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of the
NASA Tech House

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By Howard Allaway
Most of us live in what a used Cadillac salesman would refer to as "previously owned" houses; most of us dream at times of living in specially designed, tailor-made houses reflecting our own tastes and style. Unless we are confirmed traditionalists, caught up in a past that perhaps never was, we probably envisage these imaginary houses fitted out with technology's latest gifts of efficiency and convenience.

These dreams reflect awareness that the preponderance of existing houses make use of an almost archaic technology, grown from the time-honored customs of carpenters, lumber mills, and the long-established crafts of plumbers, electricians, and masons. While there are exceptions, most houses are, or were, built the way cobblers once made boots, locally, by handed-down standards. Where new technology is used—as, for example, in kitchen built-ins or those plastic preplumbed shower stalls—its products are simply substituted into pre-existing ways of construction.

Could we do better?

To test and demonstrate new ideas and new ways of using old ones, NASA built a house at its Langley Research Center in Hampton, Virginia, combining aerospace technology—advanced electronics, use of solar energy, water recycling, fire-retardant materials, and the like—with recently improved products, materials, design configurations, and construction techniques developed in other Government programs and by industry. NASA then selected a family to live in the house for a year—one full weather cycle—while engineers measured the results.

An elaborate net of hidden sensors linked to automatic recorders, supplemented with meters read by the engineers, kept tabs on water usage, consumption of electricity for various purposes, equipment running times, water flow and pressure, air velocity in the heating and cooling ducts, humidity, and temperatures outdoors, within the walls, in the attic, and at different levels in the rooms. Readings were recorded on magnetic tape for producing daily, weekly, and monthly summaries. These showed the comparative efficiency of alternative heating/cooling and hot water systems, the accuracy of computer-programmed distribution of warm and cool air to different areas of the house to suit the family's living habits, and the effectiveness of unusual design and structural features in reducing loss of heat from the house in cold weather and shielding the interior from the effects of the summer Sun.

The designers did not intend the NASA Tech House, in Tidewater Virginia, to be a house of the future—the residential equivalent of those dream cars that Detroit used to unveil at an-
annual auto shows. It was not planned as an integrated package that could be picked up and duplicated anywhere as the ideal for comfortable, convenient, economical, gracious, conservation-conscious living. Houses have to be adapted to specific sites—access, land contours, orientation to the Sun and prevailing wind—to the local climate and weather, to the lifestyle, as we say now, of the families that will occupy them. Rather, the Tech House is a laboratory for trying out, under normal living conditions, a collection of advanced systems, components, products, and ideas that, if they work, can be adapted—as they may fit individual needs—by architects, builders, and young couples planning new homes. Many of the innovations of the Tech House might also be used in remodeling older houses or in adding rooms. The Middle Atlantic coastal location—about 76° W, 37° N—has a climate fairly representative of much of the continental United States: neither fiercely cold in winter nor tropical in summer.

Ideas for the Tech House were collected and screened by a committee headed by engineers of the Langley Research Center and including representatives of the U.S. Department of Housing and Urban Development, National Bureau of Standards, Consumer Products Safety Commission, National Association of Home Builders Research Foundation, NASA Headquarters in Washington, and other NASA Centers around the country. University groups also evaluated the proposals. An architectural engineering firm was hired to weigh trade-offs among alternatives, to assist in selecting materials and equipment, to do cost studies, to draw up candidate designs, and to produce final construction drawings.

Hidden sensors linked to automatic recorders measured everything from water usage to humidity. Pictured here are temperature sensors which were embedded in several of the outside walls to monitor the effectiveness of insulation.
Two ground rules were agreed on for materials and equipment to be used in the house. They had to be products that were already on the market or that would be soon. And new technology used in the house should pay for its added cost (plus 10 percent interest) over an expected 20-year lifetime. Major considerations were water saving, safety and security, cost, and—most of all—possibilities for saving increasingly scarce and expensive energy. Homes use a fifth of all energy consumed in the United States—about equal to our imports of crude oil.

The Tech House is a modest (1650 square feet) single-level frame structure of contemporary design, with fir plywood siding and dry walls inside. It is made up of two separate 27-foot-square, gable-roofed modules. One contains a living/family room with a fireplace, an open dining area, and the kitchen. The other is divided into three bedrooms and two baths. The modules are connected by a flat-roofed hallway, 7 feet wide, and entry vestibules at the front and rear, with space in the rear one for a clothes washer and dryer. A square single-car garage, also gable-roofed to match the house modules, opens off the dining area through a vestibule which houses the hot water tanks. The steeper, south slopes of the house module roofs are faced with solar heat collectors for heating the living areas and domestic...
hot water for the bathrooms, kitchen, and laundry. Solar heat is supplemented by conventional heat pumps, also used for air conditioning, and by a standard electric domestic water heater.

The house is built on prefabricated concrete slabs over a 3-foot crawl space that houses tanks, pump, and filter for collecting and recirculating used bath and laundry water to flush the toilets. The toilets drain directly into the sewer.

The exterior walls of the house are constructed with studs that are 6 rather than 4 inches wide, making space for an extra 2 inches of insulation. The ceilings also are more heavily insulated than usual. Huge louvers limit the attic temperatures to about 6 degrees above daytime outside temperatures on the hottest days. They can be mostly covered in winter to prevent freezing of water circulating through the solar heat collectors. A deep roof overhang shields the south wall and its large windows from summer sunshine without blocking the low-elevation Sun in winter. The windows, which slide horizontally, have double panes in aluminum frames with built-in weatherstripping. Exterior shutters of plastic slats can be cranked up or down to keep heat out during the day and in at night. In the entry vestibules, separate doors to the outside and into the house—reminiscent of the air locks used in manned spacecraft—prevent the air exchange that would let warm indoor air escape in winter and admit hot outdoor air in summer.

The planners of the Tech House figured it could be built commercially, if its components were in mass production, for about $50,000 at 1976 prices—within the range of middle-income families.
The NASA Tech House was completed in 1976 and lived in by a middle-class family of four, with no engineering background, from August 1977 to August 1978. The family's use of energy and water was compared with Government figures for conventional houses built in the early 1970s in an area of similar climate. NASA engineers completed evaluation of the test results in November 1979.

