E3S Web of Conferences **197**, 02008 (2020) https://doi.org/10.1051/e3sconf/202019702008
75° National ATI Congress

Passive solar systems for buildings: performance indicators analysis and guidelines for the design

Giacomo Cillari[1,*], *Fabio* Fantozzi[1], and *Alessandro* Franco[1]

[1] Department of Energy, Systems, Territory and Constructions Engineering, University of Pisa, Largo Lucio Lazzarino, 56126 Pisa, Italy

Abstract. Data from the International Energy Agency confirm that in a zero-energy perspective the integration of solar systems in buildings is essential. The development of passive solar strategies has suffered the lack of standard performance indicators and design guidelines. The aim of this paper is to provide a critical analysis of the main passive solar design strategies based on their classification, performance evaluation and selection methods, with a focus on integrability. Climate and latitude affect the amount of incident solar radiation and the heat losses, while integrability mainly depends on the building structure. For existing buildings, shading and direct systems represent the easiest and most effective passive strategies, while building orientation and shape are limited to new constructions: proper design can reduce building energy demand around 40%. Commercial buildings prefer direct use systems while massive ones with integrated heat storage are more suitable for family houses. A proper selection must consider the energy and economic balance of different building services involved: a multi-objective evaluation method represents the most valid tool to determine the overall performance of passive solar strategies.

* Corresponding author: cillarigiacomo@gmail.com

1 Introduction

Last International Energy Agency data recommend that a relevant share of the world energy consumption is related to building industry, thus a greater energy saving must be achieved in the residential sector in near future. Renewable energies will play a core role in the balance: among different sources solar energy represent the most suitable for building application [1]. The main contribution comes from solar heating and PV solar, as active systems, but a rational and systemic application and integration of passive solar strategies in building design embed a potential, exploited only in few applications until today. Passive solar design strategies use the energy from solar radiation to reduce the heating and cooling loads, guarantying indoor thermal comfort with no use of mechanical equipment. Variety, versatility, simplicity, low maintenance costs, and long lifetime represent the strong points of passive systems. Their performance depends on a wide variety of design parameters, from building orientation and shape to climate [2].

The paper analyses the impact of these parameters as performance indicators of the passive solar design, according to a new classification based on the suitability of the various strategies on the different kinds of buildings. The general categorization of passive solar design systems, in fact, classifies these solutions among direct, indirect, and isolated gain systems, according on the mutual position of the thermal storage and the conditioning space, compared to that of the solar energy source. Direct gain systems consist of a building envelope with wide south-facing windows. Main advantages include the ease of integration and construction, and low cost. High indoor air temperature fluctuations, possible glare discomfort or degradation from UV radiation, represent the most relevant disadvantages. In an indirect gain system, a thermal mass, is placed between the incident solar radiation and the indoor space. According on the placement of the solar collector and the storage mass, indirect systems can be classified in wall storage or roof storage systems [3]. A main advantage of these systems is avoiding glare and ultraviolet degradation. The hard maintenance due to the difficulties in guaranteeing a proper access to the wall cavity represents a relevant disadvantage that can affect the lifespan of the system [4]. Isolated gain systems are made of a heat collector and a storage thermally isolated from the building. This general categorization is fraught with ambiguity as many passive systems may be included in different categories. Passive systems can be also classified on the different physical working principle or according to the building elements involved: all these classification have been specifically theorized for a learning purpose, but a practical classification based on design integrability would be more useful in promoting passive solar design application.

The net performance of a passive solar solution is related to the balance of heat gains and losses thus proportional to the incident solar radiation on the solar collector. The influencing parameters can be divided into extrinsic factors, as building position, altitude and latitude, that directly determine the solar radiation, and intrinsic factors, like collector inclination and orientation, that define the maximum collectable radiation on the building [5]. The impact on building energy demand and the selection of the most appropriate design solution depend on the integration of the passive solar system that must consider both the building use, as the system must provide heating and cooling according to the living patterns, and structure, among lightweight and heavyweight buildings that can exploit their own structure as an integrated thermal storage. On the technical side building shape is the most relevant factor as the number of stories and the development axis determine the available surface and the heat distribution. The main improvements to enhance the energy performance of a passive solution include the integration of heat storage, external reflective surfaces, and movable insulation systems but the high cost of installation could represent a deterrent [6].

In the last years national and international legislations have mainly focused on active solar systems setting specific building design parameters. As a result, passive solar strategies miss the economic benefits of active devices. The proper evaluation of passive strategies, unlike active systems cost-benefit analysis, must consider different contributions, building services involved, installation, operation and maintenance costs and energy saving, in terms of quantity and quality: the lack of clear design guidelines and evaluation methods for the energy performance represents the main limit to their application.

