

THE EVOLUTION OF SOLAR ARCHITECTURE

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Figure 1: A house opened to the sun,
Architect: F. Kühnis, Bellikon CH.

1. Introduction

History is important because it keeps us humble and offers solutions to problems which know no time barriers. The topic of using the sun as part of architectural design is an example. While we tend to compliment ourselves with inventing and experimenting with new concepts, indeed the roots of such concepts can often be found far back in history. This paper travels through time from over two millennia ago to the present. The focus is on residential construction, but a similar story could be developed for commercial and institutional architecture.

As far back as ancient Greece, making use of solar energy to condition buildings was a known art. The motivation then and up through the middle ages was to improve comfort, or possibly reduce the consumption of firewood which was labor intensive. The motivation in the 1970's was to reduce dependence on imported oil subject to politically motivated supply interruptions. Today the motivation is also reduction of greenhouse gas emissions and climate change.

Throughout history, the same basic principles apply. Sunlight is captured for both its heat and light in order to drastically reduce a building's need for other energy sources. A prerequisite is the minimization of heat losses through the building envelope and the consumption of hot water and electricity. Thereafter a large percentage of the remaining demand can be covered by solar energy. In contrast to a conventionally oil or gas heated, mechanically cooled and

artificially lighted building, a solar building holds much which adds to its fascination, including:

- the openness of the building verses the closure of buildings where insulation dominates.
- the dynamic of the interior thanks to the close tie to the outside environment (the changing light, colors and sounds) in contrast to the constancy of an encapsulated air conditioned and artificially illuminated space.
- the contrasts between light, shadow and all shades in-between to accentuate form and color rendering.
- the play of opaque and transparent, and mat or reflecting facade elements in various proportions and changing over time by the occupants operating windows, blinds or shading devices.
- the dream of being autonomous, self-supplying, truly independent of outside resources.

2. Ancient use of Solar Energy:

Already in 2800 BC solar orientation was a basic design principle for Egyptian temple construction. The great pyramids were so positioned to show the change in position between the earth and sun over the course of the year. The majestic temple in Karnak, honoring the sun god, Ra, was oriented so that the sunrays penetrated the edifice in a sharply defined bundle. At the summer solistice sunlight penetrated unhindered through the entire length of the temple to an alter, creating a very mystic effect. The path of the sunrays could be closed down or opened by the position of doors along the tunnel, analogous to the aperture of a telescope (Sir J. Normann Lockyer, Astronom).

Socrates in 400 BC considered solar design principles in house construction. He advised that in houses oriented towards south, warming sunlight penetrates past the portico deep into the house in winter, while in summer the solar orbit is so high that the portico casts the house interior in cool shade. Making use of this phenomena is the hallmark of his so named "Megaron House". Logically, the zoning of uses of rooms also reflected this principle.

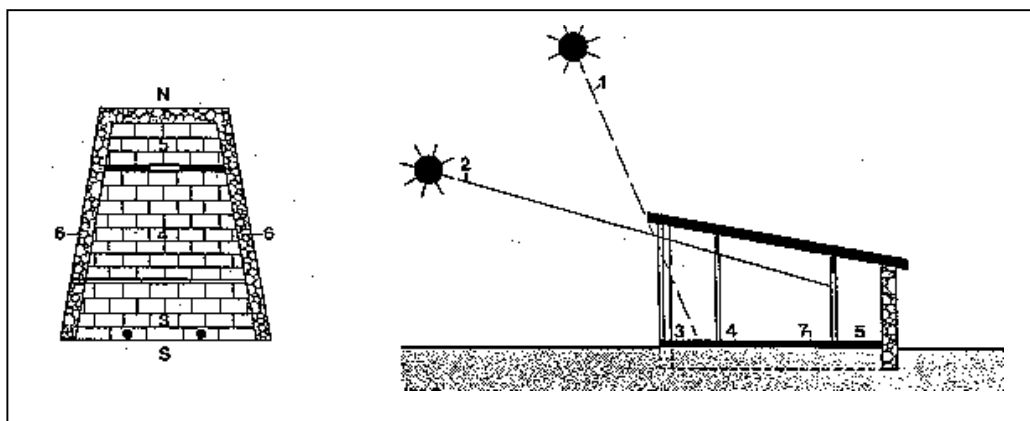


Figure 2: Socrates House

In ancient Greece the concept of concentrating sunlight was also developed for military purposes. A "burning mirror", consisting of highly polished shields which soldiers in a coordinated fashion positioned to the sun to concentrate its powers on a target. Each shield had

a concave surface to concentrate the sunlight. A hundred shields pointed to the same object in the distance could generate an extraordinary energy density and heat. According to legend Archimedes in the year 212 BC used this weapon to set on fire the sails of an attacking Roman fleet of ships.

Also the Roman Empire built edifices according to solar architectural principles. In the 6th Book, Chapter 1 Vitruvius describes passive solar design principles for residences, such as "Perystil House". This Roman house type had a colonnade which provided sunshading in summer for the living spaces beyond. Service rooms were placed to the north and served as a buffer.