What was learned that home planners and builders can use in the 1980s? What could be done better now, based on the year's experience? "The actual performance of the technology items during the live-in test," the engineers wrote in their report, "is perhaps not as important as what was learned that could be used to improve systems and design features of future homes."

Here are highlights of their findings and observations, including some surprises:

The Tech House used less than half the total energy estimated for a conventional house of the same size. Even so, the saving was less than should be expected of a similar house because the winter of 1977–78 in coastal Virginia was colder than usual and there was less sunshine than normal in the cool fall months.

Most important, 60 percent of the saving for heating and virtually all for cooling came from the thermal design of the house: the extra-thick insulation, double-door entry vestibules, double-pane windows, shutters, well-insulated floor and doors, big attic louvers.

The foam insulation in the walls shrunk and settled a little, resulting in some heat loss around the studs and eaves, but performed satisfactorily. NASA does not especially recommend the type used over others on the market, which may be as good; nor in fact does NASA endorse any of the particular products in the Tech House.

There was very little heat loss through the floor.

The shutters, though saving winter heat and helping to keep the house cool in summer, and also providing some protection against noise and possible intruders, made the house inconveniently dark when they were rolled down during the day. (This was no problem, of course, when the entire family was away at work or school.) The entry double doors, if a bit inconvenient, worked well in reducing heat loss and gain; the vestibules were usually 10–15 degrees cooler than the living areas during the heating season.

A skylight over the hallway turned out to be a mistake, letting 15 times as much heat in or out as the same area of insulated ceiling.
The solar system provided 41 percent of the energy used for heating, cutting electric bills about $240, and was nearly three times as efficient as the heat pumps for the amount of electricity used. Another $100 worth of free heat was lost because ground water damaged the insulation on the buried 1900-gallon concrete tank that stores solar-heated water for circulation through the heating system at night and on gloomy days; in areas with a high water table the tank would do better located above ground.

Still, the solar space-heating installation was too expensive to pay off in the 20 years set as a guideline for cost effectiveness. This may change as systems and components are improved and as, inevitably, rates go higher for electricity from ever-scarcer expendable fuels.

The computer-programmed zone control for heating kept temperatures in different parts of the house within two degrees of the settings. When it was not in operation, some rooms drifted as much as 10 degrees from the desired level.

The fancy computer and recorders, which took up a lot of space in the garage, were needed during the test year mainly for collecting and sorting engineering data. For just monitoring and controlling room temperatures the setup could be replaced with a cheaper microprocessor not much bigger than a pocket calculator. And the heat pumps, also in the garage, could be outdoors. As it was, the family members weren't able to use the garage for their car or storage during their year in the house.

The fireplace, with its glass doors and ducts for drawing outdoor air for combustion and circulating room air through a double-walled firebox for heating the living room, worked all too well. It made the room too hot for comfort and was seldom used. In later tests, its unusual grate, made of a coil of tubing through which water circulates to the central heating system, collected a large percentage of the heat produced by the burning wood. A fireplace of this sort, four to five times more efficient than others, could be a significant energy

This cutaway view of Tech House shows the energy-saving structural elements and solar heating system.
saver in a larger room or in a home in a cooler climate, or if it were designed with ducts to circulate warm air to other parts of the house.

The solar collectors supplied 35 percent of the energy for domestic hot water—and could have provided more with a storage tank big enough for several baths or loads of laundry before the supplementary electric heater switched on. The system could be made simpler, too, and would take up less space, if both the solar and electric heating elements were installed in a single large tank.

Water usage in the Tech House was 27 percent less—nearly 30,000 gallons for the year—than that estimated for a family of the same size in a conventionally equipped house. Water-saving shower heads saved about 8000 gallons, but “low-profile” toilet tanks proved too small to flush properly and actually wasted water from repeated flushings. They were soon replaced with standard tanks. Most of the water saving (22,000 gallons) came from reusing bath and laundry water for the toilets. This saving, too, could have been greater with a larger storage tank; sometimes the tank overflowed through a check valve into the sewer, but at other times it had to be replenished with tap water. Chlorination kept the bacteria level in the recycled water satisfactorily low—usually zero—and the filter kept turbidity, foaming, odor, and color acceptable.

To summarize the Tech House test results, then: New technology, including spinoffs from space research, can indeed help to conserve our shrinking natural resources; so can such simple sense as tighter windows and thicker insulation.

The fireplace water grate is constructed so that water from the heating system can be piped through it. Energy from the fire heats water that can be used to heat areas of the house.

Schematic diagram of the fireplace illustrates how warm air circulates through the system. Air enters the heating chamber through the lower side vents, is warmed, and then returns to the room through the upper vents.
Urea-tripolymer foam insulation proved to be more efficient than the conventional fiberglass insulation, although some settling resulted in heat loss around the studs and eaves.

The oversized louvers prevented heat build-up in the attic—a critical element in the cooling of all homes.

The double-door entrances minimized escape of controlled-temperature air.
To look at, the NASA Tech House doesn't seem all that different from the solar houses you see fairly often in magazines and Sunday papers. Most of the innovations are hidden.

They start with the floor, a 2-inch prefabricated concrete slab, strengthened by imbedded wire mesh, with 6 inches of gypsum foam insulation, on the underside, held in place by chicken wire. It was delivered in 7-by-14-foot sections, which were lowered into place by a crane on a concrete-block foundation and lightweight steel frame. This method of construction, though expensive for a single house, would be practical for a development. Usually, concrete subflooring is poured directly on the ground or bed of gravel; here a crawl space was needed for the water-recirculating equipment. Interior floorings are slate in the entrance vestibules, carpeting in the hallway and living areas, ceramic tile in the bathrooms, and in the kitchen vinyl tile with an easy-care urethane coating and a foam backing that makes this floor less tiring to work on than concrete, brick, or flagstone.