The aim of this paper is to critically analyze the main passive solar design strategies and develop a series of performance guidelines to provide a framework of the most appropriate solution according to the latitude, the climate, the building use, and the applicability in energy retrofit measures. Firstly, a brief analysis of the main elements of solar radiation is given. Then, after a critical analysis of the passive solar design solution, the paper analyzes the quantification of the impact of the most influencing factors on the performance. Finally, the selection process, regarding energy and economical evaluation, is discussed.

2 Solar radiation and passive solar systems for buildings

The efficiency of a passive solar system directly depends on the intensity of the incident solar irradiation I (W/m^2) on the surfaces that is dependent on different parameters and can be evaluated with the following equation:

$$I_{\mathrm{or}\perp} = I_{\perp} \cdot e^{-\frac{cx}{sin(\theta_Z)}} \cdot cos\,\theta \qquad (1)$$

with

$$\cos\theta = \cos\,\theta_z\,\cos\beta + \mathrm{sen}\phi\,\cos\delta\,\cos\omega\,\mathrm{sen}\beta\,\cos\gamma + \cos\delta\,\mathrm{sen}\omega\,\mathrm{sen}\beta\,\mathrm{sen}\gamma - \cos\phi\,\mathrm{sen}\delta\,\mathrm{sen}\beta\,\cos\gamma \qquad (2)$$

where θ_z is the zenith angle, β is the surface inclination, ϕ is the latitude, δ represents the sun declination, the ω is the hour angle and γ is the azimuth. As Eq. 2 states, latitude and surface inclination represent the most impactful parameters to determine the solar irradiation on a surface. The maximum amount of solar energy collectable by a surface depends on the number of hours of sunlight and on the surface orientation.

Once set latitude, orientation and inclination it is possible to evaluate the maximum amount of energy collectable, according to clear sky conditions: Fig. 1 shows the daily solar radiation per month on vertical and horizontal surfaces. As the graph clearly shows, in summer, a horizontal surface receives more solar radiation than a vertical system: moving to the heating season this difference tapers. For horizontal surfaces, the radiation decreases with an increasing latitude over 35°, while opposite occurs for vertical surfaces. On a given amount of incident solar energy, passive systems act with different strategies and different elements involved. Fig. ***2*** shows a general equivalent thermal circuit for passively heated solar building introducing the main elements involved in passive solar systems. They can directly interact with the solar radiation by proper sizing of the glazing surface according to the energy needs of the building, or shading systems that regulate the heat gain.

One of the most relevant parameters for glazing selection is the solar factor, the percentage of solar energy transferred compared to the total energy incident on the glass:

$$g = \frac{Q_t + Q_{a,in}}{H \times A} \qquad (3)$$

where H (kWh/m^2) is the global solar radiation on the glazing surface, A (m^2) is the glazing surface area, while subscript t represents the amount of energy transferred and a,in the energy absorbed and transferred inside the building.

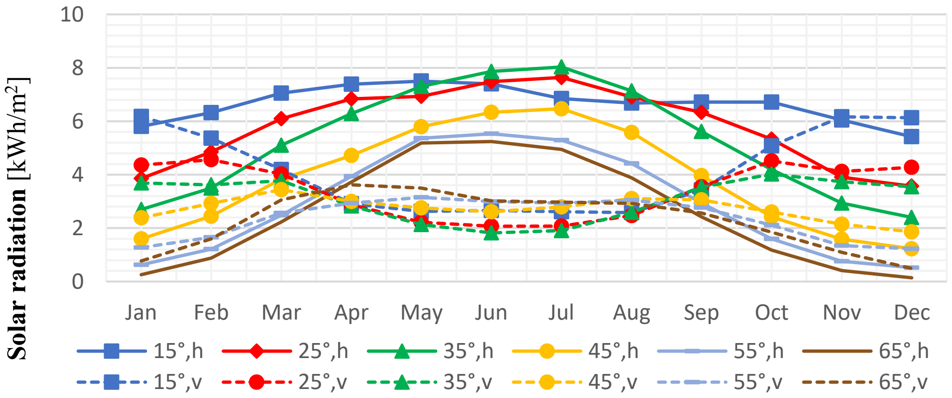


Fig. 1. Average daily solar radiation per month on horizontal (h) and vertical (v) surfaces at different latitudes

