

GEORGE LÖF: DENVER'S SOLAR PIONEER

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ABSTRACT

This historical study explores the career of George Löf and his importance to the history of the solar house. Löf, a chemical engineer, made countless contributions to solar house heating, including numerous patents and more than a hundred papers. This paper will focus on a few highlights:

- Löf's role at MIT, where he worked on Hoyt Hottel's team building and testing the world's first 'active' solar house (1939).
- Löf's 1945 'Boulder house': the first solar air heating system in the world, using gravel as a storage medium. The system, attached to an existing bungalow, was also the first retrofit solar heating system of any kind anywhere.
- Löf and James Hunter's 1956 'Denver house': a brilliant example of interdisciplinary collaboration, and a solar heating system which operated continuously for 50 years.
- Three solar houses at Colorado State University in 1974-75: One was the first in the world to be both heated and cooled with solar energy, and another pioneered the use of evacuated tube collectors.
- Löf's private company Solaron (Denver), whose collector was known as "the Cadillac of the solar heating business" in the 1970s and 80s.

This paper is excerpted, with some changes, from a book manuscript, tentatively titled *The Solar House in the 20th Century*, to be published by Rizzoli International Publications in late 2012.

1. INTRODUCTION

Nobody played a more enduring role in the 20th century solar house movement than George Löf. Today, the solar house is often understood as a product of the 1970s, and

architectural history generally ignores the fascinating experimental solar houses which were constructed in the previous four decades. In a sense, the solar house movement was 'ready' for explosive growth after 1973 due to the decades of exploratory work by pioneers such as George Löf.



Fig. 1: George Löf (1913-2009). Colorado State University.

Why would a chemical engineer devote his career to solar heating, in a time when there was little public demand for these systems? In an interview late in his life, he recalled:

My underlying motive was an interest in seeing solar utilized. It was logical that if you could save money by not having to buy so much fuel that it would be a useful thing for society. It was my hope that solar would be a medium by which fuel use could be reduced.[1]

Löf's career sheds light on many larger historical issues: the "schism" between architecture and engineering; the "passive vs. active" debates (Löf testified to Congress on this subject in 1973); the importance of research funding in the history

of solar energy; and the commercial economic context for solar houses.

2. LÖF AT MIT

Löf's career in solar heating began with his being in the right place at the right time. You might say he was present at the creation. In 1939, Löf was a graduate student at MIT, studying under Hoyt Hottel during the construction of what is now called MIT Solar House I. Though Hottel called his project "an experimental solar energy research laboratory," it is recognized as the first 'active' solar house.

MIT I was a tremendous technical success, with flat-plate collectors that heated water and stored the energy in a basement storage tank. Solar heat kept the building at 72°F for three years without any backup heating. Löf helped Hottel analyze the data from the house, but otherwise his participation seems to have been limited. (Hottel produced the first definitive paper on flat plate collectors but Löf was not credited.[2]) Löf and Hottel would remain lifelong friends and key leaders of the solar house movement as it developed.

3. BOULDER HOUSE

After earning his doctorate under Hottel, Löf moved to the University of Colorado in 1943 to establish a solar house program of his own. A military engineer had conceived a new type of flat-plate collector, consisting of overlapped glass plates encased in a box with a glass cover, and Löf set out to explore this type of "heat trap" as a method for space heating using air, rather than water, as the circulation medium. Löf and his team began with bench-scale experiments using lamps, then in 1944 they built a larger collector on the roof of a campus laboratory building.

3.1. The Project

Next, in 1945, Löf placed collectors on his existing five-room bungalow in Boulder. Löf could later claim, without dispute, that the Boulder house constituted "the first solar air heating system" and "the first retrofit solar heating system of any kind in the world."

Löf described the aims of the project:

The three principal purposes of the Boulder solar house were to:

1. Determine with what success a solar heating system of this type could be installed and used in an existing house heated by conventional means.
2. Ascertain and eliminate the operating problems associated with a solar heating system in a

typical home, and particularly in combination with a standard heating system.

