Rocky Mountain Institute

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Visitor's Guide

1739 Snowmass Creek Road • Snowmass, Colorado 81654-9199 • www.rmi.org

August 2007 Sixth Edition

Welcome

©Judy Hill

By Amory Lovins

Welcome to my home, bioshelter, and office. More than a hundred volunteers and about a dozen professional builders and artisans worked with RMI co-founder Hunter Lovins and me from June 1982 to January 1984 to create this experimental structure. We tried to make the building both technically advanced and beautiful, and after its completion those of us that use it have continued improving it ever since.

The building is jointly owned by RMI and me (with my wife Judy Hill Lovins; my former wife L. Hunter Lovins and I paid for it, and RMI bought her half-share in 2003.) To the extent our work permits, we open most of the building to the public as a demonstration project. It has received many tens of thousands of visitors from all over the world and it has been featured in dozens of television programs, and in hundreds of newspaper, magazine, and Internet articles. This self-tour guide will help you to understand some of the building's features and how they contribute to its performance. If you have questions after reading this document, you may contact RMI's Outreach Department via www.rmi.org/sitepages/pid24.php, by phoning 970-927-3851, or by emailing outreach@rmi.org.

This 4,000-square-foot (372-square-meter) structure has three functions:

- it is a house for me, my wife, and our guests;
- it is a year-round growing space for fruits, vegetables, herbs, flowers, and fish; and
- it is a research center used rent-free as the original headquarters of Rocky Mountain Institute.

Finally, please be aware that RMI does not have a receptionist in the Headquarters building and that all the people here are working. Instead of interrupting them with questions or comments, please be so kind as to contact an outreach specialist (outreach@rmi.org, 970-927-3851).

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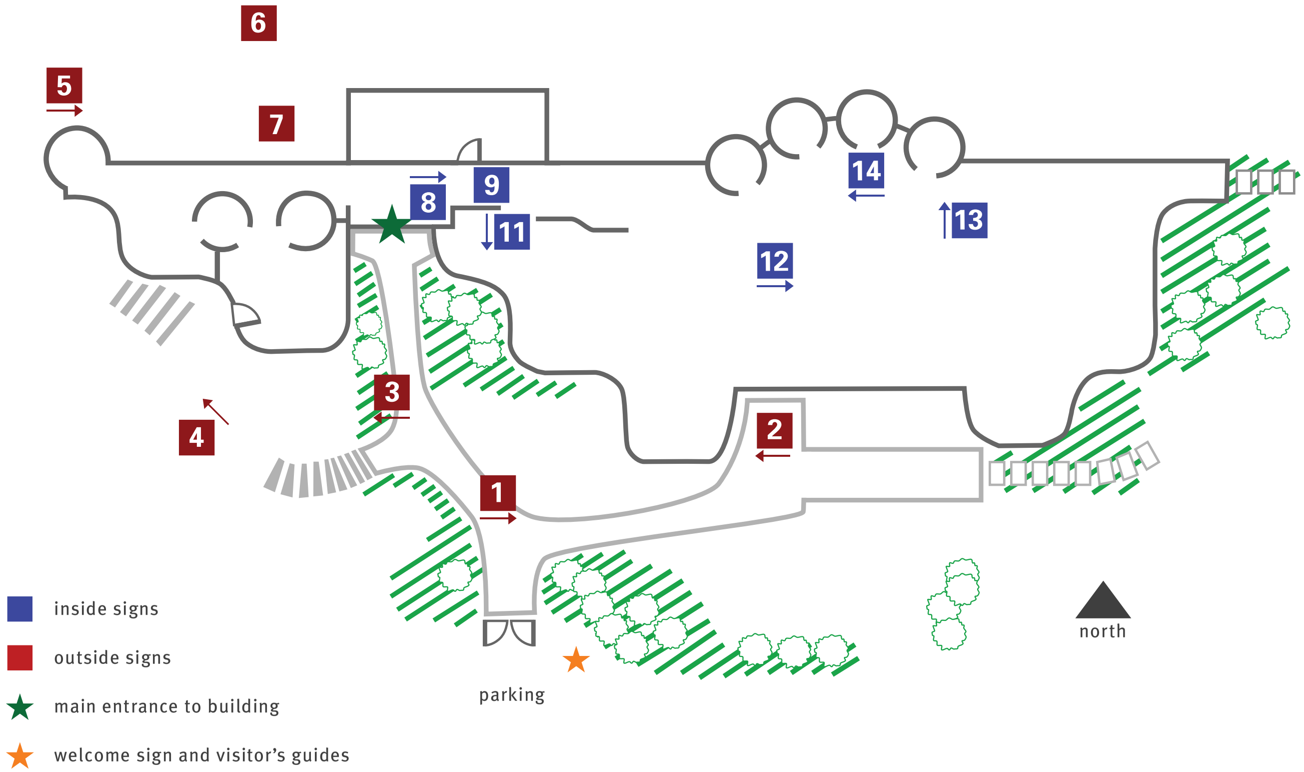
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Visiting & Touring

As you tour the grounds of RMI's Headquarters building, and Amory Lovins's (RMI Cofounder and Chief Scientist) home you'll see a series of numbered signs from 1 through 15 (1–8 are outside and 8–15 are found inside the building). These numbers correlate to this visitor's guide. Each number section in this guide relates to the area of the house or ground that its matching sign is located in.

Due to the huge number of visitor requests we get every week, we are, unfortunately, not able to accommodate everyone. If we are not able to accommodate an individual visit, our extensive website (www.rmi.org) may provide the information you seek. You may join an RMI-led public tour of the building every Friday (except holidays) at 2 p.m. The rest of the time it's open to the public for self-guided tours only, from 10:30 a.m. to 4:30 p.m. or by special arrangement.

If you would like to request a personal visit with a specific researcher, please contact us at visitors@rmi.org, specifying the proposed dates of your visit, its purpose, and whom you wish to visit (see www.rmi.org/sitepages/pid56.php for a staff list).

Please do not smoke indoors or touch the various controls and technical systems, and please do not enter any areas marked "private"—notably the wing to the left of the entryway as you come in. To avoid damage to the plants, ponds, and drystack walls, I also ask that you not enter the planted areas of the greenhouse unless invited by a staff member. If you do enter the greenhouse, please be especially careful and stay strictly on the stepping-stones. Although we try to keep the premises in a safe condition, RMI and I cannot accept responsibility for you or your possessions. If you cannot leave your pets at home, you must leave them inside your car (with adequate ventilation). Parking on the main road is both unsafe and illegal; if you cannot park in the driveway, please tell a staff member immediately.

About RMI

Rocky Mountain Institute is a nonprofit organization with almost 90 full-time staff members, most of whom work outside of the Headquarters building (chiefly at the Windstar Land Conservancy, about a mile to the southeast, and in our larger office in Boulder—the world's first LEED Platinum-rated commercial interior retrofit).

RMI's purpose is to foster the efficient and restorative use of resources to make the world secure, just, prosperous, and life-sustaining. Its research and consulting work is undertaken by three integrative teams, Energy and Resources, Breakthrough Design, Built Environment, plus an ad hoc team implementing our 2004 book *Winning the Oil Endgame* (www.oilendgame.com). We also work on global security, economic renewal, and education. More information on the Institute's purpose and programs is available in the front entryway and on our website (www.rmi.org).

Breakthrough Design Team

RMI's "think and do" approach brings hands-on experience garnered from work in dozens of industries, combined with decades of RMI research findings, to every client engagement. RMI's work considers your entire organization—from the boardroom to the shop floor. We take our intellectual capital to the heart of your operations and help your engineers, designers, operators, and managers implement realistic innovation in resource strategy.

Built Environment Team

From materials and construction to lighting, heating, and cooling, the building industry accounts for roughly 40 percent of all the energy used in the United States. As an international leader in sustainable design, we work with developers, architects, facility managers, and real-estate professionals to create high-performance buildings and communities that are less expensive to build (or retrofit), more profitable to operate, easier to lease, and healthier and more comfortable to occupy—plus, they boost worker productivity. We offer leadership and guidance at all stages of building, from conceptual design through occupancy, operation, and renovation.

Energy & Resources Team

For more than two decades, Rocky Mountain Institute has been recognized as one of the world's foremost authorities on energy use, supply, policy, and regulation. Its staff includes preeminent experts on energy efficiency techniques and technologies, energy industry structure, resource planning, technology commercialization, and competitive strategy for companies in the electric power, natural gas, and other regulated industries.

Introduction

The RMI Headquarters building's energy- and water-saving features are among the most advanced in the world: almost all the space- and water-heating energy it uses is solar, it uses about a tenth the usual amount of household electricity (mostly solar-generated), and it uses less than half the normal amount of water. Although it was designed as a comfortable home and office, most of the technologies and design principles responsible for the building's performance can also be cost-effectively applied to smaller, simpler, and cheaper buildings, allowing for differences of climate and lifestyle. That is, similar technical and economic performance—in this case, a ten-month payback on the extra cost of all the efficiency improvements in 1983—can be achieved in almost any climate and with a house that looks however you like.

Admittedly, this building is now twenty-five years old, and green building and design techniques have evolved much further. Yet it shows how very high levels of energy and resource efficiency can be achieved with smart design and straightforward building principles that are available to all and adaptable to other climates, sites, and uses.

1

[Setting & Strategy]

The building is passive solar, superinsulated, and semi-underground.

The building is located in the heart of the Snowmass Creek valley. This rural area, 16 miles (25 kilometers) west of Aspen on Colorado's Western Slope, is known locally as Old Snowmass to distinguish it from the Snowmass Village ski resort (called simply "Snowmass" on many maps). Our sloping 2.2-acre (0.9-hectare) trapezoidal site, on lean clay weathered from Mancos shale, lies alongside a main Pitkin County road on the western side of Capitol Creek. This is high desert, with about 20 inches (51 centimeters) of annual precipitation.

The building is passive solar, superinsulated, and semi-underground—built back into the hill near the north lot line, then bermed over the north wall for esthetic and microclimatic reasons. (You wouldn't normally do that to save energy, as soil is a poor insulator and holding up its weight is expensive, but we did it for microclimatic and esthetic reasons.) The site's elevation is 7,100 feet (2,165 meters); the heating climate was ~8,700 Fahrenheit degree-days (~4,900 Celsius degree-days) per year at the time of construction. Summer temperatures rise to the mid-80s of °F (~29°C). Though it is often sunny, it is not reliably sunny: in late 1983, for example, we had thirty-nine continuous days of midwinter cloud. The nominal growing season at that time was approximately fifty-six days; a local joke has it that there are two seasons, winter and July.

Because the building is superinsulated, it has no heating system in the usual sense. It is ~99 percent heated by passive solar gain through the windows and the greenhouse. The two woodstoves were installed partly for esthetics

and partly for backup heating. The passive solar design also incorporates daylighting and natural ventilation while preserving viewlines and minimizing noise.

The building was designed for a radiant temperature in the 80s of ˚F (~27–30˚C) and an air temperature in the 60s (~17–19˚C)—healthier and more comfortable than air in the 70s (~21–22˚C). The sensation of human comfort is the average of air temperature and "mean" (averaged over all directions) radiant temperature. The building's air temperature responds more quickly to changes in outdoor temperature than does the

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radiant temperature, which depends on the amount of heat stored in the floor, walls, and other "thermal mass." A lag of up to several months between these two temperatures makes the comfort sensation more constant through the year than either of its components.

The building contains more glass area, more masonry for heat storage, and more vent area than are really necessary: these "safety margins" allow for unusual weather conditions and for uncertainties in prior simulations of thermal performance.

2

[The Glazings]

Our building simply uses passive gain from the windows to balance the total heat loss from the entire structure.