The outside walls of the house are built with 2-by-6-inch studs set every 24 inches instead of the usual 2-by-4-inch studs every 16 inches. This provides about the same strength and makes room for 5½ inches of cellular plastic insulation, a nonpetroleum-based urea tripolymer foam that is nonflammable, nontoxic, odor-free, rodent-resistant, and a good sound barrier. It's mixed at the site and sprayed on, flowing around pipes and wiring and into cavities, then worked smooth on the inner face with a trowel. The attic is insulated with 7½ inches of the same foam. Outside, the framing is covered with ½-inch composition sheathing and ⅝-inch fir ply-
wood. The inside is finished with a polyethylene moisture barrier under standard ½-inch plaster board, or sheet rock, and painted.

Most of the walls between rooms are built with special 2-by-4-inch studs, set every 16 inches, devised by the Department of Housing and Urban Development to save lumber. They're made of reconstituted sawdust, about the consistency of particle board, with strips of 5/16-inch plywood glued to the narrow edges to make nailing into them easier.

As a demonstration, one interior wall, between the bathrooms and master bedroom, is a prefabricated panel of fiber-glass-reinforced gypsum filled with sand and cast in a steel frame. Because of its weight, this too had to be put in place by a crane.

Cranes were used to lay the concrete floor panels.

The prefabricated floor panels were strengthened by wire mesh, and insulation was provided by 6 inches of gypsum foam held in place by chicken wire.

The outside walls of the Tech House are built with 2-by-6 inch studs set every 24 inches (instead of the usual 2-by-4 inch studs every 16 inches) to make room for the insulation.
The precast wall, made of a steel frame supporting glass-fiber-reinforced gypsum, is lowered into place by crane. The walls between the rooms are built with 2-by-4 inch studs (set every 16 inches) made of reconstituted sawdust.

The attic of the Tech House is insulated with 7½ inches of urea-tripolymer foam.

Tripolymer foam is sprayed directly into the walls. It flows around pipes and wiring and into cavities, and is then worked smooth with a trowel.
The roof, supported by a truss structure of 2-by-6-inch rafters and joists strengthened by 2-by-4-inch braces, is built up of ½-inch plywood sheathing covered with 15-pound insulating paper and standard commercial-weight (325-pound) asphalt shingles with a 25-year guarantee—most home builders use only 240-pound shingles with a 15-year guarantee. The south faces of the gabled roofs, carrying the solar collectors, slope 58° from the horizontal. The roof was designed so that the collectors would be perpendicular to the Sun at noon on December 21. Test results indicate that the roof should be designed so that the collectors are perpendicular to the Sun in mid-winter or about the first of February resulting in a roof angle of about 45° (at other latitudes the best angle would be a little more or less); the resulting north roof slopes are about 22° from horizontal. The flat hall roof between the two house modules and the flat south overhang caused no snow-load problems in southeastern Virginia but could cause problems in regions of heavy snowfall and prolonged cold. Part of the problem is that accumulations on the flat areas might prevent snow from sliding off the sloping solar collectors, reducing the area exposed to the Sun.
The outside doors of the house have decoratively stamped, corrosion-proofed painted steel surfaces, foam cores for insulation, and magnetic weatherstripping similar to the seals on refrigerator doors. An adjustable sill with a moisture barrier helps form a tight seal that makes storm doors unnecessary. Interior doors are of hollow-core plywood construction.

All windows have double panes, low-thermal-conductive plastic separators between the inside and outside aluminum frames, and built-in magnetic weatherstripping. A large sliding glass door between the living room and the backyard, or patio, is also double-glazed but lets in a good deal of warm or cold air (depending on the season) each time it is opened. Reflective plastic sheeting on the outside of the glass helps keep out direct Sun heat; drapes that can be drawn on summer days and winter nights are also useful in preventing heat gain or loss.

A skylight about 4 feet square over the hallway relieves an otherwise dark area and affords useful ventilation when cranked open in the spring and fall but lets a good deal of heat escape in winter and seep in during summer. The leakage is reduced by installing a sheet of reflective-coated plastic for the summer in place of the screen that permits ventilation without mosquitoes in moderate weather.

A 3-foot overhang shading the south wall and its large windows keeps the wall 20–30 degrees cooler than the unprotected east and west walls on a typical clear July day, yet it doesn't block the low winter Sun. Because of the shape of the building lot, the south and north walls are shorter than the east and west walls. Normally, these dimensions should be reversed for best energy-efficient exposure to the Sun.
Thermal exterior shutters on all windows are operated from inside the house by hand cranks except for three in the bedrooms that, as a demonstration, are driven by electric motors. Because the shutters were added late in the construction, cornices were built above the windows to cover them, for appearance, when rolled up; they could have been designed to retract into the ceilings or attics.

Altogether, the Tech House design and structural features—what the engineers call the thermal envelope—saved 15,900 kilowatt hours of electricity during the test year; solar heating and the heat pumps saved about 7400, solar heating of domestic hot water 4220, lighting and energy-efficient appliances about 224—a total of $1130 worth. At today's rates the dollar saving obviously would be greater.

The shutters (shown on the left without cornices and on the right with cornices) were multipurpose, offering security, privacy, and climate control.
Energy from the Sun to heat the NASA Tech House—inexhaustible, free of charge except for a modest amount of electricity for pumps to move it inside—is collected by 16 large black panels on the south-facing slopes of the gable roofs. Each panel is 3 by 8 feet, a total of 384 square feet; two more panels collect heat for domestic hot water. Glass over two-layer steel collector plates with a black chrome coating, developed by NASA, admits sunlight and other solar radiation, then traps the reflected heat. This is the "greenhouse effect" experienced when you leave your car parked in the Sun with the windows up.

Water circulates through the collector plates to heat-exchanger coils in ducts, under the floor, through which fans blow the warmed air to the rooms. If heat is not needed at the time, the solar-heated water is diverted to the 1900-gallon underground storage tank. It can then be pumped back through the collectors to get still hotter and can be returned to the tank directly or by way of the heating coils in the ducts. When the collectors are not in use, they drain automatically to avoid freezing. During the night or on cloudy days, stored hot water is recirculated from the storage tank through the duct heat exchanger.

Solar collectors are mounted at an angle of 58 degrees on the south-facing roofs to provide maximum exposure to Virginia's winter Sun.
for warming the house. The tank is designed to store enough energy to heat the house for up to five sunless days. Backup electrical resistance heaters in the ducts were never needed during the test year.