3. Measure with as much accuracy as possible under the circumstances, actual and potential fuel savings by use of solar energy.

He also said flat-plate collectors should be designed to be "produceable on a factory basis, and suitable for installation in a new dwelling without extensive fabrication at the site." [5]

Why would Löf even consider air as a medium for heat transfer? Water can store 3000 times as much heat by volume than air, and Löf understood this physical property very well. But Löf also recognized that most homes already included a system of ducts and fans—hot air produced by solar energy could be delivered directly to the occupants. No extra plumbing systems were required. Automatic controls triggered a conventional furnace when needed.

The earlier experiments had established the best values for some of the critical variables, such as the amount of overlap (2/3) for the plates of glass and the spacing between them (1/4 inch).[6] The panes were partially blackened in the area which would lie beneath two other clear surfaces. By this arrangement, air would enter the chamber, pass between the plates, and be heated by as much as 110°.



Fig. 2: Boulder house. Carnegie Branch Library for Local History, Boulder Historical Society Collection.

Although Löf would have preferred to install the collectors at a 47° tilt, inflected towards the lower winter angles, he used the 27° slope of the existing roof. He calculated that the collectors at this flatter angle would be 92% efficient compared to the optimum, and he accepted this compromise. The collector area measured about 460 square feet and occupied about one-third of the roof.

3.2. Results

In its first winter, the Boulder house saved approximately 25% in fuel consumption, but the first generation of air-type collectors, Löff recalled, were “fragile” and experienced “many problems.”[7] The air ducts were leaky, and the glass plates frequently broke due to thermal expansion. With improvements the savings approached 50% late in the heating season. Löff said the overall efficiency matched the Hottel-type water-circulating collector. The project also concluded that heat recovery in the collectors increased with the air rate, and that non-reflective glass performed much better than ordinary glass.

The costs of the project were not relevant, Löff said, due to “much trial and error, meticulous hand labor, excessive instrumentation, and other factors.”[6] But in 1947 *Architectural Forum* reported that this system, if mass produced, could cost about \$500 and that such an effort could commence within the next 12 to 18 months.[8] (No mass production would occur until the 1970s.)

Initially, the system had no ability to store heat for use at night, but in 1947 Löff installed a 9-ton gravel storage system in the basement. Lab tests had determined the optimum size for such a storage bin (based on a single day’s collection) and the best size of gravel and resultant spacing. (Pebbles ranging from 1 to 1-½ inches in diameter were best.) Though the problem of fragile collectors continued, the gravel storage improved overall fuel savings to about one-third. Löff patented the system in 1945.[9]

3.3. Discussion

The Boulder house (like MIT I) was strictly an engineering system—not a work of architectural design at all—and the solar house movement began to struggle with some of the problematic effects of what Sigfried Giedion famously called “The Schism Between Architecture and Technology.”[10] When he moved in 1948, Löff was forced to deconstruct the solar equipment in order to sell the house. The lack of aesthetic resolution between the traditional architecture and modern machinery seemed troublesome. Löff realized the engineered solar house needed a higher level of design, and he began to envision “a modern house, planned from the start as a solar heated dwelling,” as the next logical step.[4]

4. THE SOLAR RANCH HOUSE

Löff began working with Boulder architect James Hunter in 1949, and their partnership can be characterized as the first effort in the solar house movement to aspire to an integrated design process. Together they designed a ranch-style solar house, originally meant for the Los Angeles area. Why such a benign climate? Löff said the solar equipment “might easily justify itself” there. They chose the “ranch house

image,” according to Hunter, in order to make the solar house “palatable and acceptable” to the house buying public at that time.[11] The low roof slope was not optimized for winter solar heating, even at the lower latitude of Los Angeles. The concession—placing architectural marketability ahead of engineering performance—indicated that Löff aspired to produce something more than a science experiment.

