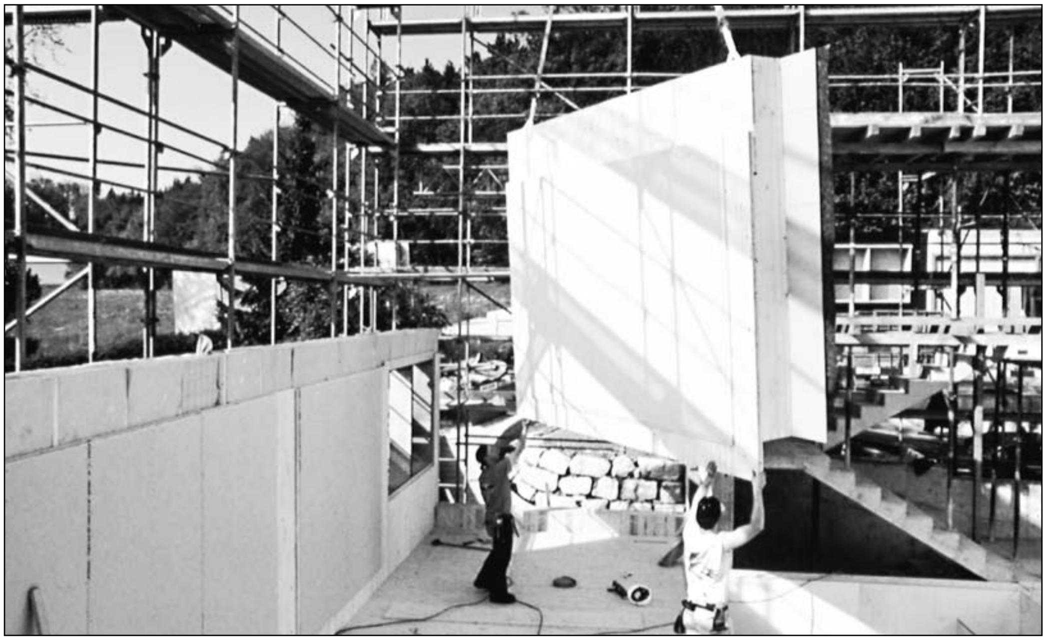

BEAT KÄMPFEN

A New Synthesis of Architecture and Energy

Architectural design has a new attitude toward the environment and follows the principles of ecology, energy efficiency, and sustainability.

by Beat Kämpfen

Zurich, Switzerland, can boast of its many advantages—its vibrancy, the postcard-perfect Alps ringing its southern edge—but not of its climate. With an average of only 1,650 hours of sunshine each year, residents of Seattle, Washington, would feel quite at home here. Both climates are characterized by very long but not very severe heating seasons; they have a comparable number of heating degree-days. In winter there can be fog for days, with average temperatures below 32°F (0°C).

Zurich's cold northern climate does have certain advantages, though. Here it is difficult to ignore the energy penalties of poor building design. Partly for this reason, new ecological and sustainable building design has taken root here as an indispensable tool in the struggle to prevent the extreme effects of global warming. Not coincidentally, this kind of design also substantially increases comfort for the occupants. In order to build sustainably in a climate like Zurich's, two design strategies have to be followed at the same time: The energy losses in a building must be minimized, and the solar energy gains must be maximized. Even in Zurich, solar building design is still relevant.

Sunny Woods, an energy-efficient, passive-solar apartment building that I designed, has won both Swiss and European solar prizes. It meets the new Swiss Passivhaus standard by incorporating features that radically cut the consumption of energy for the whole building (see "Europe's Energy Stars," p. 28). The whole building consumes about 1.4 kWh/ft^2 (15 kWh/m^2) for heating, ventilation, and domestic hot water each year. This is equivalent to using 80 gallons of oil a year for a living space of 2,000 ft^2. This is only about one-tenth of the energy a regular new building in Switzerland consumes. And according to Yen Chin of Seattle City Light, Sunny Woods uses about one-eighth the energy of a typical small, electrically heated apartment building in Seattle. The PV modules covering the roof produce much of the energy needed by the electrical equipment of the house.

The people living in Sunny Woods not only save money on their energy bills, but also enjoy much greater comfort and a better quality of life than occupants of a conventional building. There are no drafts in the rooms, since the walls and the windows have almost the same temperature on their inner surfaces as the indoor air itself. In the winter, one or two hours of sunshine are sufficient to heat the house naturally to a comfortable degree. But in the summer, the house stays cool inside, thanks to the building's excellent insulation and shading.