Figure 3: The Roman Bath of Caracalla [3]

But, the most dramatic example of Roman innovation to make use of the sun can be found in the baths and "solaria" starting from the first century AD. These were not oriented towards south, but rather towards the evening sun to the west, in order to gain as much warmth in the time when the baths were in use. A gigantic glass front facade admitted the sun and trapped the resulting heat. The sand floor stored some of this heat to extend the hours of use of the bath. This configuration was so effective that such spaces were used as "sweating rooms". [2]

3. Solar Use in Colonial Times

In colonial New England, the British settlers adapted English clapboard houses to the harsh but sometimes very sunny weather of their new homeland. These so called "Saltboxes" received their name because of a similarity to the containers used to store salt at the time. The cross section of the house had a high south facade to provide a generous area for sun-gaining windows, and a long roof sloping down to a truncated north facade, to provide a sheltering back for the house. Heat loss from the windows was reduced by closing shutters at night. In summer the "double hung" provided effective ventilation. The top sash of the window could be slid down to exhaust hot room air, the bottom half slid up to admit cooler outside air.



Figure 4: House in New England

Across the Atlantic, a small population in the Appenzel Region of Switzerland developed a house type with a very noteworthy facade. Appenzeller Houses have an innovative strategy to maximize the admittance of sunlight in the winter while providing solar protection in summer and rain protection for the windows all year round. The roof which projects out past the facade is part of the solution, protecting upper top floor windows. Additionally, at each story a small supplemental roof projection affords protection. But, still more clever, the underside of both the main roof projection and the supplemental roof projections is concave and painted a light color to capture and reflect more of the sparse light into the house in winter.



Figure 5: Typical house in Appenzell

4. Early 20th Century

In the first decade of the 20th century a strong reaction against buildings of the previous century occurred, they were considered as unhealthy. As a reaction, new buildings were erected with hygiene in mind, large windows to admit as much sun and light as possible, white walls, roof terraces - a bright, airy architecture. This was all considered a preventative measure against such diseases as Tuberculosis. The housing development Neubühl in Zürich is an example, with its strong orientation towards south and generous window areas. Strong sunshine and clean air were indeed marketable, clinics in the Alps offered convalescent stays, an example of such a tuberculosis clinic can be found in Davos, the Sanatorium: Pflughard and Häfeli [4].

Solar architecture won the acceptance of famous architects, such as Frank Lloyd Wright. The Jacobs house is a clear example of a structure laid out according to solar geometric principles. Further examples are the Robie House built in 1909 and a year later Taliesin East. Another less well known architect pair, the Keck brothers built very deliberate direct solar gain houses in the mid west of the USA. A well publicized house was the "Crystal House" of 1932. This served as a prototype for many subsequent houses. The guiding principle to such design they explained with the "Triad": Sun, mass and shading.

In the period from 1940-50 engineers became fascinated with the active solar use of solar energy. A series of houses were built by researchers, of the Massachusetts Institute of Technology. The MIT Solar Houses I-V. In these houses, however, the focus was on collectors, pumps, storage, distribution and control, not a complete architectural solution.

5 Late 20th Century

After the oil shock early in 1970 interest grew in the idea of energy self-sufficiency. The passive use of solar energy became instantly popular. This movement began in the southwest of the US where conditions were ideal, much sun all winter and cold temperatures. National Passive Solar Conferences brought together researchers who were investigating the houses, the designers of the houses and architects from all across the country. Soon passive solar design principles were being modified to adapt such houses to all climates across the continent. The US Department of Housing and Urban Development held competitions and offered thousands of grants to explore and publicize successful designs.

Figure 6: Stuby House



Europeans were not unaware of this movement and many architects came across the Atlantic to attend the myriad of passive solar conferences and workshops, take part in house tours and meet with architects. For example Stuby, Wagner, Amsler, Schäfer, Kühnis, Meier made the trip, returned to Europe and initiated a similar passive solar movement in the early 1980's. The very fundamental principles of building with the sun written about by the ancient Greeks and Romans found a renaissance. Because of its simplicity, direct solar gain through windows was the most favored approach, but often combined with solar-oriented "wintergärten".

In the south of France two engineers, Felix Trombe and Jacque Michell developed a concept still known today after their names. By placing a glass facade in front of a massive south-facing wall solar heat could be captured in the mass of the wall. The glass and buffer air space impeded the loss of the heat to the outside, so with a time delay, the heat would penetrate the wall and radiate into the room behind the wall. The time delay resulted in heat release at night, nicely complimenting the daytime solar gains of conventional windows.

In the western part of Austria and eastern Switzerland, active solar air systems were built, but unlike the earlier MIT solar houses, these systems were an integral part of the house design and construction. The collector was built into the roof construction, massive floors (hypocausts) or walls (murocausts) with channels provided both heat distribution and storage. Early systems were complex with numerous dampers, alternative air passages, and modes of operation so the occupants could exactly control and optimize the system. With time, the concepts were greatly simplified, which reduced cost and improved reliability.