During the design process, Löff and Hunter ‘moved’ the hypothetical house to Dallas, and then again to the Denver area. They did not alter the architecture significantly, and they kept the ranch-style roof with its low slope. The solar heating equipment Löff imagined was quite similar to his earlier Boulder project: an air system with overlapped-plate collectors, a gravel storage bed in the basement, and a conventional furnace for backup. He calculated that such a system could provide 70-90% of heating needs from the sun, even in Denver. Still, he acknowledged it “might not cut heating costs much” there due to cheap natural gas.[4]

They unveiled the solar ranch house in 1950, at the MIT symposium *Space Heating with Solar Energy*, and announced “blueprints were ready for a solar house suitable for the southwest area bounded by Denver, Los Angeles, and Texas.”[12] It would include 2,000 square feet of living area and cost \$25,000. Apparently they found no demand.

Overall, the symposium was a pivotal episode, a great summit meeting of solar architects and engineers, where participants specifically recognized the need for an integrated approach to the solar house’s technical and aesthetic challenges. When Löff reflected on the significance of the meeting, he noticed “the clear indication that the solar heating problem is closely associated with an architectural problem.”[13] In other words, for Löff the meeting prompted a questioning of the centuries-old implications of Giedion’s schism. Integration of architecture and engineering became the dominant theme of the solar house movement in the 1950s.

5. DENVER HOUSE

In about 1955, Löff and Hunter abandoned the 1949 scheme, began anew, and the resulting process resulted in the seminal 1956 Löff house in Denver. It was frequently hailed in the 1970s as the oldest continuously operating solar heating system in the world, and Löff lived in the home until his death in October 2009.

5.1. Design

Having found the ranch-style roof form to be a “straight jacket,” Hunter proposed a flat-roofed house, and the resulting process triggered an immensely interesting

discussion about ‘style’ and the solar house. Hunter preferred the flat roof because “[the solar house] must be the very best and timeliest architecture within our ability.” What about the tastes of homebuyers? “We feel now that the American buying public was, and is, far more discriminating in its evaluation of architecture than the speculative builder supposed.”[11] The house was later celebrated in a full-page feature in the *New York Times* for its “modern lines.”[14] (Late in his life Löff said that Tician Papachristou, who worked in Hunter’s office at this time and later partnered with Marcel Breuer, had performed considerable design work, but all other evidence points to Hunter as the designer.[1])

The concept of placing sloped collectors on a flat roof with an independent supporting structure was essentially novel and transformative. This strategy may be interpreted as an avoidance of the true complexities of the problem, as it allowed each discipline to dodge major constraints imposed by the other. Löff argued that the engineering requirements should not determine the architectural expression:

You wouldn’t build your house around the conventional furnace. So you won’t build it in the future around the solar-heat equipment. The latter has to fit into the house.[15]

Indeed, the flat roof scheme can be seen as an implicit criticism of other solar buildings where the collectors dominated the image. A *Popular Science* writer remarked that prior solar houses were “all odd looking, because they were primarily outside collectors of solar energy with the living quarters attached to them,” and praised Hunter and Löff’s design as being “the first American house to have a solar-heating unit as optional equipment that didn’t dictate and distort the design of the house to suit its needs.”[16]



Fig. 3: Denver house by Hunter and Löff (1956). Historic Denver, Inc.

Löff said the flat roof would allow for “complete freedom of choice” for the engineer in terms of positioning equipment.[4] Unlike ‘passive’ solar houses, the organization of space within the house could be disengaged from the solar path because any given plan could be rotated while the rooftop collectors faced south. Moreover, this flexibility allowed Hunter to design a relatively deep, squarish floor plan, and the deep plan would make narrow lot-types suitable for solar houses.

