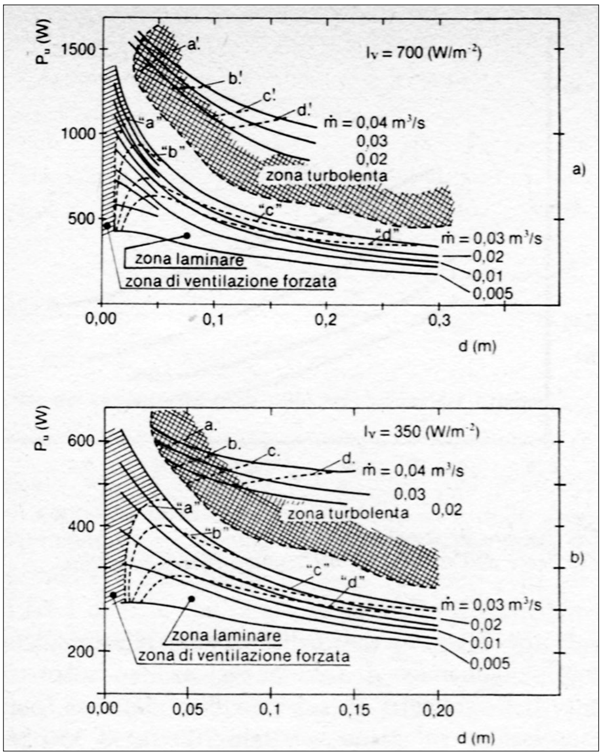


Fig. 3 Influence of thermal coat on system performance

reality for any other system: it shows the evolution of the auxiliary energy (supplementary to the solar) required by the system (in the prototype of Salisano) in cases of external thermal coat (curve a) and of the same thermal coat (same thickness of the insulator) placed inside the wall (curve b), which represents the opposite limit case (being all the other possible intermediates between the two), and that causes the contribution by the walls to the thermal capacity of the general accumulation of the house to be null. The difference is noticeable and the much greater energy required in case b is due to the continuous overheating of the house, which is unable to store the thermal energy from solar energy and is forced to reject it outside. Moreover, the case is very dependent on the external helioclimatic variability, being vice versa in the case a, evident the effect of thermal flywheel by the high thermal capacity of the house (Barra, 1981).



Finally, figure 4, describes in the most complete way the overall thermofluidynamic behavior of the solar chimney of the system in relation to all parameters from which it depends: it, for two possible values of the vertical plane insolation 700 (a) and 350 (b) W/m^2, provides the net thermal power, extracted from the chimney of width 1 m and height 3 m, transferred inside the building, according

Fig. 4 Complete picture of the phenomenology of the system to the glass-wall distance (with absorber always supposed to be the center of this distance), of the air flow rate, of the type of laminar or turbulent regime that the geometry of the absorber is able to establish (and it has been seen that except for particularly unfavorable geometries, the regime is almost always turbulent), and of the total load losses presented by the chimney + ducting system in the ceilings + air intake vents in and from the solar chimney. The four dotted curves a, b, c, d refer to four possible values of the load loss, respectively equal to Rh = 0, Rh = 10xv^2/2g (with v = air velocity in the chimney), Rh = 50xv^2/2g and Rh = 100xv^2/2g.

3. System sizing

The general sizing of the system, naturally passes through the optimization of thermal performance, obtainable in relation to the costs of realization of the various design assumptions. It will be necessary, therefore, to calculate for each design solution, the relative energy saving, compared to a similar non-solarized building, for the months of heating (or throughout the year, if you want to also take into account summer air conditioning). This final result can be calculated either through a meticulous dynamic simulation, hour by hour, of all the phenomena of heat transmission and fluid dynamics that are established in the system or through a rough assessment, which takes into account the average values of the parameters involved. The first procedure will have a much higher level of accuracy than evaluation, but will necessarily require the use of a computer and the use of a complex calculation program, where the latter can be easily completed with manual calculations and in very short time time.

Basic simplified method

Reaffirming that the dynamic simulation method is the only rigorous way to proceed with the sizing of the system, since it is the only one able to consider the transient phenomena, important in solar systems, we point out the usefulness of a approximate but simple and rapid methodology, which allows a general sizing to evaluate the feasibility of an intervention.

This simplified procedure, however, contains a profound conceptual error: it is implicitly assumed that all the thermal energy supplied by the solar collectors is effectively used by the user to cover the thermal requirement. This is true only in the theoretical hypotheses of an enormous thermal capacity of the building, to the infinite limit. The finite values of the real thermal capacities of the storage and of the rest of the structure instead involve two dissipative phenomena:

a) the thermal storage is brought to a temperature higher than the desired room temperature and therefore the thermal losses of the structure are greater than those calculated in the evaluations;

b) during the operation of the system, at certain times (especially during long sequences of days with good insolation or with a mild external temperature), overheating of the internal environment can occur and therefore part of the energy must be rejected outside.