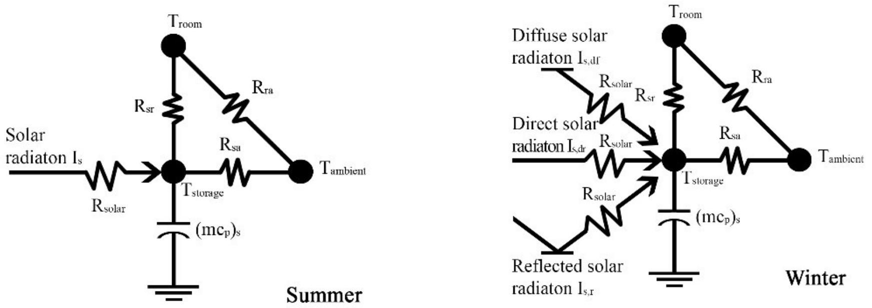


Fig. 2. Conventional equivalent thermal circuit for passive solar heating building systems

The solar factor is related to the glass transmittance and absorption indexes, that depend on the properties of the glass: from single to multi-layer low emission glasses, the solar factor is almost halved, due to the highly reduced transmittance. The glass solar factor is influenced by the exposure of the solar collector according to exposure factors: they evaluate the variation of the total solar energy transmittance of the glass as a function of the solar radiation angle of incidence.

A second strategy can focus on the building envelope: thermal resistance and thickness of the materials involved influence the building energy balance, thus passive system requirements. The last strategy is dealing with heat storage, thus the heat capacity of building envelope materials. Heat storage provided by building element's mass or integrated in passive system reduces indoor temperature fluctuation and extends the performance of system itself. The effectiveness of the storage mainly depends on material and exposure. Density, specific heat capacity and thermal diffusivity influence the rate of heat storage and the useful thickness involved in the process: under the same specific heat, a higher density and mass guarantee a higher heat capacity, while a lower thermal diffusivity means that storage is predominant for that material. Sensible heat storage and thermal diffusivity are defined as follows:

$$\Delta Q = m \int_{T_1}^{T_2} c_p(T)dT \tag{4}$$

Table 1 provides thermal properties for some common construction materials.

Table 1. Density, specific heat, and thermal diffusivity of common materials

Material	Density [kg/m^3]	Specific heat [kJ/kg K]	Thermal diffusivity [m^2/s]
Concrete	2000-2500	0.65-0.91	$0.75\cdot10^{-6}$
Steel	7500-8000	0.50	$4\cdot10^{-6}$
Wood (oak)	600-900	2.38	$0.13\cdot10^{-6}$
Brick	1400-1900	0.83	$0.52\cdot10^{-6}$
Water	1000	4.18	$0.14\cdot10^{-6}$

If not directly exposed, common rule says four times the mass is needed. The minimum thermal storage surface recommended by Balcomb [7] is six times the solar collector glazing area.

3 Classification of passive solar design solutions

From a more practical point of view, the passive design systems can be categorized in relation with their applicability to the design process and integrability to the building. Fig. 3 show this new classification system combining the effect on the equivalent resistances described in Fig. *2* and contribution to different building services. Direct gain and shadings systems integration in existing buildings can be easy and cost-effective. In cold climates, the use of triple or low-e glasses represent relevant energy saving measures. In cooling-dominated climates, moving from a double-layer to a low-e glass, heat gain is reduced from 15% to 50% on an annual basis.

