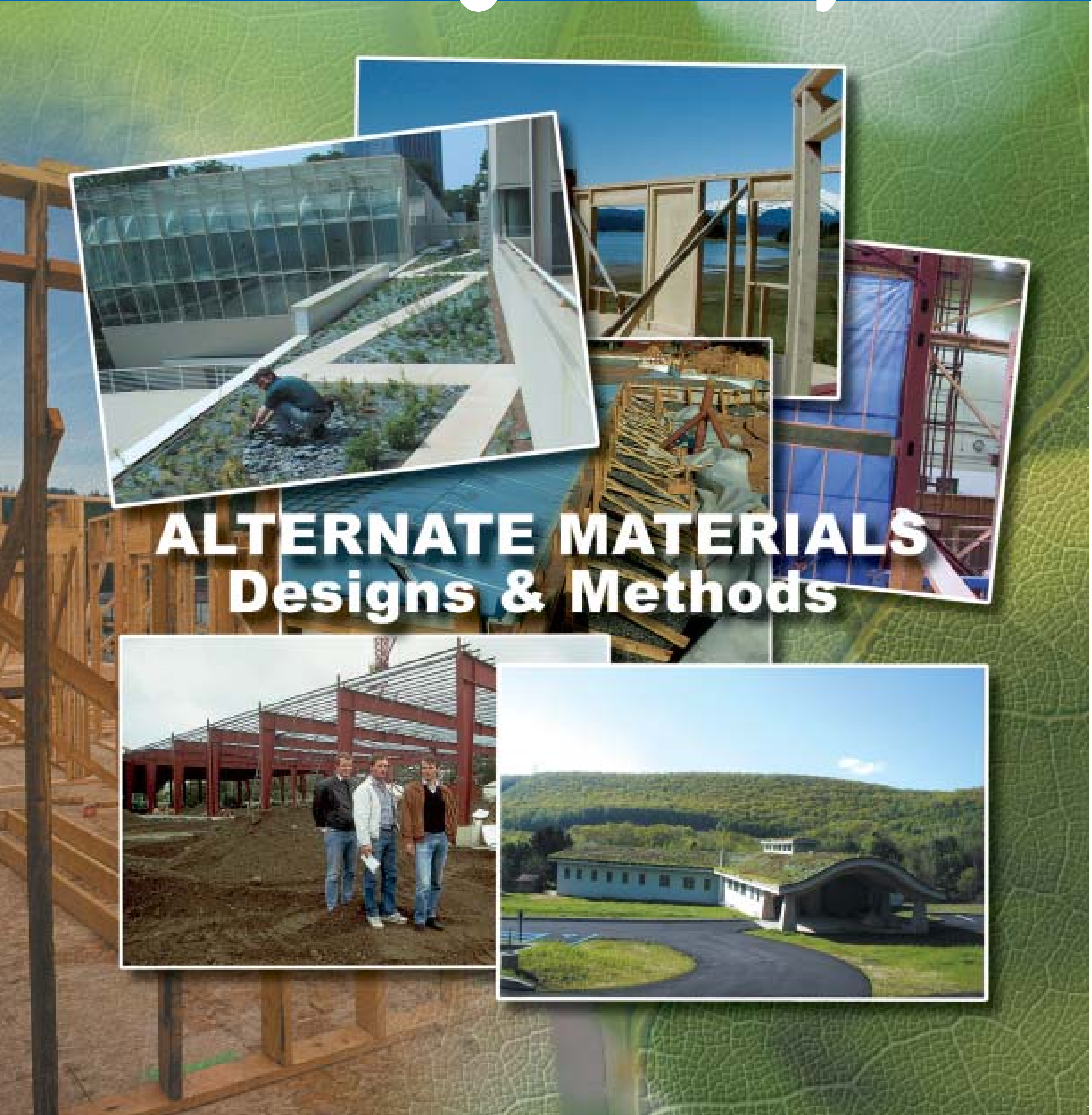
INSIDE: "MAKING FIRE ALARM SYSTEMS ADA COMPLIANT," GOING GREEN

Building Safety JOURNAL

THE PROFESSIONAL JOURNAL OF CONSTRUCTION AND FIRE SAFETY

ICC
INTERNATIONAL CODE COUNCIL®
MAY 2003



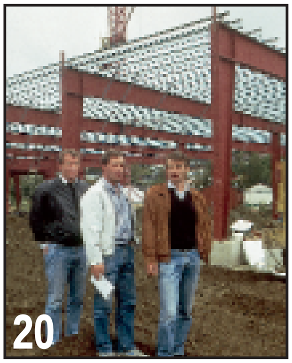
Building Safety JOURNAL™

The Professional Journal of Construction and Fire Safety VOLUME I • NUMBER 3 • MAY 2003

