# The Trombe Wall during the 1970s: technological device or architectural space?

## Critical inquiry on the Trombe Wall in Europe and the role of architectural magazines

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### Abstract

During the 1970s, before and after the international oil crisis of 1973, some European architectural periodicals were critical of standard construction methods and the architecture of the time. They described how architects and engineers reacted to the crisis, proposing new techniques and projects in order to intervene innovatively in the built environment, using energy and natural resources more efficiently.

This article will provide a critical analysis of the role of architectural magazines of the time, describing the technological innovation of the *Trombe Wall* in Europe. It will treat when, how, and what specific aspects were described. It will also carry out a critical analysis of the *Trombe Wall* itself: about its performances, its evolution throughout the 1970s, its integration in different houses, and its influence on inhabitants' behaviour. Using three houses as case studies, an analysis of the architects' efforts to integrate the technology of the *Trombe Wall* with architectural elements such as shape, aesthetic, materiality, and natural light will be carried out.

Though this article is historical in character, it aims to inform the contemporary debate, especially concerning issues of the built environment meeting the Paris agreement on climate change (AA, 2015).

### Keywords

Trombe Wall; solar house; architectural magazine; oil crisis, energy efficiency; natural resources.

# Introduction

The *Trombe Wall* is a solar collector composed of a massive south wall covered with external glazing. It is a technology, integrated with the architectural element of the wall, whose goal is to achieve energy efficiency in buildings with passive heating and natural ventilation. It was invented before the 1960s, but during the 1970s was developed further, used on several houses and largely analysed by architectural magazines. During the 1980s when the price of fossil fuels decreased, it was used less often and temporarily cast aside (Medici, 2017) (Borasi & Zardini, 2007).

During the 1970s, some architectural magazines were particularly critical of the standard ways of building, and analysed alternative innovations as the *Trombe Wall*. Around the time of the oil crisis of 1973, such events happened: the drastic increase of oil prices at the beginning of the decade, the UN Conference in Stockholm, the publication of *Limits to Growth* by the Club of Rome (Meadows, Randers, & Meadows, 2004) in 1972, the financial crisis subsequent to the oil crisis of 1973 to 1976, and the second oil crisis in 1979. There tends to be a resonance between historical events. The relationship between energy and financial crises, on the one hand, and interests in sustainable or more energy efficient architecture (Borasi & Zardini, 2007), on the other, is no exception. Rethinking the relations and connections between architecture, the vernacular, and technology in Europe within the historical context of the oil crisis, the 1970s can be identified as a moment of recalibration between architecture and its integration with these different lines. An analysis of this period is needed because the major histories of modern architecture (e.g., Curtis' Modern Architecture Since 1900 (Curtis, 1996), Frampton's Modern Architecture: A Critical History (Frampton, 2007), Colquhoun's Modern Architecture (Colquhoun, 2002), and Tafuri and Dal Co's Modern Architecture (Tafuri & Dal Co, 1987) have not thoroughly addressed the experimental ecological design of the 1970s (Stickells, 2015). According to architectural historians Sarah Bonnemaison and Christine Macy, a "whole generation of ecological architecture has not been critically analysed within the architectural mainstream (Bonnemaison & Macy, 2003)". Additionally, the *Trombe Wall* and its integration with architecture have been underestimated and therefore are not sufficiently known. The architects' attempts to integrate the *Trombe Wall* with architectural elements on façade (e.g. windows, balconies, greenhouses), the design process, and architecture culture, didn't receive much attention from critics or architectural historians. It is not easy to assess to what extent studies and applications of the *Trombe Wall* informed architecture overall during and after the 1970s. However, certain aspects might have influenced architecture, for instance in the use of greenhouse spaces, although these were built for aesthetic reasons, and not necessarily for solar light nor to improve energy efficiency. When, during the 1980s, fossil fuels and energy prices decreased in Europe, several architects apparently lost interest in investigating the integration of the *Trombe Wall* with architecture.

This article will study the development of the *Trombe Wall* in Europe throughout the 1970s, as covered by some architectural magazines. The research methodology consists of the analysis of the period, through twelve of the most influential architectural periodicals from six European countries, published in the 1970s. Among others, some of the magazines analysing the *Trombe Wall* more consistently and frequently were: *Architecture d'Aujourd'hui* (AA, 1973) and *Technique et Arquitecture* (AA, 1979), from France; *Architectural Design Magazine* (AA, 1974a) from UK; and *Casabella* (AA, 1977) from Italy. Among the editors of these architectural magazines, Robin Middleton and Monica Pidgeon for *Architectural Design*, Bernard Huet for *Architecture d'Aujourd'hui*, and Tomas Maldonado for *Casabella*, are renowned for their critical approach and their interest in ecological issues (AA, 2010) (AA, 1974b) (AA, 1977). Architectural periodicals were chosen for this analysis because, especially at that time, they were a kind of seismographic tool to trace influences on architectural debates and developments in architectural culture. It always takes a long time to publish a book, while periodicals appear very regularly, and it was in these periodicals that new architectural tendencies were articulated.

The role of the magazines, together with a critical appraisal of the *Trombe Wall*, will be processed in this article. Critique, as defined by the contemporary philosophy of the art of Noël Carroll in his book *On Criticism* (Carroll, 2009), is not necessarily negative and it does, at least partially, embed evaluation. Therefore, the goal of this article is to highlight some of the positive and constructive contributions of the magazines in relation to the *Trombe Wall*. It will analyse how the magazines described it throughout the 1970s and how they related the *Trombe Wall* projects to each other. In the conclusions, it will emerge that their main focus was on the technology. Architectural aesthetics, access of natural light, and inhabitants' behaviour were rarely central to the analysis.

The same applies to the *Trombe Wall* itself. It will be assessed: its evolution during the decade; its integration within the design process of the house; its technical results; and the feeling of living inside it. The *Trombe Wall* evolved throughout the 1970s from an innovative technology that was applied to the house, to a usable space being part of the house. From this perspective, it will be possible to conclude that the acquired knowledge of the *Trombe Wall* became a design tool for the architect. It became an architectural element and space within the house, and was part of the design process from the beginning, even if there were room for improvement.