When water coming from the solar collectors or in the storage tank is at less than 110° F, a pair of heat pumps (there are two only because one of the needed capacity was not available at the time the house was built) take over and extract heat for distribution through the ducts from well water warmer than the outside temperature. Or the heat pumps can use stored water from the big underground tank that, while too cool for direct heating, is warmer than the well water. Just using well water was found to work better, since the slightly warmer stored water sometimes causes the heat pumps to shut down. In this operating mode, which provided most of the Tech House heat during the test, all the energy comes not from the Sun, but from the energy in the well water and electricity used very economically to run the heat pumps and the well pump.

For air conditioning, the roof solar collectors are cut off and the heat pumps are, in effect, operated in reverse like a home refrigerator. Heat is extracted from the rooms and carried away by relatively cool water from the underground storage tank or the well. The cool water, usually from the well, is pumped through heat-exchanger coils in the return air duct, dropping the temperature of the return air by about 10 degrees. The water continues on to the

\[ \text{Simplified diagram of heating and cooling system.} \]
heat pumps, absorbing the heat extracted from the rooms, then is put back into the ground through a separate well. During the test year the heat pumps used one-fourth less electricity for cooling than would have been needed for air conditioning a conventional house, mainly because of the better insulation and Sun shading. Although no solar energy is used for cooling the Tech House, NASA is developing solar-cooling systems for other applications.

Radiator panels on the north-facing garage roof were intended to cool water at night for air conditioning. The idea was that heat energy removed from the house by the heat pumps during the day would be carried off by water circulated through them to the storage tank, raising the water temperature there. At night water from the tank would be pumped through the roof radiators to cool it for the next day's operation. This ingenious scheme didn't work out in Tidewater Virginia's warm, humid nights. Running cool well water through the heat pumps was found to be better.
To save energy by heating or cooling only those parts of the house which are being used, the Tech House is divided into four zones: master bedroom and adjoining bath; the other two bedrooms; the living room, dining area, and kitchen; and the main bathroom—which proved too small an area, however, to control independently. Each zone has its own temperature sensors (plus backup manual thermostat) linked to a programmable computer that takes readings every 10 minutes. The computer analyzes the input data, decides on the best operating mode for the house at the time, and signals the relays controlling various components of the heating/cooling system that distributes warm or cooled air to the separate zones to suit the family’s needs and habits. For instance, bedrooms can be left mostly unheated or uncooled during the day and the living room, dining area, and kitchen at night. Variations in the temperature pattern can be programmed to fit the differences in weekday and weekend or holiday use of different rooms. The computer can even be set to provide minimum heat or cooling while the occupants are away on vacation and turn it up shortly before they expect to return.

Tech House heating and air-conditioning zones.
NASA has done a lot of work on sophisticated systems to reduce the amount of water carried on long space voyages by recycling it for use several times. This idea is applied in the Tech House in a simpler setup that can be adapted to solve water-supply and sewage problems, and perhaps save money, for home builders in many locations.

Here's how it works:

Used bath and laundry water, instead of going into the sewer, drains into a 110-gallon tank under the floor. There it is chlorinated with laundry bleach, then sucked through a filter of diatomaceous earth, similar to the filter of a home swimming pool, into a 17-gallon steel pressure tank that, in turn, supplies water for flushing the toilets. The recycling circuit is, of course, entirely separate from the water supply for other purposes, and the toilets drain directly into the sewer.

The laundry bleach, dispensed automatically according to the weight of incoming laundry and bath water, kills coliform organisms; the filter strains out solids. Tested twice a week during the...

Schematic of the water-reuse system. Of course, this system is entirely separate from the water supply for other purposes.
The house was lived in, the recycled water was found pure enough to cause no harm if—though this is hardly recommended—a child or a pet happened to taste it. There were no offensive odors, though the reclaimed water was sometimes slightly tinted from laundering dyed fabrics. As a small plus, enough detergent remained in the filtered water to keep the toilet bowls clean. The collection tank, of polyethylene, needed to be flushed about every two months and the filter rinsed and renewed about every six weeks. The system used less than a gallon of bleach a month, and 9 pounds of diatomaceous earth were added to the filter during the test year.

At its cost of $500 to $600, the Tech House recycling system might not pay off directly in some homes with city water and sewers, but it could in parts of the country where these services are expensive. More important, it could solve problems where a deep well is necessary or where septic tank drainage is poor. And it might make continued home building possible in suburbs where municipal water supplies are already strained or sewage systems overloaded.
and new hookups suspended, or it could avert tax increases for additional waterworks or sewage treatment plants.

Recycling reduced the Tech House family's use of water by an average of 61 gallons a day. The saving could have been greater with a slightly larger—say, 135-gallon—tank: An average of 24 gallons a day of reusable water was lost through an overflow valve into the sewer when the tank got full; an average of 15 gallons of tap water a day was added, automatically, at other times when the supply for reuse fell below 10 gallons. So that the test would be conducted under normal living conditions, the family members were asked not to change their bathing and laundry schedules to make maximum use of recycled water.

The solar-supplemented system that heats water for the Tech House bathrooms, laundry, and kitchen is simple: Water heated by two of the 3-by-8-foot collector panels on the living room/dining area roof is pumped in a closed loop through copper tubing coiled around the inner tank of an ordinary 50-gallon water heater, with its electric heating element disconnected, then back through the roof collectors. In the tank, solar heat is transferred to incoming city water, heating it to about 130°F.
When a hot-water tap is opened—the bathroom shower, say—city water is drawn from this solar heater through a standard 42-gallon electric heater that switches on only if the preheated water drops below the thermostat setting, usually 140°F. Automobile antifreeze mixed with the water in the closed solar-heating circuit eliminates the need for draining the collectors on cold nights or dark winter days.

Because the electric heater usually had to take over when everyone in the family took showers in the morning, after several hours without Sun heat on the roof collectors, or when the dishwasher and several loads of laundry were run in the evening, too late for solar heating, solar energy supplied only 35 percent of the total energy required for water heating during the test year. With larger tanks—or if the laundry could have been done during the day, when solar heat was available to replenish the hot water supply—the saving could have been greater. Even so, the Tech House system would pay off the extra cost of the installation over its expected lifetime, as well as conserve energy.