Departments

Cover design by Mary Bridges

Features



Going Green

by David Eisenberg
Director, Development Center for Appropriate Technology

GREEN BUILDING AND ALTERNATE MATERIALS, METHODS AND DESIGNS

EFFICIENT WOOD FRAMING TECHNIQUES

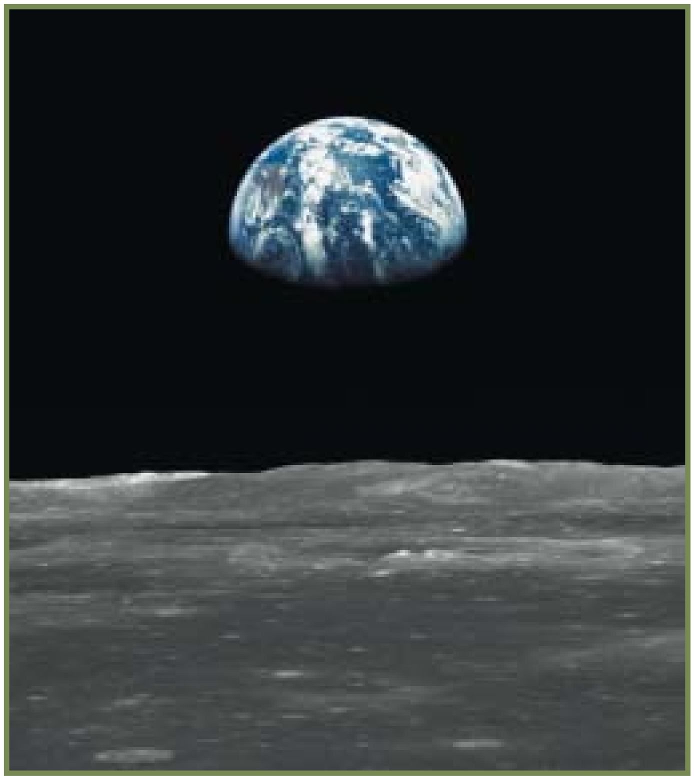
FROST-PROTECTED SHALLOW FOUNDATIONS

ALTERNATIVE APPROACHES TO VENTILATION FOR CRAWL SPACES

GREEN ROOFS

RUBBLE TRENCH FOUNDATIONS

USEFUL INFORMATION TO THE CODES COMMUNITY



It is a great pleasure to introduce the first feature issue of *Building Safety Journal*™ with a focus on green building and alternate materials, methods and designs. Although this is a first for *Building Safety Journal*, it represents the continuation of work the Development Center for Appropriate Technology (DCAT) has been doing with code organizations over many years.

Those of you familiar with ICBO's former magazine, *Building Standards*™, may recall the three feature issues with a similar focus that were published starting in the fall of 1998 (September–October 1998, January–February 2000 and March–April 2002). These features were the result of a collaboration between DCAT, ICBO and the many authors who contributed their expertise. As with those past features, DCAT was asked to help pull together this current set of articles with the aim of providing useful and accurate information to the codes community, the design and building sectors, and the public.

For those who might not have seen the earlier features, they're still available at "Building Standards Online" on the ICBO website. For an overview of DCAT's work and goals, I highly recommend the January–February 2000 *Building Standards* interview with Bob Fowler and me, "An Alternative Future for Building Regulation." It will give you a pretty good idea of what DCAT is doing and why, and what Fowler, the Founding Chairman of ICC (among a multitude of other extraordinary accomplishments), thought about this effort. A great mentor to me as well as thousands of others, Bob had many insightful things to say in that interview—perhaps none more important than the following.

We need to think about the responsibilities for our collective safety; especially the welfare of future generations who, it's worth noting, are unable to represent their interests.

Change is typically accompanied by a sense of heightened risk, but it is critical to bear in mind that only when we can see the risks inherent in current practice can we appropriately balance what may appear to be the greater risks of change.

If there is a theme that connects the feature articles in this issue of *Building Safety Journal*, it is that they all represent alternate approaches to building which may help us move in the direction of more sustainable construction. That is, they are about approaches that aim to meet current needs while taking into account the welfare of future generations.

When considering the efforts of people who are working to make buildings more environmentally responsible, it is important to note that they're as committed to building safety as everyone else. None of us want unsafe buildings. However, we are also aware of the reality that much of the risk that we think we are eliminating is actually just being moved in space and time. Many of the requirements applied to our modern buildings to ensure that they rarely burn or fall down; allow people to become trapped within or fall from them; or expose occupants to the risks of electrocution, freezing or suffocation create real and significant risks away from the building site—out in the natural systems that support all life on the planet. Similarly, our actions shift that risk from the present to the future—to our children and grandchildren and to the future generations of all the other species on whose welfare our well-being also depends. This is the responsibility that Bob spoke of and cared about so passionately.

That we don't yet know how to figure out what the appropriate safety factors are for these other types of risks—that we don't even know what all the risks are, much less how to quantify them—does not relieve us of our responsibility to address them. It requires us to be more careful in our assumptions and decisions—to balance the unknown with the known and to be willing to consider how we begin designing and building for the long haul, rather than the short-term.

The alternate approaches in this feature are steps in that direction, and like so many other such steps, they involve change. Change is typically accompanied by a sense of heightened risk, but it is critical to bear in mind that only when we can see the risks inherent in current practice can we appropriately balance what may appear to be the greater risks of change.

At DCAT, we believe that humankind is at a crucial point in history when we have both the urgent need and the phenomenal opportunity to learn to make our human systems compatible with and beneficial for the natural and living systems on Earth. Code officials are in a strategic position to either facilitate or impede this change. I and other alternate construction advocates see our work, in part, as providing good information in a broad enough context to help inspire code officials to make reasoned, well-informed decisions.

The articles in this current feature cover a range of topics, some already addressed in the I-Codes™ (such as efficient wood framing techniques and frost-protected shallow foundations), others less widely known (like alternate approaches to ventilation for crawl spaces, green roofs and rubble trench foundations). I hope that they prove both interesting and beneficial. You will be seeing articles on related topics in future issues of *Building Safety Journal*, and beginning with the June issue I will be writing a regular column similar to the "Building Codes for a Small Planet" column that appeared in *Building Standards* last year. ◆

***David Eisenberg** co-authored* The Straw Bale House *and helped write the first load-bearing straw bale construction building code for Tucson and Pima County, Arizona. He can be contacted by phoning the Development Center for Appropriate Technology (DCAT) at (520) 624-6628 or via e-mail at* david@dcat.net. *For more information about DCAT, direct your browser to* www.dcat.net.

Online Green Building Resources

The Development Center for Appropriate Technology (DCAT) – *www.dcat.net*

Ecological Building Network – *www.ecobuildnetwork.org*

Building Science Corporation – *www.buildingscience.com*

Energy and Environmental Building Association – *www.eeba.org*

U.S. Green Building Council – *www.usgbc.org*

Building America (U.S. Department of Energy) – *www.eere.energy.gov/buildings/building_america*

New Buildings Institute – *www.newbuildings.org*

The following green building articles and features can be found on DCAT's website at: *www.dcat.net/resources/reviews.php#articles.*

September–October 1998

"Building a Sustainable Future"

"Straw-Bale Construction"

"Straw-Bale Construction: A Building Official's Perspective"

"Rammed Earth: Developing New Guidelines for an Old Material"

"Rammed Earth: A Code Official's Perspective"

"Pozzolans Unpuzzled: As Mineral Admixtures, Fly Ash and Other Waste Products Add Strength and Durability to Concrete"

The "Earth Architecture and Ceramics: The Sandbag/Superadobe/Superblock Construction System"

"Sandbag/Superadobe/Superblock: A Code Official Perspective"

"Adobe: A Present from the Past"

"Adobe: A Code Official's Perspective"