Much of the building's thermal performance is due to its advanced windows (often called "superwindows"), which were used here commercially for the first time. Virtually all are krypton-filled Heat Mirror® windows. Heat Mirror is a 0.002-inch-thick (50-micrometer) clear polyester film with special, almost atomically thin, coatings that are transparent to visible light but reflect infrared (heat) rays. The film is suspended between glass panes in a double-paned window unit and performs the way a third pane would perform—only better, because it keeps in more heat and lets in more light than a third piece of glass would. In fact, the type of Heat Mirror film used in RMI's windows (Heat Mirror 88, designed to maximize solar heating in cold climates) loses only about one-tenth as much heat as a single pane of glass, and lets in three-quarters of the visible light and half of the total solar energy. It is therefore advantageous to use a lot of glass: our building has 28 percent as much glass (~1,120 square feet or 104 square meters) as floor area, or about twice the normal household ratio. Because the film is only available sealed into a prebuilt unit, the entire assembly is sometimes loosely referred to as a Heat Mirror window or glazing unit. Heat Mirror has been available for more than two decades and is now supplied as an option by several major window manufacturers. Our innovation was to fill this lightweight window with argon—a cheap, inert gas available from welding shops. This raises the heat-trapping value of the windows from about R- 4.13 or -4.2[1] to about R-5.3 or -5.4 (~k-1.05) (center-of-glass),[2] but

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adds very little cost, and in competitive markets nowadays, no extra cost. When we reglazed the building in the 1990s, we switched to krypton, which is even better (it insulates twice as well as air, vs. a third better for argon) and has a smaller optimal gap that was easier to match to convenient total thicknesses of the glazing units that would fit in normal sashes. In 2007 we are changing many of the vertical glazings to thermally broken fiberglass frames, some to xenon-filled units, and probably some to advanced frame insulation materials.

Heat Mirror windows also resist wintertime condensation (important if you have moisture-producing amenities like a jungle in your home), reduce fabric fading (because they block most of the sun's ultraviolet radiation), and aid noise control because they also block unwanted sound. Without them, no matter how good the superinsulation, it would not have been possible to eliminate the building's heating system and thus avoid the entire capital cost of furnace, ducts, fans, pipes, pumps, wires, controls, and fuel-providing equipment. Using these modestly costlier windows was thus the key to making the whole building cheaper to construct (counting just the space-heating savings but not also the water-heating and electricity savings, which swung the total construction cost back to slightly more than normal, for the ten-month payback described on p. 11; see also p. 70).

Alpen, Inc. (Boulder, Colorado—see www.alpeninc.com), which assembled the windows and injected the insulating gas before baking the edge seals, could profitably sell the original complete window assemblies (R-5.3 center-of-glass) for a lower cost than good triple glazing, but with twice the insulating value. In the early 1990s in competitive Frostbelt markets, small retail quantities of krypton-filled R-8.1 (center-of-glass) units mass-produced with two separate Heat Mirror 88 films were selling for only 10–15 percent more than double glazing, yet had four times its insulating

value. During the 1990s, most of our building's original argon-filled, single-Heat-Mirror units were replaced with krypton-filled units having a double-sided film (Heat Mirror coated on each side of a single suspended polyester film), and in some units supplemented by a low-emissivity (heat-reflecting) coating inside the outer lite of glass.[3] However, the front and west-end stormdoors are still early krypton-filled units that combine such a "low-E" glass coating with two separate Heat Mirror 88 films—perhaps the first glazings to use this four-layered construction. Our current units' center-of-glass insulating values range from over R-7 (k-0.8) to nearly R-12 (~k-0.47). Some xenon-filled units being installed in 2007 may achieve ~R-14 (~k-0.41).

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InSol-8
WINDOW
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Since the temperature drop is mainly across the Heat Mirror film rather than across the inner pane of glass, these special windows remain essentially free of condensation with outdoor temperatures down to –40˚ if not lower. (Double glazing commonly mists up at about +30˚F or –1˚C, triple glazing at +10˚F or –12˚C, and non-argon Heat Mirror at –10˚F or –23˚C—by which point ordinary double glazing will generally be coated with ice.)
Generally, the condensation occurs only at the edges—caused by frame conduction—and will be further reduced by our new advanced-frame units. Moreover, in conditions that often occur in the winter, when light bounces up off the snow, an R-5+ window can capture more solar heat than it loses even if it faces due north! This is true of R-7 (k-0.8) or better windows in any U.S. climate south of the Arctic Circle. Since R-8.1-center-of-glass ratings are widely available, windows facing in any direction, in any such climate, can now have negative R-values: they can capture enough net passive heat gain to cancel out their own losses plus additional heat losses from other components of the building shell. Our building simply uses passive gain from the windows (and from internal heat sources such as people and equipment) to balance, on average, about 99 percent of the total heat loss from the entire structure.

Later in the tour, when you enter the building, you will find cross-section demonstration samples of some of our windows sitting on a shelf in the entryway.

3

[Construction & Walls]

The relatively smooth outside surfaces minimize wind turbulence, reducing both noise and heat loss.

The walls are 16 inches (40 centimeters) thick, and consist of two 6-inch (10-centimeter) courses of masonry—a 7,000+-pounds-per-square-inch (≥48-megapascal) mortar mix—sandwiching 4 inches (10 centimeters) of Freon-filled polyurethane foam.[4] The steel-reinforced inner and outer walls were simultaneously built up 20 vertical inches (51 cm) at a time, and faced with more than 150 tons of thin Dakota sandstone rocks from a nearby hillside within wooden "slipforms." We then removed the forms after a few hours hardening, "pointed" around the rocks with narrow steel trowels to clean off the excess concrete, and washed the rocks. (Unfortunately, we didn't know enough to wash them with acid to remove the invisible lime scum that killed the lichens.) Slipforming, a technique used in some Frank Lloyd Wright houses, allows a crew of 10–18 unskilled people like ourselves to produce satisfactory finish walls inside and out, in three successive sections—from the east end to the greenhouse, greenhouse to front foyer, and front foyer to west end. The interior foyer wall and the parapets atop the outside walls, however, were laid up by a mason. In 2007, additional smooth mortar was applied over some original mortar to help protect it from ice adhesion and water damage.

The 4-inch (10-centimeter) sheet of double-foil-faced, Freon-filled polyurethane foam in the middle of all the walls was kerfed with V-notches to make it bend, and the kerfs were then sealed with expanding

polyurethane foam and foil tape. Tempered by daytime heat stored in the outer masonry, the R-332 (k-0.17) foam effectively insulates to ~R-40 (k-0.14), equivalent to more than a foot or ~32 centimeters of glass fiber). As you'll see, that's the minimum effective level of insulation in the above-ground building shell, even including the windows. The thermal mass of the inner masonry wall, trapped inside the foam, provides much of the radiant comfort that's so pleasant in the winter, and a pulse of radiant heat, slowly permeating through the walls' sandwich structure, enters the rooms around 4 a.m. when it's most needed.

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The wall's curves have 5-foot (1.5-meter) radii. We could have built straight walls, but the curves are stronger and look nicer. Curved walls also provide better acoustics (though the rough surfaces and subtle asymmetries throughout the design prevent echoes), and made the wall rigid against twisting while it was being slipformed. (We didn't realize at the time that this is the principle of Thomas Jefferson's serpentine brick walls, whose recurving kept them from collapsing in either direction, despite having just a single course (wythe) of bricks—a feat that had previously required a double wythe.)

The recurving walls make it possible from several places to see the inside and outside of the same wall simultaneously, giving it greater visual solidity. At the same time, the relatively smooth outside surfaces minimize wind turbulence, reducing both noise and heat loss; and the massing of the building's west end tends to produce a wind-eddy that keeps the front walkway clear of snow in northwesterly blizzards.

4

[West Garden]

A superinsulated hot tub heated by a solar panel backed up by a submersible, wood-fired aluminum "Snorkel Stove®."

Hot Tub: Outside, south of the bedrooms, is a terraced rock-garden and a patio with a superinsulated hot tub heated by a solar panel backed up by a submersible, wood-fired aluminum "Snorkel Stove®." The heating energy was originally downpumped passively via the obvious heat-pipe attached to the wall above the hot tub. The downpumping—the opposite of most passive (convectively circulating) solar water-heating systems—was provided by a clever "geyser pump" design pioneered by Eldon Haines and Bob Block under the tradenames "Copper Cricket" and "Bronze Lizard." Their firm, through no fault of theirs or their products, is out of business, but they have put the design in the public domain. This particular unit, a Bronze Lizard variant, operated passively for many years until it was relocated. Improper re-brazing of pipe joints led to persistent vacuum leaks that were inconvenient to repair, so the downpumping is now done by a small PV-powered active pump.

Dog Door: From outside the bedroom door, you can also see the newer (outer) and older (inner) versions of a nearly draftproof dog door: they're used in Florida to keep hot, humid air out of the house, but these keep that air in and the cold air out: the door doesn't know which side is which. Without this low-infiltration dog door, our late English bull terrier, Nanuq the Beastoid (1982–97), would have lost us more heating energy than she provided (50 watts nominal, adjustable to about 100 watts by throwing her ball).

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West Bedroom: The bedroom wing, being far from the greenhouse (the "furnace" of the building), is heated by its south- and southeast-facing windows (plus surplus heat from the people, lights, and minor heat leakage from a superinsulated solar-hot-water storage tank), so it stays a few Fahrenheit degrees cooler than the main wing, yielding more comfortable sleeping conditions.

Yard Lights: As you continue up the stairs, you'll see one of four photovoltaic-powered yard lights (with a white plastic housing)—others, in front of the main gate, are activated by an infrared sensor interlocked with a photocell so they turn on only when people approach at night. Such PV yard lights cost less than running an underground wire to power a regular fixture.

5

[Tracking Photovoltaic Panels]

The tracking mechanisms are automatically shut off at night, because they are so sensitive they would otherwise track the moon.

You'll also pass two large photovoltaic ("PV") panels, generating a rated total of 921 peak watts, and connected to small additional panels on the west nontracking array (see below) that produce an additional 488 peak watts, for a total of 1.408 rated peak kilowatts. PVs turn sunlight into electricity for use inside the building. The receptors on pedestals use electric motors to keep themselves turned toward the sun, and collect 30–40 percent more energy than they would if they were stationary. The tracking mechanisms are automatically shut off at night, because they are so sensitive they would otherwise track the moon.

6

[The Duplex]

The recent renovations now allow warm natural light to penetrate 100 percent of the interior space.

Located less than fifty feet north of RMI's headquarters, you'll see a small building we call the Duplex. It houses RMI employees. Please respect their privacy.

Supported by a grant from Aspen's Community Office for Resource Efficiency (CORE; www.aspencore.org) and our local utility Holy Cross Energy, RMI's facilities team performed an energy efficiency retrofit on the "Duplex." Prior to the renovation the building was hardly a model of energy efficiency. The victim of typical 1970s-era construction practices, the building had electric resistance heat, minimal natural lighting, and inefficient appliances. In an effort to get it to perform like its younger neighbor, the Duplex was put through a low-cost energy retrofit. In typical RMI fashion, the crew's first priority was to decrease the energy lost as a result of heated air leaking out decrepit exterior doors. They were replaced with insulated doors boasting double-paned windows that let in natural light; also added were storm doors with screens. More impressive is the tremendous amount of daylight brought into the building via Solatubes—cylinders with Fresnel lenses on their top ends and extremely reflective insides that penetrate the roof and bounce daylight deep inside a structure (while, of course, using no electricity).

Prior to the remodel, the Duplex was fairly dark and dingy—not a stimulating place to live or work. However, the recent renovations now allow warm, natural light to penetrate 100 percent of the interior space.

Additionally, the antiquated electric resistance heating system was replaced with a highly efficient propane boiler system, hydronic baseboard radiators, and programmable thermostats. Aside from reducing the electricity bills, these devices will increase the overall efficiency of the heating system—programmable thermostats reduce demand by changing the setpoint (desired temperature) during low demand periods.

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Finally, the Duplex's inefficient washer, dryer, and two dishwashers were all replaced with water- and energy-efficient Energy Star appliances that were, on average, twice as efficient. Toilets and showerheads were also retrofitted—the toilets with 1.6-gallons-per-flush models and the showerheads with high-performance, low-flow models.

While we don't expect the Duplex to attract the same following as our Headquarters building, the recent upgrades are a good example of what can be done in almost any home. Our intent was to decrease the utility bills of our building; in the process, we also created a space that is healthier and more comfortable to live and work in.