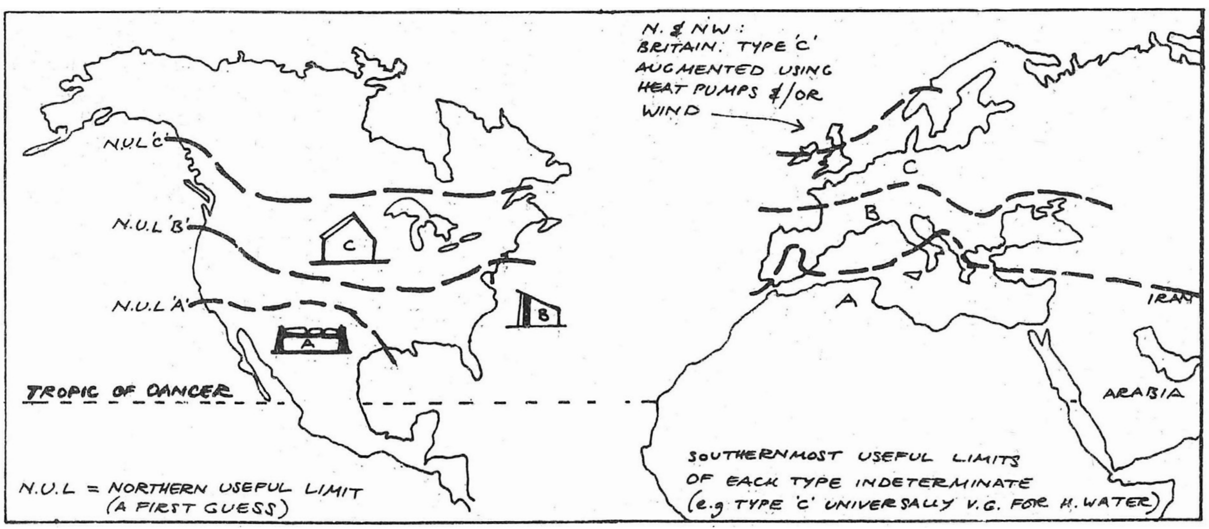


FIGURE 1 Three generic types of solar houses. These types are applicable across most of Europe and North America: A) Skytherm for heating & cooling (classified as a passive system); B) Glazed, heavy south wall for heating and some cooling effect (a passive system, the Trombe Wall belongs to this type); C) Sloping fluid-cooled, heating (an active system). The three types are suitable on areas belonging to particular climatic regions as indicated on the map. The article says that the three types all have something in common with the vernacular architecture of the related climatic region and that they are all economically affordable. They are described as a good starting point with room for improvements and a clear overall principle. (Architectural Design, 1/1976)

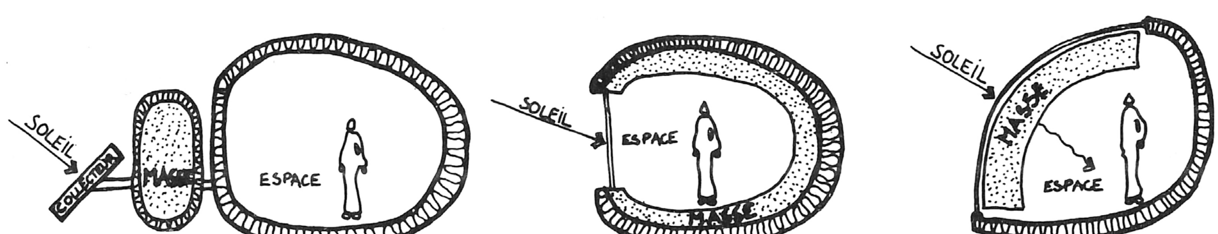


FIGURE 2 Bio-climatic architecture. Hand-drawn diagrams: solar collector external to the building; glass façade and thermal mass inside the building; Trombe Wall. (Architecture d'Aujourd'hui, 4/1977)

# Architectural periodicals on solar housing as an alternative

During the 1970s, some architectural magazines were proposing alternative building construction methods. The *Trombe Wall* was the central element of two classifications of solar devices and solar houses by *Architectural Design Magazine* and *Architecture d'Aujourd'hui*. Ian Hogan, in the special *Alternative Technologies* section of *Architectural Design* (Hogan, 1976) discerns three generic types of solar house including the *Trombe Wall* as Type B (Fig. 1). Type A is a device composed of water barrels placed on the flat roof for heating and cooling, while Type C is a solar collector for heating, mounted, for instance, on a pitched roof, with an inclination depending on latitude.

This differentiation was mainly centred on technological devices applied to the building envelope, instead of being focused on the overall architecture. It did not really investigate on which side of the building a specific program should take place, depending on the device position. It also did not take into account elements such as architectural aesthetic, internal circulation, or quality of living.

In the issue of *Architecture d'Aujourd'hui*, called *Quelle architecture solaire?* (Nicolas & Vaye, 1977), three sketched drawings of different solar houses (Fig. 2) were published. The first one depicts a solar collector and its external thermal mass storage (e.g. a water barrel), simply connected to the building: an example of innovative technology not being fully embedded into the architectural form. In the second drawing, the architecture is influenced by a vernacular technique: the south façade is open towards sunlight, which warms up the thermal mass inside the building such as internal walls and floor slabs. With insulation on the outside, the thermal mass will store and slowly release the warmth to the inside. The *Trombe Wall*, the third drawing, stands between the other two, achieving a synthesis of some of their advantages. The thermal mass is placed close to the glass, leaving an air cavity for ventilation, and creating a solar collector. As in the technique of the second example, the south façade is exposed to the sunlight. The technology of the solar collector is also part of the architectural element of the external southern wall.

This classification, in contrast to that of *Architectural Design*, considers the integration between technology and architecture to a greater degree. For example the first of the three sketches is described as "mainly solar devices allocated on top of buildings [...] with the result of formalism of the most outrageous sort" (Pedregal, 1977, pp. 2–6), illustrating that an integration of technology and architecture was needed.

# The Trombe Wall

At the beginning of the 1970s, *Architecture d'Aujourd'hui* published an entire issue called *Architecture De Soleil* (AA, 1973). In that magazine, several buildings related to solar energy were described, including the *Trombe Wall* solar houses in Odeillo, France, designed by architect Jacques Michel. These buildings comprised the first *Trombe Wall* detached house built in 1967 (Fig. 3) and three row houses completed after 1973. Jacques Michel wrote the article. Before describing the houses in Odeillo, he illustrated the *Trombe Wall* and its main technological principles, using the detached house built in 1967 (Michel, 1973) as an example. Colin Moorcraft, in *Architectural Design* (Moorcraft, 1973), described the technical principles of the *Trombe Wall* and the houses in greater detail. The first solar heating device by engineer Felix Trombe was patented in France in 1956. Later patents, including the *Anvar Trombe*, were dated 1971 and 1972. Most of the research studies related to the *Trombe Wall* were conducted at the *Centre National de la Recherche Scientifique* in France (Michel, 1973). In a comparison by Jacques Michel, the *Trombe Wall* panels installed on one of the vertical walls of the structure are more productive and efficient than external heat-capturing devices placed, for instance on the roof, as shown on the first sketch of Fig. 2. This is because the latter require mechanical extraction of the hot air produced (Michel, 1973).

With relation to general functioning, a concrete wall, which is the surface to be heated, sits behind the external glass panels of the *Trombe Wall*. It operates as the mass and it serves to transmit the heat to the interior space of the building. In the northern hemisphere, the external glass panels and the *Trombe Wall* should be placed on the south façade (Michel, 1973). The south wall absorbs the short-wave solar radiation that penetrates the glass. The thermal mass is heated up and emits radiation of a longer wavelength. This radiation does not penetrate the first sheet of glass encountered. The thermal mass absorbs the radiation and produces heat towards inside the house (Moorcraft, 1973). Heat can be stored overnight in the thermal mass without mechanical assistance. The *Trombe Wall* is not restricted to latitudes where direct sunlight is abundant, because the greenhouse principle also operates, for example, on cloudy days with diffused solar radiation. The relatively large surface of the south façade should be adjusted, with specific formulas, in relation to the total enclosed space (Michel, 1973). The *Trombe Wall* includes two gaps on its top and base for air circulation. During the winter, the air heated behind the glass panel recirculates inside the building. During the summer, an inlet on the north façade allows fresh air to enter for cross ventilation towards an aperture on the south façade (Fig. 4) (Michel, 1973). The gaps at the bottom and top of the collector areas connect the cooler air mass inside the building with the heated air mass in the collector. Thanks to the natural stack effect, cooler air flows in at the bottom, while the heated air flows out of the top. A thermal circulation of air is established throughout the building (Fig. 5) (Moorcraft, 1973). The detached house in the Pyrenees demonstrates that the thermal capacity of the collector wall is sufficient to re-radiate heat for most of the night. In effect, a 35cm thick concrete wall stores about half the heat absorbed by it. This is sufficient to maintain, until the early hours of the morning, a warm air current (Moorcraft, 1973).

