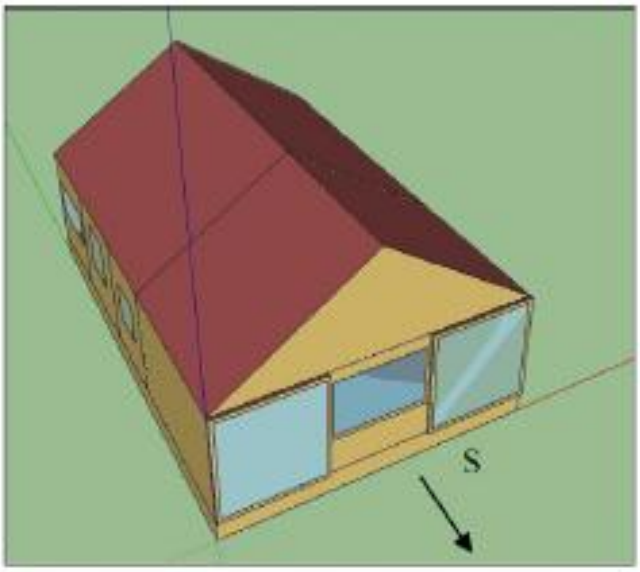
Example name: **MOZART HOUSE - PASSIVE TROMBE WALL**

Template completed by:
Danijela Nikolic, University of Kragujevac, danijelan@kg.ac.rs, Jasna Radulovic, Milorad Bojic, Ivan Miletic

Photographs



For installations

BISTS Location: Lyon, France, *longitude=* 4° 51' 0" E, *latitude=* 45° 45' 0" N

Climate Type: *Köppen climate classification=Cfc*
Building Use: *Residential house*
Level of BISTS integration
Level 3. Visible, surface change
Ox New Build

Type of BISTS:

Passive

Function(s):
O x Air heating
Ox Cooling/ventilation/shading

Building element:

O Facade

The performances of six variants of Trombe walls are studied. Each variant consists of a window, frame, a massive (accumulation) wall, and an air space between the window and the massive wall. The window has two glass panes with a light opaque window shade between them. The between-glass window shade serves as a thermal insulation during night. Consequently, it is on during night if low outdoor temp is 19 ◦C and it is off during day. The frame is from PVC. The massive wall has three layers: outer mortar layer, core layer, and inner mortar layer. Table 2 lists the names of layers of window and massive wall with their thicknesses, thermal conductivity, density, and specific heat.

Table 2 – Constructions with their layers used in Trombe walls

	Layer	Thickness (m)	K (W/m/K)	Density (kg/m^3)	Cp (J/kg/K)
Window	Glass	0.003	0.900	2600	840
Window	Air	0.005			
Window	Window shade	0.003	0.032	72	1860
Window	Air	0.005			
Window	Glass	0.003	0.900	2600	840
Air		0.100			
Massive wall	Outer mortar	0.013	0.700	1920	1000
Massive wall	Core	Optimized	Variable	Variable	Variable
Massive wall	Inner mortar	0.015	0.350	1600	1000

The studied variants of Trombe walls have the core of massive walls that differs in materials and its thicknesses. The core layer would be either of concrete or of clay brick. The studied core layers are with different densities: three types of clay bricks, one type of concrete blocks, and one type of concrete. Table 3 gives thermal conductivity, density, and specific heat for different studied core layers.

Table 3 – Properties of the core material used in Trombe walls (TW) and some house envelope material

Material	k (W/m/K)	Density (kg/m^3)	Cp (J/kg/K)	Remarks
Clay brick 1120	0.405	1120	790	TW core
Clay brick 1760	0.78	1760	790	TW core
Clay brick 2400	1.34	2400	790	TW core
Concrete block 1440	0.33	1440	880	TW core
Concrete 2210	1.13	2210	920	TW core
Glass wool	0.035	45	1030	House envelope

BISTS characteristics:

The house with Trombe walls has 0.45 m layer of clay brick 1220 as the Trombe core material. Compared to the house without Trombe walls, it can be seen that the house with Trombe walls uses captured solar energy to save around 14% of all electricity, and around 20% of electricity for space heating. If in both houses, electricity is used to cover space heating, lighting, and operation of different electrical equipment, the percents of used electricity for different tasks are shown in Fig. 4.

