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FIRST U.S. PASSIVE HOUSE RETROFIT

First U.S. Retrofit to Passive House Standards

A San Francisco Bay Area row house is launched to a high standard of whole-house performance, comfort, and beauty.

by Nabih Tahan, AIA and Christopher Polk

The San Francisco Bay Area, like many popular metropolitan areas, is full of neighborhoods with single-family homes in various states of repair. Many timeless and beautiful homes aren't maintained for their energy efficiency and durability. Rather, they are maintained for their street appeal and are valued for their location. It is common to find homes that are of dubious architectural quality and are energy inefficient besides. Yet many residential properties have the potential for infill of additional units—which, especially in prime neighborhoods, can increase their value and can help prevent urban sprawl. While remodels to update these bungalows are common, sometimes allowing for an additional unit, the new unit often doesn't perform any better than the original house. Since remodeling existing buildings to higher energy performance standards is just as important as high efficiency new construction, we must develop some new strategies.

Nabih Tahan's family has a classic wood-framed Craftsman bungalow in the center of Berkeley, California. It is close to good schools, transportation, and cultural resources, yet—like most of its neighbors—it was leaky and in need of a facelift, and its large lot would allow for a second unit. To bring this house up to a high standard of quality and efficiency, we decided to apply the Passivhaus principles, popular in Europe (see "What Is a Passive House?" p.28) We wanted to demonstrate that it can be done, and we learned by doing so that we can show others how to do it.

The Passivhaus Concept

The Passivhaus concept, (the word is German for "passive house"), which is rapidly gaining in popularity in Central Europe, evolved from the American superinsulated buildings of the '70s. It forms the basis of the Passive House standard—one of the most demanding energy performance-based standards in the world. Because the building envelope is super insulated and is almost completely airtight, a Passive House can recycle heat generated from the residents' daily activities, such as the use of lighting and appliances. This heat is recycled through a heat recovery ventilator (HRV), making a conventional heating system unnecessary. However, the building code requires a heating system, which is why we had to install electric baseboard heaters to meet Title 24 requirements. Homes built according to Passive House principles have three important attributes of sustainable design and construction. These attributes are energy efficiency, comfort, and excellent indoor air quality (IAQ).

ENERGY EFFICIENCY. The energy consumption of a Passive House is measured in kilowatt-hours per square foot (kWh/ft^2) per year. A Passive House uses significantly less energy than existing and conventional new buildings.


KATE HENKE

Nabih Tahan

COMFORT. Temperature and humidity levels in a Passive House are relatively constant. They do not fluctuate, as they do in houses that are heated and cooled with fossil fuels. Constant temperatures help to make the house comfortable.

IAQ. A Passive House is supplied with fresh, filtered air 24 hours a day, without the need to open the windows. A ventilator is constantly introducing fresh air into the living spaces and removing stale air from wet spaces. A heat recovery component in the ventilator transfers the heat from the outgoing air to the fresh, incoming air.

A Bungalow in Berkeley

We set out to modernize Nabih's house aesthetically and functionally. At the same time, we wanted to bring it up to a much higher level of energy performance than Title 24 requires. We were aiming for the Passive House standard—and we achieved our goal. Nabih's family is now enjoying the benefits of a house remodeled to that standard, and today their house is a demonstration green home, offering tours to local architects, homeowners and builders, and setting an example to its neighbors of an affordable solution to a common problem.

2440 Grant Street was originally a two-story house with a brick foundation. It was built in 1904 on a long and narrow site (33 feet x 138 feet). The ground floor, which was originally built for storage, was less than 7 feet high, but it had always been used as livable space, even though it did not conform to the height requirements of the building code. The second floor, with its 9-foot ceilings, was the main living area. Over the years, the foundation

The new street facade on the Tahan home in Berkeley was created with the original redwood siding as a rainscreen on the second floor.

bricks had deteriorated, and the house was settling, allowing rainwater to leak through the foundation. In 2005, it was time for a remodel.

Nabih Tahan did not want to prepare bidding documents and hire a general contractor to perform the work. He was looking for partners to work with him on a daily basis, resolving problems and assuring that quality of construction meet the passive house standard. Nabih had stayed in contact with his friend, and general contractor Christopher Polk, from their college days at UC Berkeley where they studied architecture. On several occasions, in Berkeley and in Austria, Nabih and Chris had discussed advancements in design and construction in Europe and because of his experience in working on sustainable projects, Nabih felt that Chris would be the best person to assist him with this project. George Nesbitt of Environmental Design/Build in Oakland assisted with the insulation, air sealing, and ventilation.

The house was lifted about 3 feet, the ground floor was completely rebuilt, and the second floor was remodeled.