For the solar heating system, Löff again employed overlapped-plate collectors, hot air distribution, and gravel storage. Löff undersized his system; it was designed to provide only 25% of the heating load with solar energy. The collectors, 600 square feet in total, were organized in two rows atop the roof and set at a 45° tilt angle. Then, perhaps paradoxically, Hunter added a plywood screen to (partially) shield the collectors from view.

Löff had determined, for engineering reasons, that the gravel bins should be vertical rather than horizontal, because stratification was desirable. Hunter realized that the vertical bins could be treated as a major expressive feature. He specified two cardboard tubes, three feet in diameter and 18-feet tall, and located them in the staircase in center of the house, visible from the entrance, and he painted them bright red—“unique totems to today’s solar technology.”[17] In the context of the solar house movement, it marked the first time an engineering feature was prominently expressed inside the building.



Fig. 4: Denver house by Hunter and Löff (1956). Photo by author.

5.2. Results

Initially the system showed “no net savings” due to the large amount of electrical power required to push the air through the gravel tubes.[18] Additionally, the collectors suffered considerable leakage, pointing yet again to the broad theme

that solar gains are easily defeated by convection losses. After improvements, 25% of the heating load was carried by solar energy. But, while he had saved \$80 in natural gas, he spent \$60 more in electricity; for a \$10,000 first cost, he saved about \$20 per year. Still, Löff reported: “the economic aspects of this application are encouraging,”[19] in large part because he believed the collectors could be improved and made considerably cheaper if mass produced.

The system did prove durable. In 1974, Löff decided to reassess its performance to see if it had degraded over time. No maintenance had been needed in the intervening period. He discovered that the system operated at 72% of its original capability, a decline of about 2% per year, probably due to broken glass inside the collectors and increased air leakage due to degradation of caulking.[20]

5.3. Discussion

The small proportion of collector area to interior space (600:3200 square feet) reflected Löff’s detailed attention to economics—particularly the first-cost of the collectors and the low price of natural gas. In fact, Löff argued:

A hand-made, one-of-a-kind collector, such as this one, costs so much, and fuel is of sufficiently low cost, that the economic optimum collector size is zero, i.e., no solar heating at all.[19]

Even years later, Löff admitted the system “cannot yet compete with Denver’s cheap natural gas.” But, he emphasized, “if the alternate source of heat in our house were electricity, we would have paid for the collectors long ago.”[17]

6. THE 1960s

While the 1950s represented a “golden age” for solar house experiments in America, it is generally accepted that the movement experienced a significant decline in the 1960s. Just a few years into the decade, D.S. Halacy could conclude that “the solar bubble” had “burst” about 1958, in part because the public was disillusioned by “fanciful” and expensive schemes.[21] “Most of its leading practitioners,” Daniel Behrman recalled, “had busied themselves with other things” during the “forgotten” 1960s. [22] Indeed, when old friends Hoyt Hottel and George Löff corresponded in summer 1964, Hottel said “I have got pretty much out of the solar energy field,” and Löff replied that his own efforts were “dormant at the present time.”[23]

Some of Löff’s activities in the 1960s reflect the globalization of the solar house movement during that period. He visited Tokyo in 1960 and was “much impressed” by the solar house of engineer Masanosuke

Yanagimachi. In 1961, the United Nations held a large conference on “New Sources of Energy” in Rome. Löff chaired a panel and delivered two technical papers. Then he spent a month in the Soviet Union on a visit arranged by the National Academy of Sciences. He found: “the Soviets have at least 100 scientific personnel directly engaged in solar energy work.” By comparison, he said he “cannot count 20 such people in the United States.”[24]

7. CSU SOLAR VILLAGE

Saudi Arabia’s oil embargo beginning in October 1973 gave new momentum to the solar house movement in America. Löff assembled a team of engineers and built a “Solar Village” at Colorado State University (CSU) in Fort Collins in 1974-75. It consisted of three houses—identical as architecture—each containing its own method of solar heating, so that their performance could be directly compared. Additionally, House I was touted as the first in the world engineered to be both heated *and cooled* with solar energy. The CSU project probably represents the most ambitious research program ever in solar architecture. Löff’s Solar Energy Applications Laboratory (SEAL) had a staff of eighteen.[25]

Löff engaged Denver architect Richard Crowther to design the CSU structures. Crowther had been using passive strategies since the 1940s. Likewise, Löff told Crowther he wanted a house with a “typical” rather than “extreme” or “unusual” appearance.”[26] At 3000 square feet, the design was considerably larger than any previous ‘laboratory’ house, indicating a desire to appeal to the marketplace.