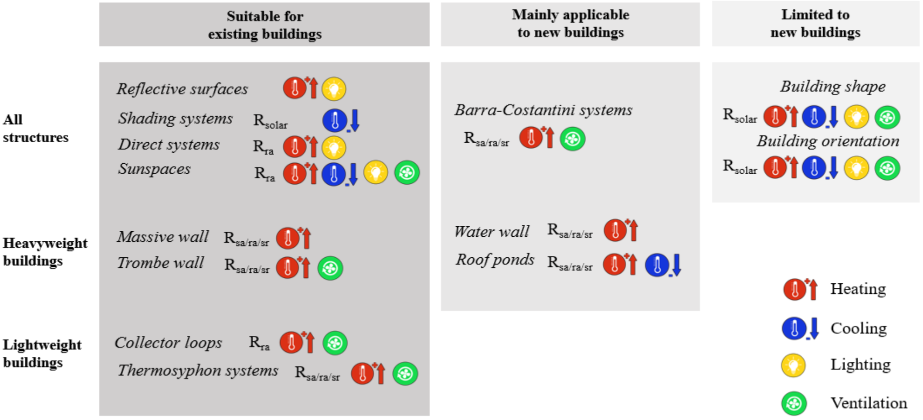


Fig. 3. Classification of passive solar design strategies

Nielsen at al. [8] generate a graph showing the net energy gain. According to their results, with a glass U value of 1.5 W/m^2K a solar factor at least 0.3 is needed to have a positive energy gain. The low thermal resistance of the glass determines the heat loss during night or cold days: common insulation methods, as roller-shade devices, hinged insulation panels or automatic louvres, are profitable. Shading represents the simplest kind of passive solar strategy for cooling, as easily integrable in existing buildings or with a low add-on cost in new ones. Appropriate shading systems can modulate the heat gain during winter and avoid overheating in summer, while guaranteeing optimal lighting levels. At low latitudes, blinds on east and west windows reduce the heat gain around 20% more than south windows orientation. From 20° latitude, the contribution of the blind on the south façade increases, achieving the same relevance of those on the east and west. The tilt angle of louver affected the energy performance in a significant way: from 90° to 30° the reduction of heat gain moved from 15–20% to 40–50% [9]. External or integrated reflective surfaces improve the heating and lighting performance by reflecting more solar radiation to the building.

Sunspaces, as additional volumes or realized in south faced porches, are a passive solution easily integrable in existing buildings, but the high construction cost can represent a relevant obstacle. Integrated sunspaces act as large direct gain systems, while externally attached sunspaces, instead, work as indirect systems. The sunspace can be exploited to preheat external air for building air exchange, and work as a buffer zone, reducing heat losses from the envelope. Integration of massive systems, collector loops and thermosyphons can be easily achievable in heavyweight and lightweight buildings, respectively. In massive wall the wall works as a storage mass; the greenhouse effect of the external glazing improves the performance of the system tempering the irradiation trend. The heat transfer rate, the time lag and attenuation depend on the thermophysical properties of the wall's materials and its

thickness. A low indoor temperature swing combined with the protection from undesired glare are the advantages of the massive wall system. Collector loops can be realized by adding an external glazing to the south façade. The heat transfer rate depends on the air speed and the transfer surface. Backdraft dampers prevent reverse convection during night or cloudy days. Thermosyphon systems are made of a glazed solar lightweight structure placed outside the building. Orientation and position are chosen to maximize the heat gain.
More complex solution as Barra-Costantini system and roof ponds, that require high costs and deep design modification, usually result more cost-effective for new buildings. In the Barra-Costantini system the warm air is released at the non-sun facing rooms, heating the distant part of the building, and flowing back guaranteeing the best heat distribution. A main disadvantage is the hard maintenance: air movement can collect dust between the glazing surface and the wall or condensation may occur during cold nights. Roof pond systems have water bags or tanks integrated inside the roof structure. The system is effective for single-story buildings. The use of water and large ceiling surfaces guarantee a more uniform heating distribution, lower indoor temperature swings and a more ready system. Typical efficiency of roof ponds is around 45% as less than half of the collected heat is transferred downward to the building. The high structural loads and the low efficiency at medium-high latitudes, due to the low horizontal irradiance represent the main disadvantages: to mitigate this side effect, in northern latitudes south-sloping systems can be implemented. Water wall has the same working principle of massive walls, but by using a fluid as storage, heat transfer occurs by convection and the system is quite isothermal, thus the attenuation of the "heat wave" connected to external temperature variation is lower. The main advantages include the low heat loss due to a lower surface temperature, a more uniform heat transfer coefficient and a fast achievement of steady-state operating conditions. Heat accumulation and transfer rate directly depend on the water storage system. Basic passive solutions as building orientation and shape factor have an application limited to new buildings but can highly influence the building energy consumption and the performance of advanced passive solutions: proper site orientation, promoting wide south façades, and building shape can reduce the initial energy demand up to 40%. Aesthetic acceptability of passive design represents another possible issue to passive solar design implementation: while commercial or office building commonly have large glazed surfaces, this kind of structure is unusual for residential buildings.

4 Passive solar systems: performance evaluation

The quantification of a passive solar system depends on a variety of parameters. Some early stage parameters, as orientation and shape, control the design at the beginning, that must be adapted to maximize the final performance. Then fixed parameters, as latitude, climate or building use influence the selection of the most suitable solution. The performance must be determined according to the desired effect based on the energy transferred, for heating purpose, or rejected, for cooling, compared to the available total solar energy. Fractional indexes evaluate the energy ratio: fractional saving index (Fs) is the ratio of the energy savings achieved by the solar heat gains to the heating or cooling load before passive solar treatment:

$$F_s = \frac{Q_{saved}}{Q_{nosolar}} \tag{5}$$

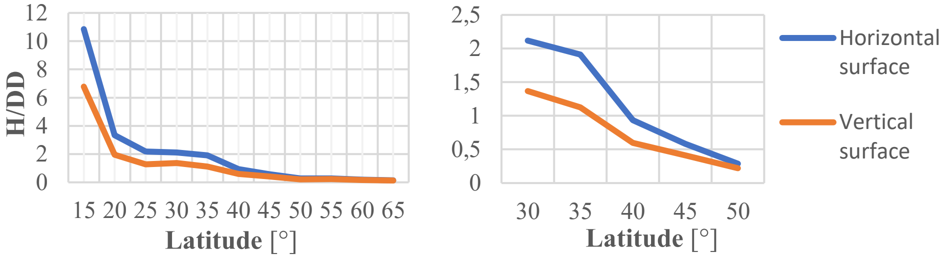
This index is useful for cost-benefit evaluation. The fractional utilization index (Fu) instead, is the ratio of the solar heat gains used to the total available incident solar radiation:

$$F_U = \frac{Q_{saved}}{H_{inc,tot}} \tag{6}$$

Fractional utilization allows a better understanding of the behavior of different systems as it represents the efficiency of the systems itself in converting available solar radiation to energy for heating or cooling. As the amount of incident solar energy on the glazing increases compared to the building load, thermal storage become more relevant.

4.1 Climate, orientation, and latitude influence

Passive systems efficiency is affected by climate, latitude, and orientation of the system as they directly influence the solar radiation. Average daily temperatures and degree days rule the system energy balance: the graph in Fig. 4 describes the trend of the ratio between average solar radiation and degree days per latitude.



(a) (b)

Fig. 4. Correlation between solar radiation and degree days ratio for different range of latitudes: high (a) and low (b).

Below 20°, the correlation shows a high ratio with a predominance of the solar radiation, that highlights the possible profitability of passive systems, while for latitudes over 40°, the ratio is low, below 1, underlying a lower efficiency.

Actually, at low latitudes, the short heating season makes the integration of passive solar system less cost-effective: at high latitudes, with proper insulation, the energy saving can be higher, but the lower solar radiation and shorter day time limit the operativity. The maximum impact on the building energy demand can be achieved at medium latitudes: moving from 30° to 50°, systems with a higher thermal resistance are required, from direct gain and sunspace to massive and Trombe walls. Glass sizing varies according to climate condition: from mild climates, with 333 monthly average degree days during heating season, to cold climates, 833 monthly average degree days, the ratio values move from 0.11 to 0.42, or 0.27 with night insulation [10]. Climate influence the number of glazing layers needed to achieve yearly benefits. In cold climates, use of multi-layer glazing systems is cost-effective as the first insulation strategy, even if it reduces from 10 to 20% the solar gain [11]: in Norway the annual heating demand can be reduced from 20 to 40% by substituting a double window with a quadruple pane or vacuum glass [12]. Shading system proves to be cost-effective in hot climates, whereas in cold climates external insulation systems extend the heating effectiveness of sunspace. Other climates factors have an impact on the possible use of passive solutions: roof ponds are not suitable for climates with frequent snowfall. Orientation influences the amount of incident solar radiation: south-facing windows performs better than east or west glazing: Fig. 5 shows average correction factors for tilted surfaces, as the inclination rises, the correction difference between south and east/west surfaces increase. South orientation performs better than a common one-family house distribution, in terms of energy savings for the heating period [8].

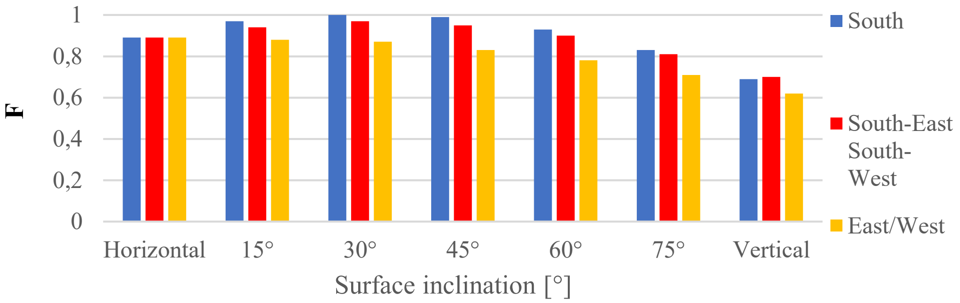


Fig. 5. Correction factor (F) of tilted surfaces for different orientation

Shading is highly influenced by orientation, as the high position of the sun in summer make it easy to shade south exposed windows while systems like roof ponds are not affected. Orientation must consider occupants living pattern: east-facing zones provide sunlight and heat early during the day, perfect for kitchens that require heating in the morning; west-facing spaces instead, become warm in the afternoon, being suitable for bedrooms. The latitude is a discriminating factor for the inclination of the collector. As the graph in Fig. 6 shows, when the latitude rises the amount of solar energy incident on a horizontal surface decreases, while that on a vertical surface slightly increases. Systems like roof ponds better work at low latitudes, while moving towards north, vertical systems have a better performance. Appropriate shading depends on the solar height, thus latitude: at high latitudes shading issues occurs due to the low height of the sun in summer. Roof ponds efficiency is not influenced by building orientation but is highly affected by latitude: at high latitudes, the low sun height reduces the insolation on horizontal surfaces [3].