Architecture Wears New Clothes

The name of the building—Sunny Woods—is self-descriptive. The six-unit building is located on a south-facing hill close to the woods. The use of solar energy and the use of wood as the main material for construction determine the design concept. The building is divided into three sections and four floors, with two floors for each unit (see Figure 1). The 2,000 ft^2 units each have four bedrooms on one floor and all the other rooms on the other floor. The lower unit opens onto a small garden; the upper unit has a private roof terrace and large windows open to the sky. Simple variations like these create living spaces with diversity and individuality. Each apartment has its own private entrance directly from the outside. The entry is on the bedroom floors. The lower apartment has an additional entrance on the lower floor, providing direct access to the garage.


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(left) The entire roof of Sunny Woods is covered by PV panels, yet the integrity of the roof is not compromised by penetrations into its aluminum surface. *(right)* Only the garage and basement of Sunny Woods are made of concrete. Red cedar from Oregon was chosen for the façade.

It is unusual for a building in Switzerland to have only the garage and the basement built out of concrete. Sunny Woods is one of the first buildings in Switzerland with four-story wood construction. The wood structure was largely prefabricated in a carpenter's shop and was erected on-site in a few days. Entire walls and floor slabs up to 12 ft x 40 ft were prefabricated. An advantage of prefabrication is that it dramatically shortens on-site construction time. Other advantages are greater safety and better working conditions for the carpenters, which in turn can result in higher building quality.

Not surprisingly, wood construction consumes much less material than more massive construction. One-and-a-half-inch plywood panels bear the load of the four-story structure. Since these panels support the ceilings, thermal bridges are reduced to a minimum. This detail also allows more space for insulation. For fire safety reasons, the inside surfaces of the walls are covered with gypsum board. Party walls between apartments are double-wall construction with a total of 10 inches of fiberglass insulation acting as a firebreak and providing high-quality sound insulation.

The wood construction is visible only from the outside. For aesthetic reasons, red cedar from Oregon was chosen for the façade. European wood has more irregularities and therefore degrades in appearance with time.

Energy-Conscious Design

To meet the minimal energy consumption goals that I set for Sunny Woods, I combined a variety of technical measures. First of all, any energy-conscious design has to give priority to reducing the loss of energy through the building envelope. By designing the rooms to have a low surface-to-volume ratio, I kept the space that needs to be heated as low as possible. Sunny Woods saves up to half of the surface area for the façade, roof, and ground floor, compared with six Swiss standard single-family house plans. This economical design saves heating energy, material, and money, but it also saves embodied energy.

Insulation reduces energy losses. The thin load-bearing wall construction was designed to leave space for sufficient insulation. The walls are insulated with 12 inches of fiberglass, for an insulation value of up to R-50. The roof insulation is up to 20 inches thick. The basement and the garage are separated from the heated rooms with an amount of insulation comparable to that in the exterior walls (11 inches). Hot water and heating-pipe runs are avoided in the unheated basement. Agreeably, the cellar stays cool all year at an ideal temperature for storing wine.

Critical parts of the building have an additional 1-inch layer of vacuum insulation. The thermal efficiency of vacuum insulation is 8 to 10 times greater than that of ordinary fiberglass or rock wool insulation. The price is also about 10 times higher, so the material is used sparingly. For instance, in Sunny Woods the entrance doors are insulated with vacuum insulation, which gives them the same R-value as a conventional wall insulated with 12 inches of fiberglass. In order not to raise the floor of the roof terrace above the floor of the penthouse living room, the thin vacuum insulation was used on the terrace slab. This vacuum insulation, added to 1 ft of conventional insulation, increases the R-value of the roof terrace to an incredible 63.

South façade lets the sunshine in. The south façade has to gain as much solar energy as possible. Most rooms are oriented toward the south and have very large windows. The façade is completely glazed and lets the sun penetrate deeply into the rooms in winter. A special triple solar glass was used. Its U-value is extremely low (0.1), but it still has a high transparency (75%). The solar heat gain coefficient is 0.6. For reasons of thermal comfort, the floors are covered with slate on a massive concrete slab. They are warmed by the sun during the day and release the stored heat during the night. Of course, the massive floors also have acoustic advantages.