6. The Present

Two technology developments have had a strong influence on the further development of solar architecture now, after the turn of the century:

Powerful high speed personal computers

Computers with processing speeds now advertised in units of GHz. (operations timed at thousand millions of a second) and storage capacities of 40 thousand million bytes are affordable for home use. With this speed and capacity comes the ability to analyze the performance of a solar building for a year long period in seconds. Whereas design of the passive solar houses of the 1970's was done with the help of hand calculators with a small magnetic strip which could feed in a few steps of instructions for monthly energy balances, today a full dynamic simulation can be run. While office applications, graphics and the whole technology of user interface has kept up and even pushed the state of technology, the building design profession has not provided an adequate market for the truly professional development of energy and environmental analysis tools for planner. Indeed programs dating back to the 1980's in modified form are still in use today.

High performance building components

Components hardly imaginable 20 years ago are taken for granted today. Following are a few examples:

- New glazings: Glass with a U-value of $0.7 \text{ W/m}^2\text{K}$ or less is offered by many manufacturers today. Development of window frame technology has lagged behind, with the result that window frames are often the thermal bridges of recently built solar houses. Only now are high-insulation frames coming on the market as part of high performance window constructions. The consequence of this is that today indeed, windows and passive solar gain can cover a very large percentage of the heating demand of highly insulated houses. An extreme example can be found in the village of Trin built by the architect A. Rüedi. Here the passive solar gains are adequate to keep room temperatures at or above 20°C 95 % of the time. There is no auxiliary heating system, no wood stove, only windows.



Figure 7: Trin House by A. Rüedi

- Transparent insulation (TWD). This is an improvement on the Michell Trombe Wall. By filling the air space between the glass and mass wall with a capillary transparent material the heat loss of the wall by convection in this air space is drastically reduced. Different types of plastics and geometries are available for this purpose. The end effect is that the wall no longer has a heat loss, but over the heating season can achieve a net heat gain, becoming a part of the heat supply system for a house. The system is not without problems, however. It is so effective that overheating of the house can occur, or still worse overheating can lead to self-destruction of the plastic material.



Figure 8: Windberg, Th. Herzog

- Accordingly a solar protection system is necessary, particularly for the spring and fall months when the sun angles are still low, striking the glass and the days can be warm. The need for a sun protection leads to the other major problem, system costs are still high in comparison to the energy savings. One innovative application of this system is found in a zero-heating house in the Domat-Ems, Switzerland by the architect R. Schwarz. He solved the overheating problem by detailing a back-ventilated TWD wall with dampers at the bottom and top to ventilate away the potential overheating.
- Solar air collectors have undergone optimization in both performance and manufacturing. Today several firms in Europe offer a selection of high-performance, mass-produced collectors. The simplest version is the unglazed perforated absorber collector for ventilation air heating. This patented invention of a Swiss engineer is marketed worldwide by a Canadian firm with great success today, thanks to the cost-effectiveness of the concept. [6].

The combination of both extremely good insulation, mechanical ventilation with heat recovery and solar energy use is the basis of the newest generation of high-performance housing, the so called "passive houses". The remaining heating demand of such houses may not exceed 15 kWh/m²a (55 MJ/m²a). Founder of this "Passivhaus" movement is W. Feist of Darmstadt Germany. [7]. Today hundreds of such houses have been built across Europe, from Sweden to Switzerland. A research program of the European Union, CEPHEUS, is documenting selected exemplary houses [8]. A research and demonstration program of the International Energy Agency is now striving to improve performance towards achieving a wide market penetration. Energy, ecological and economic performance is being optimized by evaluating monitoring data of built projects, carrying out sensitivity studies with computer models, and building next-generation demonstration projects. [9]



Figure 9: The first passivhaus in Darmstadt 1991 (W. Feist)

7. The Future (History continues)

The very recent explosion in oil prices is a preview of the future. Oil prices are not yet dictated by diminishing supplies (this will come), but rather by politics and national economics. We have seen that is possible for oil prices to double within one year. The current fleet of energy squandering cars, i.e. sports utility vehicles and vans can be phased out of operation within a decade, but buildings can stand for a century or more. Considering this, and given the attention to climate change and greenhouse gas emissions, it can be anticipated that the market for high energy performance buildings will grow.

Inevitably the path to such performance included the merging of high insulation technologies and using the solar resource. Today, high insulation still requires enormously thick constructions, this will motivate the development of more compact systems. High performance windows are already available, it only remains to be learned how to rationally use them to win useable solar energy without overheating. This raises the issue of the need for microprocessor control systems to optimize the usability of passive solar gains relative to the control of mini-backup heating systems. When such a controller is present in a house, it can also take over a multitude of other functions, such as optimizing the performance of solar domestic water heating, photovoltaic systems, even burglary and fire alarms systems. Such multiple-function controllers have long been in use for commercial buildings, they must be adapted in function and price now for residential applications.

Another trend which can be expected is that the development of such housing will also stimulate new concepts for whole settlements of housing. Many planners are already developing vision for "solar cities".

Lastly, as architecture finds a link back to climate and basic principles it can be expected that the quality of indoor life will become more stimulating and better satisfy instinctive, ingrained human needs. The currently evolving architecture again offers more daylight spaces, better air quality, and a tie back to nature - curiously, the same aspirations which architects strived for at the turn of the 19th to the 20th century.

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