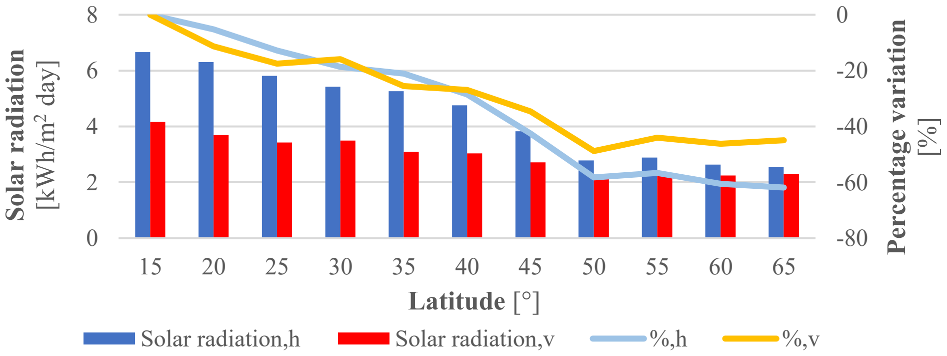


Fig. 6. Average annual global solar radiation and percentage variation per latitude

4.2 Building use and shape influence

Building use and living pattern influence the efficiency of a passive solar system, defining the operative period and condition. Daytime use buildings like academic buildings, directly exploit the heat provided by the system and are the most suitable for direct systems and convective loops. Residential use is strictly related to storage effectiveness. In office buildings, the main activity is focused in the middle of the day, from 7.00 a.m. to 17.00 p.m., while in residential buildings, the time slot shift to evening. The specific use of the building impact the acceptability of the passive solution and its integration on the architectural design. The Barra-Costantini is the most suitable for multi-story buildings. Massive systems represent a valid solution for residential buildings, as the wall thickness can be adapted on the use of the heated space: these systems can be also adopted in retail and high-rise buildings, providing structural stability and fire resistance. The compactness and shape factors of a building influence the conditioning loads, changing the dispersant surfaces, and the construction costs [13]. Surface to volume ratio is the typical parameter to evaluate the efficiency of the building shape, as shows. Perimeter–area ratio has a greater impact on energy consumption, followed by depth ratio and width ratio [14]. Adoption of a squared shape save more than half of the energy demand if compared to an irregular U-shape building.

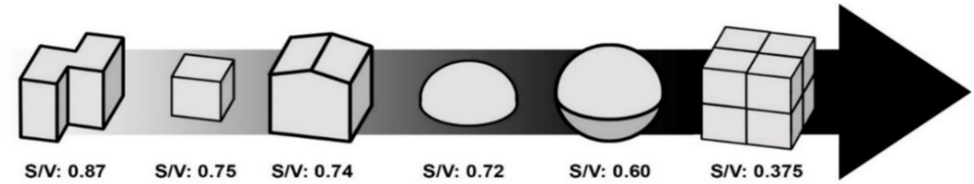
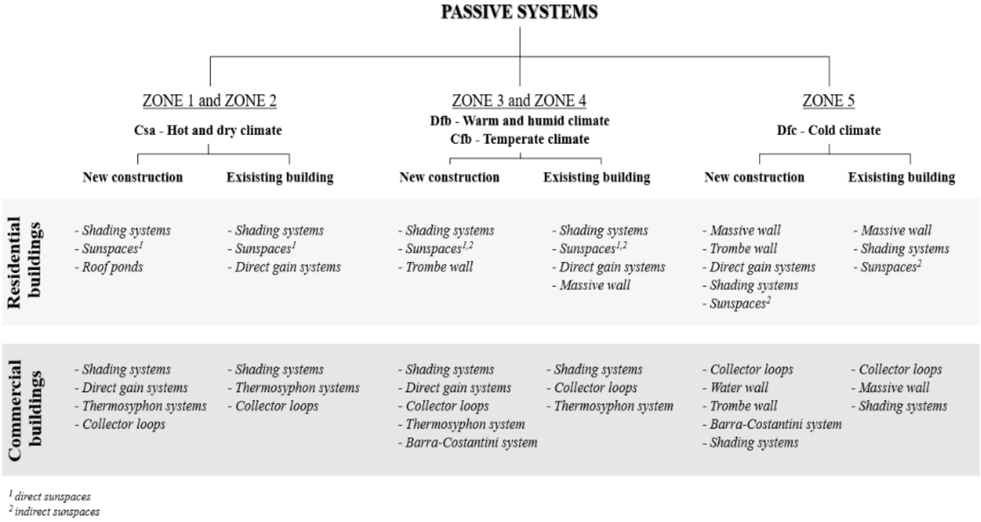