It has been seen, however, that these effects are moderate if a thermal storage capacity is realized is at least 613 kjoules/°C for each square meter of transparent surface in direct gain systems, of at least 900 kjoules/°C for each square meter of chimney solar in the south wall of the Trombe-Michael system, of at least 800 kjoules/°C for each square meter of solar chimney in the Barra-Costantini system floors and a general thermal capacity of the rest of the structure of at least 2000 kjoules/°C for each square meter of collecting surface of solar radiation. By following these indications, acceptable solutions are realized in relation to the relationships between performance and size and the cost of storage and structure, but it is advisable (since these thermal capacities are considerable but not huge) to increase the values of S previously found in 10-20 %.

Moreover, sometimes, considerations outside of what has been said so far make the pair of values determined for storage capacity and for *s* unworkable; for example, it may happen that it is less expensive to increase the thermal capacity of the storage than the surface of the solar chimneys, or that the determined S/V ratio is impossible to be achieved within acceptable costs in specific architectural or environmental conditions, even with the smallest value of hypothectable G, or even a type of intense but very occasional use advise against the adoption of large thermal capacities, which introduce great thermal inertia in the initial response of the system.

4. Two different applications

The system has been applied on several occasions, but by way of example, we mention briefly two different applications: the first involves a determining use of the solar chimney in an extreme condition such as the Sahara desert in Egypt; the second in a housing complex in Marostica in Italy.

Progetto EIRES

Italian and Egyptian governments have decided to implement a Large Development Project (LDP), 12 hectares in area, accordingly to the Nairobi United Nations 1981 Conference results, finalised to the design construction and operation of an agricultural settlement in Egypt, based on the exploitation of renewable energy sources (EIRES: Egyptian-Italian Renewable Energy Settlement). The gross design of a complex project which aims to get several purposes. It comprises:

- solar-assisted passive residential housing;
- solar passive thermoventilation of swine stables;
- solar-assisted maize dryer.

The last two elements are joined in a sole aggregate, and work together, with functional links. The stable waste heat works as the heat source for the dryer, being the draft ensured by solar chimneys. Such an aggregation is a new concept, which allows noticeable advantages and savings, minimising the energy path. The passive system used is the experimented and well-know Barra system, in this case complemented by a high-performance solar absorber (Coppersun).

A very interesting feature of the project is the evidenced flexibility of the solar passive system used, reliable for housing as for agricultural and other purposes, with slight adjustments (Barra, Lepore, Pugliese-Carratelli, 1984).

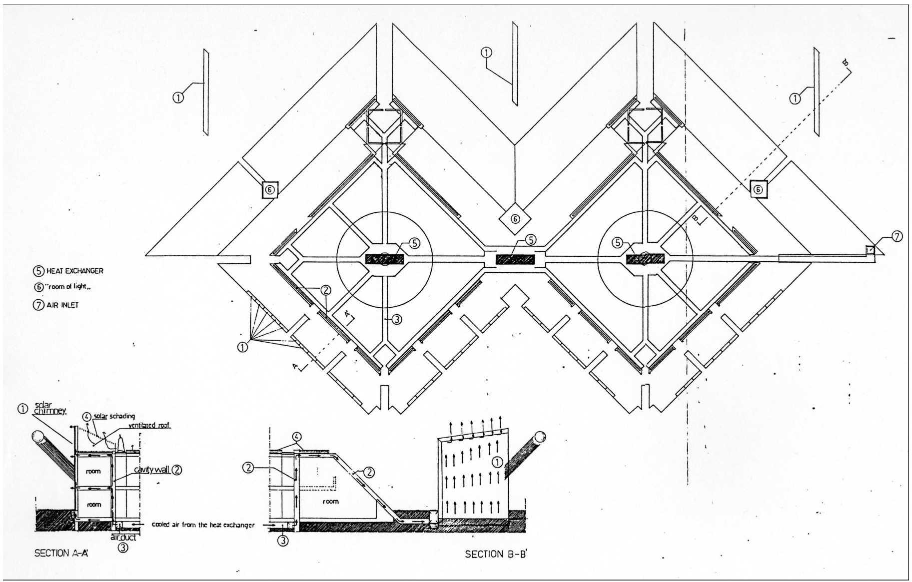


Fig. 5 Functional schemes of the Main building (project. M. Lepore)

Conceptual design

The project will define, set-up, realize and test on significative interventions a system for the building thermoventilation, exploiting the solar energy available on site, with is:

1- The technical synthesis of the “Barra Solar Passive System” with the photoconverter “Coppersun”. It is known that the Barra System is formed by solar chimneys located on the building south walls (the chimney are composed, sequentially from south to north, by a transparent surface, an air gap few centimetres deep, a low thermal capacitance solar absorber, a second air gap few centimetres deep and few centimetres of insulating material) and by a channel network inside the building horizontal (and sometimes vertical) structures where the hot air coming from the chimneys, flows in; in this way the massive structures of the building become simoultaneously heat storage subsystems and heat distribution grids. The photo converter Coppersun, as it is known, can be considered as a diode for the photothermal conversion, formed by two different sides, the first one (exposed to the solar radiation) with high level thermooptical characteristics and specialised in the selective photoabsorption, the second one optimised for the thermoemission in order to allow a good heat transfer from the Coppersun to the fluid (air or water) flowing around it. In the project the Coppersun it has been planned in the solar chimneys of the Barra Systems, as photoabsorber element, will simultaneously allow: for the Coppersun to get advantages from the high fluidodinamica characteristics of Barra system, which is able to introduce a continuous turbulence in the chimney enhancing in this way the Coppersun properties; for the Barra system to get advantages from Coppersun selectivity and diode characteristics not easily available elsewhere in the commercial market; for Barra system to reach also greater total efficiencies, specially in low insolation conditions and in the upper zones of the solar chimneys - i.e. when the employment of selective surfaces is more suitable - with increases in the cost of the whole system.

2- the reliable candidate for a large scale solar assisted passive residential housing, without storey, shape, or prefabrication of this basic components, such as the absorbers, the solar chimneys, the building horizontal structures with channels inside, the passive control devices, etc. (Barra, Lepore, Artese, 1985).

Progetto a Marostica

This project consists of four separate buildings; three terraces comprising 24 dwelling in all, and one four-storey housing block containing 16 flats. The principal objective was to build low-cost housing in which innovative passive solar components could be incorporated at cost acceptable for public housing schemes (maximum 10% of the overall cost). The open-loop passive system, developed by Barra-Costantini, was chosen. Warm air produced in the solar air panel circulates freely in the storage ceiling, into the rooms and back to the bottom of the air panel by gravity. The system supplies 30% of the net space-heating load (European Commission, 1987). Starting from a craft-made solar air panel, the team of designers and manufacturers build a prototype solar system (Salisano project), which was subsequently mass-produced at law cost (by Industry Secco, Treviso). The system is modified seasonally and daily with dampers. In Marostica, controls are user-dependent: a lever connected to the dampers is pushed down for winter operation and up for summer operation. Revers circulation at night is prevented by a plastic film damper, which opens by itself when the sun shines and warm air begins to flow. It is closed against a

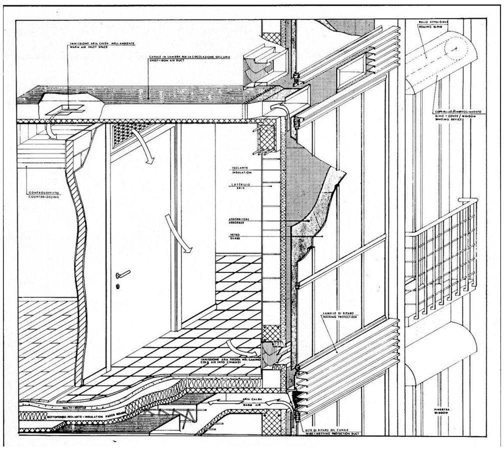



Fig. 6/7 Facade and split of the system

grid by the cold air of the solar panel when the sun is not shining (Scudo, 1984).

Efficiency is defined by the ratio between the heat delivered by the system to the heated space (by convention through the inlet and by radiation from the thermal ceiling) and the solar radiation incident on the collector. The efficiency increases quickly during the morning, stabilizes around midday at 35% (on a sunny day) and then declines to zero in the evening. On the cloudy day the efficiency is around 15%. The ceiling fraction is the quantity of heat transferred to the heated space through the concrete ceiling, which is the ratio of the heat delivered by ceiling to the total heat delivered by collector. The ceiling fraciion is around 14% on sunny days. The overall performances of Barra System was 10-15% lower than simulated values and the misused data from the Barra-Costantini experimental house in Salisano. This is due to the concentration of the air return damper for each air panel; originally dampers were distributed along the full length of the wall, giving a better air distribution. Furthermore, storage efficiency was diminished by negative thermal flow during the night from the front part of the ceiling (Hastings, 1999).

6. Conclusion

The work wanted to define the salient features of the Barra-Costantini system, pointing out, in addition to some scientific data, also two applications for example. The deepening of these projects will be dealt with elsewhere. What we want to define is the original conception of the system, (in our opinion the passive solar system that performs more energetically), also because they have been, on several occasions, recently published incorrect and misleading technical information about the concept and the functioning of the system itself.

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