The San Francisco Bay Area is attractive, densely populated, and has one of the best public transit systems in the United States. We felt that for maximum sustainability, the design solution for this project should achieve two goals. First, the house itself should be as energy efficient as possible. Second, to capitalize on the inner-city location of the site, the design should allow for adding a second unit in the future, without further remodeling the existing house.

The site is zoned R2 which would allow 2 units on the property as long as one on-site parking space is provided for each unit. The only solution for the parking issue was to create a driveway on the side of the house, which gave birth to the cantilever on the north side of the house

When Is a House a Passive House?

In order to apply the Passive House standard to the new and existing portions of the home, Nabih consulted with Eco-lab, in Urbana, Illinois, to perform some initial calculations using the Passive House Planning Package (PHPP). Our purpose was to determine what kind of building would be adequate to meet the standard in the mild California climate. Eco-lab was already familiar with PHPP and after some discussions on how buildings are built in California, Eco-lab entered different values for insulation, windows, shading, and so forth into the PHPP program until we arrived at a combination that would meet the standard.

Though these calculations might appear daunting, it's not hard to understand how a Passive House functions.

The goal is to prevent air from traveling through the building envelope in both directions—outside to inside, and vice versa. The building must be very airtight. A layer in the building envelope has to be designated as the continuous line of defense to prevent infiltration, from the lowest point of the foundation to the top of the roof. After this barrier has been created, a mechanical ventilation system is installed. Since it is not healthy to live in an airtight building, it is necessary to ventilate by supplying fresh air to the bedrooms and living spaces and removing stale air from the bathrooms and kitchens. Build Tight, Ventilate Right should be the motto for every house. A ventilator has two small fans, each the size of a bathroom fan, which are constantly running; one fan brings in fresh air and the other sucks out stale air.

Under typical use, occupants are constantly using electric and gas appliances inside the house, turning on lights, or using tools. Lighting and appliances are a steady source of heat. Every lightbulb, computer, refrigerator, oven, hair dryer, and toaster generates heat. In conventional homes, this heat travels with the air and leaks through the building. In a Passive House, this heat travels with the interior air, but it cannot escape through the insulation and the sealed airtight layer. The only place the air can go is through the ducts of the ventilation system, which is always sucking out old air and replacing it with the same amount of fresh air.

Besides circulating air, some ventilators can transfer heat and moisture, from the outgoing air to the incoming air. These are called air-to-air heat exchangers. Ventilators that exchange heat only are called heat recovery ventilators (HRVs). Ventilators that exchange heat and moisture are called energy recovery ventilators (ERVs) or air-to-air heat exchangers. In a Passive House, before the warm interior air leaves the building through the ventilator, the heat in the air is transferred to the fresh, incoming air. During the heating season, the interior air enters the ventilator warm and leaves it cold, while in the opposite direction the exterior air comes into the ventilator cold and goes into the house warm. The heat is recycled.

A home that is built using the Passive House strategy of combining a well-insulated, airtight envelope with heat recovery has an 80% lower heating requirement than a code-compliant house, according to European studies of Passive Houses. A Passive House does not need a conventional heating system; it can be kept warm with a small alternative system—one that uses renewable resources, such as solar electric power, solar thermal energy, pellet stoves, geothermal heat pumps, and so on.

Dehumidistats and timers in the bathrooms and kitchen control ventilation that removes moister and smells.

How We Did It on Grant Street

Here's a summary of how each of the home's systems were brought to the passive house standards.

FOUNDATION

To begin with, a 15-mil vapor barrier was laid below the foundation slab and carefully sealed at all plumbing and electrical penetrations. For the concrete, we used cement with 25% fly ash. In order to reduce heat losses from the ground, 1 inch of rigid Dow Corning Styrofoam Bluecor R-5 insulation was installed below the slab and on the exterior of the footings. Two layers of 1 1/2 -inch Dow Rmax Polyisocyanurate (at R-9.8 per layer) were installed on top of the slab, between two layers of 2 inch x 2 inch battens. A 3/4-inch layer of tongue-and-groove (T&G) plywood was fastened to the top of the battens, as a subfloor.

FRAMING

The PHPP calculations determined that R20 cellulose insulation in a 2 x 6 wall would be adequate to meet the standard in this climate zone. Of course, thicker walls with more insulation would be needed in colder climates.