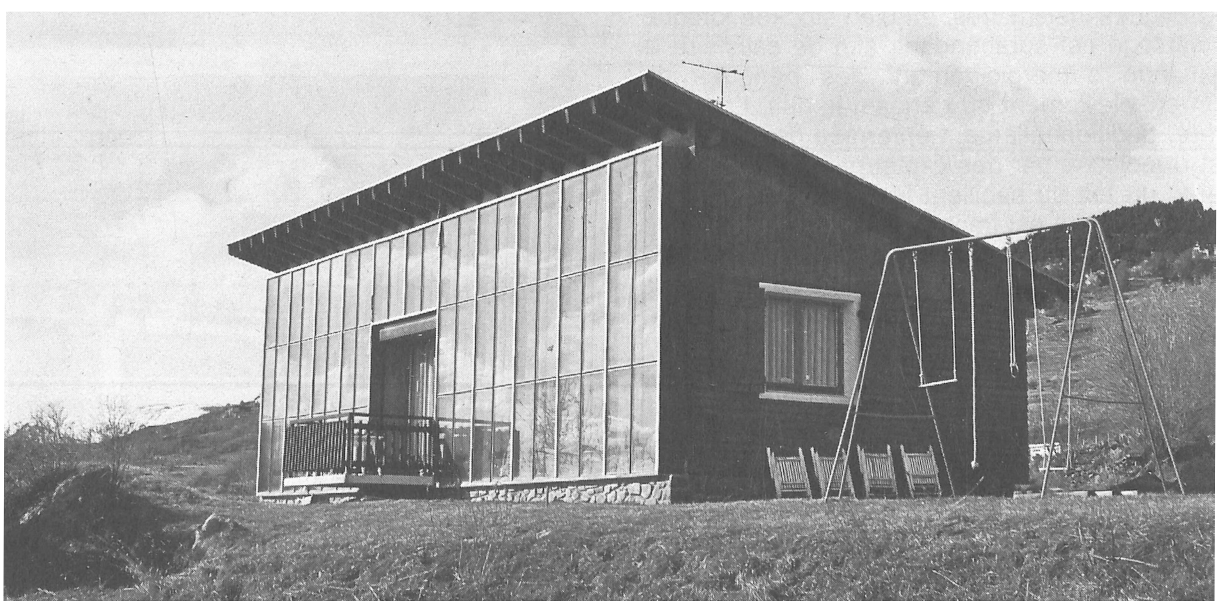

FIGURE 3 Single solar house in Odeillo. Detached house with Trombe wall, built in 1967 in Odeillo, France. (Architecture d'Aujourd'hui, 4/1977)

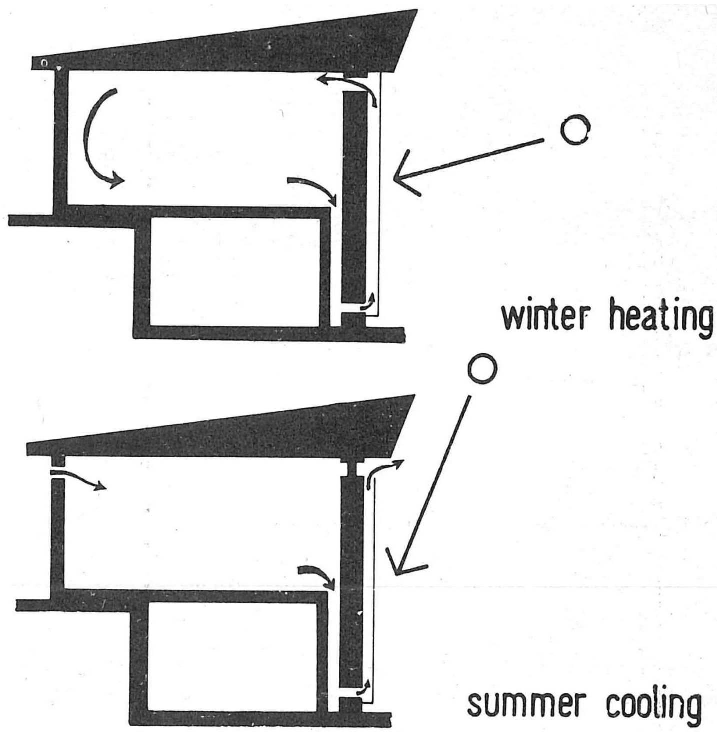


FIGURE 4 Trombe Wall, Winter heating and summer cooling. Section of the detached house with Trombe Wall, built in 1967 in Odeillo, France. (Architectural Design, 1/1975)

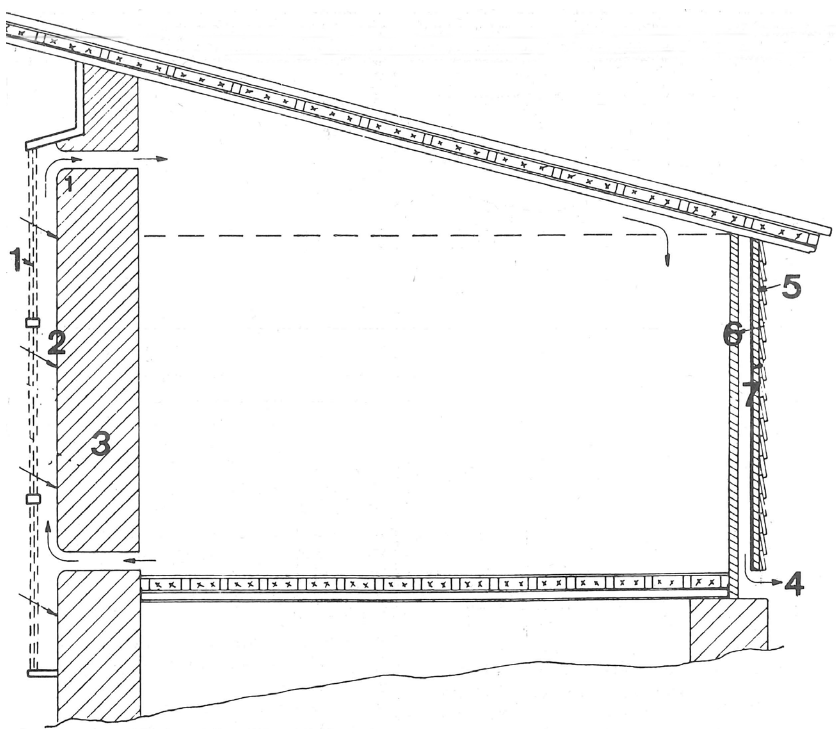


FIGURE 5 Section of prototype detached house built in Odeillo, French Pyrenees. One layer of glass covers the area of the wall intended to collect solar energy (1). The external surface of the wall (2) is painted black or very dark, roughcast or with an absorptive coating. The south wall (3) consists of a structural concrete wall that also functions as a heat store. Inlet on the north façade (4). The curved arrows indicate the flow direction. (Architectural Design, 10/1973)

However, some magazines also described some technical limitations of the *Trombe Wall*. Ian Hogan in *Architectural Design* (Hogan, 1975) defined the *Trombe Wall* as more suitable for heating in areas with cold winters and clear sunny summers, stating that the system was only capable of supplying 70-90% of the heating needed. Mario Scheichenbauer in *Casabella* (Scheichenbauer, 1977) described the *Trombe Wall* as solar panels, extremely simplified but with poor control of the temperature, and with difficulties to heat a room not directly exposed to the sun or next to the *Trombe Wall*.