January–February 2000

"An Alternative Future for Building Regulation"

"Lunar and Terrestrial Sustainable Building Technology in the New Millennium"

"Cast Earth: A Revolutionary Building Concept"

"Cob and the Building Code"

"Cob Construction"

"Building With Bamboo"

"Earthship Building: An Ecocentric Method of Construction"

January–February 2002

"Building Codes for a Small Planet" (inaugural column)

March–April 2002

"Building Codes for a Small Planet"

"Green Building Programs—An Overview"

"Daylighting and Night Darkening"

"Integrated Design"

"Integrated Water Systems Design: The Beneficial Use of Non-Traditional Water Sources"

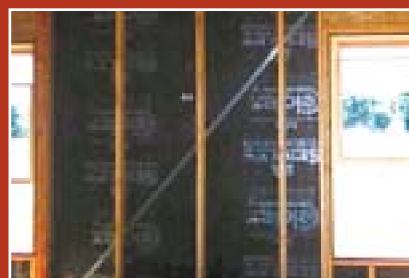
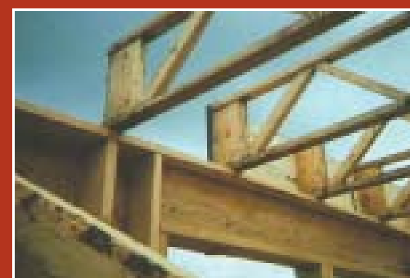
May–June 2002

"Building Codes for a Small Planet"

July–August 2002

"Building Codes for a Small Planet"

Optimizing Wood Framing

by Peter Yost and Ann Edminster

We have a 400-year history of building with wood in this country. We have stacked logs, hewn and fitted heavy timbers, nailed light frames, and finally even glued up engineered wood systems. With each step, we have used this elegant resource more efficiently, haven't we?

The answer is: not entirely. Research conducted by the National Association of Home Builders (NAHB) and the NAHB Research Center shows that 87.7 percent of the 1.7 million homes built in the U.S. in 1999 were stick-framed, that a "typical" home consumes just over 13,100 board feet of framing lumber (about three-quarters of an acre of forest) and that the wood scrap pile for the construction of this "typical" home is pushing 2 tons.

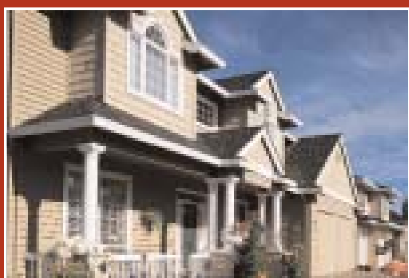
How did this happen? A combination of factors have worked to drive up our consumption of wood in home building.

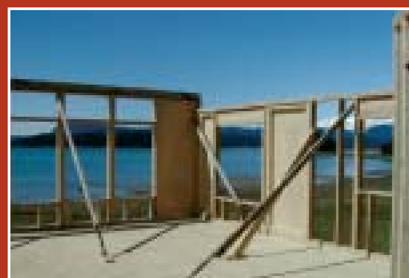
- **Single-family detached units.** Realizing the American dream of owning one's own home uses more wood per household than multi-family housing. According to NAHB, single-family detached units went from about 71 percent of overall housing starts to nearly 80 percent just between 1978 and 2001.
- **Home size.** In the last 40 years, the median new U.S. home size has increased from 1,365 square feet to well over 2,000 square feet, this despite the fact that household size has actually decreased by 20 percent.
- **Complexity.** Not many of today's homes are simple in form. Jogs, dormers, vaulted ceilings, convoluted roof lines and elaborate staircases abound.
- **Safety standards.** We require more of our structures today, particularly in regions with seismic and wind considerations. Re-engineering for these loads has resulted in some increase in wood use requirements, but has also spawned site practices that simply "throw more wood" at the problem.
- **Lumber versus labor.** Just as the relative value of materials versus labor seems to have reversed (today, materials are "cheap—it's the labor that is "dear"), the typical skills set of both designers and framers has diminished, leading to waste at the front and tail ends of wood construction.[1]
- **The nature and structure of the industry.** Home building is like no other production process in the 21st century. Nearly all of the 1.7 million homes built each year are site-built, making home building one of the most fragmented of U.S. industries. It is journeymen framers—not architects, engineers or even general contractors—who control what and how much wood goes where on the job site. And most training occurs informally, by word-of-mouth, during production.

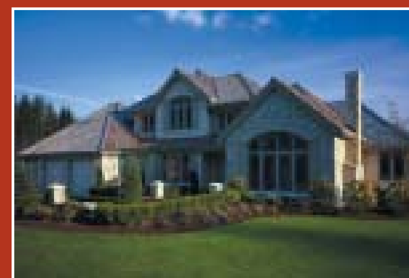
This article is really about the last three of these factors, why optimized framing makes so much sense and how building code officials can work with builders to use less wood (and build a better house, too).

WHY OPTIMIZED FRAMING?

There are a number of substantial advantages to optimized framing: it saves time and money up front, it improves







home buyer satisfaction, its saves money and energy over the long term, and it improves builder image.

- **Reduced wood purchase and disposal costs.** Actual field counts for a production builder in California have found a 40-percent reduction in the cost of a wall-framing package after implementing optimized framing methods: a purchase savings for the builder of over $1,100 on each house. Another builder in Maryland reduces total wood waste disposal by 15 percent using efficient framing. Note that neither of these examples takes into account the labor savings from handling less wood and wood waste.
- **Fewer callbacks.** A Chicago builder reports drywall callbacks dropping from more than $1,200 to only $150 per house with the switch to optimized framing.
- **Improved thermal performance.** The R-value for a "typical" eave wall (framed 2x4, 16 inches on-center, with oriented strand board sheathing) goes from R-11 to R-20 with optimized framing (framed 2x6, 24 inches on-center, with 1-inch rigid insulating sheathing).
- **Reduced environmental impact.** The annual toll for residential construction in the U.S. is 2 billion board feet of framing lumber and nearly 2.5 million tons of wood waste. That translates into 1.1 million acres of clearcut forest and 30-yard dumpsters lined up end-to-end from Phoenix to Chicago! Clearly, builders can achieve and claim significantly reduced global and local environmental impact with optimized framing.