7

[The Roof]

The adjacent solar panels are one part of a system that heats water for domestic use.

Please do not proceed onto the flat roof as there are no railings, and the owners cannot accept responsibility for your personal safety. The roof is unsafe for unsupervised children, as the low parapet has no protective railing to keep them from falling off the edge.

Solar Hot Water System: Sticking out of the roof at the far western end of the bedroom wing is the west office clerestory, a cylindrical shaft that lets light into my personal office below. The other clerestory, to the northeast and next to a row of four active solar thermal panels, is the clothes-dryer pod clerestory. Both clerestories contain a destratifying fan and a small heat exchanger that provides a flow of prewarmed, dry air. Also in this area is the downpumping passive heater for the hot tub.

The adjacent solar panels are one part of a system that heats water for domestic use. The water is warmed to about room temperature as it passes through pipes in the concrete arch in the greenhouse area below. These roof-mounted panels then boost the water temperature. The warm water is stored in a ~1,500-gallon (~5,678-liter) tank under a closet in the residential part of the building. When someone turns on a faucet, the water is drawn off the top of the tank, where it is normally about 140ºF (60ºC), and heated just to its final temperature, if needed, by an on-demand propane water heater in the RMI workshop (which you'll see when you go inside).

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Roof's Solar Panels: The lower, main section of roof has two rows of adjustable-tilt photovoltaics (each with several panels apiece). These PVs don't track the sun, but they can be raised and lowered seasonally to catch the sun's rays at better angles. They generate 2.4 peak kilowatts of electricity, roughly a third of the building's annual electricity needs. The Omnion inverter sells any surplus electricity back to our supplier, Holy Cross Energy, through a second utility meter at the power pole, at its avoided wholesale power cost. Advances in PV technology enable today's panels to be much less conspicuous than these; indeed, many modern PVs are designed for flush installation as wall and roofing material. The roof is penetrated by various water drains and plumbing vents (with spring-loaded valves to confine sewer gas: had County building codes permitted this at the time, as they now reportedly do, we would have kept them inside the house, saving heat loss and cost). A number of ducts carry air in and out of the six air-to-air heat exchangers, each fitted with a flow-operated butterfly damper to exclude drafts. The sound you may hear at roof level and in the workshop is a blower depressurizing the gravel beneath the building's floor slab to prevent any buildup of radon gas. (Pre-construction tests said the soil didn't produce radon, but they were wrong.)

8

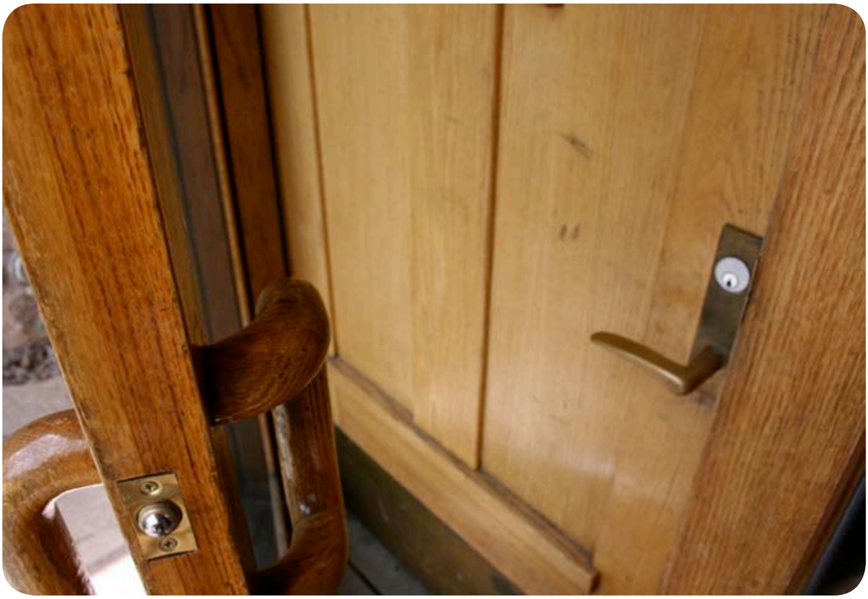
[Entryway]

> The entryway serves as an airlock, which is a key component of the insulation system.

The Entryway—where the walls and glass can be seen closely—is a good place to reexamine the insulation characteristics of the building. The entryway serves as an airlock, which is a key component of the insulation system.

Insulation: Approximate insulation levels in this building are: R-40 walls and R-80 roof (k-0.14 and k-0.05, respectively, roughly twice "good" U.S. levels); R-8–12 (k-0.47–0.70) windows (measured at the center of the glass without counting edge losses, improved from the R-5.3 (k-1.05) originally installed, and two to three times as insulative as triple glazing); R-9 to-11+ (≤k-51–0.63) glass stormdoors; and an R-25+ (≤k-0.23) perimeter skirt around the foundations, 4–8 feet (1.2–2.4 meters) deep. The building is recaulked every few years to keep uncontrolled air leakage below ~0.1 natural air change per hour (on a calm day), but is well ventilated through operable windows in every room (except in the workshop and bathrooms) and six air-to-air heat exchangers. If all the heat exchangers are turned on, they have the capacity to replace all the air in the building several times per hour. However, they're sited in the places where odors and humidity tend to originate, notably the kitchen stovehood, bathrooms, drying-pod, and greenhouse, so ventilation is concentrated mainly in the places where it's most needed and effective.

Thanks to careful airsealing details, periodic blower-door tests, most recently in early 2007, have shown that the building is one of the most airtight ever measured, with a total uncontrolled leakage area smaller than



a human hand. That also helps to retain ~40–55 percent relative humidity in the winter. This helps reduce respiratory infections: the winter air here is so dry, even inside many ordinary houses, that cracking lips and noses can be a problem. The building's only control is a humidistat set to maintain this humidity via the main heat exchanger behind the greenhouse.

Airlock and Door: The airlock entryway confines cold air, and is sun-warmed via the krypton-filled Heat Mirror windows (especially convenient to examine in this location, where you can see the film-supporting groove in the steel frame between the glass). In the east wall is an unfilled slot, at the top of which you can see the 4-inch (10-centimeter) Freon-filled polyurethane foam that is sandwiched in the middle of all the walls.

The front door, donated by Denver cabinetmaker Michael Schuster, has a special air-sealing feature (as do the other outside doors). Fitted into a slot along its bottom edge is a rubber sweep that drops down and seals against

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the threshold when the door is closed. Opening the door instantly lifts the sweep so it doesn't drag and wear out. (Usually we activate this feature only in the outer stormdoor.) There is also a "thermal break" (the black plastic strip) to reduce heat loss by conduction through the metal threshold. The triple-weatherstripped double-Heat-Mirror krypton stormdoor insulates more than three times as well as triple glazing, or eight times as well as the wooden door inside. Even newer and better glass stormdoors, about four times as insulating as triple glazing, cover the building's other three exterior doors.

Orangutans: Many of our ~36 taxidermically challenged orangutans (made of Orlon and similar synthetics) meditate in the front hall. They appreciate being left alone. We suspect that after midnight they might be coming alive and raiding the bananas, since our interns disclaim our knowledge of banana depredations.

Private Residence: Although the area to the left (west) of the entryway is my private residence and is closed to the public, I'll briefly describe some of the advanced devices found herein.

There are two small bedrooms; one has been converted to an office. Both bedrooms get solar heat only from windows, although the underfloor soil in the east bedroom receives a small, but in such a superinsulated building still significant, amount of heat escaping through the 4-inch (10-centimeter) foam insulation surrounding the quasi-seasonal-storage hot-water tank. The west bedroom includes a cylindrical office pod at the west end of the building (if you went up onto the roof you probably saw its clerestory). Nearby begins a mechanical chase, described later in the text. We didn't implement the original concept of a "starpod"—an observatory above the bedroom closet, so one could climb up a ladder and sleep beneath superwindows, under the stars in all respects but weather.

The shared bathroom contains another air-to-air heat exchanger and a 4-liter (1.1-gallon) Ifö Swedish toilet. This model, like those from a dozen

(continued)

other manufacturers at wholesale costs as low as $89, can directly replace standard U.S. toilets, and generally work better. (The 3-liter model in the lower bathroom, however, can be used only in new installations because it has a non-standard rough-in dimension.)

The upper bathroom contains two "Min-Use" showers, developed for submarines after a Buckminister Fuller concept. They propel the water with a blast of compressed air, and thus provide a very wet and tingly shower while each using only half a gallon (1.9 liters) per minute—4–5 times less than a low-flow showerhead and eight to fifteen times less than a standard one. A 432-watt air blower (above the drop ceiling) comes on automatically when the water is turned on, and saves water-heating energy equivalent to about 20,000 watts compared to a low-flow showerhead (up to 75,000 watts with a high-flow head). Thus the whole shower unit, which retailed for about $260 with mixer valve, could pay itself off within a year against electric water-heating costs, or save sizing and hence capital cost on solar water-heating collectors. The showers do require a fairly tight curtain or door to confine the warm air, which the blower recirculates. They worked well for several years, but then went out of service awaiting electrical repairs, and haven't yet reentered the market; they are mentioned here only to illustrate technical potential and an apparently sound concept.

9

[Workshop & Mechanicals Room]

Another small (30-watt) air-to-air heat exchanger exhausts the warm, humid air and brings in pre-warmed, dry air from outside.

Behind the entry foyer is the "workshop"—the only room in the house (other than the bathrooms) not receiving copious daylight. It is partly daylit, though, via the glass patio door that opens into the passive solar clothes-drying closet in the northeast corner. This is simply a shaft rising to a clerestory glazed with an R-8 krypton-filled Heat Mirror window. Light enters this efficient window and strikes the dark-painted walls, heating the air at the top of the shaft. That hot air is blown downwards and around the clothes, which are hung both on the dowel racks and on the "ladder clothesline" raised by a boat winch. (The plastic hood of a destratifying fan suffered a "solar meltdown" the first summer and had to be rebuilt from a stainless-steel mixing bowl; in the west pod, where a similar clerestory uses ~R-11 glass, a similar meltdown occurred one February.) Another small (30-watt) air-to-air heat exchanger exhausts the warm, humid air and brings in pre-warmed, dry air from outside. (That outside air also picks up a little heat by passing first through a rooftop shed whose south side bears the solar water-heating collectors, whose heat losses thus end up preheating the clothes-dryer air.) The three fans use electricity at ~1 percent the rate of an electric dryer but for up to about ten times as long, for a net saving of about 90 percent. We plan shortly to "borrow" daylight from the clerestory and convey it across the south side of the workshop into the back hallway north of the kitchen.

(continued)

The Passive Dryer, unlike the other energy-saving devices, is a change in lifestyle: we can't simply toss the clothes in a dryer and expect them to be done in a half-hour. Drying typically takes from a few hours to much of the day, and could take up to two days in bad weather or with extra-heavy clothes. Drip-dry clothes also don't come out as wrinkle-free, because they're not tumbled. On the other hand, the lack of tumbling makes the clothes last twice as long; there's no static cling, lint, noise, or fire hazard; and there's no risk of overdrying, so cottons and woolens can be left indefinitely without fear of shrinkage.

The Clothes Washer is one of the horizontal- or almost-horizontal-axis types introduced in the 1990s. The drum rotates the clothes through a small amount of water rather than agitating them within a drum-full of water. This means about a two-thirds saving in water, water heating, and soap (which also works more effectively at the higher concentration), and reduces agitator-induced wear on the clothes. Even more sophisticated and efficient models are now available.

Solar Power Systems: The building has two different solar power systems. Most circuits in or north of the greenhouse, and all the office areas at the east end of the building, are powered by a grid-interactive solar system whose two seasonally tilt-adjustable photovoltaic racks and inverter are on the roof. However, for the rooms from the greenhouse westwards—the common and private areas of the building, more or less representative of normal household usage—all the required electricity normally comes from a stand-alone photovoltaic system. The inverter it uses to turn high-voltage direct current from the photovoltaics into line-voltage alternating current is high on the north wall near the west end of the workshop. At the west end of the workshop, in two sections, is an array of Chinese nickel-iron batteries[5] that provide many days' storage. We have never been without household electricity.