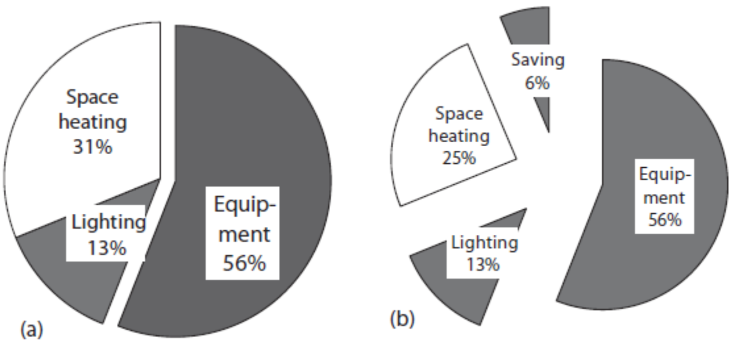


Fig 4 – House energy consumption – (a) base house, (b) house with Trombe walls

The existence of Trombe wall on the house would generate the saving of primary operating energy up to 21% compared to that for the basic house. This saving will be higher with thicker core layer of clay brick as ticker core layers can accumulate more heat from solar rays (see Fig. 5). In addition, the existence of Trombe wall on the house would mean saving of primary life-cycle energy (benefit to environment) compared to that for the basic house however its amount will depend on the thickness of the core layer and also on the type of energy used for heating. Namely, different types of energy use different amounts of primary energy for their production. For the case in Fig. 5, the heating by electricity would save the maximum of 14% of the primary energy. Furthermore, the heating by using natural gas would save the maximum amount of 11% of the primary energy.

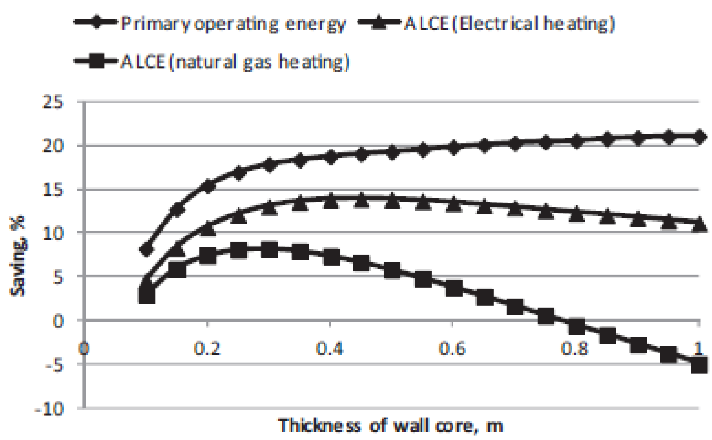


Fig 5 – The savings of annual primary operating energy and of ALCE (SPOE and SALCE) as functions of the thickness of Trombe wall core layer (clay brick 1220) for different types of heating

When applying Trombe wall to the house, the energy saving per unit of embodied energy (the energy ratio) and the energy payback time depend on the thickness of the wall core and the type of heating (see the results of investigation in Fig. 6 when the core material is clay brick 1220). Generally, thicker Trombe wall core yields lower ER and longer EPT. For electrical heating the ER is higher and EPT is lower than that for natural gas heating, as the primary energy factor for electrical heating is higher than that for natural gas heating. For optimum core thickness and for the electrical heating, the ER is around 5 and for the natural gas heating around 3. Then, for the electrical heating, the EPT is around 10 years and for the natural gas heating around 23 years. This means that it is better for environment and for energy resources to apply Trombe wall to buildings heated by electrical energy than that to the buildings heated by natural gas.

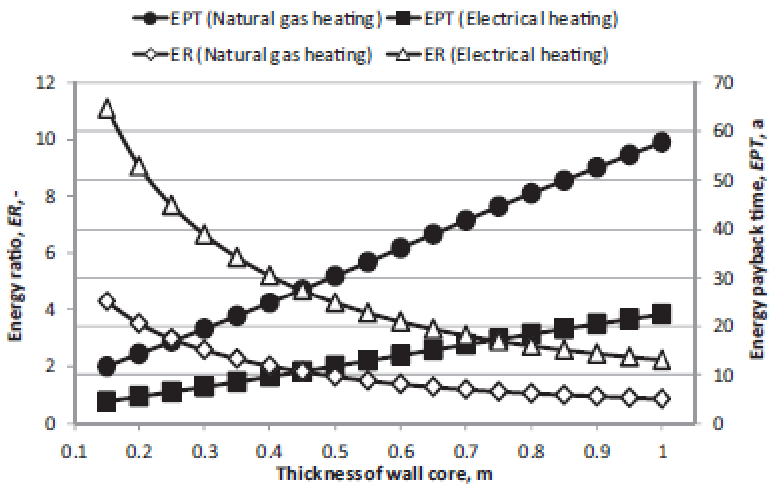


Fig 6 – Energy ratio (ER) and energy payback time (EPT) as functions of the thickness of Trombe wall core for different types of space heating

Stage of Development: **Responsible:** *Faculty of Engineering, University of Kragujevac, Serbia.*

Ox Idea/Patent ……………………………………..