The first CSU house used a Hottel-type system of flat-plate collectors and water circulation and storage, plus an absorption air conditioner assisted by solar heat. The engineers tested a variety of new types of glass in the collectors, including one specially treated to reduce reflection losses and another with infrared reflective coating on the interior of the glass. With 768 square feet of collector area for 3000 square feet of space, the system provided 86% of the space heating plus 68% of the hot water needs, and 40% of the cooling load.[27] House II used a variation of the air-and-gravel system that Löff had invented thirty years earlier.[28]

The researchers found the performance differences between House I and II were “not great,” and Löff, as usual, emphasized economics in his conclusion:

The question is: Can you pay for it? And the final answer is Btus per buck. We have no doubt that with present technology in flat plate collectors you get more Btus per buck with the air system than you do with a liquid system. And maintenance,

and the cost of repair and replacement, are far less for an air system.[7]

For House III at CSU, Löff and his team used a new system of evacuated tube collectors. This technology, developed in the 1960s and used today, places a narrow tube-in-plate absorber within a vacuum-filled glass tube; the vacuum reduces heat losses and therefore creates hot water very efficiently. With 384 tubes, six pumps, and at least six separate tanks, House III was probably the most mechanically-elaborate solar house to date. It worked well, and the engineers concluded that this type of system could supply “up to twice the space heating and several times the cooling obtainable from an equal occupied area of good quality flat-plate collectors.”[29] Additionally, the CSU project represented a landmark in the early history of computer simulation of energy-use, leading to the development of the *TRNSYS* software program at the University of Wisconsin.[30]

8. SOLARON

When government incentives created a commercial market for solar heating systems in the mid-1970s, Löff founded a private company called Solaron. These were heady times for solar house heating. Over 1.1 million people took advantage of federal tax credit for residential solar systems between 1978 and 1984.[31] “Hardly a week goes by without the formation of a new company eager to sell collectors or associated equipment,” William Shurcliff observed.[32]

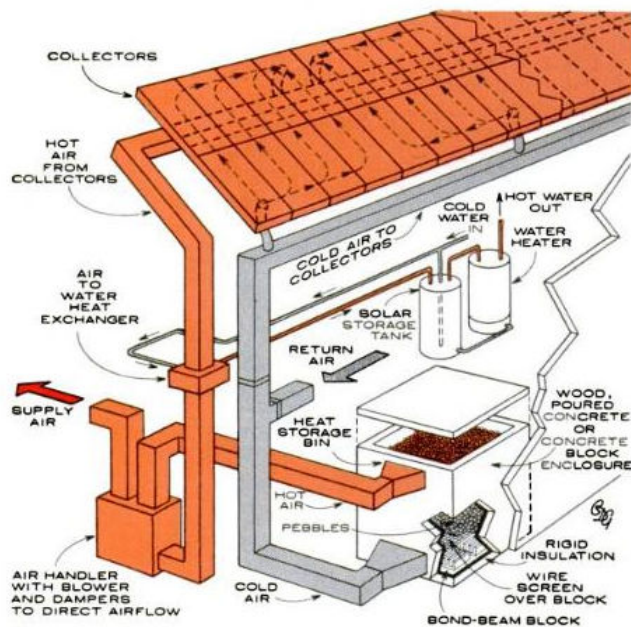


Fig. 5: Solaron system (1978). Popular Science.