Demand Heater: In the cupboard at the west end of the workshop (above the batteries) is a French Aquastar (now Bosch) propane "demand heater" used for domestic hot water before the active solar system was installed in 1985. It remains in place for backup in case the solar system ever needs repair, and provides an average of ~1 percent of the annual water-heating energy during periods of up to a few weeks in the cloudiest winters. At such times, the heater turns on automatically when the hot water tap is engaged, so it runs only when needed, and modulates its flame to add just the few degrees needed to reach the desired output temperature. It then turns itself off automatically. Since there is no tank, there is no standby loss, and such a water heater is about 78 percent efficient (higher with newer models). The original model's pilot light was recently displaced by a newer model's electronic igniter. The latest igniters on larger models are powered not by batteries but by an ingenious little microturbine spun by the incoming water.

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Active Solar Water Heating System: The circulating pump, expansion tanks, and controls for the active solar water heating system are also in the same cupboard. A water/glycol mix heated by four conventional Novan active solar panels on the roof circulates to the bottom of a 1,500-gallon (5,678-liter) superinsulated tank under the bedroom closet. There the heat is exchanged into stored water, and the hottest water rises to the top of the tank, normally at 140ºF (60ºC) or more—we've measured >180˚F (>68˚C) in late summer. Water preheated in the greenhouse arch, as described on p. 58, circulates through a copper coil at the top of this tank and is then used. If needed, a diverter valve in the workshop sends the water to the propane demand heater for a little extra heating, but no more than needed, thanks to a modulating valve that modulates down to zero. The very high solar fraction is due to an unusual "quasi-seasonal-storage" mode of operation: the stratified tank maximizes the solar panels' winter efficiency because they work into the coldest water at the bottom of the tank, while the hottest water, floating at the top, heats the water we'll use. Noting that such systems had worked with 0.7 cubic meters of storage per square meter of collector in Denmark and 0.3 in New Mexico, we tried 0.42 and it worked.

The high-frequency ballasts and lamps in the workshop are turned on automatically by an "occupancy sensor" when you enter the room, and automatically turn themselves off minutes after you leave. We try various kinds of lamps to demonstrate their ability to render color faithfully.

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10

[Building Energy Monitoring System]

The PVs originally produced from one-fifth to more than one-third of the total electricity used in the building.

In the hallway near the entryway and just to the right of the workshop door, we are replacing old electricity monitoring meters with a new flat-panel display that will make it easy to see all of the building's energy flows. I apologize if this system isn't yet ready when you visit.

The PVs originally produced from one-fifth to more than one-third of the total electricity used in the building, depending on the season and weather. Expansions in the 1990s brought the total capacity to 3.8 kilowatts—about five or six times more than is needed to meet the average annual needs of the household since average solar output in a good climate is about one-fourth of peak rating, and the household's lights and appliances use just over 100 watts. However, most of the building's electricity is used for office equipment, not household needs: I estimate about a tenth for household lights and appliances, nearly the same for the waterfall and hot-tub circulator pumps (when the hot tub occasionally runs), twice that for controlled ventilation, and at least three-fifths for computers, printers, photocopiers, etc. By 2002, solar electricity was providing about two-thirds of the entire building's annual electricity, and that summer, when solar output was slightly exceeding total usage, the utility called to ask if I was still living here—"Is everything okay? We haven't shown a bill for you for a couple of months!"


SOLAR METER KEY

11 [Living/Dining Room & Kitchen]

Cooking fumes are vented and stove heat is recovered by a special air-to-air heat exchanger built into the hood.

West of the greenhouse is a versatile open area suitable for meetings. The dining table, of Colorado red spruce, is a gift from the late Stuart Mace and his son Kent Mace. The Mace family's Ashcroft gallery was recently moved to nearby Basalt. The kitchen island is of granite from Mount Airy, North Carolina. The cabinetwork is by our neighbor, the late skydiving champion Joel Zane, who also made the chapel doors at nearby St. Benedict's Monastery.

Lighting: The overhead lamps in various locations illustrate the immense variety of compact fluorescent lamps. Each uses 20–25 percent as much electricity as an equivalent incandescent bulb, lasts ten to thirteen times as long (and thus pays for itself just by avoided maintenance costs, making its electric savings better than free if maintenance time is valued), and over its lifetime will keep up to a ton of carbon dioxide out of the air. Some lamps are "integral"—screw-in adapter base, ballast, and folded-up lamp all in one piece—and some are "modular" so that only a cheap plug-in lamp need be replaced. Many modulars use reflectors or other optical accessories. Some compact fluorescents use miniaturized high-frequency ballasts to boost efficiency by one-third and eliminate flicker and hum. Special phosphors tuned to your red, green, and blue retinal cones render color quite accurately and make the light cool or warm as desired. Universal use of such lamps would save the United States about fifty giant

power plants that would cost at least $75 billion to build. Every 5–10 years, advances in lighting technology make it worth replacing much of the lighting equipment in the building. The photocell in the black housing on the ceiling to the left of the stovehood (above the sink) measures daylight, enabling a microcomputer in the wall box to the left of the refrigerator to dim the fluorescent lamps accordingly. Such daylight dimming usually increases high-frequency ballasts' electric savings in offices from about 40

(continued)

percent to 70–90 percent.[6] A major lighting and daylighting retrofit is currently being designed for installation in summer 2007. This description will be updated then.

Sinks and Drainage: Under the large sinks is a valve enabling us to send particularly greasy loads of dishwater to the blackwater (sewage) system—a septic tank and leachfield, both required by code in 1982–3 when we built. The building plumbs blackwater and graywater separately so that if Colorado eventually permits graywater reuse (as California does), the graywater can be sand-filtered and then fed by gravity to irrigate the pasture below, extending its grazing season via warmth and trace nutrients. The kitchen sinks, like those in the bathroom, use faucet aerators, which get things wetter using less water and can be temporarily turned off with a fingertip valve without losing the temperature setting. The small sink, however, has at times been equipped instead with a non-aerating "laminar-flow device" whose smooth flow enables a low volume of water to wet hands or vegetables thoroughly without bouncing off, yet still permits full flow for filling pots quickly.

Stove: The commercial stove currently runs on bottled propane, but could later be converted to biogas or even to surplus hydrogen generated offpeak by solar power. Cooking fumes are vented and stove heat is recovered by a special air-to-air heat exchanger built into the hood. It has an improvised condensate drain for cold weather.

Cooking Vessels: On or near the stove are two cooking vessels each of which saves ~30–40-plus percent of the fuel required for cooking in conventional devices. The English "Simplex" copper kettle uses a heavy coil and rim to entangle hot gas so that most of its heat goes into the water rather than escaping around the sides to heat the kitchen. And the Swiss Rikon double-walled and -lidded pots, made of stainless steel with brass fittings, save cooking energy that would otherwise escape from the pot itself, then hold it in for hours once taken off the stove and set on an insulating base. These efficient pots also improve flavor and nutrition because one needn't push so much heat through the food in order to cook it.

Refrigerator: The refrigerator (the left-hand set of oak-veneered doors) is a 16-cubic-foot (453-liter) hybrid model that uses about 8 percent the usual amount of electricity. The hybrid looks and works like a conventional refrigerator but is so well insulated that it uses less than 100 kilowatt-hours per year instead of the 1,200-odd norm for new models in the early 1980s (2001 federal standards are three-fifths lower), saving nearly $100 worth of electricity each year. Its universal use could displace a couple dozen U.S. power stations. Each year, one such refrigerator saves enough electricity to avoid burning its entire interior volume full of coal.

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This refrigerator not only uses thick insulation and puts its heat-producing components above rather than below the food compartment (as you can see from the pantry). It also gets half its annual cooling passively from a cooling fin on the exterior wall of the entryway. Whenever the outside air is cold enough, the refrigerant (connected to the cooling circuit by a small, well-insulated copper tube that goes through the outside wall) condenses in the fin, runs back down the pipe by gravity, and keeps the compressor off.

Freezer: The freezer, similarly engineered but without the passive cooling fin and heat pipe, uses roughly 260 kilowatt-hours per year—~15 percent of the usual amount. Both models are pilot-produced by hand, and therefore cost $1,900 each, but in mass production they should probably cost no more than standard models. By 2002, additional improvements in vacuum insulation and linear Stirling compressors made it possible and worthwhile to save two-thirds of what these units use, but we could not get them quite in time for our order; nowadays such technologies are mass-produced in Japan.

Dishwasher: The dishwasher, an Asko D3530 from Sweden, was the most efficient on the U.S. market at the end of 2003. It has a 1.2-kilowatt variable-intensity electric booster heater (seldom used because our solar-heated water is normally already hot enough), rugged all-electropolished-stainless-steel construction, and silent operation. The U.S. Department of Energy test procedure gives it a top energy rating—222 kilowatt-hours per year for both operating and water-heating electricity, assuming 322 standard cycles a year "washing" clean dishes (the test procedure tests only energy use, not cleaning power). This is 159 percent better than the 2001 Federal minimum standard for standard-size models, which is an Energy Factor (cycles per kilowatt-hour) of 0.46. Energy Star® models must have an Energy Factor of at least 0.58. This model's EF is 1.19. It features automatic sensors that prompt the machine to wash the dishes only until they're clean, optimizing water flow and temperature (DOE plans to change the test procedure to count such "soil sensors"); settings so we can wash only the upper or lower basket, or dirtier dishes below and cleaner ones above; and varying fan- (not heater-) driven dry cycles with an optional cool-down cycle afterwards. Since we run the unit seldom and when full, and it uses ~99 percent-solar-heated water (which accounts for about 80 percent of the energy usage by a typical dishwasher under the official test procedure), the Asko D3530 will use only a tiny fraction as much electricity and water as the test procedure indicates, raising the building's already small household electricity use by probably nearer 1–2 percent than the one-fifth implied by the test procedure's 222 kilowatt-hours per year.

Building Structure: Once inside the building's main space, you can see some of the basic structural components—like the slab, beams, and decking. The slab is integrally red-dyed 4-inch (10-cm) concrete, poured over mesh and gravel on grade and then steel-trowelled. It contains coils of polybutylene pipe for solar radiant heating if needed, stubbed out into the plumbing chase, but they have never been connected. The masonry inside the insulation, plus the slab and a couple of meters of earth below it, total about a million pounds (~450 metric tons) of heat-storing "thermal mass"—so much that in a total solar eclipse in January, the original simulations predict a loss of ~0.9 F° (~0.5 C°) per day. Because radiant heat distribution from the slab coils is more efficient and better controllable than woodstoves can provide, we are currently designing an expansion of the active-solar panel array and a second stratified water storage tank to heat those coils so we can eliminate the woodstoves for the last ~1 percent of the building's heating. This will free up floorspace, increase convenience, and let us convert the woodstoves' flues into light tubes for additional daylighting.

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Ceiling: The ceiling is 3×6-inch (8×15-centimeter) tongue-and-groove cedar/fir decking, supported by eighty-eight 6×12-inch (15×30-centimeter) oak purlins. These, in turn, rest on two master beams (and several smaller sections) of 12×16-inch (30×40-centimeter) solid oak. This extraordinary oak, weighing some 50 tons, was donated by the folks at the Meadowcreek Project in Fox, Arkansas, who felled and milled the ~200-year-old four-foot-diameter (~1.2-meter) trunks. The house was designed around the beams. Much of the felling, milling, and kilning was done by Professor

David Orr of Oberlin College (now an RMI Trustee) and his brother Will, who with their Meadowcreek colleagues built the wood-steam-powered mill and the solar kiln themselves.

Beams and Decking: To save wood, the purlins were spaced harmonically. Those near the south side of the house, where they span a shorter distance, are farther apart than those near the north side. The total design load of the roof is 250 pounds per square foot (1.2 metric tons per square meter), sufficient for ~6–8 inches (15–19 centimeters) of earth, grass, and wildflowers, or any of the modern variants of a "green roof." We hope to install such a system soon, and expect the building will then have a slightly larger green area than before we broke ground, since the overlap area at the back of the greenhouse plus the interior "jungle" exceeds the non-green land area covered by the parapets.