_Simplified diagram of solar hot water system._
Some possible savings from the use of advanced technology in home building or remodeling are not readily measured. For example, the cost of installing solar equipment or heavy insulation may be partly offset by local as well as Federal tax breaks. Fire-retardant materials or an effective security system may qualify a house for lower insurance rates.

The Tech House concrete floor is fireproof, of course, and the carpets, drapes, and furniture coverings are made of fire-retardant materials. The triopolymer foam insulation in the exterior walls and ceiling is self-extinguishing: in tests, a flame will not advance beyond the point of ignition, and the foam forms only a charred surface when the flame is removed. The gypsum insulation under the concrete floor and in the one prefabricated interior wall and the foam filling in the steel-clad outside doors are also noncombustible.

A smoke detector in the hallway outside the bedrooms is a standard commercial model, one of twenty-some on the market, of the ionization type. A radioactive source transforms air inside the device to a conductor of electric current, and a small current passes through this ionized air. When smoke particles enter the detector, they impede the flow of electricity, and electric circuitry that senses the current reduction sets off a warning horn.

(There's also an ingenious tornado alarm, invented at NASA's Marshall...
Space Flight Center in Alabama. This is a light-sensitive device built into a suction cup and attached to the face of a television picture tube. If there should be a tornado warning for the area, the TV set could be switched on and tuned to an unused channel, and the brightness turned down. Electrical energy from a tornado that came within 18 miles would cause the screen to light up and trigger the detector to sound an audible alarm. Luckily, there was no need to test it in the Tech House.

Energy-efficient appliances in the house include a standard microwave oven, which cooks quickly, saving electricity, and doesn't heat up the kitchen. For use in the regular electric oven, NASA has come up with a little "heat pipe" (the pipe is used to radiate heat from electronic equipment in spacecraft) that employs the capillary action of liquid in a sealed tube to transfer heat. Pointed at one end, the pipe is inserted into the middle of a roast to heat the inside as well as the outside, cutting cooking time in half. It's on the market under the name Super Skewer.

A tornado alarm with a detection range of 18 miles was installed in the Tech House, but fortunately was not needed during the live-in year.
Electrical-resistance devices called theristors (they were used in Saturn rockets), designed to prolong the normal life of ordinary incandescent light bulbs, are installed in the Tech House ceiling fixtures. About the size of a quarter, the thermistor serves as an electrical cushion, momentarily limiting the initial surge of current into a cold filament when the light is switched on—the time an aging bulb is likely to fail. Available now from half a dozen suppliers, thermistor devices can increase the life of a bulb by at least three times.

NASA foresees wide usage for one modest space-based innovation demonstrated in the Tech House: flat electrical cable—it looks like three flat wires printed on cardboard—developed at the Marshall Space Flight Center and now common in spacecraft and aircraft. (It is also still functioning on the Moon to link scientific instruments, left there by the astronauts and now on stand-by, to radio transmitters that relay their readings to Earth.) Flat cable takes less copper than round wire and less labor to install. It can be run under carpets and clipped along baseboards, outlets being located or moved wherever desired, without drilling through walls, solid masonry construction, or studs. Recently approved by Underwriters' Laboratories, it’s handy for remodeling or rehabilitating old houses as well as in new homes.

Thermistor discs installed in two Tech House light bulb sockets increased the life of the bulbs up to 300%.

The flat electrical cable used in the Tech House has the same current-carrying capacity as round wire, but requires less copper and is easier to install.
Emergency lights in the Tech House are powered by solar cells, like the ones that provide electricity for many spacecraft, which generate current directly from sunlight without moving parts. A small solar array on the south-facing garage roof charges an ordinary 12-volt automobile battery. This, in turn, supplies current to special low-drain 6-watt fluorescent lamps in the living room, kitchen, and hall outside the bedrooms and main bathroom and to a driveway spotlight. These switch on automatically in case of a power failure. The long-life lamps, drawing low-voltage, high-frequency current from self-contained solid-state electronic drives, were developed for Skylab. The ones in the Tech House would light for 400 hours from a fully charged battery.

Also from space technology comes a pocket ultrasonic transmitter called Scan, about the size of a fountain pen, that can turn on the front-entrance lights and one on a post on the lawn from 30 feet away. Another space spin-off is a flexible urethane foam furniture-cushioning material, called Temper Foam, developed to pad the astronauts' seats in the Apollo command module to ease the stress of liftoff and the jolt of splashdown. Adapting to the contours of a user's shape and distributing the weight evenly over the contact surface, the foam padding absorbs shock and vibration. It has been tested successfully for hospital and nursing home beds.
A sophisticated outdoor intruder alarm, planted in the lawn, its antenna hidden by bushes, transmits to an unused channel of an FM radio in the house. Based on a seismic detector that measured quakes on the Moon, it can pick up footsteps as far as 260 feet away—and distinguish between walking and running. This proved too sensitive for the small size of the Tech House building lot—it could have been set off by passing traffic—and was not regularly used. The idea might prove more practical for an isolated house or even just a larger lot.

The outside doors of the house are hung on self-locking hinges devised at the Kennedy Space Center for doors and cabinets in security areas. They prevent the doors from being opened even if the exposed hinge pins are pulled out. Since the main doors of the Tech House open inward, like those of most houses, the special hinges were mainly for demonstration here but could be useful for many special circumstances.

Self-locking hinges, fabricated at Langley Research Center, were used to secure the outward-opening exterior doors of the Tech House.

The intruder detection system proved to be so sensitive that it was set off by the family dog. Consequently, it was only used for an occasional demonstration.
The interior burglar-alarm system has detectors at the windows, doors, and under the hall carpets. It operates on house current but could be converted to share the emergency-light battery, charged by solar cells. Detectors at the windows are wires woven into the screens; a siren sounds if the screens are cut or removed. Those under the carpet are pressure-sensitive pads. Detectors at the outside doors have a built-in 1-minute delay that gives a home owner time to shut off the system after coming in, or to get out the door when leaving, without triggering an alarm. It is set on leaving the house, or at bedtime, by punching a code of numbers into a digital keyboard like a push-button phone. While the house was lived in, the system was left turned off, except for an occasional demonstration, after the family collie, Susie, set off an alarm when everyone was out for a Sunday afternoon. The police were not amused.