Under the Department of Energy's "Building America" program, 7,000 homes built by Building Science Consortium production builders have achieved the results listed above. These gains are the products of "systems-thinking" and a breakdown of age-old myths about how wood framing works.

BREAKING DOWN THE MYTHS

To convince builders (and building code officials) that optimized framing not only works but is a better way to build, some pretty entrenched ways of thinking about construction and how houses work must be tackled head-on.

MYTH #1: "THE CODES DON'T ALLOW ME TO USE ADVANCED FRAMING TECHNIQUES."

Following are all of the major optimized framing techniques, with support from the *International Residential Code*® (IRC®), if applicable, cited in brackets.

- **Frame at 24 inches on center**. The prevailing practice among builders is to frame walls, floors and often roofs at 16-inch centers. However, 24-inch centers are structurally adequate for most residential applications. Even when the stud size must be increased from 2x4 to 2x6, changing spacing from 16 to 24 inches can reduce framing lumber significantly. [IRC Table R602.3(5).]
- **Align framing members and use a single top plate.** Double top plates are used principally to distribute loads from framing members that are not aligned above studs and joists. By aligning framing members vertically throughout the structure, the second plate can be eliminated. Plate sections are cleated together using flat plate connectors. For multistory homes that are framed with 2x4s, this may increase the stud size on lower floors to

2x6; however, there is still typically a net decrease in lumber used. [In IRC Section R602.3.2, a single top plate is listed as an acceptable option for in-line framing and with properly tied joints.]

- **Size headers for actual loading conditions**. Headers are often oversized for the structural work that they do. Doubled-up 2x6 (or 4x6) headers end up in nonload-bearing walls. Doubled-up 2x12 (or 4x12) headers end up in all load-bearing walls, regardless of specific loading conditions. "Load-tuned" headers should be in the vocabulary and practice of all engineers, architects, builders and framers. [Section R602.7.2 states that non-bearing walls do not need structural headers.]
- **Ladder block exterior wall intersections.** Where interior partitions intersect exterior walls, three-stud "partition post" or stud-block-stud configurations are typically inserted. Except where expressly engineered, these are unnecessary. Partitions can be nailed either directly to a single exterior wall stud or to flat blocks inserted between studs. This technique is called "ladder blocking" or "ladder framing." This also creates room for more insulation.
- **Use two-stud instead of three-stud corners.** Exterior wall corners are typically framed with three studs. The third stud generally only provides a nailing edge for interior gypsum board and can be eliminated. Drywall clips, a 1x nailer strip or a recycled plastic nailing strip can be used instead. Using drywall clips also reduces opportunities for drywall cracking and nail popping, frequent causes of builder callbacks. [IRC Figure R602.3(2) shows let-in 1x4 bracing in place of sheathing and has a note at the bottom of the page for two-stud corners and drywall clips. The figure also shows "optimized" cripples (on spacing pattern, with no sill support cripples at the jack studs).]
- **Eliminate redundant floor joists.** Double floor joists are often installed unnecessarily below nonload-bearing partitions. Nailing directly to the subfloor provides adequate attachment and support. Partitions parallel to overhead floor or roof framing can be attached to 2x3 or 2x4 flat blocking.
- **Use 2x3s for partitions.** Interior, nonload-bearing partition walls can be framed with 2x3s at 24 inches on-center or 2x4 "flat studs" at 16 inches on-center. [Section R602.5.]

Myth #2: "The frame is just a frame."

Most of us think of the framing in a building envelope as just structural, so the more wood and support that goes in the better. However, since a building is a system, the framing is involved in a lot more than just its structure. The frame is also a key part of the thermal envelope. Every stick or skin of wood (which has an R-value of about 1 per inch) that you can take out and replace with cavity or sheet insulation (with R-3.5+ per inch) represents more than a three-fold improvement in resistance to heat loss or gain. The techniques listed under Myth #1 do not compromise the structural integrity of a home, but yield significant thermal gains, particularly in cold climates.

Myth #3: "The more I attach drywall to wood, the better."

Wrong—since wood and drywall behave quite differently under different thermal and moisture conditions, they do best together if they are attached only where necessary. This is why drywall clips and slotted truss anchors reduce rather than increase the potential for drywall cracking callbacks.

Myth #4: "Wider stud spacing and insulating sheathing make the walls wavy."

Using structural sheathing and tighter stud spacing to try to correct a lumber-quality problem is just throwing good money after bad. Use straight studs to get straight walls (2x6s tend to be much straighter than 2x4s, as do finger-jointed and oriented strand board studs), instead of wasting structural materials to try to hide bad lumber.

Myth #5: "You just can't do optimized framing in high wind and seismic zones."

Building Science Corporation (BSC), in collaboration with the U.S. Army Corps of Engineers Construction Engineering Research Laboratory and Pulte Homes, is developing an innovative new shear panel design that accommodates 24-inch on-center stud spacing, a single top plate and insulated sheathing to provide a resource-efficient, optimized framing solution.

In BSC's basic shear panel configuration, the walls are framed with 2x6s at 24 inches on-center, then a shear panel is fabricated to be inset within a double-stud bay where one stud is omitted, leaving a 4-foot nominal space. The panel is a nominal 4-foot by 8-foot frame made of 2x4s, sheathed in oriented strand board and nailed at the panel perimeter with 8d nails at 4 inches on-center. The frame, which is predrilled at each end of the top and bottom 2x4s, is inserted in the wall framing void over sill-plate anchor bolts. A wall-height threaded rod is then coupled to each anchor bolt with a coupling nut and run up through the top plate and a flat steel bearing plate. Above the plate, the rods are secured with nuts, developing 6,000 to 8,000 pounds of post-tensioning in the rods.

This panel provides 650 pounds per linear foot in 8-foot-high panels or 500 pounds per linear foot in 10-foot-high panels, and dramatically reduces the amount of wood needed to address high lateral-loading conditions.

WHAT CAN CODE OFFICIALS DO?

We need more builders and code officials who are students of building science. Lake County, Illinois, provides a great example. During the development of an early Building America project at Prairie Crossing (near Chicago), the local code prohibited several systems-integrated strategies, including optimized framing. After hearing the systems engineering logic behind the building details and seeing how they were all part of a comprehensive approach to a high-performance home, local officials called for an alternate code to be drawn up. The new code permitted the package of optimized strategies, so long as they were all used.[2] This ensured that the integrity of the systems-thinking inherent in the alternate code was protected.