Narrow balconies shade the windows from the high summer sun but let the low winter sun reach far into the rooms. Sun blinds that are controlled automatically by a sun sensor protect the rooms from overheating. A wind sensor protects the blinds from storm damage. Solar collectors are integrated into the south façade of the building. The balcony balustrades serve as guardrails and collect energy with vacuum pipe collectors. The water in these pressurized collectors can reach a temperature of up to 230°F (110°C), while the outside gets no warmer than a bottle lying in the sun. Normally, the water reaches temperatures between 140°F (60°C) and 160°F (71°C).

The balustrade resembles a stack of eight long bottles. Inside each of these 4-inch-diameter glass tubes, a finger-thick pipe with a metal absorber transports water. The collector as a whole is oriented vertically, but each absorber is turned to an optimum angle of about 55° toward the sun, to collect the maximum energy in the fall and spring. If the solar collectors were pitched, too much energy would be produced in the summer and too little in the other seasons. As it stands, the production of energy is continuous for eight to nine months; in the winter, it is insufficient. Beside the energy advantage, the solar collectors create aesthetic value by throwing a changing pattern of light and shadow on the floors of the rooms.

Apartments with occupant controls. When the sun does not shine, an air-to-water heat pump in each apartment can take over the energy production for space and water heating. The heat pump is placed, together with a 450-gallon (1,700-liter) energy storage tank, in a small mechanical room located inside the insulated envelope and next to the bathrooms. The building does not have any heated common rooms, so no common mechanical equipment is needed.

The very short water pipe runs have obvious advantages—lower distribution heat losses and improved comfort—because the hot water flows out of the faucet in seconds. There is 10 inches of insulation between apartments, so very little heat is transferred from one unit to another.

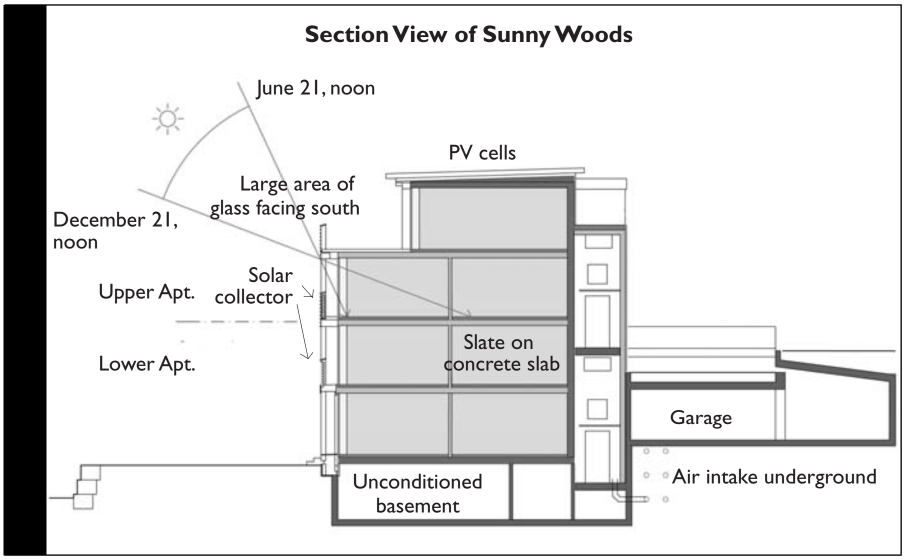
Section View of Sunny Woods

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Figure 1. Sunny Woods combines passive-solar design, excellent insulation, and energy-efficient technologies to make the most of the sun's energy in a cloudy climate.

Apartment owners have full control of the energy consumption in their living space. Different meters control the flow of electrical power. The production of the PV panels, the power fed into the grid, the power consumed by the heat pump, and the remaining electricity are each metered separately. The building does not force people to change their habits, but it does give them incentives to use energy economically.

Ventilation and heating. Since energy consumption is very low, Sunny Woods does not need a conventional heating system. Fresh air is blown into the apartments 24 hours a day. Even in the winter, with all of the windows closed, all rooms have excellent air quality. People who had been used to sleeping with open windows now prefer to close them. The fresh air is preheated naturally in 100-ft-long underground pipes before it enters the building. If necessary, the air is heated with the heat pump to a maximum of 95°F (35°C) and blown into the rooms at a very low velocity. The circulation of the air cannot be felt. The air ducts are integrated into the ceiling in the middle of each unit, in order to make the system as simple as possible. Each of the two stories of each apartment can be regulated individually.