It was remarkable how much the *Trombe Wall* was embedded in the architecture, especially when compared to its predecessor, the external solar collector. The *Trombe Wall* in the detached house in Odeillo was also a structural wall and one of the longest of the house, running adjacent to 4 rooms. However, some architectural aspects were not solved. The southern façade is a full dark *Trombe Wall* with the entrance door as the only opening. The south façade is completely blind, with no landscape view or access of natural light. Bathroom, kitchen, and entrance spaces are located in the north side (Fig. 6), probably because these areas with services and for internal circulation need less heating. Aesthetically, from the outside the full dark façade could be considered as an architectural statement about the importance of saving energy, as well as a very strong and visible technological device. These considerations show the potentials of the *Trombe Wall* as a design tool, for the architect, which were still not sufficiently explored.

The above-mentioned magazines, compared to other magazines of the time, analysed the *Trombe Wall* extensively in different articles and entire issues.  However, they focused mainly on the technological aspects and on the technical properties rather than on quality of architecture and living. In the case of the detached house in Odeillo, the periodicals of the time never considered the quality of the interior, the view of the inhabitants from the inside, the natural light coming in. In their analysis, the magazines did not go into the behaviour of the inhabitants and to what extent their life would change with the *Trombe Wall*. Moreover, the rooms that heated up more were the ones closer to the *Trombe Wall*, which could have had an influence on their use during different hours and seasons. Not much was said about the different behaviour of the inhabitants in such a house compared to a standard one. Reflections about aesthetic are also missing, such as, for instance, how the extended dark glassed façade would fit in the natural context and with the local traditional architecture.

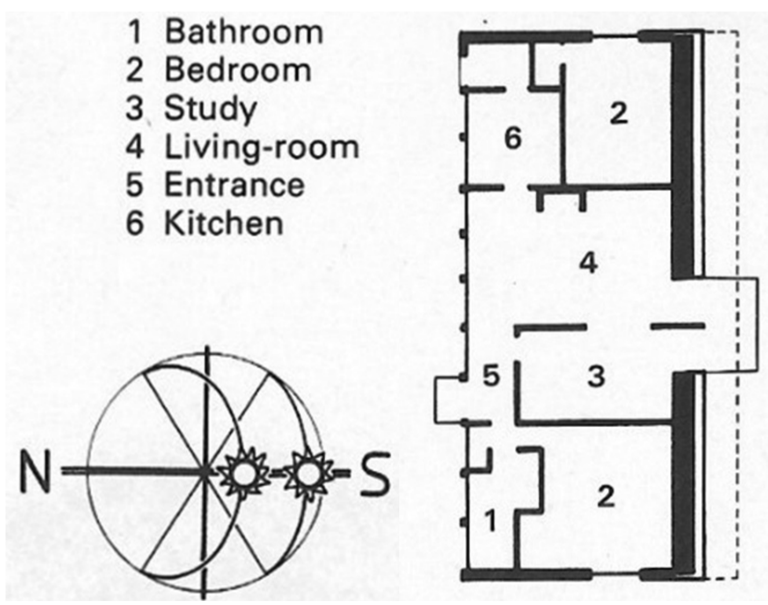


FIGURE 6  Trombe Wall, Winter heating and summer cooling. Section of the detached house with Trombe Wall, built in 1967 in Odeillo, France. (source: https://jjureidini.wordpress.com/2011/01/18/trombe-wall-case-studies/)

# Three solar row houses

Jacques Michel in *Architecture d'Aujourd'hui* (Michel, 1973), also describes the three solar row houses (Fig. 7) in Odeillo, which he designed. In this case, both the openings and the *Trombe Wall*s are in the southern, eastern, and western façades. The solar collectors' glass panels are placed on top of the thermal mass (i.e. concrete walls) and are supported by an aluminium structure behind some elements of Polyglass, constituting the *Trombe Wall*  (Michel, 1973). Michel explains that the design of the façades is customisable and flexible before the construction (Michel, 1973). Additionally, in this case there is a missed chance for an architectural analysis. Probably the architect intends that every apartment could have *Trombe Wall*, balconies, and windows located within various façade designs. However, this important architecture detail regarding both the interior and the exterior of the building is not clearly explained or analysed.

In the first example mentioned above – the detached house – the *Trombe Wall* was simply applied to the entire southern side of the rectangular form of the detached house. In the second example, the *Trombe Wall* was used on three sides of the three row houses instead of one side. Looking at the plan (Fig. 8), the eastern and western walls are diagonal to the sun and the southern wall is curved, with a peak at the central part, to catch the highest possible amount of solar radiation. The southern façade has a curved shape, following the daily solar path. It is thus able to catch the sunlight from both morning and afternoon. Moreover, there are several windows embedded in the façade. This dramatically changes the aesthetic with an alternation, all along the façade, between dark *Trombe Wall*s, lighter coloured panels, balconies, and transparent windows.

In this case, the technology of the *Trombe Wall* itself developed and evolved thanks to the experimental integration within a different architecture. In effect, in the three row houses, the *Trombe Wall* was built on two different levels along the south façade (Fig. 9). The *Trombe Wall* is subdivided and has more openings, compared to the door as the only opening of the detached house. The masses of air heated up by the *Trombe Wall* move to the rooms upstairs because of the stack effect. The engineers had the chance to test the efficiency of the fragmented *Trombe Wall* in a more complex double height space compared to the preceding example. As regards the architectural program, the northern part of the row houses accommodates the areas with less need of heating, such as staircases, bathrooms, and toilets. In effect, in this case also, the *Trombe Wall* heats up the house during the winter and cools it down during summer. During the summer, the *Trombe Wall* contributes to cross ventilation using the inlets in the north façade, while in wintertime the *Trombe Wall* heats up the interiors. Since the warmer rooms are those close to it, the living rooms are often located there.

Even in this case, the architect in the periodical is focused mainly on the technological aspects of the *Trombe Wall*. Only a few words were spent on its curved shape in plan and on the fragmentation by windows and balconies. Not much is mentioned in terms of comfort of the inhabitants. Something is said about the thermal comfort but not much about the views from the inside, the amount of natural light coming in, or the differences in the inhabitants' behaviour by having the southern wall emitting heat. Nor is there any focus on the aesthetic, even if the alternation of dark *Trombe Wall* panels with windows and white panels substantially changes the aesthetic of the façade, in comparison to the example of the detached house.