The beams are supported by posts made of the trunks of beetle-killed Colorado red spruce, chosen because the bark won't fall off. Contrary to customary but structurally incorrect post-and-beam construction practice, the stair-stepped, steel-dowelled beam joints are at the "zero-moment" points where the beam doesn't bend. Each purlin is also steel-doweled into the beam below. Solar-kilned oak planks left over from the wood/steam-powered milling of the beams went into the stairs, trim, and cabinets, providing nearly all the lumber for the finish carpentry.

Above the decking is a three-eighths-of-an-inch (1-centimeter) base layer of Freon-filled polyurethane foam; a polyethylene vapor barrier sealed at its edges to the wall insulation; and, depending on location, another 4–8 inches (10–20 centimeters) of polyurethane. The 2-foot (0.6-meter) squares of insulation are arranged like a topographic map, with thickness increasing in 0.5-inch (13-millimeter) increments, so that the synthetic-rubber (EPDM) membrane on top of all the insulation slopes properly towards the roof

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drains. Above that membrane, in turn, is a protective synthetic "stonemat" of spunbonded polyolefin. Originally this was topped with ~4–5 inches (~10–13 centimeters) of gravel. However, in the 1990s, tens of thousands of pairs of visitor feet began to pull the north edge of the roof membrane adrift from its counterflashed anchor in the north parapet, causing incipient small leaks. To arrest this problem—and block any potential paths for warm air to escape between the panels of polyurethane insulation—I had the roof covered with an additional layer of modern sprayed polyurethane, which by then had proven durable on local commercial building roofs. This sealed the roof-to-parapets joints and increased the total insulating value of the roof from ~R-60 (k-0.08) to ~R-80 (k-0.05).

12

[The Greenhouse]

The greenhouse is the furnace of the building and provides excellent semitropical growing conditions year-round.

This 900-square-foot (84-square-meter) space is the "furnace" of the building and its spiritual heart. It collects energy in five ways: photosynthesis, heat, light, hot air, and hot water. The overhanging side arches block the high-angle summer sun from getting far into the wings—lest overheating result—while allowing the low winter sun to penetrate all the way back to the north wall. The recurving walls also permit east-, southeast-, and southwest-facing windows to inject heat and light all the way back to the north wall. Thus heat and light are automatically conveyed to the area north of the "jungle" in the greenhouse, not concentrated only near the south façade. This "zone coupling" is the key to the interior's brightness and, along with superinsulation, to its fairly uniform warmth. However, that warmth is slightly deficient in the loft, which in hindsight should have had thicker insulation on its above-grade north wall (which is effectively a giant cooling fin) and an additional southeast-facing window for a morning heat boost in winter.

The living space and research center get extensive spillover heat from the central greenhouse as well. Sunlight entering its vertical and overhead glazings transfers both radiant heat and warm air to the adjacent "wings" of the building and, when the heat is not needed, out the vents high in the back of the greenhouse arch. Extra heat is also stored in the arch, the greenhouse earth, the inner walls, the floor slab, and the soil beneath. Heat stored farther from the air transfers to and from it more slowly, so the thermal behavior of the building is slow and complex, occurring on timescales ranging from hours to months.

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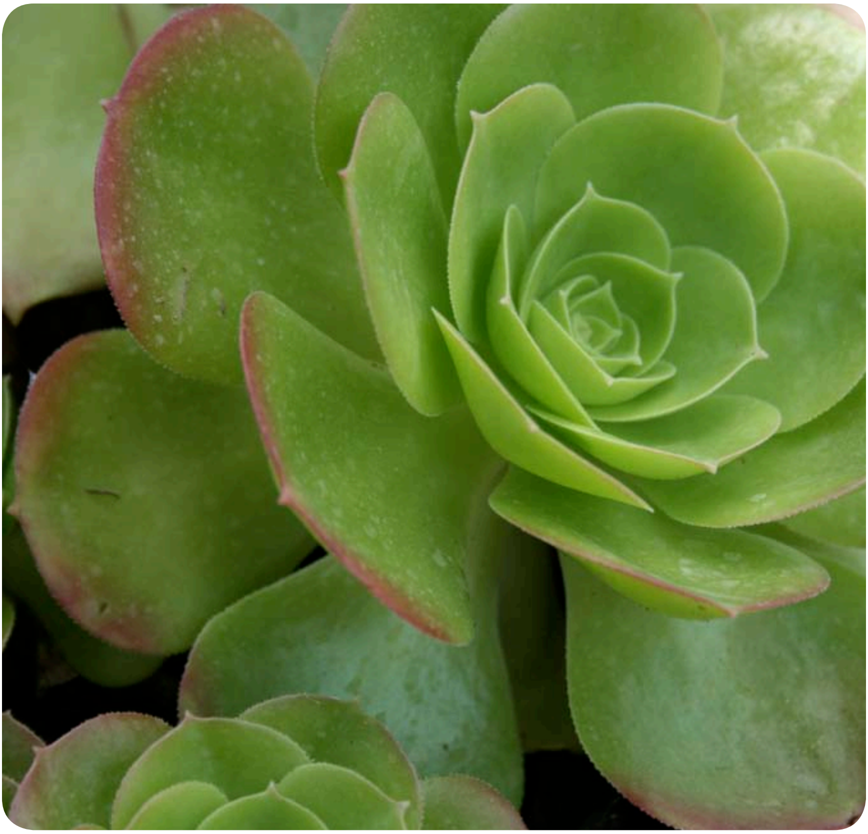

The greenhouse provides excellent semitropical growing conditions year-round. Its terraces support a wide variety of trees and smaller plants, protected from pests by a half-dozen kinds of biological predators. The original banana tree (botanists note it's a plant but not a true tree) was just south of the upper fishpond. It was supposed to grow from one to two meters high and never fruit, but someone forgot to tell it, and as soon as it tasted the twelve-year-old horse manure it was planted in, it went bananas. In the first year and a half it grew to seven meters and gave five bunches of fruit. (During much of the year it needed trimming to stop its great leaves from growing into the fans overnight. At one point it had to be cut down, dug up, and walled off to keep it from growing into the adjacent pond and causing a flood.) Oddly, crops don't seem correlated with day-length; the old tree's last banana crop emerged on the Winter Solstice in 2001. On a New Year's Day in the late 1980s, with blizzards outside, our Hawai'ian tree fern put forth a new shoot, which then sprouted seedlings in the front bed in a couple of days.

After twenty-seven crops over more than a dozen years, the original banana tree wore out, at twice its design life, and was replaced with others in the front of the greenhouse, which yielded a first practice crop (number twenty-eight) in summer 2003 but then failed to thrive, due to improper varietal choice or depleted soil. Meanwhile, several other older specimens were lost, and it became clear that the soil needed replacement and more consistent care. Therefore, the "jungle" is being completely renewed in 2006–07, as described below.

Fans in the greenhouse, mostly photovoltaic-powered, help to move air over the leaves, especially in winter, thus aiding plant growth and discouraging insects. We are currently changing the old inefficient fans to new superefficient ones with highly aerodynamic blades. Over the years various reptiles have inhabited the greenhouse, notably two roughly meter-long green iguanas—Iggy and Juana, now deceased. Their regular Advanced Lizarding lessons gave staff members insights into the functionings of nature that textbooks never could.[7] Occupants have also included African pygmy hedgehogs to control armored insects (chiefly sowbugs) and a half-dozen kinds of predatory insects. Possible future additions may include a chameleon or gecko.

The cantilevered greenhouse arch is essentially a bridge: the 16×24-inch (41×61-centimeter) beam that supports it contains some 16 tons of concrete and a ton and a quarter of reinforcing steel in thirteen groups. (That beam, supervised by a bridge engineer, required a month and a half of scaffold- and form-building, then an hour and a half of pouring.) The

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arch's dozen functions include controlling and storing heat; esthetics and acoustics; diffusing light; holding up the roof beams and the glazings; distributing varying cantilevered loads; housing the cooling vents and atrium lights; and actively collecting solar heat in two ways:

> 1. The hottest, most humid air is drawn down through the two blue ducts into a Carrier/Venmar condensing-core polypropylene crossflow air-to-air heat ex-changer (above the drop ceiling in the bathroom behind the greenhouse). This device can recover more than three-fourths of the outgoing heat to warm the cold outside air before it enters the building.[8] (I hope in due course to run the double-sized heat ex-changer at half-speed using variable-speed electronic drives, saving most of the fanpower and boosting efficiency to at least 92 percent.) The warmed incoming air is then routed to registers in the under-loft office, the adjacent north hall, and the front entry foyer (warming the sunless back-hall floorslabs with the buried but uninsulated ducts). In winter, the heat exchanger serves as a dehumidifier—a vital service because the building is virtually airtight and the plants and waterfall release a great deal of moisture. In summer, the heat exchanger cools the hot outside air with cool air from the shaded north side of the building. Formerly, the building used a rotary heat exchanger whose slowly turning drum contained thousands of metal tubes coated with a moisture-absorbing substance, but this design proved unsuitable for such a cold climate.
>
> 2. Cast into the face of the arch, below the vents, is a 100-meter-long, zigzagging polybutylene pipe. Heat stored in the mass of the arch during the day preheats water going to the active solar system, reducing the needed solar collector area by more than a third. In fact, most of the water-heating is done passively inside the masswall: water enters the house at 35–55ºF (~2–12ºC), but leaves the arch, depending on weather, at 68–105ºF (20–40ºC) regardless of the season.

In addition, the arch forms a white plaster "lightscoop," bouncing light into the sides of the building and helping make it ~95 percent daylit (less, perhaps ~80 percent when the jungle is luxuriant). The "multilateral" daylighting—light from many directions—isn't sophisticated, but it's effective enough so that one can read at the north wall of this earth-sheltered building during a winter snowstorm. The building's lighting energy requirement averages about 0.01–0.02 watts per square foot (~0.1–0.2 watts per square meter)—about 1 percent of the norm for offices. Indeed, the research center's nighttime ambient- and task-lighting power is only ~0.08 watts per square foot (0.8 watts per square meter), supplemented by low-wattage

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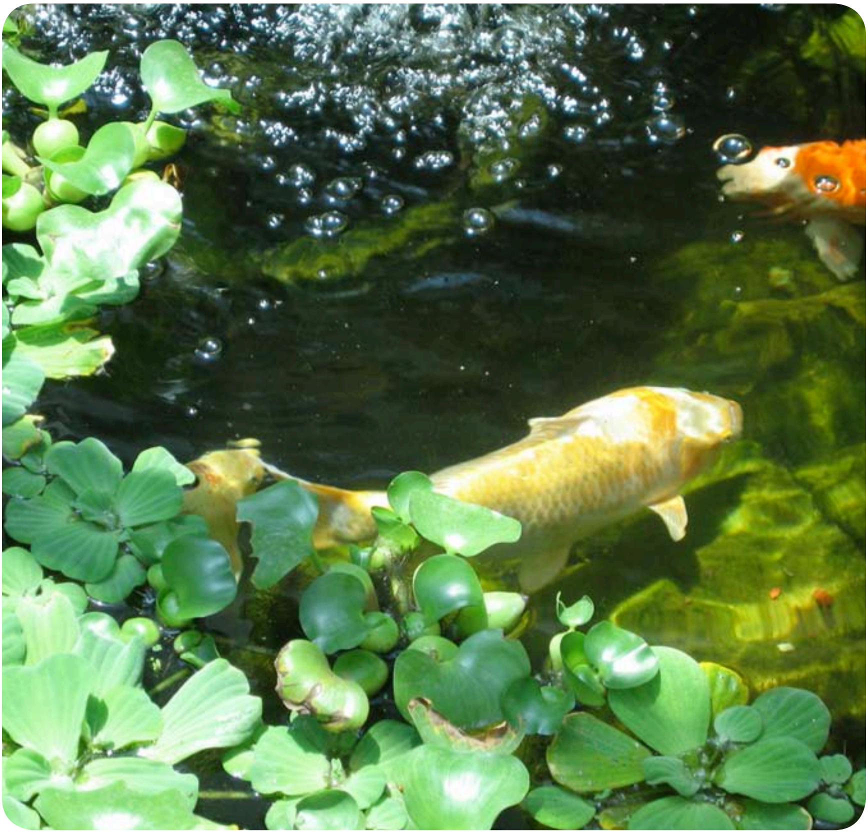

compact fluorescent task-lamps. A normal modern office would use ~1.5–2.0 watts per square foot (~0.15–0.2 watts per square meter). Additional major lighting and daylighting improvements are underway in 2007.