A building inspector can become a resource for (as much as a regulator of) builders by actively contributing to their education, and code officials can be instrumental in elevating optimized framing from the "exceptions" and "footnotes" currently in the codes to the "better way to build."

The building code community is singularly positioned to be a green light rather than a stop sign for an approach to framing that offers benefits to the builder, the home buyer and the community, both local and global. Use the technical resources listed below to become a local hero—saving builders on their construction costs, improving the local housing stock and conserving natural resources. ◆

Notes

1. Ironically, this is the market economic "reality," whereas the world resource situation is the opposite: we have an ever-increasing abundance of human labor at our disposal while materials grow ever-scarcer and more precious.
2. *Lake County Building Code*, Section 326: "Advanced Energy Efficient and Resource Efficient Single Family Residence Code."

Resources

Building America, *www.eere.energy.gov/buildings/building_america*.

Efficient Wood Use in Residential Construction: A Practical Guide to Saving Wood, Money, and Forests. Ann Edminster and Sami Yassa. National Resources Defense Council, 1998. *www.nrdc.org*.

Energy and Environmental Building Association Builder's Guides. Joseph Lstiburek and Betsy Pettit. *www.eeba.org/mall/builder_guides.asp*.

"Using Wood Efficiently: From Optimizing Design to Minimizing the Dumpster." Stephen Baczek, Peter Yost and Stephanie Finegan. Building Science Corporation, 2002. *www.buildingscience.com/resources/misc/wood_efficiency.pdf*.

***Peter Yost** is Senior Building research Associate with Building Science Corporation (BSC). His experience includes seven years as a builder/remodeler in seacoast New Hampshire, seven years as a senior researcher at the NAHB Research Center (including two years as Director of Resource and Environmental Analysis) and a year-and-a-half as Senior Editor of Environmental Building News. Yost carries this latest experience to BSC, working extensively on editing and writing technical resources for builders and building researchers.*

***Ann Edminster** is an environmental design consultant and educator whose work focuses on the investigation and evaluation of building materials and systems. She is currently co-chairing the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) Rating Program Materials and Resources Technical Advisory Group and chairing the development effort for "LEED Homes"—the Council's green home rating program. Edminster, who holds a master's degree in architecture, has published and spoken widely on resource-efficient building.*

For more information about BSC, write to: Building Science Corporation, 70 Main Street, Westford, MA 01886; phone (978) 589-5100; fax (978) 589-5103; or direct your web browser to *www.buildingscience.com*.

2003 I-Codes Adopt Revolutionary Frost-Protection Technology

by

Dick Morris, Senior Advisor

National Association of Home Builders

Changes to frost-protection requirements adopted in the 2003 *International Codes*™ (I-Codes™) promise a leap forward in construction productivity for commercial and residential construction in Northern climates. Now, foundations constructed in accordance with Structural Engineering Institute/American Society of Civil Engineers (SEI/ASCE) Standard 32-01, Design and Construction of Frost-Protected Shallow Foundations (FPSFs), can be as little as 12- to 16-inches (305–406 mm) deep instead of starting below the design frost line or being built on solid rock. Code recognition of this new technology will speed construction, reduce site disturbance, save energy and lower construction costs. Because FPSFs can be used on heated, semi-heated or unheated structures, their widespread use also promises to improve the frost-protection of churches, schools, commercial and office buildings, warehouses, motels, apartment buildings, and one- and two-family dwellings.

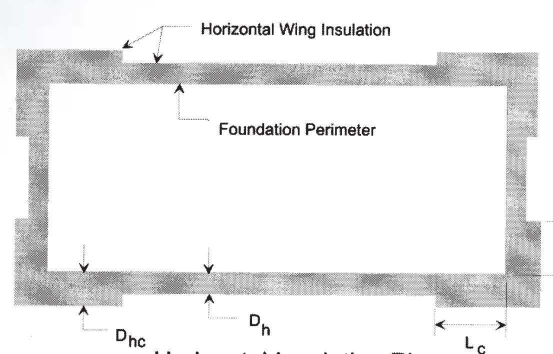
The Council of American Building Officials pioneered the use of this technology in the U.S. by approving FPSF requirements in the 1995 edition of its *One- and Two-Family Dwelling Code*. The International Code Council® (ICC®) went on to approve FPSFs in the 2000 *International Residential Code*® (IRC®), the 2002 *Accumulative Supplement to the I-Codes*™ referenced SEI/ASCE 32-01 in both the IRC and the *International Building Code*® (IBC®), and during its last code revision cycle ICC approved the addition of provisions on FPSFs in the IRC that extend the technology to the remodeling industry and approved the attachment of unheated structures on deep foundations to FPSFs.

With SEI/ASCE 32-01, engineers have a powerful new design tool at their fingertips, allowing them to use FPSF techniques to protect foundations from frost. For example, shallow monolithic slabs, a dominant foundation type in warm climates, can now be used throughout the U.S. Heavy point loads from steel columns can be supported on shallow spread footings, and 16-inch-deep grade beams or thickened edge slabs can support nonload-bearing walls between the columns. Light foundation loads can be supported by the polystyrene insulation itself if the type used has sufficient compressive strength. Type V extruded polystyrene insulation, for example, has an allowable bearing capacity of 4,800 pounds per square foot (234 357 km/m^2): more than the presumptive load-bearing value of sedimentary and foliated rock (IRC Table R401.4.1).

It is important to note that FPSF technology is not recognized by the NFPA 5000 code, which requires foundations to start below the design frost depth and offers no exception for building on solid rock.

New Applications

Although SEI/ASCE 32-01 contains frost-protection requirements for heated, semi-heated and unheated buildings built on slabs, unvented crawl space foundations, walk-out basements, strip walls, posts and piers, IRC prescriptive requirements for FPSFs are currently limited to heated buildings on slabs-on-ground. Heated buildings are considered to be those which have a minimum average monthly indoor temperature of ≥63°F (17.2°C) expected during the intended useful life of the building [semi-heated buildings: > 41°F (5°C) < 63°F; unheated buildings: ≤ 41°F]).