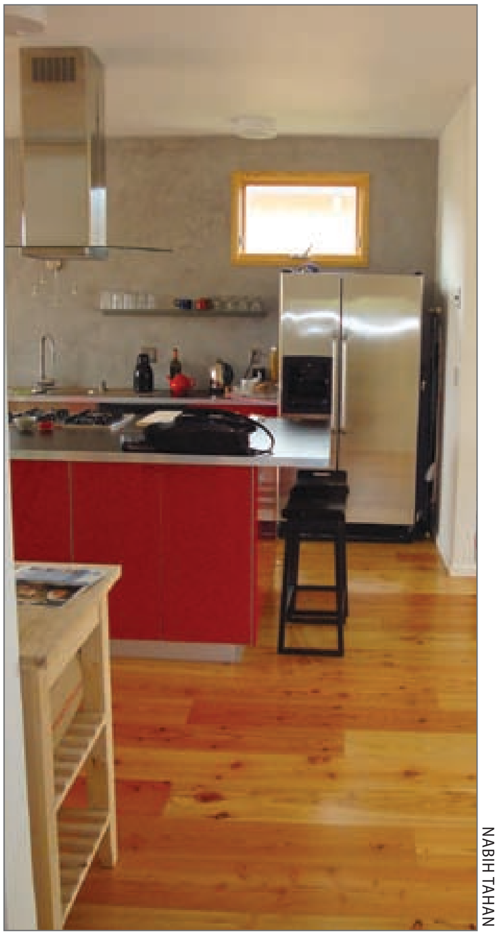
FIRST FLOOR. For the new ground floor, we used Optimum Value Engineering (OVE) techniques, first, to reduce the amount of lumber needed while maintaining the structural integrity of the building, and second, to optimize the insulation system. The walls were framed with 2 x 6 studs set 24 inches on center (OC). For our initial large load of lumber, we ordered Forest Stewardship Council (FSC)-certified stock. Our local lumberyards did not carry FSC lumber, and it would have been prohibitively expensive to ask them to special order it for us. We therefore ordered it from Mead Clark Lumber Company in Santa Rosa (53 miles away), and it turned out to be less expensive than the conventional lumber we buy locally.

SECOND FLOOR. For the second floor, we retained the existing 2 x 4 exterior studs at 16 inches OC and framed in new openings as required.

INSULATION

It is very important to design the insulation system as a continuous layer, from the foundation to the top of the building envelope. The critical points are at the intersections of walls, floors, and roofs, where heat can easily escape through voids in the insulation. We blew in GreenFiber Cocoon, cellulose insulation because it is a recycled product from renewable resources and can fill every cavity completely without leaving any voids.

FIRST FLOOR. For the new first-floor walls, R20 GreenFiber dry cellulose insulation was blown in between the 2 x 6 studs. By designing these walls with fewer studs (and thus fewer thermal breaks) than is standard and by doing an extremely complete job of insulation, we feel that the performance of our insulation is



NABIH TAHAN

The kitchen has a recirculating fan to recycle heat.

NABIH TAHAN

The floor is built up in two layers of insulation. Infiltration is eliminated at the critical points.

NABIH TAHAN

Calking and foam create an airtight layer.

much closer to the specified values than is typical in standard construction.

SECOND FLOOR. On the second floor, the same dry cellulose was blown into the existing 2 x 4 stud cavity reaching an R13 value. A new layer of exterior plywood sheathing was installed, and a 2-inch layer of R13 Thermax Polyisocyanurate rigid insulation was installed on the exterior of this sheathing. The second floor has a total value of R26.

CEILING. The attic and roof were not part of the conditioned space. The ceiling above the second floor was strengthened by sistering 2 x 10 joists next to the existing 2 x 4 joists. Dry cellulose insulation was blown in between the 2 x 10 joists. A layer of T&G plywood was installed on top of the joists.

INTERIOR WALLS AND FLOOR. All the interior walls, as well as the floor between the two levels, were insulated with cellulose insulation. This insulation was installed to improve the acoustics through the house and to contain the heat in each room as much as possible. It is not common to insulate interior floors in homes framed and insulated using conventional methods. The walls above and below the floors are insulated, but the floor is not, leaving a ring of thermal bridging at the floor level. It is necessary to insulate the perimeter of the floor to prevent heat from escaping. The required insulation used for the walls must be also installed in the floor around the perimeter. In the case of Grant Street, this issue was resolved by insulating the entire floor.

THERMAL BRIDGING. A very important factor in designing the framing and insulation system is the reduction of thermal bridging. Heat can escape through elements in the building envelope which are poor insulators such as concrete, wood, and voids where insulation is missing. In the Grant Street house, the walls of the first and second floor were framed and insulated differently. The ground floor has the advantage of using less lumber, spaced at 24 inches on center, and therefore more insulation. But studs and headers are poor insulators compared to the cellulose insulation and therefore act as small thermal bridges, where the heat has an easier path to escape. The second floor has framing at 16 inches on center, but the continuous layer of rigid insulation on the exterior, reduces the chances of thermal bridging because it spans across all framing members. Because California's climate is so mild, these differences should not affect our building as much as it would in a colder climate. The PHPP modeling tool can calculate thermal bridging in a building envelope so that the design eliminates potential problems caused by thermal bridging, which could lead to condensation, mildew and possible decay.