Solar electric power. The roof of Sunny Woods is a multifunctional part of the building. Not only does it shelter the occupants from the rain and cold, but it also supplies the building with electrical power. Invisible from the ground, a PV power plant on the roof provides electrical energy to run the technical equipment of the building. The whole roof is covered with amorphous triple-cell PV modules manufactured by Unisolar. It is the largest amorphous triple-cell PV system on a residential building in Switzerland. To guarantee the supply of electricity during bad weather and in wintertime, the system is connected to the grid of the local power company. The grid acts something like an electrical battery; surplus energy is fed into the grid, and the same amount of energy can be returned to the building when needed, for free.

Standard components were used for the roof of Sunny Woods to eliminate the risk of leaks. PV systems perform better with ventilated panels, and it is easier to replace these panels than it is to replace panels that are integrated into the roof.

Underneath the PV modules, the roof is covered with conventional aluminum. The modules are attached to the roof with metal clips. The panels are ventilated, and rainwater can run under them. The photoactive layer of these modules is much thinner than that of conventional modules. Even though each module produces about 30% less electricity than a conventional module, the whole roof can produce more electricity, because the panels cover the whole surface without shading each other.

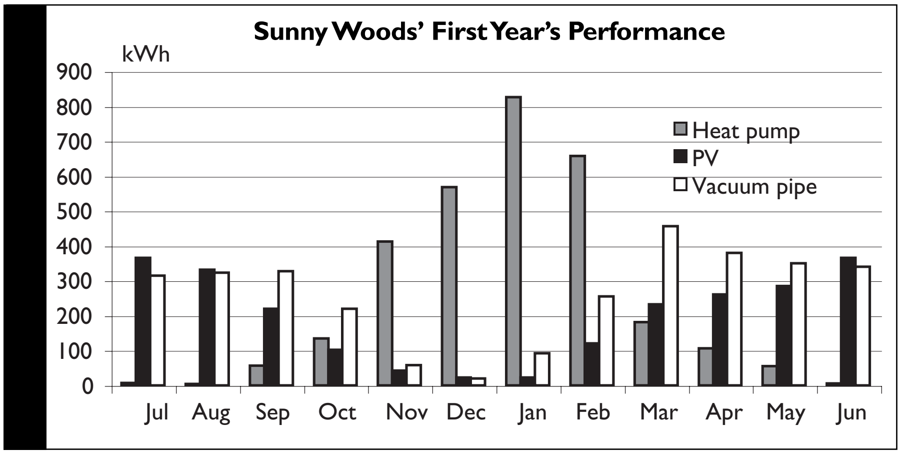

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Figure 2. The goal was to balance the energy use of the heat pump with the energy generated by the PV system, but the PV system only produced about 80% of the energy the heat pump used. The energy from the vacuum pipes was sufficient to meet occupants' heating needs from February to October, but insufficient to meet them from November to January.

Construction Costs and Energy Use

The construction costs for Sunny Woods were roughly 10% higher than construction costs for a conventional building in Switzerland. Two things in particular raised the cost of construction: the technical equipment for each apartment, including the heat pump, storage tank, and ventilator; and the PV roof. A central-heating system for all six units would have been substantially less expensive, even with longer pipes and ducts. But comfort would have been reduced with a central system, and thermal control in each apartment would have been compromised. The interiors of Sunny Woods are spacious, the detailing is neat, and the materials are solid, but the apartments do not appear luxurious or showy. Part of the extra cost of better wall insulation and higher quality glass was saved on the interior finish and materials.

Sunny Woods was finished in January 2002, and energy use has been measured since July 2002. After the first year of metering, the building has yet to reach the goal of zero energy balance (see Figure 2). During that first year, the heat pump consumed 3,000 kWh, while the PV system produced only 2,400 kWh of electricity. Possible explanations for this disparity include the weather, the present high cost of PV power, and occupant behavior.

The climatic conditions of last winter were very unfavorable for our solar design. January and February were about 7°F (4°C) colder than the average over the last ten years, and from November to February there was 25% less sunshine. On the other hand, March 2003 was far sunnier than average.

Solar electric power is not yet economical. Its installation at Sunny Woods was made possible only through the support of a project of the Swiss federal department of energy, and of the city of Zurich's power company. (Sunny Woods is being used by the Swiss government to gather data on the Passivhaus standard and on PV power.) And the PV systems produce only about 90% of the calculated energy, a result that is confirmed by most PV testing (see "Just How Big Is a 2 kW Photovoltaic System?" *HE* Jan/Feb '03, p. 24).