Horizontal Insulation Plan

Basics

FPSFs require slab edge insulation to reduce heat loss to cold ambient air. Wing insulation, which extends horizontally from the base of the slab or grade beam, is required in climates with an Air Freezing Index (AFI) exceeding 2000 (colder than Chicago). Insulation is typically required to be wider at outside corners of buildings than along sidewalls because more heat is drawn into the ground at outside corners. The height of the slab above grade is limited because more area above grade results in more heat lost by the foundation to cold ambient air. As previously noted, the required minimum depth of the foundation is 12 to 16 inches.

A Performance Standard

In many ways, SEI/ASCE 32-01 is a performance standard. It permits designers to:

- use an "approved design . . . supported by engineering analysis" (Section 4.1, paragraph 3);
- substitute nonfrost-susceptible fill for increased foundation depth (Section 4.2);
- vary the height above ground up to 24 inches (610 mm) and the R-value of sub-slab insulation up to R-28 (Table A4);
- eliminate wing insulation along walls and at corners or use corner insulation only by increasing foundation depth or using nonfrost-susceptible fill under the foundation (Table A5); and
- trade off the width and R-value of horizontal wing insulation (Table A6).

Climate Data

The Air Freezing Index is a measure of how cold a climate is, and is used to determine insulation requirements. The 100-year return period value AFI (F100) given by IRC Figure R403.3(2), SEI/ASCE 32-01 Figure A1 or in the far right column of the tables located at *http://lwf.ncdc.noaa.gov/oa/fpsf* (AFIs for over 3,000 U.S. weather stations) may be used. Mean Annual Temperature (MAT) is used in determining insulation requirements for FPSFs for unheated buildings. MAT values can be found in SEI/ASCE 32-01 Figure A2 and the AFI tables appearing on the National Climate Data Center website above.

General Requirements

SEI/ASCE 32-01 Section 4.1 requires that:

- soil and insulation have adequate bearing capacity;
- foundation depth be greater than that required by the

Shopping mall in Trondheim, Norway. Steel columns on insulated spread footings and nonload-bearing walls (grade beams) on FPSFs with insulation on the inner side and under the grade beams. Eliminates the need to protect exterior vertical insulation. Left: Svein Erik Torgersen, Right: Jan Vincent Thue, leading Norwegian FPSF researchers in the early 1970s.

Elementary School near Stockholm, Sweden. Insulated stay-in-place slab edge forms (EPS coated with ½-inch high-strength concrete) and sub-slab insulation under monolithic FPSF. In Scandinavian countries, 2-inch thick insulation, either EPS or XPS, is widely used under concrete slabs to keep the concrete warm for thermal comfort.

Four-story office building near Stockholm. A reinforced FPSF monolithic slab bearing on deep concrete piles spans weak soil between piles.

standard or for adequate bearing (but not less than 12 inches);

- the site be sloped to drain surface water away from the building;
- stone layer under the insulation be drained to daylight or to an approved foundation drainage system, except in naturally draining soil;
- fill material more than 12-inches thick under foundations be compacted;
- termite protection comply with local codes; and
- insulation above grade to 6-inches (152 mm) below grade and any portion of below-grade insulation that extends more than 24 inches from the foundation be protected.

Cold-bridging must be avoided by maintaining the continuity of the insulation (Section 8.4).

Insulation Type

The type of polystyrene insulation used is critical to the performance of FPSFs, which must be insulated with Type II or IX expanded polystyrene (EPS), or Type X, IV, VI, VII or V extruded polystyrene (XPS), as specified in ASTM Standard C578. Required R-values are divided by the resistivity of the particular insulation type in SEI/ASCE 32-01 Table A1 to get the required insulation thickness; nominal (advertised) R-values are not used. Table A1 also lists the allowable bearing capacity and minimum insulation thickness of the various insulation types.

Chapter 5–Simplified Method

1) Find the row in SEI/ASCE 32-01, Chapter 5, Table 4 corresponding to your AFI;
2) read across to the required insulation R-values, vertical and horizontal wing; and
3) divide those values by the effective resistivity of the insulation Type being used (Table A1).

Example: If the AFI is 1500 and the insulation is Type IX, divide the required vertical insulation R-value of 4.5 by the effective resistivity of 3.4 for Type IX vertical to get 1.32 inches. Since 1½ inches is the minimum thickness for vertical Type IX, 1½ inches would be required.

Read further across the row in Table 4 to get the horizontal insulation, sidewall and corner dimensions, and minimum foundation depth. Horizontal wing insulation is only required in climates with an Air Freezing Index of over 2000. The maximum R-value of sub-slab insulation under the Simplified Method is R-10.

Chapter 6–Design Method for Heated Buildings

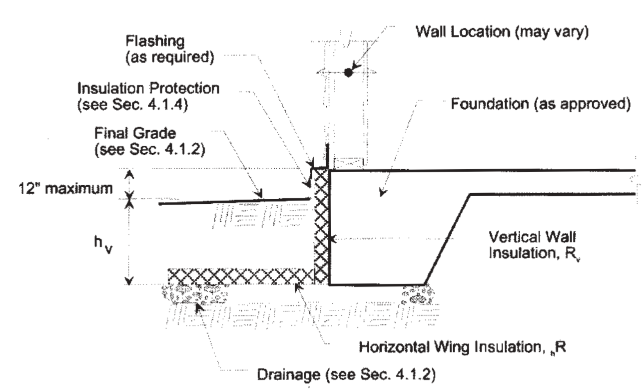
SEI/ASCE 32-01 Chapter 6 has many more design options, each with required R-values that are divided by the resistivity of the insulation type to get the required thickness. Unvented crawl space foundations are designed the same way as slab-on-ground foundations except that the maximum R-value for floor insulation is R-28 and the maximum height from the exterior ground to the underside of the floor is 24 inches. FPSFs for semi-heated buildings (> 41°F < 63°F) are designed in the same manner as FPSFs for heated buildings (> 63°F), but are made 8-inches (203 mm) deeper. Insulation for walk-out basements should normally be on the outside of the foundation, from bottom to top.