The burglar alarm system:
(top) Wires woven into window screening.
(left) Pressure-sensitive pads under the carpet.
(right) Keyboard used to set alarm.
Living with Technology

What would it be like to live in a Tech House? The Swain family did so for a year, and this is their story. It has to do, inevitably, with their experiences in the house as a laboratory as well as a home.

Dr. Charles W. Swain, called Bill, was 40 years old and a professor of religion at Florida State University (FSU) in Tallahassee. His wife, Elaine, 37, was head nurse in the local hospital; their daughter, Carol, 17, was a junior in high school, and son Charles S., 12, was in middle school. After 15 years of teaching, Bill was at the point in his career when it would be customary to take a sabbatical leave to reflect on his life course as his most productive years were about to begin.

Because FSU didn’t have a policy of granting sabbaticals, Bill got in touch with the American Council on Education, which arranges 1-year temporary assignments with Federal agencies for outstanding teachers in order to broaden their professional outlook and bring fresh views into Government service. Selected for the program, Bill first passed up a couple of offers that didn’t interest him.

Then came a phone call from NASA’s Langley Research Center in Hampton, Virginia. Would the Swains like to live for a year in the experimental NASA Tech House—designed to test engineering ideas for saving energy and water without compromises on size or comfort—while Dr. Swain worked in the Langley personnel office, helping to set up a new career-development program? The Swains were NASA’s first choice among six families nominated by the Council as fitting the requirements: a family of four, including two school-age youngsters, middle class in background and living habits, without engineering training that might get them overly involved in the technical aspects of the experiment.

Bill was immediately enthusiastic. Though no ecology zealot, he was well aware, from rising gasoline prices and electric bills, of the growing energy shortage and the need to conserve natural resources. The Langley proposal seemed an interesting and worthy project. Elaine approved, figuring that as a nurse she could find work fairly readily and that experience in a new area might be stimulating. Carol was not thrilled with the prospect of moving away from Tallahassee and her friends for her senior year in high school; she thought of staying behind with a neighbor family but in the end decided that being with her family just before going off to college was more important. (Before the year was out, she would find Virginia so attractive that, after a freshman term at Florida State, she returned to attend Mary Washington College in Fredericksburg.) As for young Charles, he saw the chance to move as an adventure that would plunge him into the wonders of space exploration and the exciting world of computers.

Their selection confirmed by interviews with NASA envoys, the Swains rented their home in Tallahassee, where they had lived for 12 years, took leaves of absence from their jobs, left col-
leagues and schoolmates, and migrated hundreds of miles north to unfamiliar country and into a strange house surrounded by research laboratories—of which, in fact, the Tech House itself was one.

The primary objective of the Tech House experiment was to test whether technology could achieve significant home energy and water savings without requiring adjustments in the occupants' lifestyle. To remind the test family of the real world, NASA billed them for rent and utilities. But, for the Swains, keeping to their accustomed living habits wasn't easy.

In Tallahassee they had lived in an ordinary but comfortable 25-year-old house situated on an ample wooded lot, furnished with two decades' accumulation of their own things, laid out to afford individual privacy—a den, a solarium, a screened porch—for homework, writing, reading, or listening to music, which all but Charles preferred to watching television, and handy to stores, schools, and church.

At Langley the house was an odd shape, the furnishings motel modern. The layout provided a single large family room and no separate retreats except the bedrooms. The compact building lot was unshaded: there were no leaves to rake, and NASA grounds keepers even cut the grass and tended the few shrubs. Next door were a huge and noisy wind tunnel, a field of solar collectors for heating and cooling an adjacent office building, and the busy Langley Visitors Center, whose patrons sometimes mistook the Tech House for one of the public displays. And the Swains could never quite forget that computer out in the garage, noting down every time one of them turned on a light or a bathroom faucet.

The experiment was conducted with proper scientific protocol. NASA, besides keeping elaborately detailed engineering data, contracted with the Old Dominion University Research Foundation, Norfolk, Virginia, to evaluate the family's behavioral patterns and user reactions. Questionnaires and interviews, personal and by telephone, before, during, and at the end of the year's test recorded their living habits, use of appliances, leisure activities, and adaptation to their new surroundings and to the Tech House resource-conserving innovations. In the end the academics could report: "The analysis of the observations made indicate beyond reasonable doubt that the test family was a typical middle-class household and that they maintained a lifestyle consistent with their former home environment."

As a small example, Carol, oblivious to

*The Swain family (l to r) Charles S., Charles W. (called Bill), Carol, and Elaine enjoy breakfast in their "laboratory disguised as a house."*
the silently recording meters, stuck by her morning ritual of washing and blow-drying her hair for school and church.

There were minor annoyances: odd noises heard in the master bedroom from the water-recycling pump under the floor, a pinkish cast to the water in the toilet bowls the day after a new red sweater had been laundered, two doors to open and close every time you came into the house or went out. Because the water meters were located in the rear of the house, where the NASA engineers could read them without coming inside, there was a delay of a minute or two for hot water while it flowed from the heater tanks out to the meters and back to the kitchen or bathrooms. The glass doors on the fireplace made it wondrously efficient but less cheery than an open blaze and the faint smell of wood smoke.

There were some extra chores: remembering to crank the window shutters down or up according to the weather and time of day; to shut off the solar hot-water system if the family were going away for more than a day or two, lest the water get too hot and form scale in the tubes and tank; to take samples of the toilet-tank water every Monday and Thursday morning and set them out in the garage to be picked up for bacterial testing; to switch the computer-controlled heating/cooling system to the weekend program when Elaine was home in the daytime during the week she worked a night shift at the hospital.

Mostly, though, the Swains managed to resist any temptation to change their ways in order to make the technology look good. "They gave us a Ferrari," Bill said, "and we drove it like a Model T."

After the family had moved back to their home and normal life in Florida, Bill Swain talked about their year at Langley and how it had affected their attitudes, making some of the same points noted by the NASA engineers and the Old Dominion University observers.