The three insulated arch vents, totaling 36 square feet (3.4 square meters), provide convective "stack" cooling when opened, provided some other aperture at a lower height is also open. On hot days, opening the operable south windows creates a chimney-like draft. (Originally the two westernmost banks of south-facing windows were designed to hinge outwards like a large clamshell hatch so that gardening supplies, or replacement soil if surface watering with the hard local water has salted up the soil, could

be wheelbarrowed in and out. This feature was later removed to simplify the control of air infiltration.) The greenhouse glazing's Arkenstone metal flashing system provides excellent mechanical integrity and watertightness. The tempered overhead glass is so strong that a 220-pound (100-kilogram) installer cheerfully bounced around on it with no damage whatsoever. Snow normally sticks to the 30º-sloped glass if it falls at night, but then avalanches off next morning, lubricated by a water film created when the infrared component of sunlight filtering through the snow bounces off the Heat Mirror and melts the snow touching the glass.

Behind the greenhouse are four cylindrical "pods." The westernmost one

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was equipped with multiple "lazy susan" revolving shelves for storage. (You might try to guess how this was done after the doorway had already been framed and trimmed out.) To its right, a waterfall recirculates and aerates water from the lower pond. Most aeration, however, is via an energy-efficient bubbler that doubles in functionality to accelerate bacterial filtration in the bottom of the pond. This feature uses the rising bubbles to pull water through perforated pipe that is buried under gravel along the pond's bottom. This creates a small convection current that pulls water through the bacteria-laden gravel, which breaks down noxious ammonia from the fish waste. The waterfall was designed mainly as an acoustic mask: otherwise, with no mechanical noise and a very soundproof building shell, the building would be so silent that even distant conversations might be distracting. The waterfall also prevents the ponds from stagnating, and ensures that nutrients and small animals (fish fry, clam larvae, etc.) can flow properly into the lower pond.

Over the years, the two ponds have contained decorative carp and such edible fish as catfish and bluegills, plus occasional turtles, frogs, freshwater clams, and crayfish. (The crayfish weren't a success—they kept wandering downhill to the library looking for swamps—and the frogs were eaten by the mouse-controlling ferrets.) Although water hyacinths and duckweed, and bacteria living on plastic substrates placed in the tanks, strip out most of the nitrogen and other fish wastes, residual nutrients can also be recovered by using the fishwater for hand watering by can, hose, or drip irrigation. Currently, every other watering uses pondwater.

Normal irrigation has also been provided in years past by "leaky-hose" subsurface drip, which emits water only if the surrounding soil is dry. This is preferable to the soil-salting habit of surface watering currently favored (partly for leaf health), but also requires some maintenance to ensure the buried hoses don't clog. Beneath the entire greenhouse is a synthetic-rubber "bathtub"—a liner membrane attached to drains—so that if a glass-fiber pond ever fails, the leaking water won't get into the expansive soil under the arch pillars and cause structural damage.

Starting in August 2006, Aaron Westgate has led a major greenhouse renovation to improve soil health, broaden plant biodiversity, increase edible crop production, and improve esthetics. EDAW landscape architects David Sacks and Greg Hurst, with advice from Cheyenne Botanic Garden director Shane Smith, chose and arranged specimens to yield a year-round succession of fruits, vegetables, beauty, and fragrance. The original fiberglass tanks and cement stream were replaced with new naturalistic EPDM-lined rock water features, and the upper pond moved to the west under Aaron's new cedar

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bridge. The south pond was enlarged to capture more solar energy and to reflect more light into the surrounding spaces, adding a lovely glimmering daylit effect to the east and west wings. The joists were belatedly painted white to improve daylight capture and distribution. The soil was rejuvenated with compost, horse manure, coconut coir, and worm castings, and a diverse spread of beneficial cover crops was planted: clover and peas to fix nitrogen, buckwheat to add carbon, and deeply rooted vegetables such as carrots and beets, which break up the hardpan subsoil with their aggressive taproots. Computer-controlled drip irrigation was installed to improve water efficiency and ensure reliable irrigation of our prized tropical crops. New specimens are now being planted, and the replacement banana trees are growing more than an inch a day, aided by tropical mycorrhyzae from Fungi Perfecti and liquid worm poop from TerraCycle. The new jungle is starting to grow out rapidly during 2007.

13

[The Research Center]

There are up to sixteen workstations in a variety of settings here, including two workstations in the loft.

The ~1,200-square-foot (~111-square-meter) east wing houses the support staff, equipment, and technical library of my office as Chairman and Chief Scientist of Rocky Mountain Institute. Like my private residence at the other end of the building, this area is not open to the public and we ask that you do not disturb people working here, but here are descriptions of some of the devices and amenities found in this part of the building. There are up to sixteen workstations in a variety of settings here, including two workstations in the loft. The loft's operable north window serves as a high vent for cooling this end of the building and provides a view for office workers of the earth berm sloping down to the airlocked east entrance.

The many pieces of office equipment contribute heat to this end of the building—but less all the time as newer, more efficient equipment displaces older. Our newest computers, from the MacBook Pro series from Apple, boast low-energy LCD screens and efficient circuitry, and use a fraction as much electricity as most of our old, now-retired machines. Our newest portable Macs use only 15–20 percent as much electricity as the desktop models. Their efficiency and internal batteries enabled us to retire the uninterruptible power supply that previously hummed away in the under-loft office to protect desktop computers from disruptions of rural electric supply in an area with frequent ice- and thunderstorms. At various times we have also pioneered the use of cold-fuser photocopiers (~90 percent energy savings), belt-fuser photocopiers (~70–75 percent energy savings compared to drum-fuser models that use standby energy to keep the fuser warm), and

(continued)

inkjet fax machines (97 percent energy savings compared to laser faxes). Even the relatively efficient photocopier now in use can double or triple the building's average electric usage when it's running.

The lighting fixtures in the office under the loft use radial polarizing lenses to cut "veiling glare" so that screens and paper can be read with greater contrast and less light. That room's fluorescent lights, and those in the northeast hallway, kitchen, and workshop, also substitute solid-state, high-frequency ballasts for the traditional "core-coil" electromagnetic ballasts. The electronic versions last longer, increase lamp life, eliminate flicker and hum, reduce electrical consumption by ~40-plus percent, reduce cooling loads in the summer, and repay their extra cost in about a year. If used throughout the country, they and other improvements to the fluorescent lighting (reflectors, lamps, controls) in use when these were installed in 1984 would have displaced roughly sixty large power plants costing over $100 billion. Today, both the in-place and the new technologies are much better; the net savings available are still enormous; and the new lighting and daylighting retrofit now underway will save even more, look better, and help us see better.

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[The Bathroom]

The best low-flow showerheads on the market use only 1.0–1.2 gallons per minute.

The third of the four pods contains a bathroom with a 3-liter (0.8-U.S.-gallon) Swedish Ifö toilet (a handmade prototype believed to be the first copy brought to the United States by the late Wendy Corpening). It's still among the most water-conserving flush toilets not using special chemicals or compressed air. In 1992, the National Energy Policy Act mandated that all toilets sold in the United States use no more than 1.6 gallons per flush (and that showerheads flow at 2.5 gallons per minute or less). Previously, toilets had required 5–7 gallons (20–30 liters), but they worked no better and often worse, because their peak flow rate, which mainly transports the solids, was severalfold smaller than that of the brief, carefully shaped pulse of the ultra-low-volume toilets. That is, the inefficient old models swirled a lot of water around for a long time to little purpose. We expect one day even our toilet will use too much water. Potter Tara Miller is also helping us to convert the tank lid of this toilet, in Japanese fashion, into a little washbasin in which you can rinse your hands with clean water, thereby creating graywater which then runs down into the tank for the next flush.

The installed showerheads—examples of others are on the shelves—illustrate two types using only 1.5 gallons per minute (5.68 liters per minute), compared to pre-1992 showerheads, which usually operated at 3–5 gallons per minute, and some still older ones, which used 4–7 gallons per minute; yet good design makes them effective and vigorous. The best low-flow showerheads on the market use only 1.0–1.2 gallons per minute (3.8–4.5 liters per minute), but some are so strong that people often throttled them to a lower flow rate.

In the mid-1980s, RMI showed that over twenty years, giving away and installing for free a basic set of water-efficient fixtures (toilets, showerheads, faucet aerators) could save a town like Aspen about a half-million dollars more than it would cost, because saved water-heating energy would more than pay for the giveaway. Similarly, RMI found that such fixtures, plus efficient landscape watering, could save at least as much water as the billion-dollar Two Forks dam could provide (this comparison helped persuade USEPA to cancel the project), but at a fifth of its cost per gallon (or an eighth counting the saved water-heating energy).

The small plastic box above the showers is an air-to-air heat exchanger. Its 30-watt fan exhausts stale air and delivers fresh air. The two airstreams are separated by the thin walls of a plastic honeycomb, so that the warm outgoing air preheats the cold incoming air, recovering about three-fourths of the heat that would otherwise be blown outside. Many manufacturers offer air-to-air heat exchangers for various climates. The building has one large and five small heat exchangers: one in each bathroom, one in the office pod at the west end of the building, one in the clothes-drying pod, and one in the stovehood.

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Building Economics

Total direct construction cost for this building, excluding land and finance, was slightly over US$500,000 (1983–84 $)—$130-odd per square foot (~$1,425 per square meter), including the extensive built-in furniture and counting all labor and donated or discounted equipment at market value. This may sound expensive, but building costs in the Aspen area in the early 1980s were nearly twice the national average: all non-native materials must be trucked over the Continental Divide, skilled craft labor is very expensive, and the building season is short, with a killing frost possible on any day of the year. The per-square-foot cost of this building was actually below the local median for contemporary custom buildings of comparable quality. More importantly, the features that eliminated the conventional heating system cost ~$1,100 less than it would have cost to install (let alone operate)—i.e., the ~99 percent saving on space-heating energy reduced our construction cost. We then reinvested that saved construction cost plus an extra ~$4,800 to save ~99 percent of the water-heating energy, ~90 percent of the household electricity, and half the water too. Thus all the energy and water savings together increased construction cost by ~$6,000, or ~$1.50 per square foot ($16 per square meter), or just over 1 percent.

Compared with normal local building practice and the cheapest conventional fuels (firewood and propane) plus normal household electricity usage, the building saves at least $7,100 in energy costs per year, or an average of ~$19 per day—economically equivalent to the output of a barrel-per-day oil well; but unlike oil, it doesn't pollute, can't be interrupted, and won't run out. Overall, the investments made in saving energy paid for themselves in about ten months with 1983–84 technology. One could do better today,

even eliminating initial capital cost differences between an advanced home and a standard one. By about 2054, the building's energy savings will have repaid its entire construction cost (at constant energy prices, without counting financing costs or discounting cashflows). It should last longer than that: we built it for the archeologists, who will doubtless conclude from its southerly orientation that it was a temple to some primitive solar cult.

New Projects at the RMI Headquarters Building

Twenty-four years after construction was finalized, RMI's Headquarters building is undergoing some exciting retrofits. We're working to improve the functionality, aesthetics, and educational aspects of the building while striving to push the envelope with state-of-the-art technologies and new applications of integrated design. Please check back with us as we work on the following upgades:

PV Monitoring

The building's solar electric system was originally installed with Metricom meters that collected data and tracked the system's performance. An enthusiastic intern would then download this unprocessed information and graph the results. Much better technology has become available, and we're upgrading our system to demonstrate the current technology. We are installing an interactive, web-enabled data-monitoring system that will automate this process and display it on an attractive flat-screen monitor at the building's entrance and on our website. This system will also allow us to report a broader range of data, including information on ambient weather, thermal performance, solar hot-water analysis, etc.