Chapter 7–Unheated Buildings

SEI/ASCE 32-01 Chapter 7 contains requirements for slab-on-ground foundations for unheated buildings. Insulation is placed under the entire slab, under the slab edge or grade beam, and horizontally beyond the foundation for several feet, according to Table A8. Find the row corresponding to your AFI. The first column states how far outside the foundation the insulation must extend [between 30 inches and 6 feet (762 mm–1829 mm) in most U.S. locations]. The far right column applies to most U.S. climates and requires R-values of 5.7 to 14.2 [1.5 to 4 inches (38 mm–102 mm) thick for extruded polystyrene]. Section 7.2 shows a similar unheated application for continuous foundation walls, and 7.3 a similar application for column or pier foundations. Section 8.1 contains design requirements for small, unheated areas in otherwise heated buildings.

Other Frost-Protection Requirements in the 2003 IBC and IRC

The 2003 editions of the IBC and IRC exempt freestanding buildings of 400 square feet (37 m) or less in area with eave heights of 10 feet (254 mm) or less if they are accessory buildings (IRC), or if they are in Importance Category I—agricultural, certain temporary facilities or minor storage facilities (IBC). Neither code permits construction on frozen



Insulation Detail

soil unless it is "of a permanent character" (permafrost). Unlike the IBC, Section R403.3 of the IRC contains prescriptive language for FPSFs for heated slab-on-ground buildings.

Unheated Attachments (e.g. Garages, Porches)

New in the 2003 IRC are requirements for the attachment of homes on FPSFs to unheated slab-on-ground structures with deep foundations. In these, the vertical insulation on the FPSF and any horizontal wing insulation required must continue uninterrupted under the garage floor or porch slab as well as through foundation walls of the adjoining structure. Any load on horizontal wing insulation can be carried by using insulation with high compressive strength or by bridging over the insulation with lintels, beams or cantilevers built into the walls of the adjoining structure.

FPSF Additions

Also permitted in the 2003 IRC are heated additions built on FPSFs that are attached to heated buildings. Insulation between the addition and building is not required. In climates over 2000 AFI and where the addition is in line with the outside corner of a building, the vertical and horizontal insulation of the FPSF addition is required to continue onto the existing building a distance equal to the width of horizontal sidewall insulation (dimension A in IRC Table R403.3). ◆

Suggested Plan Review and Inspection Plan Review

- Verify design conditions—heated, semi-heated and unheated spaces.
- Check foundation depths for each type, and depth of nonfrost-susceptible fill.
- Determine ASTM C578 Insulation Type being used.
- Verify Air Freezing Index for the building site.
- Check calculations and verify insulation dimensions, continuity and compressive strength.
- Verify that insulation meets energy code.
- Check drainage plan and termite precautions.

On-Site Inspection

✓Insulation Types (per ASTM C578)
✓Insulation dimensions and continuity
✓Foundation depths and non-frost-susceptible fill depths
✓Distance from top of slab to grade
✓Protection of insulation
✓Termite precautions
✓Drainage

Dick Morris *has been employed with the National Association of Home Builders (NAHB) Construction, Codes and Standards Department since 1988, prior to which he was with the NAHB Research Center, where he initiated research into frost-protected shallow foundations that led to code development in this area.*

Morris served on the consensus committee that wrote SEI/ASCE Standard 32-01, Frost-Protected Shallow Foundations. He now manages the www.NAHB.org *webpage on Frost-Protected Shallow Foundations* (www.nahb.org/reference_list.aspx?section ID=235).

FPSF Requirements Supported by a Half-Century of R&D

The roots of frost-protected shallow foundations (FPSFs) may lie in Frank Lloyd Wright's Usonian houses of the 1930s. Wright used shallow foundations built on rock-filled trenches; in-slab heating provided warmth to the ground and raised the frost-line around the buildings.

World War II saw development of polystyrene foam insulation for flotation devices, and insulation board followed. William Levitt and others popularized slab-on-ground foundations in cold climates. The foundations had perimeter heat ducts which supplied heat to the soil.

In 1947, research by the American Society of Heating and Ventilating Engineers (the predecessor of the American Society of Heating, Refrigeration and Air-conditioning Engineers) showed a "heat bulb" of warm soil that builds up under slab foundations and supplies heat to the perimeter of the foundation. Scandinavian research added polystyrene slab-edge insulation to retain this heat and raise the frost line around buildings. Decades of research, construction and computer modeling led to acceptance of FPSF technology in the Swedish building code in 1968, the Norwegian code in 1972 and the Finnish code in 1978. Well over a million buildings of all types have been built on FPSFs in the Nordic countries over the past half-century.

In the U.S., the NAHB Research Center began exploring the technique in 1984. The Society of the Plastics Industry provided funding for a background study. Later, Peter Steuer worked on behalf of the U.S. Department of Commerce National Oceanic and Atmospheric Administration's National Climatic Data Center to develop Air Freezing Index maps and tables with the Research Center's Jay Crandell. The U.S. Department of Housing and Urban Development then funded the monitoring of five demonstration houses and preparation of a design guide, under lead investigator, Jay Crandell. ◆

by Dr. Nathan Yost, M.D.

The Case for Conditioned, Unvented Crawl Spaces

Prior to the Second World War, crawl space construction in the U.S. was predominately a Southern phenomenon in which houses were elevated several feet above ground, supported by block or stone piers. Damp soil conditions and problems with termites are thought to be the primary reasons for using this foundation method. In the Northern region of the country, crawl spaces were usually limited to portions of the foundation that were located below porches or additions, and often opened into a basement.

During and after WWII, efforts to decrease the cost of foundations and houses led to an increase in the construction of crawl spaces in many parts of the U.S. The majority of these crawl spaces were excavated below the exterior grade and contained air distribution ducts and air handlers. This increase in crawl space construction was quickly followed by reports of moisture problems in the floors above crawl spaces and in the attics of houses with crawl spaces. Moisture problems related to crawl space construction continue to occur in new homes using this type of foundation.

History of Building Code Requirements

Over the past 50 years, building code requirements for crawl space construction have evolved largely in the absence of research or a basis in moisture physics. According to Rose (1994) the first requirement for crawl space ventilation appeared in a 1942 publication by the Federal Housing Administration entitled *Property Standards and Minimum Construction Requirements for Dwellings*. The requirement was for “a total ventilating area equivalent to ½ percent of the enclosed area plus ½ square foot for each 25 lineal feet of wall enclosing that area.”