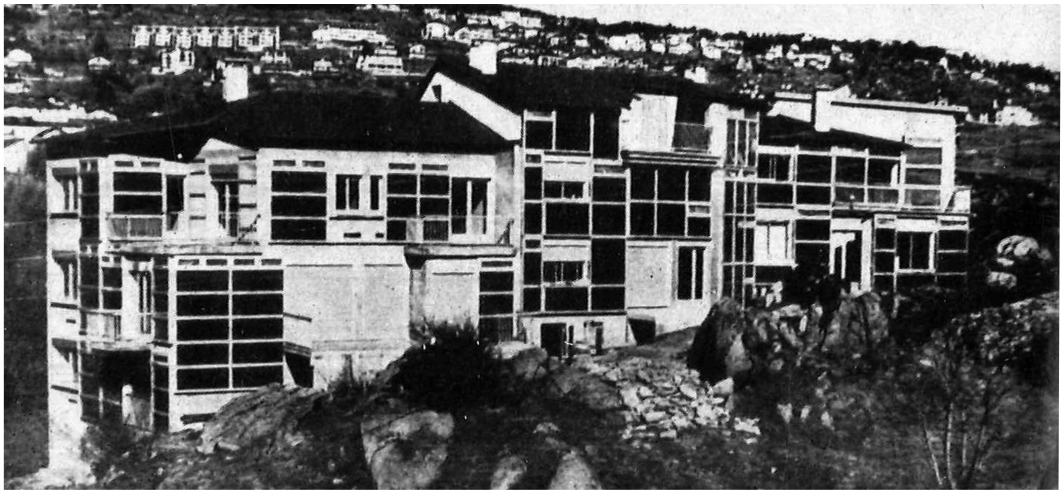

FIGURE 7 Single solar house in Odeillo. Detached house with Trombe wall, built in 1967 in Odeillo, France. (Architecture d'Aujourd'hui, 4/1977)

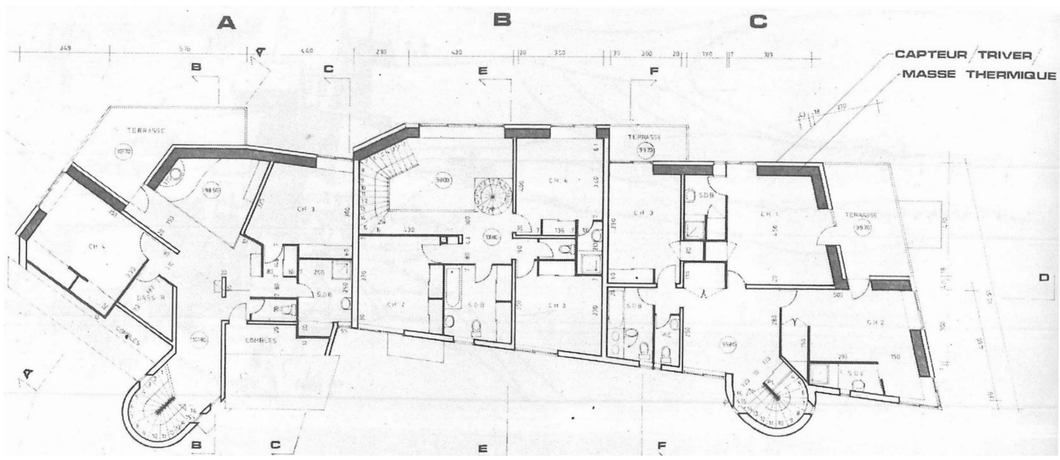


FIGURE 8 Single solar house in Odeillo. Detached house with Trombe wall, built in 1967 in Odeillo, France. (Architecture d'Aujourd'hui, 4/1977)

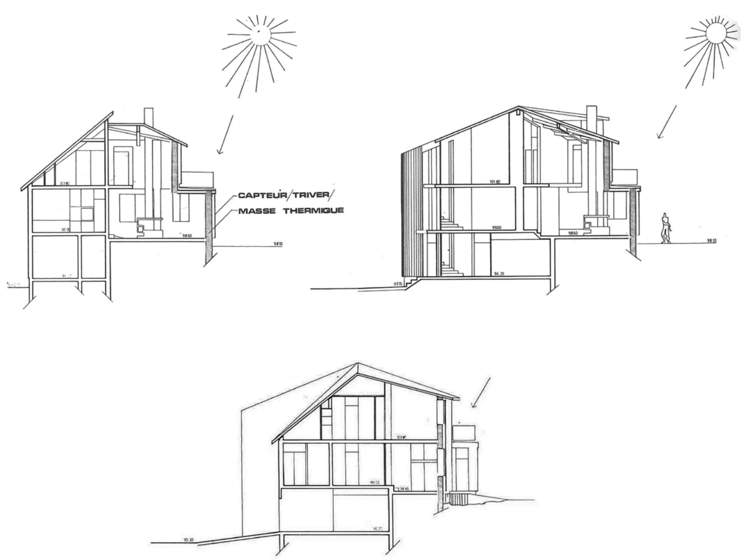


FIGURE 9 Three solar apartments in Odeillo, France. Sections with the dark Trombe Wall on two levels. (Architecture d'Aujourd'hui, 5/1973)

# The Trombe Wall as architectural and technical reference

In *Architectural Design*, Greenhill & Jenner's design for public housing (Fig. 10-11), is illustrated as a second stage scheme for the Royal Mint Housing Competition in London, UK (Mulcahy, 1975). In this case, the *Trombe Wall* is taken as a reference, both technological and architectural. Climatic houses are described as using the air cavity space, unused by the *Trombe Wall* houses in Odeillo. The engineer Sean Mulcahy, author of the article, writes: "in the French prototypes the opportunity was lost of using the inter-space between