The building occupants also contributed to the less than optimum functioning of the building. The owners do not seem to mind paying the minimal additional cost of setting the thermostat higher than the recommended temperature. For example, the average room temperature last winter was approximately 72°F–73°F (22°C–23°C) instead of the recommended 68°F (20°C). This increased energy consumption 10% –15%. Even in winter, the sun blinds are mostly shut by occupants on sunny days, giving a wonderful soft light to the living spaces, but keeping out important solar energy. And the occupants use a variety of less than optimally efficient appliances.

Solar Works in Switzerland

The goal in designing Sunny Woods was to achieve a zero-energy balance by utilizing the energy of the sun. This goal was not reached, even though Sunny Woods consumes radically less energy than a similar-sized traditional new building in Switzerland. However, solar energy did provide most of the energy needed to maintain the comfort of the occupants. Sunny Woods shows that a range of simple measures that work together can achieve success in solar design, and that solar design can be made to work even in a climate with little sunshine. The Sunny Woods project also demonstrates that the principles of sustainability and ecology do not have to lead to boring architecture. They can produce a building that is energy efficient, beautiful, comfortable, and suited to the needs of the individual occupants.

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Europe's Energy Stars

A new generation of low-energy buildings introduces new superinsulation materials and technologies in Europe.

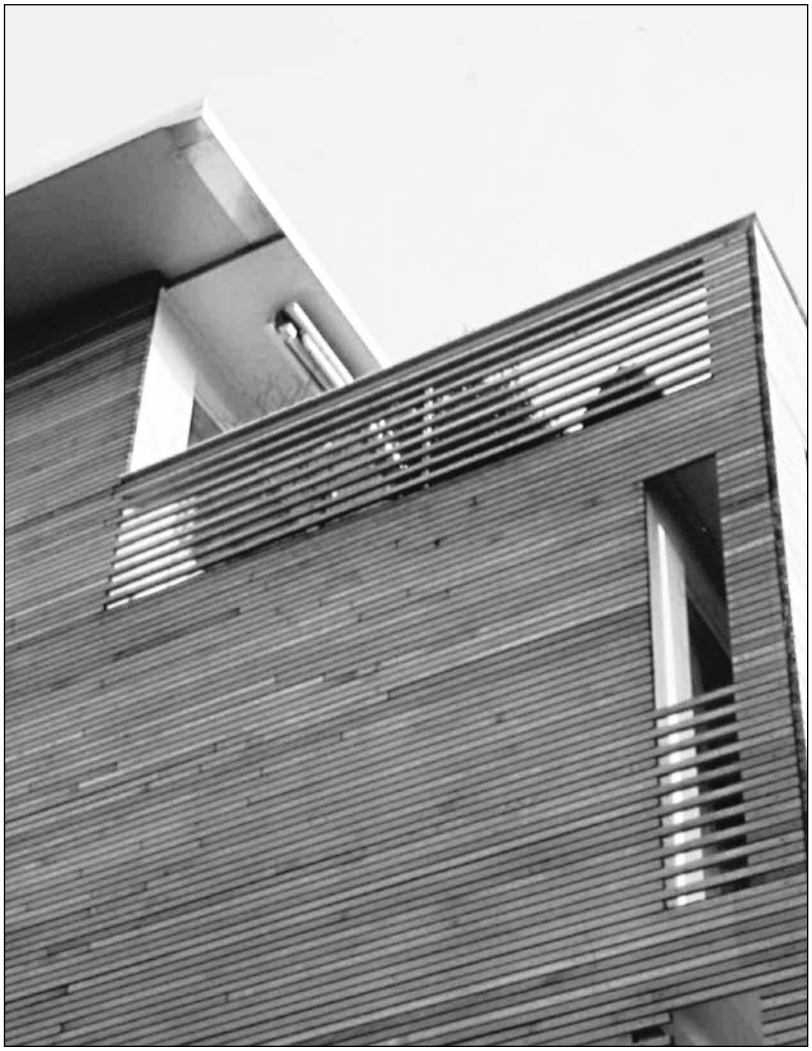
by Armin Binz

Over the last ten years, a remarkable development in energy-efficient building has taken place in Europe, encouraging architects, builders, manufacturers, and building scientists to further improve energy-efficient buildings and to develop better efficiency technologies. This can be illustrated with a few examples from Switzerland.