Had they, in fact, been able to live normally in the Tech House?

"The answer to that is yes," Bill said. "You do have to be aware that the Tech House is really a laboratory disguised as a house, filled with monitoring equipment and so on. You and the family really have to consciously restrain yourselves from thinking that every bit of energy and every amount of water you use is being monitored by the engineers. While we knew the engineers would be aware of those, they did not want us to dramatically change the way we lived on a day-to-day basis. The whole idea of the test was to find out what would happen with this carefully designed house if a normal family lived normally. Obviously, there were things that we could have done in the Tech House to save energy that we really didn't do."

Did they feel isolated and lonesome for old friends, familiar community surroundings?

"I don't think we felt isolated except in a psychological sense, when other people went home at 4:30 and there were just us and those wind tunnels," Bill said. "There we were right in the middle of the research center, yet free to get involved in the life of the community to whatever extent we wanted to. We went to church regularly. The children went to school. Elaine and I had our jobs. Our daughter, Carol, was very active in extracurricular activities. Our son, Charles, was out in the community a good bit. Elaine and I were not as much so, partly because she had her job as a nurse, with irregular hours sometimes, and I worked right at the Center, my office only ten minutes away. Still, there were moments when it was a lonely feeling. But I think the children enjoyed that, just walking around. It was like having a big park all to yourself. I don't think the isolation was difficult."

Did they make use of all the technical systems and equipment that are in the house?

"Well, we were aware that some of the Tech House systems, of course, were designed for emergency use—the security system, the smoke detectors, the

"They gave us a Ferrari and we drove it like a Model T."
tornado warning. Obviously, we were grateful that we didn’t have to use some of those. But we did play with them enough to know that they were operable and would work. As far as the normal systems in the house, we did use them—yes, we did.”

Were there features of the Tech House that the Swains particularly didn’t like?

“For one,” Bill noted, “the space was not very well designed for our family lifestyle. The big common room meant that we couldn’t diversify, and we’re a family of diverse interests. Our home in Tallahassee has a number of areas where various individuals can have privacy to pursue their own interests. We finally made some adjustments: We moved the television set into my son’s bedroom, and I had some office space in my bedroom where I could write. And the four separate zones for heating and cooling didn’t seem necessary for us. Just two zones would probably have been enough, one for the daytime living areas and one for the bedrooms.”

Were there any of the Tech House innovations that the Swains liked so well they were putting them into their Florida home?

“We are actually in the process right now of making some changes because of our experience in the Tech House,” Bill said. “The systems that catch the public eye, the ones that most people are curious about in the Tech House, are of course the solar energy systems. In our house in Tallahassee they’re not appropriate. We live on a tree-shaded lot and we couldn’t really use solar collectors. But we are re-doing the thermal envelope, the outside of the house. We are increasing the insulation. We are replacing all the windows in our home in Tallahassee with the sliding casement type windows that are in the Tech House, with double-pane glass and magnetic weather seals. We are also thinking about trying a forthcoming commercial version of the water recycling system, though Tallahassee happens to be blessed with an ample supply of spring water and has no sewerage problem. It is very clear from the Tech House experience that in terms of money saved the best way to incorporate some of the features is to pay attention to insulation, window treatment, and that sort of thing rather than the more highly technical systems.”

As a result of changes made to their Tallahassee house, the Swains have cut their monthly bills for heating and air conditioning (the bigger item in that climate) by about two-thirds—around $50 a month compared to $125 and $130 for some of their neighbors, Bill said. Before they went to Langley, he added, “I wouldn’t have been able to tell you how much energy we used in a given period. Now I keep a daily energy record for the house.”

Publicity about the Swains’ year in the Tech House brings Bill frequent requests to speak before community and professional groups about energy conservation. He is also chairman of a statewide task force for consciousness-raising, as he put it, concerning energy matters in the university curriculum, trying to integrate energy issues into the course work.

“One of the main things that struck us about living in the Tech House,” he concluded, “was that a technically designed, very efficient house is not really the total answer to the question of saving energy for the average family. We didn’t make as efficient use of the Tech House as we might have, partly because some of the features didn’t fit into our lifestyle very well. I would like to see a lot more attention devoted to the way in which the technological systems that we are going to use to meet the energy crisis interact with people’s habits, the way they live, what they think about their house, and so on.”

To stimulate that kind of thinking, to nudge us toward new attitudes about how an increasing population can best get along on dwindling nonrenewable resources, may be the most important contribution made by the NASA Tech House to rational housing and living patterns of the future.
Appendix:
Tech House Systems and Performance

The Reference House used to make comparisons with the NASA Tech House is a composite comparably sized single-family house based on a study made for the Department of Housing and Urban Development of energy and water consumption for conventional middle-income homes built in the early 1970s in the Washington-Baltimore area. All energy systems and devices are electrical except for space heating, which employs a natural gas, forced-air system. The figures for space heating represent equivalent electrical energy required by gas furnaces.


Annual electrical energy use of Tech House versus HUD reference house.

<table>
<thead>
<tr>
<th>Use</th>
<th>Electrical energy use by HUD reference house, kW-hr</th>
<th>Electrical energy use by Tech House</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Projected use, kW-hr</td>
<td>Projected savings, percent</td>
</tr>
<tr>
<td>Domestic hot water</td>
<td>4380</td>
<td>1500</td>
</tr>
<tr>
<td>Heating</td>
<td>29 300</td>
<td>6000</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>3600</td>
<td>2100</td>
</tr>
<tr>
<td>Base load (lights, appliances, etc.)</td>
<td>8720</td>
<td>5400</td>
</tr>
<tr>
<td>Total</td>
<td>46 000</td>
<td>15 000</td>
</tr>
</tbody>
</table>

*Would be 35 percent if based on actual energy required to heat water (6392 kW-hr) at the Tech House; 4167 kW-hr of electricity, and 2225 kW-hr of solar energy.

*Value based on electrical energy used by HUD reference house.

Monthly electrical energy consumption of Tech House versus HUD reference house.
Annual Tech House water use.