AIRTIGHTNESS

In all surfaces of the shell, extra attention and work was dedicated to airtightness. From the bottom plates (which were installed over a foam air seal) to the ceiling assembly (which was capped with T&G plywood and caulked at the joints), every potential air leak was stopped. The critical points where infiltration must be eliminated are the intersections of walls, floors, and roof elements, as well as any penetrations through these elements. Air that is allowed to infiltrate from outdoors usually has a higher (or lower) temperature and humidity than the temperature and humidity that residents want indoors. A Passive House saves all the energy that would otherwise be needed to condition the indoors because it prevents accidental infiltration.

We decided to tackle air infiltration at the layer of structural sheathing on the exterior of the building. It is more common to rely on the house wrap to make the house airtight. The house wrap is installed on top of the sheathing; its main purpose is to waterproof the facade. We felt that the layer of house wrap was not solid or stable enough to prevent infiltration for the life of the building. During construction, it is usually left exposed for long periods, during which it is constantly moving with the wind. Therefore, we decided to make the sheathing airtight instead. We did this by sealing all joints in the plywood with caulk.

We sealed all the gaps at the intersection of walls and floors, at the intersection of walls and ceiling, and at all blocking with Dow's expandable sealant, applied with a foam gun. We also foamed all holes penetrating this layer of sheathing, including holes around conduit for electric panels, hose bibs, and so forth. The holes around all pipes and wires that were installed through the studs were also sealed with expandable foam.

WHAT IS A PASSIVE HOUSE?

A Passive House, from the German Passivhaus (not to be confused with passive-solar design, though there are overlapping principles), got its name because it uses so little heating energy that a conventional heating-and-cooling system is not necessary. The temperature in the house remains constant; the house keeps itself warm passively by reusing heat from internal sources, such as lighting, appliances, and people. This makes a house so energy efficient that heat generated from passive-solar or other renewable resources is enough to provide any additional heating required.

The Passive House Institute in Germany has developed the Passive House Planning Package (PHPP). PHPP is the energy-modeling tool used during the design stage to determine if a house will meet the Passive House standard. By monitoring completed projects designed according to the standard, the developers of the tool have proven that it can accurately predict the energy consumption of buildings under design. To use the PHPP tool, the user enters all of the elements of the building into the program. The program then calculates how much heating and source energy the building will consume. Elements that can be entered include climate zone, floor and wall areas and R-values, windows, ground heat losses, thermal bridging calculations, shading factors, ventilation, heat loads, summer shading and summer ventilation, domestic hot water, electricity requirements, and internal heat sources.

The Passive House Standards:

- Heating requirement cannot exceed 1.4 kWh/ft^2 per year.
- Source energy requirement cannot exceed 11.1 kWh/ft^2 per year. Source energy includes heating, cooling, lighting, hot water, and appliances consumed on-site, plus energy consumed during generation and transmission in supplying energy to the site.
- The building shell must be airtight, defined as less than 0.6 air changes per hour at 50 Pascals of pressure, measured with a blower door test.


NABIH TAHAN

The second-floor kitchen and dining room open to the west-facing deck.

DOORS AND WINDOWS

We used Sierra Pacific wood-framed windows, clad with aluminum on the exterior for durability and manufactured in California. After reviewing the test results for double-hung, slider, awning, and casement windows, we chose to install casement and awning windows, because they provide the best airtight seal. We also chose to install out-swinging French doors, to provide a tighter seal in windy conditions. We installed the windows paying special attention to airtightness: We caulked the nailing flanges and the metal sill flashing; we taped over the flanges; and we sealed the gap between the window frame and the rough opening with expandable foam.

HEAT RECOVERY

Once we had achieved a high level of insulation and airtightness, we installed an Ultimate Air Recuperator (ERV) to supply fresh air throughout the house. The ERV softly blows (at 70 CFM) a supply of fresh air to each bedroom and into the living room, and returns the same amount of air from the bathrooms and kitchen. The heat in the outgoing air is transferred to the incoming fresh air through a heat exchanger. Thus whatever heat is generated by the residents' daily activities is captured and returned to the house, as we explained above. We also added dehumidistats and timers in the bathrooms and kitchen to quickly remove moisture or smells by turning the ventilator to "high."