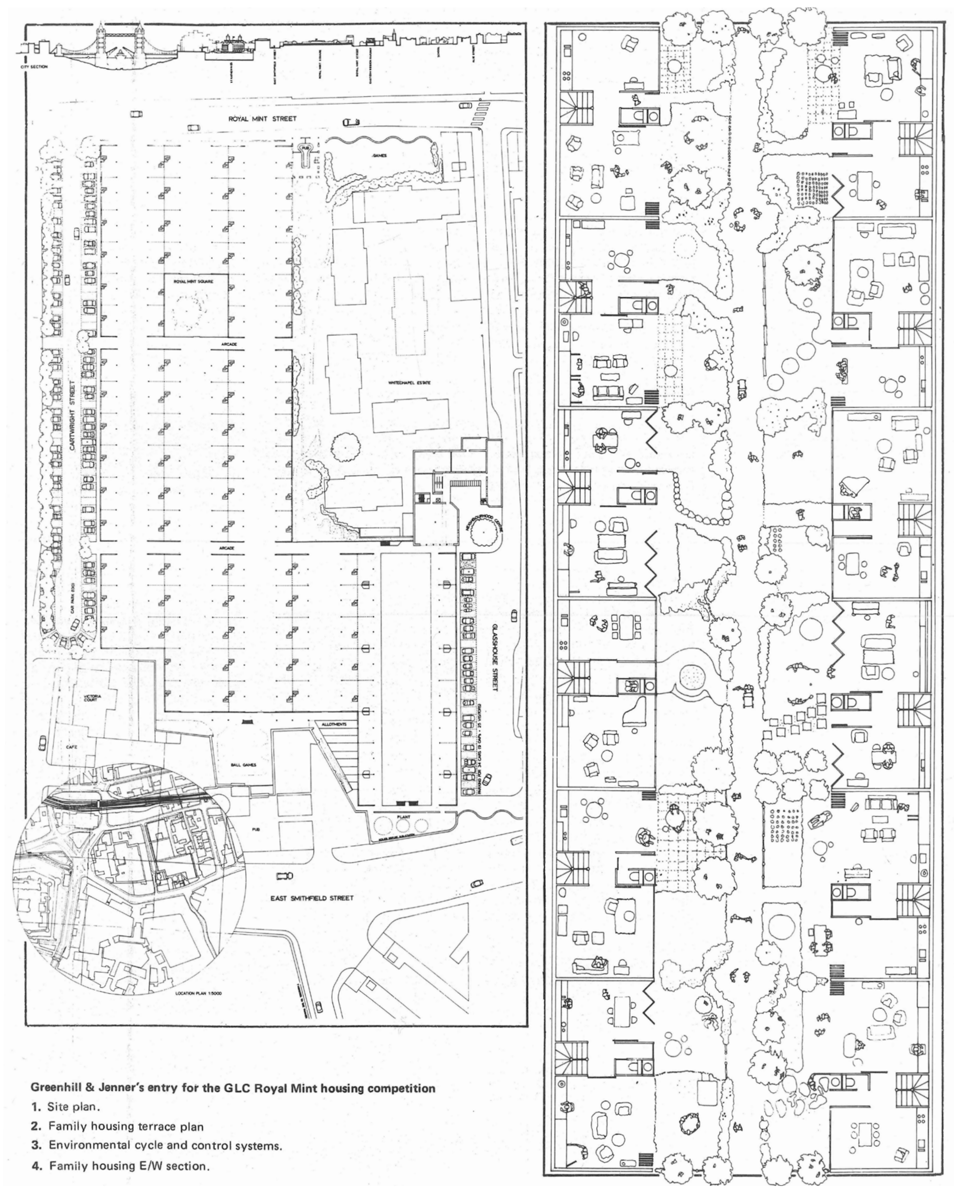


FIGURE 10 Single solar house in Odeillo. Detached house with Trombe wall, built in 1967 in Odeillo, France. (Architecture d'Aujourd'hui, 4/1977)

the glass wall and thermal-storage wall as an internal garden (Mulcahy, 1975, pp. 144–148)." In Mulcahy's analysis, the *Trombe Wall* technology was used as a reference for an architectural space. More specifically, Mulcahy mentions a technical feature of the houses at Odeillo: the use of summer sun for cooling by means of increased ventilation. The project scheme is composed of two rows of houses with glass-covered front gardens in between. The glass-covered garden malls are defined by the architect as "socially critical spaces that permit community formation (Mulcahy, 1975, pp. 144–148)."

In this case, the glass panel of the original French *Trombe Wall* becomes the glass roof between the two rows of houses. Sunlight penetrates the glass and reaches the garden, warming up the thermal masses of floor slabs and walls. Ventilation and stack effect are favoured by air gaps on different parts of the glass roof. The result is a kind of *Trombe Wall* rotated 90 degrees to the horizontal, becoming the roof between the row houses; the greenhouse underneath is the air cavity while the walls and pavements are the thermal masses. Compared to the *Trombe Wall* of the detached house in Odeillo, its scale increases both in height, being three floors tall, and length, as the row of houses is approximately 60 metres.

*Architectural Design* highlights the missed opportunity of transforming the air cavity of the *Trombe Wall* into a usable space. Although this concept was merely mentioned, it contributed to spreading the culture that inspired such projects as the one described in the next paragraph, the *Maison à Argenteuil*.

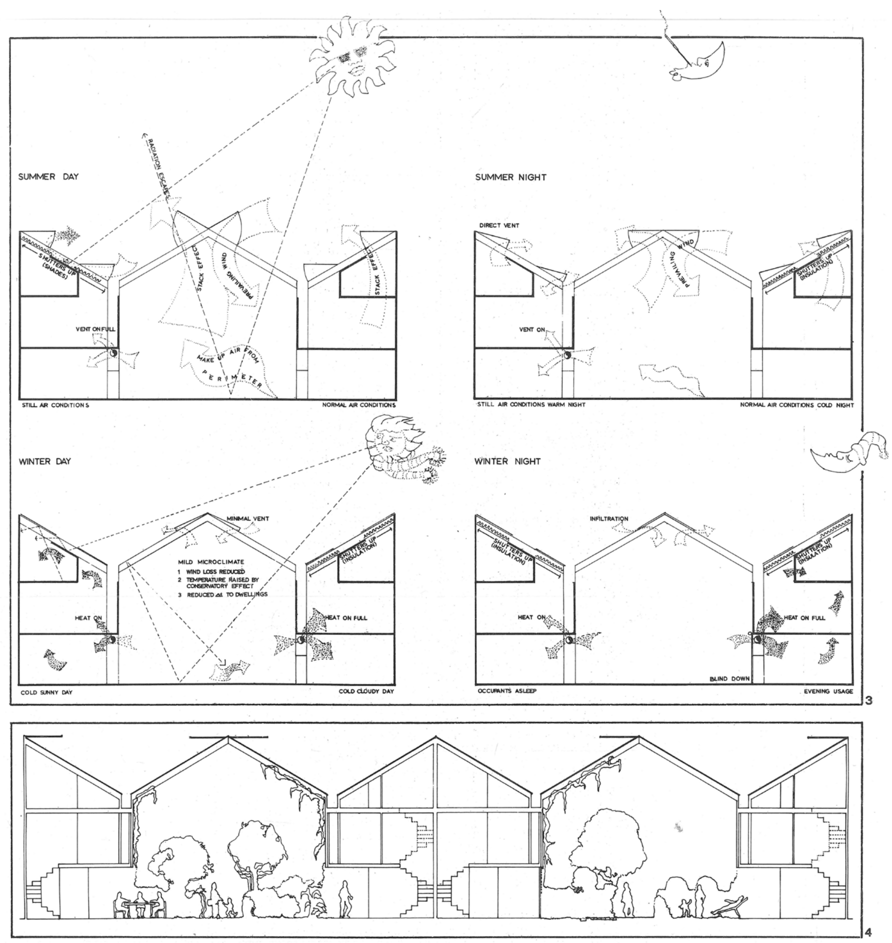


FIGURE 11 Trombe Wall, Winter heating and summer cooling. Section of the detached house with Trombe Wall, built in 1967 in Odeillo, France. (Architectural Design, 1/1975)