Active Solar-thermal Hydronics System

The building demonstrates elegant passive-solar design through the combination of proper orientation, super-insulation, a tight building-envelope, and "superwindows" that incorporate Heat Mirror technology. We have used two woodstoves for supplemental heat on the coldest days of

winter, but we're now evolving so we don't use fire at all. When the building was constructed, radiant floor tubing was laid in the concrete slabs as insurance in case the experimental passive design didn't provide adequate heat. Though we've been very happy with the performance over the last twenty-four years, we're finally putting the radiant floor investment to use. We're planning to install new active solar-thermal hot-water panels provided by SunEarth, Inc. (www.sunearthinc.com) to heat our floors directly with the sun's energy. We'll be using superefficient micropumps to circulate the water through the radiant tubing. This addition is an exciting update for this building, and a great opportunity to keep expanding the boundaries of passive design and technology. Come by next winter to feel a toasty warm floor heated by our favorite source of nuclear fusion (the kind that is conveniently located 93 million miles away).

Electric Lighting

In our quest to continually raise the bar in terms of electrical efficiency, we're undertaking an electric lighting retrofit that will reduce our electrical consumption while dramatically improving the lighting performance and aesthetics of the building. We'll be demonstrating state-of-the-art LED, CFL, and highly efficient halogen lighting, while simultaneously updating our luminaires to add a new level of beauty to the space. Robert Sardinsky, an RMI alum who left the Institute to start Rising Sun Enterprises, Inc., is spearheading this effort.

Daylighting

The headquarters building is designed to optimize the use of sunlight for heating, plant production, and interior lighting. In practice, however, there are a few areas on the north side of the building that don't receive adequate sunlight and therefore rely on electric lighting even during the daytime. With a bit of clever design work we have figured out new ways to redirect sunlight to these areas. Low-tech solutions include bouncing light from the clothes-dryer clerestory into the front hall and using Solatubes mounted on the roof to flood sunlight into the space. Never scared to experiment with new applications of high technology, we are exploring installing a sun-tracking fiber-optic lighting system to light the northeast side of the building.

Greenhouse

The most obvious change to the building is a complete overhaul of the greenhouse. After twenty-four years of productive growth, the soils had become salty and exhausted, the biodiversity had declined, and a few too many pests had found homes amidst the tropical environment. We have created a new floor plan that feels much more welcoming and natural, complete with rock ponds and a patio area to relax in. We've resuscitated our soils with compost, horse manure, coconut fiber, peat moss, mycorrhizal inoculants, and worms, and the plants are growing beautifully. We have an upcoming fruit forest that features four banana plants, avocado, mango, lemon, pineapple guava, passion fruit, brugmansia, papaya, and ginger, along with an understory of vegetables, greens, and herbs. We're gratefully using liquid worm castings donated by Terracycle (www.terracycle.net), an inspired natural capitalist company that turns waste into profit. Check in during the coming years to watch the space grow into a lush oasis!

Interior Design

The interior aesthetics of the building are being beautifully modernized. We're installing new window treatments, creating a new living room with furniture featuring gorgeous upholstery made from recycled and organic materials, and relocating years of backlogged files to create a more spacious and accessible interior. Judy Hill Lovins is leading this charge, with exceptional help being provided by the Eagle Valley Alliance for Sustainability, and Rachael Hollister, ASID, and Jennifer Green, ASID, both of whom volunteered much-needed design time and research.

Headquarters Signage Project

By Artist Cody Thomaselli

This past Feburary, I was contacted by RMI to help them create a unique and sculptural sign system for their Headquarters builiding and home of Amory Lovins and Judy Hill Lovins. With my background in metal, glass, and wood sculpture, I was excited about this opportunity. Most of my art has focused in the past on the relationship between science and nature and I was excited to learn more about RMI's similar interest and work.

This project specifically focused on creating a unique signage system for the headquarters building and home. Together with Susan Rich, RMI Communications Design Fellow, we designed this self-touring system around a simple framework that incorporated goals of: longevity, way finding, aesthetics, and material efficiency. We developed this system to provide a cohesive navigation of the HQ building for visitors. The sign system also needed to be easily updatable, as the building itself is often changing. The sign system also needed to last 40-plus years for an efficient use of energy and materials.

The materials for this project were selected to complement the natural surroundings of the HQ building. We incorporated local rocks to serve as foundations for the numbered signs and utilized the natural patina created from the oxidation of bronze and steel. One of the more challenging processes was developing a composite material made from rock powder combined with an aliphatic outdoor casting resin. We used this material to give the signs their form as well as to aid in the interchangeability of the numbers themselves. I feel these materials combined made a diverse, natural, and resource-responsible palate for this project.

It is my wish that these signs will enrich the conversation between the visitor, the place, and the ideas for which RMI stands.

I would like to thank, RMI and Amory and Judy Hill Lovins for this opportunity, as well as the RMI Communications Team, and the wonderful Maintenance Staff for the use of their equipment and shop.

I would also like to thank all of our suppliers; Myers and Co., Harsh Enviro, and BJB Enterprises, Inc. for their great work and attention to detail.

In Closing

You have now finished your tour of this demonstration building. I hope it has stimulated your imagination and increased your knowledge of some of the exciting technologies and designs that permit very resource-efficient buildings to be both beautiful and comfortable. Please remember, though, that they don't have to look or cost like mine in order to work like mine: similar energy and dollar savings are achievable in ordinary tract houses too. What are those savings? In round numbers, I'm saving 99 percent of space- and water-heating energy, 90 percent of household electricity, and 50-plus percent of household water. The electricity that the building saves will avoid burning its own volume in coal about every twenty years.

Many buildings save heat, but mine also saves just as much electricity—by far the costliest form of energy. Careful monitoring in the mid-1980s established that the household used only 0.3 watts of average power per square foot, because it doesn't use electricity for space or water heating, air conditioning, cooking, heating air to dry clothes, or (mostly) refrigeration. Those are all the normal big uses. All I have left is lights and appliances, and their electric usage runs about $5 a month at ~7 cents per kilowatt-hour. In contrast, at that time it was not uncommon for local all-electric houses of comparable size in this area to incur a $1,000-a-month winter electric bill.

Even more important than the technologies, I believe, are two other features of the building: its integration of dwelling, farm, and workplace under one roof, and how it makes you feel. You may already have noticed that it's an unusually pleasant space. I certainly feel more happy and productive here than in a normal home or office. Why? Perhaps the reasons include the curves, the natural light, the good indoor air quality (natural materials and careful choice of cleaning compounds), the low air temperature and high radiant temperature, the relatively high humidity, the lack of mechanical noise, the sound of the waterfall, the sight and scent and oxygen and ions (and sometimes the taste) of the plants, the virtual lack of electromagnetic "smog" (since very little electricity is used except by the office equipment), and perhaps other factors not yet known. Whatever the real reasons may be, buildings are supposed to make you feel good, and many people report that this one does.

Not all the technologies used here are suitable for all people or climates. The greenhouse's large overhead glass area, for example, would overheat in most lower-altitude sites, even using the best superwindows; if the outside air isn't reliably cold every night, glazings should normally be in a vertical plane with a shading overhang. The rapid evolution of new and even better technologies, too, makes this building's technology suite far from the last

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word. I hope that you will share with others what you have learned here; will offer your reactions; and will pass on to RMI any interesting developments you may find elsewhere.

This building has been made possible not only by the effort of many people and organizations (those to date, other than the volunteer crew, are shown at the back of this guide and inside the front cover), but also by the ideas and skills of many diverse visitors like you. If you wish to support the programs of Rocky Mountain Institute, your tax-deductible donation would be most welcome. Publications about the Institute are available in the front entryway, or you can visit us online at www.rmi.org. I also invite you to sign the guestbook near the front door. If you wish to receive RMI's newsletter (recent issues are free in the rack in the front entryway) *RMI Solutions*, three times a year (and we hope, offer a nominal donation to help cover its costs), please ask a staff member or visit us online at rmi.org/sitepages/pid106.php

Thank you for your visit and for spreading what you've learned here. I appreciate your interest in our home and RMI's work, and hope you will travel safely and return soon.
— Amory

P.S. As you leave the building you'll probably pass my blue Honda Insight aluminum hybrid car which at this altitude averages about 64 miles per gallon (3.7 L/100 km, 27 km/L). It's nearly three times as efficient as the average U.S. light vehicle.

Endnotes

1 Heat flow is measured in American units as BTU/hour per square foot of area per F° of temperature difference. Insulating value (R) is one divided by heat flow. An R-20 wall resists heat flow twice as well as an R-10 wall. Double glazing is about R-1.7; a foot of glass fiber, about R-38. In metric units of W/m2K, our walls and roof are k~0.14 and ~0.09 respectively, windows from 0.47 to 1.05 or less (center-of-glass, excluding edge losses), glass stormdoors 0.62 to <0.5 (likewise), and footer insulation 0.22 to a depth of 1.2–2.4 m (3.9–7.9 feet). As is explained below, the effective wall insulation values given here are better than would be expected from their materials alone.

2 All insulating values given in this guide for glazings are "center-of-glass," excluding edge losses.

3 Some of the replaced units had suffered a variety of failures, mostly due to improper installation (which allowed condensate to build up and attack the seals) exacerbated by high indoor humidity while the original rotary main air-to-air heat exchanger was being replaced with a model better suited to our cold climate. These conditions were corrected. Modern Heat Mirror glazing units also have very robust seals made of water-resistant material and protected by a multilayered metal-and-plastic tape. No further seal problems have been experienced or are expected.

4 When we built, non-CFC foam was not available as it is now, so we used a specially stoichiometry-controlled composition of polyurethane in which Freon is almost insoluble. This minimized CFC losses. In addition, now that the foam is sealed inside masonry, further CFC leakage will be infinitesimal.

5 These sodium-hydroxide-filled batteries are based on a Thomas Edison design that is still in service in some upper Midwestern phone companies; it doesn't mind deep discharge or low temperatures, and if occasionally maintained seems to last for well over a century. Time will tell if the Chinese ones are that durable.

6 This particular dimming system is of historical interest—it's an early handmade prototype of a brilliantly simple circuit designed by Stanford electrical engineer Steve Stevens and commercialized by Luminoptics, then suppressed by the main magnetic-ballast maker, Universal, which in consequence had to pay more than $100 million in damages. Part of the defendant's case was that the dimming ballast didn't work. I was unconvinced, since this version had been working fine for our visitors for well over a decade. The jury agreed. See www.luminoptics.com/images/NYT97_article_LUMY.pdf. Stevens and his original CEO Bill Alling have recently brought the design back to market.

7 The prerequisites were Elementary Hedonism and Intermediate Decadence.

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8 Had we needed to, we could have prewarmed the outside air to ~50˚F (~8˚C) in a buried "earth tube," and recovered the latent heat from water vapor in the exhaust air using an air-to-air heat pump, discharging the air saturated at the freezing point. We did neither of these things because we already had enough heat.

9 Since I'm allergic to cats, and we don't want mice to come into the building (as they do everywhere hereabouts in the winter) because hantavirus is approaching our area, we used to control mice with a pair of large snakes that lived in the chase. This worked fine most of the time, but on rare occasion, if the snakes subtracted faster than the mice multiplied, the snakes would emerge in search of food, curl up on a secretary's desk, and cause unfavorable reptile-mammal interactions. The snakes ultimately escaped and were replaced by ferrets, which were higher-maintenance but more sociable. The ferrets eventually died of old age. Now we use mousetraps. During the brief snake/ferret interregnum, however, some mice did come in, and nested in the warm area at the bottom of the [then] drum-fuser photocopier. They whiled away the winter nights eating wires at a thousand dollars per circuit board. If you started up the photocopier at the wrong moment, out would come a mouse tortilla; the mouse and the copier would both die, the latter very expensively. Switching to an energy-efficient belt-fuser copier with no standby energy solved this problem temporarily, and the ferrets, more lastingly.