BISTS description and context

In this research, thermal behavior of two houses is simulated. Each house is built according to a "Mozart" house design – the famous house design in France. This house has a garage located next to the living room of the house (Fig. 1a). Each investigated house is slightly modified compared to the original Mozart design as it does not have the garage, and the windows toward north. The first house is without Trombe walls denoted as the basic house (see Fig. 1b). The second house is with two Trombe walls located at the south side of the house (see Fig. 2a) at the part of the external wall of the living room.

Each house is used by one family. The house has 10 rooms (see Fig. 2b). There are one living room of 36.5 m2, three bedrooms of 10.9 m2, 11.1 m2, and 10.1 m2, one bathroom of 7.2 m2, kitchen of 9.5 m2, two anterooms of 5.7 m2, and 4.8 m2, and storage room of 2.6 m2. The total floor area for all these rooms is 99.6 m2, where the living area of 97.1 m2 is obtained without the storage room.

Each house has an envelope that satisfies the French thermal regulation. The exterior walls are made (from inside to the outside) by using 0.013 m thick outer mortar, 0.14 m thick glass wool as thermal insulating layer, 0.2 m thick concrete blocks, and 0.015 m thick inner mortar. They have U-value of 0.226 W/m2/K. The windows are double glazed with the air gap of 13 mm between 3 mm thick glass panes having U-value of 2.72 W/m2/K, SHGC = 0.764, and visible transmittance of 0.812. The overall area ratio of the windows to the entire envelope walls is 0.125, where the total area of the envelope is 102 m2 and the total area of the windows 12.75 m2. The interior walls are made by using 0.01 m thick plaster, thermal resistance of 0.15 m2K/W of air gap, and 0.01 m thick plaster. The roof is made by using 0.01 m of roof tiles. It has a U-value of 5.17 W/m2/K. The ceiling is made (from the inside to the outside) by using 0.013 m of plaster board, and 0.14 m of glass wool having U-value of 0.240 W/m2/K. The floor is made (from the inside to the outside) by using 0.005 m of tiles, 0.053 m of PSE, and 0.2 m of concrete. It has a U-value of 0.567 W/m2/K. The installed windows and doors on the building envelope provide the infiltration of 0.00017 m3/s/m2.

Each room has the internal heat load (people, lighting, and electrical equipment). The house ventilation is taken to be 0.15 ach through the living room, the bedroom 1, the bedroom 2, and the bedroom 3. The heating season runs from October 1 to March 31. During the heating season, the operative temperature of indoor air is maintained from 16 ◦C to 19 ◦C by using heaters.

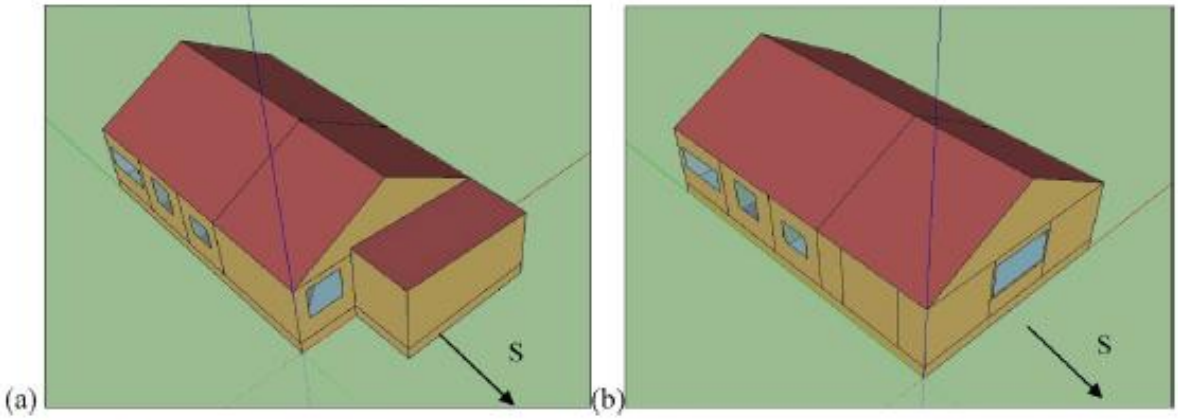


Fig. 1. (a) The original Mozart house design in France and (b) basic modified Mozart house without Trombe walls.