Fig. 7. Trend of external surface to volume ratio

In warm climates, an almost exponential correlation exists between the cooling load and the building aspect ratio for wide glazed commercial buildings. On the same occupied floor area, a single-storey building has a lower demand than two-storey ones, confirming the effectiveness of compact shapes, [15]. Building development axis influence surface orientation: east-west axis is preferred, to have a large south facing surface to exploit. Skylights represent a possible alternative in single-story south-north buildings. User influence the operativity of passive solution: if not integrated within a building automation system, for example, shading systems or convective loops require user interaction [16].

5 Discussion

The various elements involved in the selection of a passive solution previously analyzed allowed to get a schematic view of the best options for different climates, latitudes and building use, between residential and commercial or academic buildings, described in Fig. 8.



PASSIVE SYSTEMS

	ZONE 1 and ZONE 2 Csa - Hot and dry climate		ZONE 3 and ZONE 4 Dfb - Warm and humid climate Cfb - Temperate climate		ZONE 5 Dfc - Cold climate	
	New construction	Exisisting building	New construction	Exisisting building	New construction	Exisisting building
Residential buildings	- Shading systems - Sunspaces[1] - Roof ponds	- Shading systems - Sunspaces[1] - Direct gain systems	- Shading systems - Sunspaces[1,2] - Trombe wall	- Shading systems - Sunspaces[1,2] - Direct gain systems - Massive wall	- Massive wall - Trombe wall - Direct gain systems - Shading systems - Sunspaces[2]	- Massive wall - Shading systems - Sunspaces[2]
Commercial buildings	- Shading systems - Direct gain systems - Thermosyphon systems - Collector loops	- Shading systems - Thermosyphon systems - Collector loops	- Shading systems - Direct gain systems - Collector loops - Thermosyphon system - Barra-Costantini system	- Shading systems - Collector loops - Thermosyphon system	- Collector loops - Water wall - Trombe wall - Barra-Costantini system - Shading systems	- Collector loops - Massive wall - Shading systems

[1] direct sunspaces
[2] indirect sunspaces

Fig. 8. Classification of the most suitable passive solar solution in different configurations

A main difference occurs between new constructions and existing buildings: in the first case any solution can be integrated, the systems listed represent the theoretically most suitable options. The climate classification is based on the European climate zones according to the Köppen-Geiger classification [17]. Even if with a different impact, effectiveness of proper shading is useful in every climate zone. If care is taken to overheating, direct systems and sunspaces are suitable at low latitudes, where high average temperatures minimize heat losses due to the low thermal resistance: with integrated heat storage and insulation, these systems represent a valid but less cost-effective option in cold climates, due to their fast effect. At low latitudes, the high position of the sun favors the performance of roof ponds or sunspaces. With increasing latitude vertical systems are preferable while at high latitudes the low outdoor temperatures make massive systems a most suitable solution. Regarding the building use, the difference between residential and commercial buildings is related to the different occupancy patterns: commercial buildings prefer daily use systems, with zero or low thermal storage and a faster heat transfer than massive systems. Barra-Costantini and other solar chimneys solution are particularly suitable to achieve a cooling load reduction during work time. Direct gain systems and sunspace, with the proper thermal storage, or massive walls represent the most suitable solution for residential application, with an ease architectural integration and acceptability. A selection of the proper passive solar system can be exclusively based on an energy balance or consider the environmental impact, determining the reduction of fuel consumption and greenhouses emissions. This evaluation, by equating all the kinds of energy, disadvantages solar energy that has low available power and conversion efficiencies. In addition, it does not consider the payback time: cost evaluation must consider the credit of original constructions elements replaced. A common economic analysis aims to minimize the total cost evaluated as follow:

$$C_{TOT} = c_{fuel} \times E_{in-fuel} + c_{energy} \times E_{in-energy} + \sum C_{system,conv} + \sum C_{system,sol} + \sum C_{ins} \tag{7}$$