Over the last ten years, Switzerland has developed fairly stringent building codes governing insulation, HVAC, and appliances. Voluntary standards to complement the codes were created for architects and building owners who wanted to exceed the minimum requirements. Now there is a labeling program in place that guarantees high thermal quality in houses. The program defines two types of energy-efficient house. Houses that consume about half the heating energy of a normal new building are labeled "Minergie." "Minergie-P" is the label for an even more energy-efficient residential building. The "P" stands for "Passive House"—the term that is used for these houses in Germany and Austria.

A passive house has an energy-efficient building envelope and uses a ventilation system with a highly efficient heat recovery unit. The goal is to build a house that does not need a conventional heating system. This means that the builder can save money by leaving out not only a heating system, but also the chimney, the oil storage room, and so on. And at least part of the cost of the added insulation and the ventilation system can be recovered through reduced heating expenses. To achieve this goal, it is necessary—in middle European climates—to include about 12 inches of mineral fiber or polystyrene insulation to achieve R-values above R-30, and to install windows with triple glazing and two low-e-coated surfaces.

Not only are Minergie and Minergie-P houses less expensive to heat, but they are also more comfortable to live in, as numerous questionnaires filled out by people living in Minergie and Minergie-P houses have proven. Several thousand passive houses already exist in Europe. In certain cantons of Switzerland, up to 10% of the new buildings are Minergie labeled.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Wolfgang Feist, the founder of the Passivhaus Institute, which does research in energy efficiency, initiated the idea for this type of passive house in the early '90s. The idea was developed through a large international project of the European Union called Cost Effective Passive Houses as European Standards (CEPHEUS). The project gathered detailed information about technologies for energy-efficient building and stimulated industry to develop and market new products, such as ventilation heat recovery systems that are quiet, draft-free, and cost-effective; superinsulated windows; and building envelope systems without thermal bridges.

The thick layers of insulation in passive houses created a need for insulation materials with higher R-values than already existed. There was (and still is) intense research being done on vacuum insulation for buildings. The International Energy Agency (IEA) is conducting an ongoing research project entitled "High Performance Thermal Insulation in Buildings and Building Systems" (ECBCS Annex 39). The focus is mainly on vacuum insulation panels (VIPs); the project examines basic material problems, applications, and system development and demonstration.

Vacuum insulation panels have approximately 8 times more thermal resistance for a given thickness than fiberglass or rock wool, and about 6 times more thermal resistance for a given thickness than rigid foam insulation. The panels consist of a core of microporous or—even better—nanoporous materials sealed in an evacuated gastight film envelope. The size of the pores defines the necessary level of evacuation. With nanoporous cores, a pressure of 0.7 psi (50 millibars or 0.05 atmospheric pressure) would still provide good thermal resistance.

Three different manufacturers are currently developing vacuum insulation panels for buildings in Europe. Some products are already on the market—such as Va-Q-floor, vacuum floor insulation by Va-Q-tec AG. It is the goal of the research team to help get these new materials into the building sector. With legal warranty times of 5 years and life expectancies of 50 years, there is the risk that products may be launched that will fail to meet expectations—by losing their vacuum and therefore their spectacular thermal resistance. It is urgently necessary to provide standards regarding accelerated aging, moisture, and temperature stress, to be used for testing and qualifying VIPs. It is also important to devise tests to detect the crucial technological weaknesses of the current materials, in order to initiate the necessary improvements. The IEA project is creating these standardized testing procedures, but it will be at least two years before they are in place.

There is still work to be done before VIPs are reliable enough to be used widely in the construction industry. But the outlook is promising. Vacuum insulation offers a great opportunity to reduce energy demand in buildings. On the one hand, this technology will make it easier to create buildings that have almost no demand for heating and cooling even in climates with up to 4,000 heating degree-days, such as the middle and northern European climates. On the other hand, vacuum insulation will be especially suited to retrofitting existing buildings. Thin layers of the insulation can be the solution in cases where there is no room for a layer or two of conventional insulation.

Armin Binz is a professor at the University of Applied Sciences in Basel, Switzerland. He is head of the Institute of Energy, which offers interdisciplinary courses on energy, with a focus on energy efficiency and renewable energy. The Institute is dedicated to applied research in these same areas.

For more information:

For more on Minergie, go to www.minergie.ch.
For more on passive houses and CEPHEUS, go to www.passiv.de.

For more on vacuum insulation, go to www.vip-bau.ch.

To find out more about the Institute of Energy, go to www.fhbb.ch/energie.