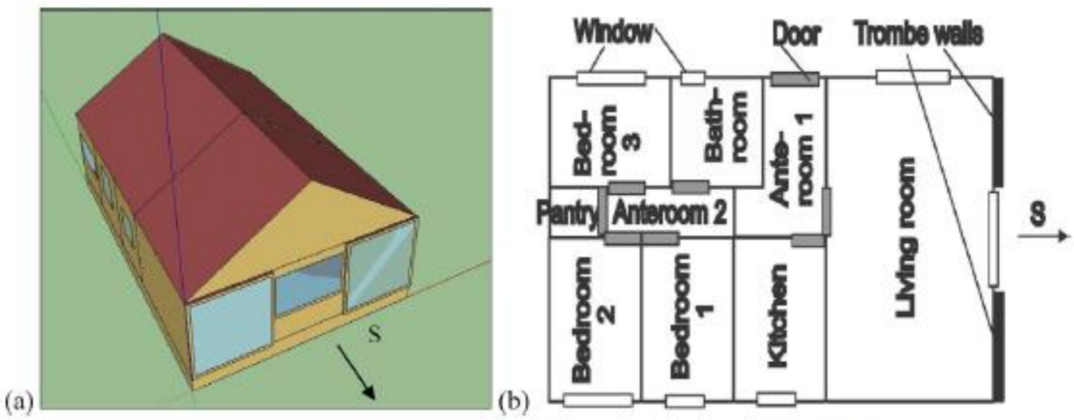


Fig. 2. (a) Analyzed house with two Trombe walls and (b) plan schematic of the Mozart house.

The investigated buildings are located in Lyon, France. Its average elevation is 240 m, above sea level, latitude 45◦43_ N, and longitude 5◦4_ E. Time is GMT +1.0 h. Lyon's weather is strongly influenced by its geographical location in the Rhone Valley, which means that cold winds blow in from the Alps, whilst warm breezes arrive from the Mediterranean in the south, affecting the climate.
As a result, Lyon enjoys a fairly temperate continental climate with four distinct seasons (winter, spring, summer, and autumn). However, temperatures remain generally quite pleasant at this time of year, averaging around 10 ◦C, and sometimes rising to around 15 ◦C. Lyon enjoys warm, sunny weather and a particularly pleasant climate between June and September. In fact, Lyon enjoys an average of 2000 sunshine hours per year. July and August can be very hot, with daytime temperatures often reaching a maximum of 35 ◦C. Lyon enjoys relatively mild weather and a pleasant climate during the autumn months, although this is the time of the year when rainfall is at its highest levels. As its location is close to the Alps,
Lyon's weather turns cold during the winter months. Winter temperatures stay at or just above freezing and the biting winds with sleet and snow showers can make the overall climate seem much colder.

System viability

Economic viability-not calculated, embodied energy- calculated, primary operating energy – calculated, LCA – calculated, energy payback time – calculated, environmental performance - calculated.

Modelling and simulation tools developed/used

The simulation is performed by using EnergyPlus, Genopt and parametric algorithm.
The EnergyPlus software is used to simulate a thermal behavior of these houses. This software is a very useful tool for modeling of energy and environmental behavior of buildings. The program is initially developed by Lawrence Berkeley National Laboratory, U.S. Army Construction Engineering Laboratory, and the University of Illinois. In the software, it is possible to input how people use building during its space heating. In this direction, the complex schedules of heating can be defined together with the schedules for use of lighting, internal energy devices and occupancy in the building.
In this study, the GenOpt code is used to find the optimal thickness of the Trombe wall core layer. GenOpt code is devised to help connection of an optimization and parametric routine and external simulation programs. The GenOpt code solves optimization and parametric problems. In these investigations, the GenOpt code is programmed to calculate the appropriate functions and use of parametric method. The variables in used in these functions are calculated by external simulation programs.