<table>
<thead>
<tr>
<th>Water use</th>
<th>Water use without water-saving features, gal</th>
<th>Actual water use with water-saving features, gal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathing</td>
<td>26,671</td>
<td>18,937</td>
</tr>
<tr>
<td>Dishwashing</td>
<td>4,601</td>
<td>4,601</td>
</tr>
<tr>
<td>Laundry</td>
<td>12,392</td>
<td>12,392</td>
</tr>
<tr>
<td>Lavatory</td>
<td>10,540</td>
<td>10,540</td>
</tr>
<tr>
<td>Sink</td>
<td>5,548</td>
<td>5,548</td>
</tr>
<tr>
<td>Toilet</td>
<td>27,777</td>
<td>5,533</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>3,670</td>
<td>3,670</td>
</tr>
<tr>
<td>Total</td>
<td>91,199</td>
<td>61,221</td>
</tr>
</tbody>
</table>

*Estimated.
*Reused gray water provided 22,244 gal of required toilet flush water.

Monthly flush water required and savings provided by reuse system (cumulative).
Domestic hot water system performance.

<table>
<thead>
<tr>
<th>Month</th>
<th>Amount used, gal</th>
<th>Average city-water temperature, °F</th>
<th>Average hot-water temperature, °F</th>
<th>Temperature difference, °F</th>
<th>Energy to heat water, kW-hr (a)</th>
<th>Tank loss, kW-hr (b)</th>
<th>Total energy required, kW-hr (c)</th>
<th>Electrical energy, kW-hr</th>
<th>Solar energy, percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug. 1977</td>
<td>1177</td>
<td>81</td>
<td>135</td>
<td>54</td>
<td>154</td>
<td>52</td>
<td>206</td>
<td>143</td>
<td>31</td>
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<tr>
<td>Sept. 1977</td>
<td>2040</td>
<td>79</td>
<td>133</td>
<td>54</td>
<td>268</td>
<td>104</td>
<td>372</td>
<td>130</td>
<td>65</td>
</tr>
<tr>
<td>Oct. 1977</td>
<td>2046</td>
<td>62</td>
<td>135</td>
<td>73</td>
<td>360</td>
<td>108</td>
<td>468</td>
<td>370</td>
<td>34</td>
</tr>
<tr>
<td>Nov. 1977</td>
<td>1911</td>
<td>60</td>
<td>138</td>
<td>78</td>
<td>354</td>
<td>104</td>
<td>458</td>
<td>450</td>
<td>2</td>
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<tr>
<td>Dec. 1977</td>
<td>2232</td>
<td>50</td>
<td>135</td>
<td>85</td>
<td>408</td>
<td>108</td>
<td>516</td>
<td>431</td>
<td>16</td>
</tr>
<tr>
<td>Jan. 1978</td>
<td>2889</td>
<td>44</td>
<td>140</td>
<td>96</td>
<td>676</td>
<td>108</td>
<td>784</td>
<td>591</td>
<td>25</td>
</tr>
<tr>
<td>Feb. 1978</td>
<td>2608</td>
<td>41</td>
<td>140</td>
<td>99</td>
<td>629</td>
<td>97</td>
<td>726</td>
<td>497</td>
<td>32</td>
</tr>
<tr>
<td>Mar. 1978</td>
<td>2952</td>
<td>45</td>
<td>137</td>
<td>92</td>
<td>662</td>
<td>108</td>
<td>770</td>
<td>545</td>
<td>29</td>
</tr>
<tr>
<td>Apr. 1978</td>
<td>3031</td>
<td>56</td>
<td>125</td>
<td>69</td>
<td>509</td>
<td>104</td>
<td>613</td>
<td>360</td>
<td>41</td>
</tr>
<tr>
<td>May 1978</td>
<td>3111</td>
<td>61</td>
<td>125</td>
<td>64</td>
<td>485</td>
<td>108</td>
<td>593</td>
<td>346</td>
<td>42</td>
</tr>
<tr>
<td>June 1978</td>
<td>2774</td>
<td>72</td>
<td>125</td>
<td>53</td>
<td>358</td>
<td>104</td>
<td>462</td>
<td>199</td>
<td>57</td>
</tr>
<tr>
<td>July 1978</td>
<td>1508</td>
<td>77</td>
<td>125</td>
<td>48</td>
<td>176</td>
<td>52</td>
<td>228</td>
<td>99</td>
<td>57</td>
</tr>
<tr>
<td>Aug. 1978</td>
<td>1343</td>
<td>81</td>
<td>125</td>
<td>44</td>
<td>144</td>
<td>52</td>
<td>196</td>
<td>68</td>
<td>65</td>
</tr>
<tr>
<td>Total</td>
<td>29622</td>
<td>62</td>
<td>132</td>
<td>69</td>
<td>5183</td>
<td>1209</td>
<td>6392</td>
<td>4229</td>
<td>35</td>
</tr>
</tbody>
</table>

*Calculated, not including storage losses.

*Estimated based on hours of operation per month of conventional hot water heater.

*Calculated.

Domestic hot-water system energy required.

![Bar chart showing electrical energy use with and without solar for each month from Aug. 1977 to Aug. 1978. Without solar electrical energy use is shown in light gray, with solar in dark gray. The chart indicates a decrease in energy use with the addition of solar energy.](chart.png)
Domestic hot water system energy use.

[Diagram showing energy use from Sept. 1977 to Sept. 1978 with labels for months and energy use in kW-hr.]

Tech House heating requirements.

[Bar chart showing heating requirements from Oct. 1977 to May 1978 with labels for months and Btu amounts.]

Summary of heating-system performance.

<table>
<thead>
<tr>
<th></th>
<th>Input, kW-hr</th>
<th>Output, kW-hr</th>
<th>Output/Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat pumps</td>
<td>4900</td>
<td>8000</td>
<td>1.63</td>
</tr>
<tr>
<td>Solar heat</td>
<td>1180</td>
<td>5500</td>
<td>4.66</td>
</tr>
<tr>
<td>Total</td>
<td>6080</td>
<td>13 550</td>
<td>2.23</td>
</tr>
</tbody>
</table>

*Value based on total output/total input.*
Outside and wall temperatures on December 27, 1977 (clear day).

Outside and wall temperatures on July 21, 1978 (clear day).