where c_{fuel} is the unitary fuel cost, c_{energy} represent the unitary cost of electrical energy, $C_{\mathrm{system,conv}}$ is the cost of conventional auxiliary system, $C_{\mathrm{system,sol}}$ that of the solar device and C_{ins} is referred to building thermal insulation. A system is designed if, considering its lifespan, the saving from energy consumption exceeds the construction cost. This analysis is strictly country dependent. In this perspective, the construction of passive solar systems strictly depends on the opportunity to exploit possible local tax benefits. The Italian legislation provides specific classes for shading systems and glazing surfaces, while other advanced solutions fall in the building energy improvement category. The deduction policy includes no distinction between active and passive solutions. Further, the building energy policy requires renewable sources to cover at least 50% of the energy consumption, not counting passive contribution: integration of these systems, that reduce the overall building energy demand, would thus have a negative impact, make it harder to achieve the set threshold. In some countries, the low price of energy, subsidized by the local government, results in an even lower passive systems profitability [18]. As an economic analysis would not suggest their implementation, passive solar systems contribution to the reduction of greenhouse gas emissions or energy degradation connected with the use of fossil fuels, must constitute integral elements of the analysis.

6 Conclusions

In conclusion, a wide range of parameters affects the selection of the proper passive solar design solution, with climate and building related performance indicators. Resuming the main elements:

- the common classification can be considered outdated for a practical approach. A categorization focused on the integrability in building better highlights the proper range of applicability for each solution: while shading and direct systems are completely suitable for existing buildings, shape and orientation are limited to new ones, whereas other solution integration depend on the kind of structure.
- quantification of the energy performance is firstly related to extrinsic and intrinsic factors as climate, latitude, and building orientation that determine the incident solar radiation: an optimal performance is achieved between 30° and 50° latitudes for south faced windows. The building use and shape, affecting the integrability, represent performance indicators of the impact of passive design on building energy demand: offices and commercial buildings prefer daily use systems or ones that can contribute also to daily cooling. Family building instead, promote the use of systems with integrated thermal storage, that can provide heat late in the day.
- to include heating, cooling, ventilation, and lighting effect the selection process should include a coefficient related to environment and energy degradation.

A single passive system hardly fulfils the heating needs, but different combined passive solutions guarantee a better energy performance. A zero-energy building prospective cannot disregard an integration of active and passive solar systems. Future activity will focus on passive solar system evaluation, that includes energy and economic analysis involving heating, cooling, ventilation and lighting for new buildings or energy retrofit, in order to define a multi-objective method that properly weighs all these factors and promote the integration of passive and active solar systems, to maximize the building efficiency in exploiting renewable solar energy.

References

1. I.E.A. (IEA), *World energy balances and statistics* (2019).
2. F. Kreith, Y. Goswami, *Handbook of Energy efficiency and Renewable energy* (CRC Press, New York, 2007).
3. B. Givoni, En. Build. **18**, 11–23 (1992).
4. S. Balcomb, J D; Barley, D, *Passive Solar Design Handbook* (DoE, Los Alamos, 1980).
5. J. Morrissey, T. Moore, R.E. Horne, Renew. Energy. **36**, 568–577 (2011).
6. B. Bajcinovci, F. Jerliu, Environ. Clim. Technol. **18**, 54–63 (2016).
7. J.D. Balcomb, Int. Pas. L. En. Arc., *2nd International PLEA Conf.,* **1**, 547-561 (1983).
8. T.R. Nielsen, K. Duer, S. Svendsen, Sol. Energy. **69**, 137–143 (2001).
9. Y. Huang, J. Niu, T. Chung, Appl. Energy. **134**, 215-228 (2014)
10. E. Mazria, *Passive Solar Energy Book* (Rodale Press, Emmaus 1979).
11. B.P. Jelle, Sol. Energy Mater. Sol. Cells. **116**, 291–323 (2013).
12. O. Andresen, I; Aschehoug, *Inter. conference on solar energy at high latitudes*, (1994).
13. S. Belniak, A. Lesniak, E. Plebankiewicz, K. Zima, J. Fin. Man. Pro. **18**, 90-102 (2013).
14. X. Ying, W. Li, Sustainability. **12**, 2079 (2020).
15. M. Premrov, M. Žigart, V. Žegarac Leskovar, Energy. **149**, 496–504 (2018).
16. P. Hoes, J.L. Hensen, M.G. Loomans, B. de Vries, En. Build. **41**, 295–302 (2009).
17. A. Hermelink, S. Schimschar, T. Boermans, L. Pagliano, EU Comm. (2013).
18. K. Imessad, N.A. Messaoudene, M. Belhamel, Renew. Energy. **29**, 357–367 (2004).