BISTS Performance data

Based on:
Ox Detailed simulation EnergyPlus,

Specify software(s) used
O Measurement/testing
O Long-term monitoring
tick all that apply

Performance parameters

For integrated systems: key performance indicators -

Solar savings fraction: %
Light transmittance: %
Solar transmittance: %
Total solar energy transmittance: %:
Solar heat gain factor: %
Building fabric U-values: W/m²K
Noise, fire, etc ratings
Other:

For separate collectors: performance rating coefficients -
(EN12975, a0,a1,a2), ASHRAE, etc

These investigations revealed that the building with Trombe walls in Lyon, France, by using solar energy may save around 20% of the operating energy during heating compared to that used by the building without Trombe walls. Due to the fact that different types of heating consume different amounts of primary energy while embodied primary energy in Trombe walls does not change, the space heating by electricity saves (up to 15%) more primary energy than that by using natural gas (up to 11%) so it is more beneficial to environment that the houses with electrical heating are equipped with Trombe walls. In addition, the energy ratio is higher and the energy payback time lower.

For maximum primary energy saving and minimum benefit to environment, the core layer in Trombe walls has to have the optimum thickness. These values depend on the type of heating.

As amount of used embodied energy depends on the density of the core material, then using the core material with low density and low embodied energy inside Trombe wall may save up to 5% of primary energy.

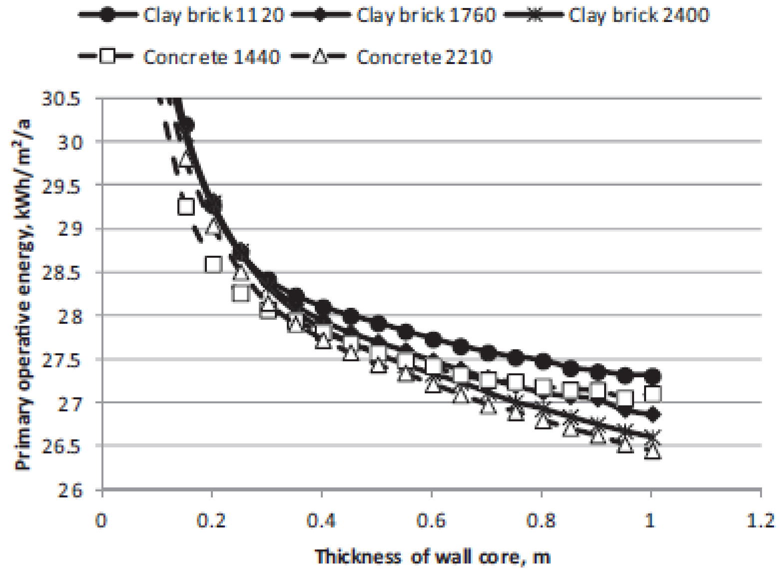


Fig. 7. The primary operating energy consumption (E_{pry}) as a function of the thickness δ_c of Trombe wall core layer for different core layer material (the house is heated by electricity).

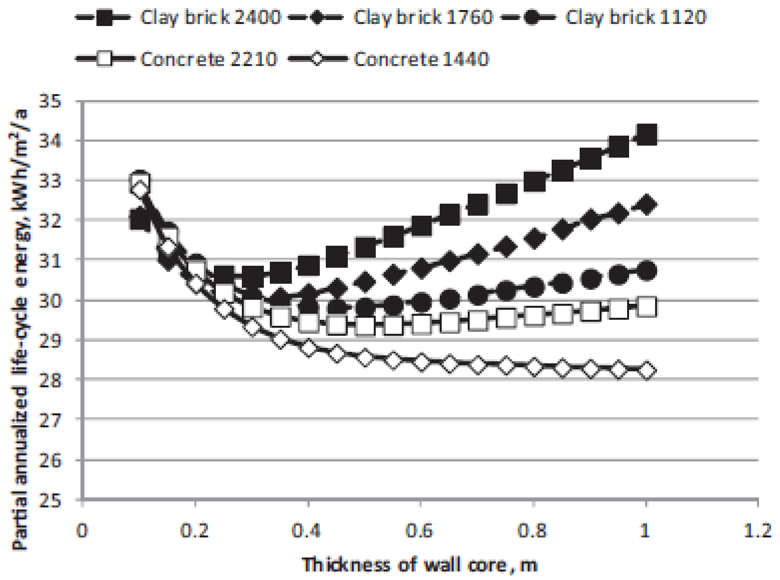


Fig. 8. Partial annualized life cycle energy use ($ALCE_{P,c}$) as a function of the thickness δ_c of Trombe wall core layer for different core layer material (the house is heated by electricity).