# Evolution of the Trombe Wall

*Architecture d'Aujourd'hui* (Nicolas & Vaye, 1977) described a case study that was characterised by further experimentation between the *Trombe Wall* and architecture on the ground floor, while the solar collectors are integrated with the façade on the first floor. On the ground floor, the air cavity between the glass and the dark thermal mass wall of the *Trombe Wall* is extended and transformed into a usable green space. It is the *Maison à Argenteuil,* in Val d'Oise (Fig. 12) by architects Marc Vaye and Frédéric Nicolas, also authors of the book *La Face cachée du soleil* (Nicolas, Traisnel, & Vaye, 1974), which puts forward an ecological approach in architecture. In the house, the space between the glass and thermal mass wall is used as a greenhouse (Fig. 14). The solar technical operation of the envelope on the ground floor, on the southwest and southeast, is similar to the *Trombe Wall*. It is a space where the air still separates glazing from masonry and air circulation is still provided via gaps on the top and bottom of the thermal mass wall (Fig. 15). The greenhouse space is also integrated with the main entrance of the house. In this case, part of the *Trombe Wall* technology is transformed into an architectural space. The expanded greenhouse becomes a space defined by the article as temporarily habitable. A second innovation listed by the article is the abandoned linearity of the southern façade, as it was in the detached solar house in Odeillo. The two main façades are in fact oriented to southeast and southwest. Moreover, the angle formed by the façades is underlined by the extension of the "greenhouse" towards the south. The architects describe the building as one of the first experiments where the volumetric rigidity of the solar house is broken (Nicolas & Vaye, 1977). It is also broken in the three row houses in Odeillo with the curved southern wall. In this example, the *Trombe Wall* evolved by becoming a usable space also hosting some vegetation.

Vaye and Nicolas built the 130 $m^2$ area house (greenhouse included) for Vaye's parents. It materialises the ecological concept defined by the architects in their book *La Face cachée du soleil* (Nicolas et al., 1974). The house has the disadvantage that the ground floor doesn't get much solar light. The architects weakly justify the choice of the blind wall behind the greenhouse, not only for energy efficiency reasons, but also to preserve the privacy of the inhabitants.

The vernacular principles of the second sketched drawing of Figure 2, characterised by a totally transparent element warming up the internal thermal masses of the south façade, are also partially embedded in the ground floor project. In this sense, the article describes the greenhouse by introducing the design concept of relative transparency (i.e. due also to the vegetation and to the different opacity of the glass panels) whose variations are accomplished in the double rhythm of day and night, summer and winter. The experimental house stands between the vernacular solutions proposed in the second drawing of Figure 2 and the *Trombe Wall* on the ground floor. However, the innovative space of the usable greenhouse with *Trombe Wall*, paradoxically makes the living room dark.

From both a technical point of view and an architectural one, the building envelope proposed by Vaye and Nicolas opens up an original research path. In an issue of the French magazine T*echniques et Architecture* from 1979, the house in Argenteuil is described as "a house in a garden, a garden in a house (Cabessa, 1979, p. 80)". The 42$m^2$ greenhouse area can be used during the hot season for 70% of the time, and 100% of the time during other seasons (Cabessa, 1979). In reality, this house was able to produce the 70% of energy needed for heating. The increased energy efficiency was also due to the standard solar collectors on the upper floor.

Even if it is a remarkable fact that the interest of the magazines was already directed towards energetic autonomy (i.e. 100% of energy needed produced by the house itself) only a couple of years after the first *Trombe Wall* prototypes, the main focus is still on the technological innovation of the *Trombe Wall* with the greenhouse. Not much is mentioned about the fact that, for instance, the living room doesn't have a view to the outside. The natural light is only entering the living room from the triangular opening on the first floor, through the double height space. The fact that a rotating shutter (Fig. 13) is applied on the *Trombe Wall* is also barely mentioned. It is a crucial point because it affects the behaviour of the inhabitants. It is manually manoeuvred, protecting the thermal mass of the *Trombe Wall* overnight, in order to avoid releases of warm air to the outside. It can be seen as a paradox that the technology, which is transformed and integrated in the architecture, needs a manually manoeuvred protection in order to be more efficient. The architects and the magazines did not extensively describe and investigate these problems and considerations. In an interview with the architects, who knew the inhabitants, they maintained that the wall never reaches very high temperatures meaning that is always comfortable to stay close to it on the living room side. They also confirmed that that the manual manipulation of the shutters can affect the optimum efficiency of the *Trombe Wall*. The shutters are realised to improve performances and if left open the entire night, the wall loses only a minimal part of its efficiency. On the other hand, if they are left closed during a sunny day, a huge amount of solar energy is not captured (Medici, 2017).

The acquired knowledge of the greenhouse embedded in the *Trombe Wall* could be a design tool with several potentials. Especially if such issues are solved: inhabitants' behaviour, natural light access, and internal program depending on the different temperature in the rooms and view from the inside. With a solution for these issues, the technology might have become an even more powerful design opportunity and tool instead of a constraint, even during the 1970s.

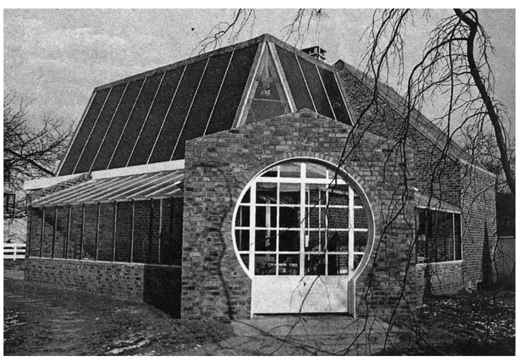

FIGURE 12 Maison particulière, Argenteuil, Val d'Oise. Main entrance on the south. (Techniques et architecture, 6/1979)

FIGURE 13 Maison particulière, Internal view of the greenhouse. Detail of the (white) rotating shutter closed in front of the thermal mass wall.(Image by Marc Vaye © , 1980)

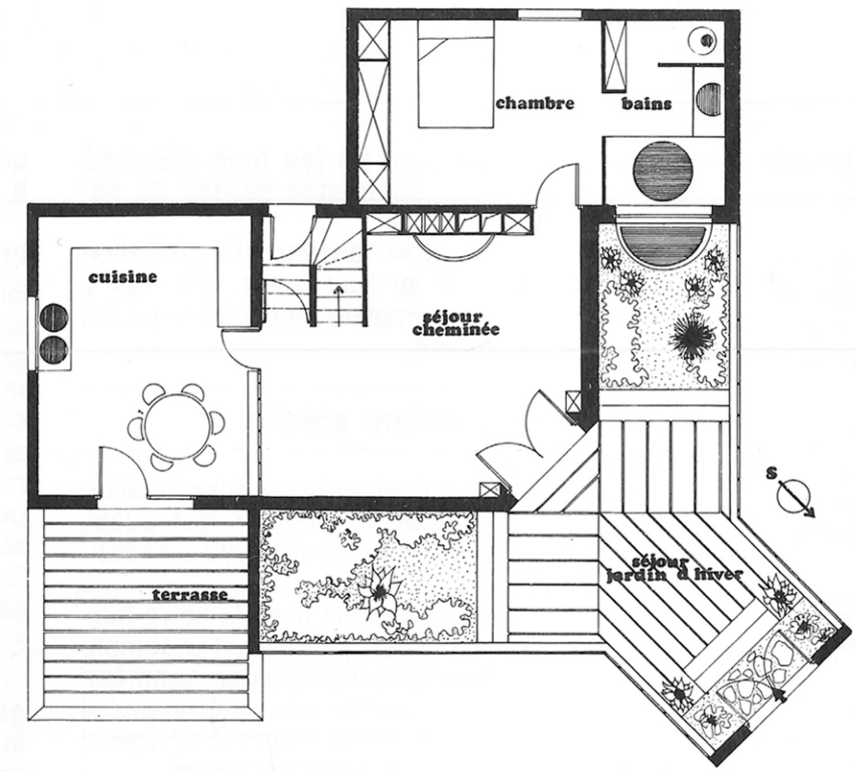


FIGURE 14 Maison particulière, Argenteuil, Val d'Oise. Plan and program. (Architecture d'Aujourd'hui, 4/1977)