RAIN SCREEN

A home lasts years longer when it has a rain screen system. It protects the framing, insulation, exterior sheathing, house wrap, and caulk so they perform as they were designed to do for the life of the structure. A rain screen system creates a layer of air behind the facade. This allows any water that penetrates the facade to drain down to the bottom of the wall.

The rain screen on the second floor was created by salvaging the existing old-growth redwood siding, which had been on the building for 100 years. We get the most compliments on the house for how the siding looks. Many older buildings in the Bay Area have the same siding, which usually ends up at the dump after a remodel. We carefully removed the shiplap siding and ripped the top and bottom lips at slanted edges, so that water drains off the boards. The boards were flipped over, planed, stained, and installed over battens.

On the ground floor, we installed a plastered facade as a rain screen to demonstrate that a stucco finish need not be directly attached to the building. When cement stucco is installed directly onto the wall, it can crack over time, and water leaks into the building. The water cannot dry out, and eventually it decays the wood. A rain screen prevents this from happening; it provides the same stucco appearance, but it does not allow any water to penetrate the wall. We installed 1 inch x 2 inch battens on top of the house wrap and covered them with 4 x 8 sheets of cement board. We installed an insect screen between the battens on the top and bottom of the wall to prevent insects from nesting behind the cement board. An acrylic plaster was applied on the cement board to imitate a high-polish Venetian-style plaster finish.

MONITORING

One of the reasons the PHPP energy-modeling program can predict the energy consumption of a building at the design stages is that many Passive Houses in Europe have been monitored during occupancy. The results indicate that the PHPP program is accurate, with slight variations in energy consumption due to the habits and comfort levels of the users. To learn more, go to www.cepheus.de/eng.

We are interested to compare the interior temperature and humidity throughout the house with the exterior temperatures. We would also like find out the temperature of the air at the inlets and outlets of the ERV to measure how much energy is being recycled. We would also like to find out how much additional energy is needed (besides heat recovery) to keep the house at 68°F during the heating season. Once the data has been compiled and analyzed, we hope to publish another article summarizing the results and lessons we have learned.

A New Perspective

Designing a home to the Passive House standard makes one look at a building from a different perspective. It makes one analyze the simple problems that have caused buildings to negatively affect the environment, and at our attempts to resolve them.

One of the simple questions a Passive House raises is, Why do we waste "free"

NABIH TAHAN

An energy recovery ventilator with ductwork is installed in the attic. Whatever heat is generated by daily activities is returned to the house. A Takagi instantaneous water heater is on the right in the photo.

heat every time we use our lighting and appliances? Because we did not pay for that heat through our heating system, we seem to feel that it isn’t valuable. We allow this “free” heat to escape—and then turn up the thermostat when we get cold. A Passive House resolves this issue by circulating air while recycling the heat. The result is better IAQ, better energy efficiency, and increased comfort.

The Grant Street house is possibly the first remodel in the United States that is built to the Passive House standard. The strategy and techniques described above are aimed at achieving concrete, measurable energy consumption targets for homes. Building to the Passive House standard is one effective strategy to reduce the effects of home construction and occupancy on global warming. It can help architects and builders to comply with the Architecture 2030 Challenge, which is an initiative aimed to achieve a dramatic reduction in the global-warming-causing greenhouse gas (GHG) emission of the Building Sector by changing the way buildings and developments are planned, designed and constructed. The Passive House standard makes serious, quantifiable progress in the struggle to prevent catastrophic environmental collapse.

Our goal is straightforward: to achieve a dramatic reduction in the greenhouse gas (GHG) emissions of the Building Sector by changing the way buildings and developments are planned, designed, and constructed. He

Nabih Tahan, AIA, MRIAI, began his career 30 years ago in the Bay Area as a forensic, diagnostic, and remedial architect, analyzing and repairing defective buildings. In 1992 he moved to Europe where he spent 13 years living and working in Austria and Ireland. He decided to return to Berkeley with his family and remodel their old home on Grant Street while demonstrating sustainable design and construction techniques practiced in Europe. Christopher Polk is a general contractor in Berkeley specializing in sustainable construction practices.

For more information:

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To learn more about German and American Passive Houses and the Passiv Haus Institut, go to www.passiv.de and www.passivehouse.us.

To order a copy of PHPP, go to www.e-colab.com.

Web sites for some of our suppliers:
Mead Clark Lumber Company—www.meadclark.com

Cocoon Insulation—www.cocooninsulation.com

Sierra Pacific Windows—www.sierrapacificwindows.com

The Ultimate Air Recuperator—www.ultimateair.com