Solaron developed an air-and-gravel system, essentially similar to the system Löff invented in Boulder in 1945. The company did not build houses, but worked with architects and builders to install the system in new homes and commercial buildings. (Retrofits were found to be extremely difficult.) Solaron’s flat-plate air collector, which now used a ducted metal absorber plate rather than overlapping glass plates, was known as “the Cadillac of the solar heating business.”

In 1985 Congress allowed the solar tax credits to lapse and companies like Solaron folded in 1987. Löff recalled: “When they removed the subsidies the market disappeared.”[1] It is unknown how many projects Solaron completed—probably thousands; the company produced two million square feet of collectors in 1976 alone. It is also unknown how these systems performed or how long they survived. This is an excellent subject for future research. Solaron technology was also relatively expensive, with one publication reporting a payback period of “plus or minus 70 years.”[33]

9. CONTROVERSIES

In 1970, Löff and economist Richard Tybout completed a landmark study that warned against attempting 100% solar heating in cold climates, because the costs would be too high.[34] This became a rallying point for passive and hybrid proponents like William Shurcliff, who called Löff’s position “the classic rule.” After Norman Saunders completed the 100% solar-heated and low-cost Shrewsbury House in 1980, Shurcliff enjoyed announcing: “the classic rule is dead.”[35]

Then in 1973, Löff, by now a legendary figure, offered Congressional testimony where he claimed:

Virtually all of our knowledge of solar heating and cooling has resulted from the work of a few forward looking, persistent university faculty members; ample support of their continuing research should receive high priority in order that the data needed by potential manufacturers can be available.[36]

This statement aroused the ire of Harry Thomason, an independent inventor of a highly-effective and inexpensive trickle-type collector. Thomason called Löff’s statement “baloney” and “poppycock.” He complained: “All of that ‘knowledge’ of the university faculty members *has not produced one single solar heating and cooling system for public use.*”[37] He argued against what he called “solar welfare”—federal funding of academic projects. Thomason even asked the *Congressional Record* to remove Löff’s

Denver house from a list of solar-heated houses, because it did not receive a majority of its heat from the sun.[36] (Similarly, Harold Hay complained: “This whole business of Ph.D.’s and other fancy titles and bureaucratic credentials of all kinds is vastly overrated. The whole field of research has become institutionalized.... This is one of the big problems in the field of solar energy. Certain people have come to dominate ‘the club’.”[38])

These issues simmered and later in the decade Löff wrote “A Problem with Passive,” which appeared in *Solar Age* in 1978 and before a Congressional subcommittee allocating research funds.[39] He argued that passive houses were “impractical” for “people who require reasonably uniform house temperatures” because they were cold in the morning and hot in the afternoon. He acknowledged that storage devices such as Trombe walls could help, but still he emphasized that thermal mass always operates “out of phase” with the envelope.

10. LEGACY

Since Hottel-type water systems for solar heating worked well, and passive-type systems (pioneered by George Fred Keck) followed a different but also successful trajectory, it is possible that solar air-heating systems may not have been developed at all if not for Löff’s unique interest and persistence. Löff-type air-and-gravel systems became quite popular in the late 70s and 80s, both in America and probably even more so in Europe. The cumulative effect—including the incalculable total energy savings—can be traced directly to Löff.

As always, the full scope of Löff’s legacy is impossible to describe. Surely he helped influence the US Congress to subsidize solar energy in the 1970s and 80s. Certainly, too, he mentored dozens of graduate students whose later achievements are part of his legacy. More obliquely, some companies like Solaron and their technologies, Thomas Friedman has noted, “ended up being bought by Japanese and European firms—helping to propel those countries’ renewable industries.”[40]

Today, Löff’s legacy is indirect—the solar air-heaters he pioneered are not widely used. Still, it is proven technology, likely to become attractive again in the future as economic variables change. When that time comes, anybody building a solar air-heater with gravel storage would be well-served to study Löff’s patents and technical papers.

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