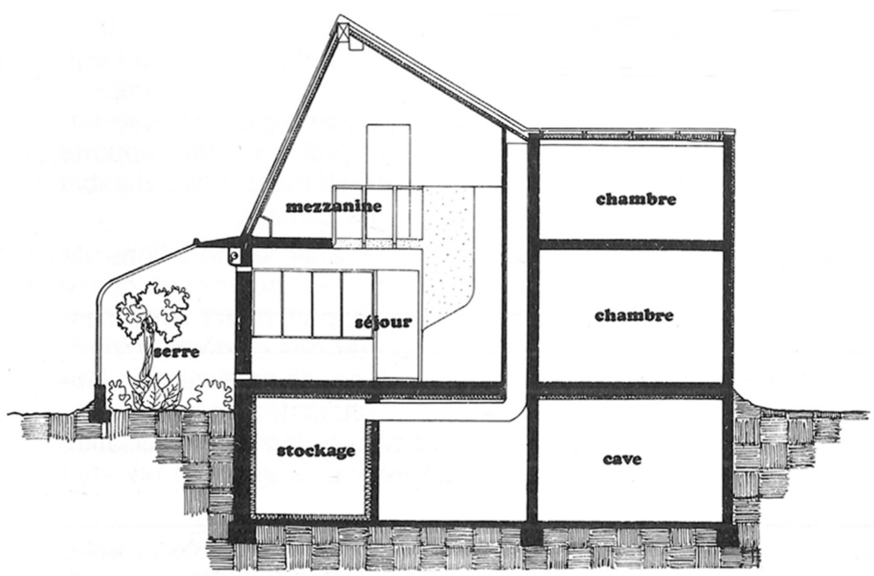


FIGURE 15 Maison particulière, Argenteuil, Val d'Oise. Section and program. Air inlets visible on the top and bottom of the Trombe Wall next to the greenhouse. (Architecture d'Aujourd'hui, 4/1977)

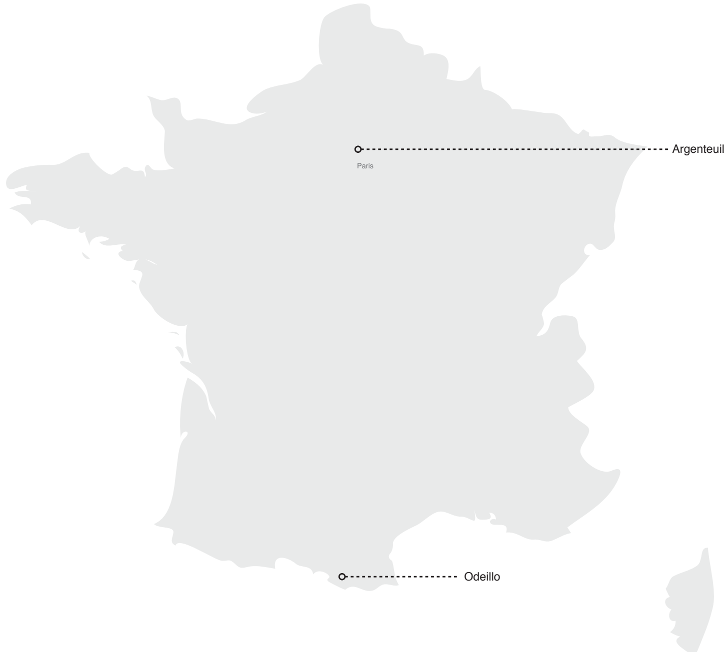


FIGURE 16 The location of Argenteuil and Odeillo in France

# Conclusions

With the development of the *Trombe Wall*, the possibility to integrate the solar collector with elements of architecture such as the wall, the façade, the garden, and the greenhouse, was explored.
At first, the architecture was hidden behind a dark wall until the air cavity, between glass and thermal mass, was transformed into a usable space: a garden and an entrance preserving its ventilation properties. In the third example that used the *Trombe Wall* as a reference, the garden between glass and thermal masses increased its size, becoming, instead of a wall, a space with a roof connecting two rows of houses. The *Trombe Wall* technology, when integrated in more complex architectures, achieved new developments. Engineers had the chance to test its efficiency when the thin air layer became a garden or when the *Trombe Wall* was fragmented into a façade of a double level open space. In some cases, the *Trombe Wall* became a design tool for the architect. This design tool is intended as the acquired knowledge by the architect about the *Trombe Wall* technology embedded in the architecture of the house. In effect, the *Trombe Wall* was an element to improve energy efficiency, while at the same time generating architecturally innovative spaces and solutions. Throughout the 1970s, architects had the chance to learn different methods to integrate the *Trombe Wall* with façades impacted by solar radiation directly or through a greenhouse.

In the first example, in Odeillo emerged the contradiction between the need for an energy efficient architecture and a house with almost blind walls to the south. In the second example, this problem was solved by fragmenting the curved *Trombe Wall* facing south, west, and east. This was the first effort to make the technical space more habitable. In the last two examples, the need to transform the technological device into a habitable space emerged even more clearly. In the final built solution, transforming the device into a usable space brought back the problem of creating a living room almost without direct natural light, as in the first detached house example. The trajectory during the 1970s was from a functionalist architecture towards a different way of living. In the house in Argenteuil, the use of the greenhouse space was different during the seasons and throughout the day. Moreover, because of the manually manoeuvred shutters, the life of the inhabitants unexpectedly changed their daily behaviour, with manual actions contributing to the house's energy efficiency.

As visible in the examples above, during the 1970s some architectural magazines focused more often on the technological solution, while quality of architecture and quality of living were not so central in their descriptions. Written analyses about these topics were missing, as were visual descriptions, for instance: pictures or artistic impressions of the interiors, views from the interiors to the outside, view of the technical installations from the inside. Useful analytical and representation tools were rarely used, for instance: diagrams illustrating energy flows and social quality of spaces; 3D images illustrating the comfort of the interiors looking towards the outside through the greenhouse. Only a few of them were realised at that time. In effect, there was still not enough knowledge on integration between solar technologies and design process or architecture culture.

The incomplete analysis by magazines and architects, and the fact that some disadvantages were not clearly identified or solved, probably didn't help in spreading its implementation within the culture of standard architecture even further.  If side effects and problems had been better stated, analysed, and understood, the *Trombe Wall* could have become a stronger design tool.

Now that the implementation of sustainable and energy-efficient strategies have, again, become imperative, as they were in the 1970s, these strategies are used more often than not as add-ons to existing architectural schemes, without much interaction, and without much consideration of their possible spatial, social, and experiential qualities. The 1970s development of how the *Trombe Wall* became embedded in the architecture of the house, and its reception and description by the magazines, can inform the contemporary debate about the sustainable and energy-efficient architecture of today.

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