Service Providers

Author's note: in our first edition of this Visitor's Guide we listed locations for the following service providers. Since then, some have moved, some have gone out of business, some have changed their companies' names, and some have been bought by other companies. In this issue, we have removed their locations to avoid confusion and we have kept the names of the original service providers that worked on the building. These lists will be updated to reflect the many firms and individuals who have generously helped with the current round of renovations, which are led by Aaron Westgate and Nash Evans.

Owner-builders

Amory B. Lovins and L. Hunter Lovins

Current Owners

Amory B. Lovins (Hon. AIA), Judy Hill Lovins, and Rocky Mountain Institute

Architects

Steven Conger AIA & The Aspen Design Group

Coordinator of Volunteers

Christopher Cappy

Crew Foremen and Design Consultants

Jock de Swart
Lawrence A. Doble PE
Christopher Cappy

Additional Design Consultants

Jim Logan
Ivar Eidsmo
Charlie Manlove
Stuart Mace

Engineers

Jon Giltner PE, Nicol & Giltner, structural
John Ehlers, ENSAR, thermal simulations
Lincoln-De Vore Testing Laboratory, soil
Wright Water Engineers, water
Lawrence A. Doble PE, structural details

Finance

First National Bank in Aspen
First Western Mortgage Corporation
Colonial Savings & Loan
Michael Stranahan & Toledo Trust Company
Gerald & Miriam Lovins
Arman Simone & Westport Bank & Trust Company
Alpine Bank
Robert & Pamela Wilkinson
Philip S. Weld
Howard Quirk
Radcliffe Killam
Treya Killam-Wilber

Legal

Martin Kahn, Esq.

Insurance
The Valley Agency
Title and Escrow
Stewart Title Company

Land
Anne Burrows Ibbotson, Mason & Morse

Layout
Glenn Rappaport & Jock de Swart

Excavation
Snowcap Excavation & Weinreis Construction

Concrete
Fox Concrete
DeRoeck Crane Service, pumping
T.E. Chase, north wall
MacKenzie Cement, flatwork

Masonry
Lewis Gordon and Matt Lenoe

Roofing
Mark Kovacs Roofing

Mechanicals
Charlie Manlove

Plumbing
GRT Plumbing & Heating

Electrical
The Electricians of Aspen

Sheetmetal
Western Refrigeration & Heating
Western Slope Mechanical Contractors

Drywall
Alpha Interiors

Plaster
Don Sarver
Garden Wall
Mike Garrett
Larry Turner
Empire Plastering
Rail Fence
Leroy Lyons

Tile
Frying Pan Tile

Glazing
Alpen, Inc.
Bob Ferenc AIA PE
Green Mountain Solar Works
Rocky Mountain Solar Glass

Upholstery
Black Mountain Leather Co.

Cabinetwork
Joel Zane
Beam Joints
Dick Wingerson

Front Door
Michael Schuster
Joel Zane

Finish Carpentry
John Black
Lou Dawson
Christopher Cappy
Kevin Fetch
Chuck Miller
Ivan Warman

Painting

Mountain Brush
Airtightness
Colorado Energy Savers
Greenhouse Landscaping
Keith Keating
John Wolfe
Arnell Hinkle
Tom McKinney
Jeff Gersh

Aquaculture Design

John Wolfe
Barry Costa Pierce
Kyle Datta

Landscaping

Tom McKinney
Peter G. Williams
Peter Butler
H. Richard Heede
Jim & Pam Dyer
Colin Laird

Hot Tub

Peter G. Williams
Warren Stickney
Empire Plastering
Peter Butler
John Woodwell
Aspen Pool & Spa

Photovoltaic Installation

Brady Bancroft, system designer
Johnny Weiss
Alvin Eshe
Howard Stewart
Norm Smith
Joel Neymark
Bill Browning

Donors of Services & Equipment

Author's note: although we have tried to update these references to the best of our ability, some of these companies have moved, some have gone out of business, some have changed their names, and some have been bought by other companies. We apologize for any confusion resulting from inaccuracies in this list.

Accounting Services
Reese Henry & Company, Inc.
Aspen, Colo.
www.reesehenry.com

Active Solar System and Most of Its Installation
Novan Energy, Inc.
Boulder, Colo.

Architectural Advice
William Mead, AIA
Shepley Bulfinch Richardson and Abbott
Boston, Mass.
www.sbra.com

Architectural Advice
Malcolm Wells
Brewster, Mass.
www.malcolmwells.com

Tunable High-frequency Ballasts
for fluorescents
Luminoptics
San Ramon, Calif.
www.luminoptics.com

Btu Meters
ISTA Corporation
Roselle, NJ

Chip Motor Controllers
Harris Corporation
Melbourne, Fl.
www.harris.com

Compact Fluorescent Lamps
Philips Lighting Corporation
Somerset, NJ
www.lighting.philips.com

Compact Fluorescent Lamps
Panasonic USA
Secaucus, NJ
www.panasonic.com

Compact Fluorescent Lamps
Osram Sylvania
Danvers and Beverly, Mass.
www.sylvania.com

Compact Fluorescent Reflector Lamps
Teron Lighting
Fairfield, Ohio
www.teronlighting.com

Computers and Peripherals
Apple Computer
Cupertino, Calif.
www.apple.com

Computer Services
Sam Cox
Aspen, Colo.

Computer Services
Kelly & Joe Harvey
Basalt, Colo.

Data-analysis and Presentation Software
Supersymmetry Services
Singapore

Design And Installation of Hot-tub Mechanicals
Warren Stickney
Aspen, Colo.

Drip Irrigation Valve
Sturman Industries
Woodland Park, Colo.

Electric Pumps
Grundfos Pumps
Bjerringbro, Denmark
www.grundfos.com

Fabrication of Front Door
Michael Schuster
Denver, Colo.

Flagstones
Northern Stone Corporation
Oakley, Idaho

Greenhouse Fertilizer
TerraCycle, Inc.
Trenton, New Jersey

Heat Exchangers
Mitsubishi Electric Sales America, Inc.
Cypress, Calif.
www.mitsubishielectric.com

Insulated Greenhouse Vents
First Law Products, Inc.
Keene, NH

Interior Landscape Design (2006–07)
EDAW, Inc.
San Francisco, Calif.

Locksets
Schlage Lock Co.
San Francisco, Calif.
www.schlage.com

Overhead Projector
Jim Leath
North Canton, Ohio

Passive-solar Hot-tub Heater
Sage Advance Corporation
Eugene, Ore.

Photographic Services
Hill Gallery
Aspen, Colo.

Photography Throughout Construction
Doug Lee
Aspen, Colo.

Interior Architectural Photography
Edward Levinson
Oakland, Calif.

Photovoltaic Arrays, Current Combiner, and Sunshine Inverter
Mobil Solar Corporation
Billerica, Mass.

Photovoltaic Fan Controller
Dinh Company
Alachua, Fl.

Photovoltaic Tilt Adjusters
Level Leg Corporation
San Diego, Calif.

Original Photovoltaic Arrays
CalTech Jet Propulsion Laboratory
Pasadena, Calif.
www.jpl.nasa.gov

Barn Photovoltaic Arrays
Energy Office
Grand Junction, Colo.

Shipping of North Carolina Granite Slab
Jim Roush & Cynthia Wayburn
Aspen, Colo.

High-efficiency Showerheads
Energy Technology Laboratories
Modesto, Calif.
www.energytechlabs.com

Stratojet™ Destratifying Fans in Solar Dryer
Energy Products
Denver, Colo.

Tables
Ralph Braden
Aspen, Colo.

Red Spruce Dining-room Table
Stuart and Kent Mace
Aspen, Colo.

Scanning Digital Thermometer
Exergen Corporation
Newton, Mass.
www.exergen.com

Four-liter Ifö Toilet
Western Builders Co-op
Prescott, Ariz.
www.ifo.se

Cast-iron Defiant™ Woodstove in Library
Vermont Castings, Inc.
Randolph, Vt.
www.vermontcastings.com

Soapstone Woodstove in Living Room
Hearthstone Corporation
Morrisville, Vt.
www.hearthstonestoves.com

Fifty Tons of Oak Beams
The Meadowcreek Project
Fox, Ark.

Storage And Handling of Oak Beams
St. Benedict's Monastery
Old Snowmass, Colo.
www.snowmass.org

Side of Beef to Feed Crew
Sally Forbes
Sheridan, Wy.

Suppliers of Services & Equipment at Below Cost

Architecture And Drawings

The Aspen Design Group
Aspen, Colo.

Consultancy on Construction Process and Costing

Ivar Eidsmo Builder, Ltd
Telluride, Colo.

Polyurethane Roof and Wall Insulation

Thermal Systems, Inc.
Denver, Colo.

Thermal Analyses

ENSAR/Solar Pathways Associates
Boulder, Colo.
www.ensargroup.com

Suppliers of Services & Equipment at Cost

Aquastar™ Propane Demand Heater
Solar Water Works
Albany, Ore.

Discounted NiFe Batteries
Trojan Batteries
Santa Fe Springs, Calif.

Doors Including Midnight Sun® And Morning Sun® Doors
E.A. Nord Company
Everett, Wash.

Efficient Lighting Equipment and Design
Rising Sun Enterprises, Inc.
Basalt, Colo.
www.rselight.com

Electronic Power Meters
Metricom Corporation [out of biz]
Campbell, Calif.
12VDC greenhouse fan
Energy Science, Inc.
Gaithersburg, Md.

Glass and Greenhouse Glazing
Rocky Mountain Solar Glass, Inc.
Denver, Colo.

Arkenstone™ Greenhouse System and Installation
Bob Ferenc, PE AIA
Denver, Colo.

Greenhouse Glazing
Thomas O'Moore & Green Mountain Solar Works
Boulder, Colo.

Operable Greenhouse Windows
Pozzi Corporation
Bend, Ore.
www.pozzi.com

Greenhouse Plants
Missouri Botanical Garden
(Dr. Peter Raven, Director)
Gray Summit, Missouri
www.mobot.org

Greenhouse Plants
Kyle Datta
Keauhou, Hi.

Main Air-to-air Heat Exchanger
Carrier Corp.
Farmington, Conn.
www.global.carrier.com

Sharp Economini™ Rotary Heat Exchanger
[originally used]
Berner International Corporation
New Castle, Pa.
www.berner.com

Heat Mirror® Glazings
Alpen Products
Boulder, Colo.
www.alpeninc.com

Inverters
Trace Engineering
Burnaby, B.C.
www.xantrex.com

Inverters
Exeltech
North Fort Worth, Texas
www.exeltech.com

Photovoltaics
Midway Labs
Chicago, Il.

Photovoltaic Panel Trackers
Heliotrope General
(bought by JED Engineering, Inc. – www.jedengineering.com)
Spring Valley, Calif.

Discounted Refrigerator, Freezer,
and refrigerator heat pipe
Sun Frost
Arcata, CA
www.sunfrost.com

Retrofit Lighting Design
Clanton Engineering
Boulder Colo.
www.clantonassociates.com

Roof Membrane and Stonemat
Kelley Energy Systems
Waterbury, Ct.

Solarex Photovoltaic Panel
Dinh Company
Alachua, Fl.

Submersible Woodstove for Hot Tub
The Snorkel Stove Co.
Seattle, Wash.
www.snorkel.com

Teflon®-coated Shower Curtain Cloth
Saturday Knight, Ltd.
Cleveland, Ohio

Previous Telephone/intercom System
Nitsuko Communications
(formerly TIE/Communications, Inc.)
Shelton, Ct.
www.nitsuko.com

Three-liter Ifö Toilet and Ifö Sinks
Western Builders Co-op
Prescott, Ariz.
www.ifo.se

Uninterrruptible Power Supply
Best Power
Necedah, Wis.
www.bestpower.com

Use of Flatbed Truck
Windstar Foundation
Old Snowmass, Colo.
www.wstar.org

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