Additional information:
Sources and references: [1] M. Bojić, Kevyn Johannes, Frederic Kuznik, Optimizing energy and environmental performance of passive Trombe wall, Energy and Building 70 (2014), p. 279-286. http://dx.doi.org/10.1016/j.enbuild.2013.11.062

INSTRUCTIONS

Please fill in as much information as possible.

Tick where appropriate.

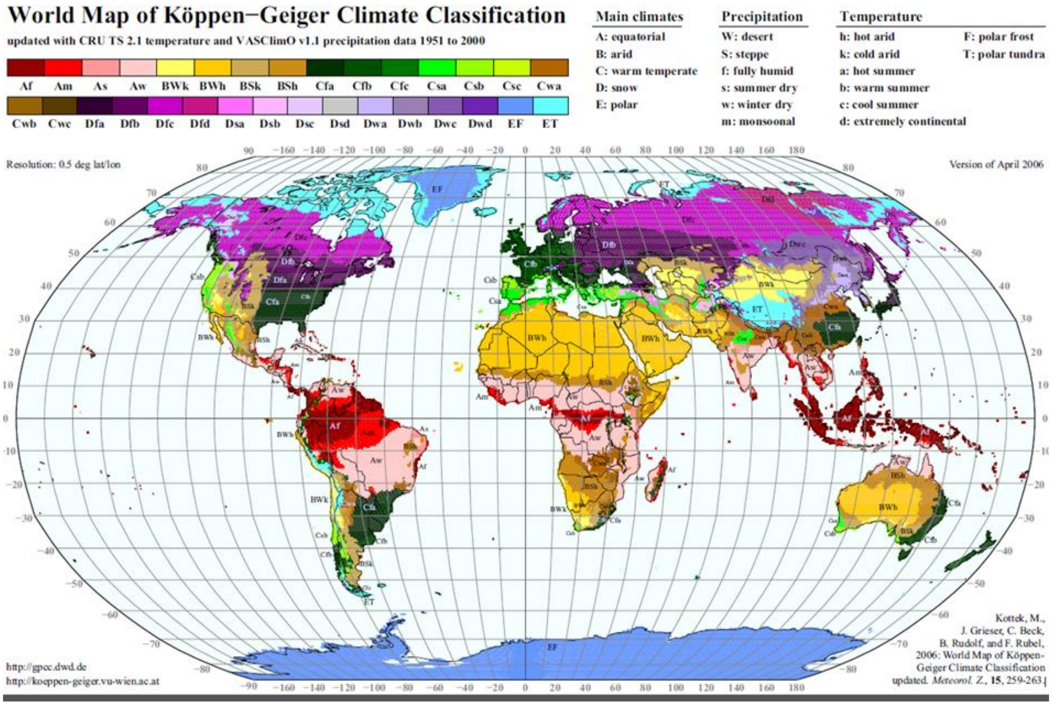
Text in red is suggested guidance. Insert information in provided space, removing red text as appropriate

If possible, use metric values.

If necessary, supply additional information on separate sheets

Reference listing

Köppen climate classification



(Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel, 2006: World Map of Köppen-Geiger Climate Classification updated. Meteorol. Z., 15, 259-263.)

Reijenga classification

The integration of PV systems in architecture can be divided into five categories:

1. Applied invisibly
2. Added to the design
3. Adding to the architectural image
4. Determining architectural image
5. Leading to new architectural concepts.

(Reijenga, TH and Kaan, HF. (2011) PV in Architecture, in Handbook of Photovoltaic Science and Engineering, Second Edition (eds A. Luque and S. Hegedus), John Wiley & Sons Ltd, Chichester, UK)

Rush classification

The architectural/visual expression of building services systems are identified as:

Level 1. Not visible, no change
Level 2. Visible, no change
Level 3. Visible, surface change
Level 4. Visible, with size or shape change
Level 5. Visible, with location or orientation change

(Rush, RD. (1986) The Building systems integration handbook Wiley, New York, USA)

Collector test standards

BS EN 12975-2 2006 'Thermal solar systems and components solar collectors - Part 2 test methods'

ASHRAE Standard 93-2010 'Methods of Testing to Determine the Thermal Performance of Solar Collectors'
ASHRAE Standard 95-1987 'Methods of Testing to Determine the Thermal Performance of Solar Domestic Water Heating Systems'