While working for the Housing and Home Finance Agency, Ralph Britton investigated moisture problems in housing with crawl spaces. He recognized two strategies for controlling crawl space moisture: condensation control by ventilation, and condensation control by ground cover. However, neither Britton nor anyone else at the time determined the relative contributions made by ventilation versus ground cover. The majority of ground covers available during the 1940s and early 1950s were not very durable, so ventilation of crawl spaces was probably recommended even in the presence of a ground cover as a permanent back-up system. By the mid-1950s, the durability of polyethylene sheeting had been proven and many building codes began requiring a ground cover in crawl spaces in addition to venting to the exterior.

Problems with Current Crawl Space Construction

There are three characteristics typical of homes built over crawl spaces and which have moisture problems: excavated crawl space floor without effective drainage, absent or poorly installed ground cover, and exterior venting. Moisture problems and poor indoor air quality continue to affect new buildings constructed over crawl spaces. Some of these problems are the result of poor workmanship and maintenance, but others are the result of poor design and a lack of understanding of moisture dynamics. Ground covers are frequently installed incorrectly in that they are not continuous or sealed to the perimeter walls and piers. The floors of crawl spaces are often irregular and littered with sharp rocks and construction debris so that proper installation of the ground cover is virtually impossible. Subsequent work occurring in the crawl space often results in tears in the ground cover, allowing ground moisture into the crawl space air. Because this under-floor space is not considered “habitable” or “usable,” most crawl spaces are not provided with effective drainage.

Few designers, contractors and homeowners understand the connection between a crawl space and the living space above. Even when insulation is carefully installed to the underside of the floor above a crawl space, effective air-sealing is rarely accomplished. Penetrations for plumbing,

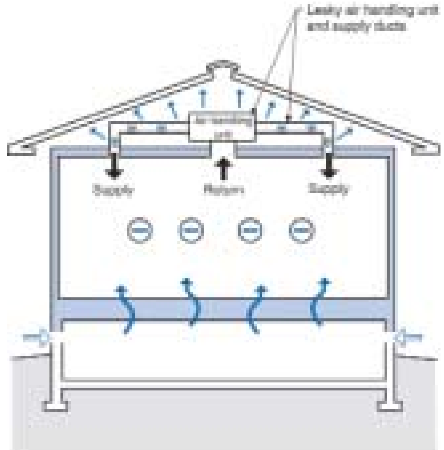


Figure 1: Leaky Ductwork and Air Handler in Vented Attic

- Supply ductwork and air handler leakage is typically 20% or more of the flow through the system

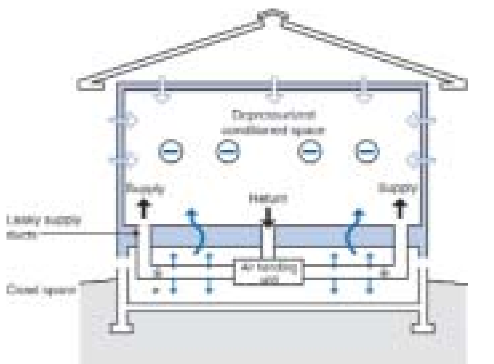


Figure 2: Leaky Supply Ductwork and Air Handler in Vented Crawl Space

- Air pressurization pattern with mechanical system ducts and air handler in the crawl space

wiring and air ducts provide multiple pathways for crawl space air to enter the living space. During heating periods, the "stack effect" can easily draw crawl space air up into the structure above. Leakage from supply ducts in the attic can cause the air pressure inside the house to become lower than that in the crawl space. Because of this pressure differential, air containing moisture and other contaminants from the crawl space can then enter the house. (see Figure 1).

Air distribution ducts and air handlers placed in a crawl space can contribute to moisture problems in several ways. Air ducts, whether metal or flexible, and air-handler cabinets always leak to some degree. They leak a lot when installed in the typical manner, and still leak a little even when conscientiously installed with mastic sealing connections. When supply air ducts leak, the air pressure within a house's living space becomes lower than the pressure in either the attic or the crawl space. Air moves from the crawl space into the living space due to this pressure differential. (See Figure 2)

That crawl space air may contain high levels of moisture, soil gases or mold, depending on soil conditions and the adequacy of the ground cover. Leaky air ducts in a vented crawl space can increase cooling costs by 20–30 percent due to the large volume of unconditioned air that is drawn into the air conditioning system. In addition, the moisture in this air frequently results in high indoor relative humidity, decreasing occupant comfort. Lowering the air conditioner's cooling set point in an attempt to improve comfort not only increases energy consumption but draws even more humid air into the system.

Today, the cooling systems of nearly all houses in the U.S. built over crawl spaces deliver cooled air through ducts located in the crawl spaces. The temperature of these ducts and the subflooring around floor registers is frequently below the dew point of exterior air. Venting these crawl spaces results in condensation on the duct work and on the subflooring around the floor registers. Meticulous sealing of ducts and duct-to-boot or -register connections may still not prevent all condensation. Water plus organic material is a recipe for mold growth, and leakage in the ducts or the floor provides pathways for mold to enter the living space.

Traditionally, the floor above a crawl space was not insulated and the crawl space—especially its ground or floor—was warmed by heat from the house. Insulation installed in the floor over a crawl space decreases the flow of heat from the house, but condensation becomes more of a problem because warm, moist air entering the crawl space contacts colder surfaces. That is to say that insulating the floor above a crawl space separates it from the house thermally, but lack of air sealing still leaves the crawl space coupled with the living space.

Building Science Basics

All residential structures built in the U.S. today should be durable and energy-efficient while providing comfort and good indoor air quality for occupants. Contrary to the opinions of some in the building community, these objectives are not mutually exclusive but in fact go hand-in-hand. Meeting these goals requires controlling the flow of heat, air and moisture—in both its liquid and vapor forms.

Controlling moisture from liquid sources requires effective control of ground water and rainwater. Rainwater must be diverted away from the building through proper drainage; similarly, ground water must also be properly drained and kept out of crawl spaces.

Although attempting to control the diffusion of water vapor through the use of vapor barriers is a common approach, controlling air flow across the building envelope is much more important. Under normal temperatures and conditions, the diffusion of moisture is a slow process. Airflow, however, can quickly deposit large amounts of moisture within a building assembly. Along with moisture, controlling airflow also helps manage the flow of heat and airborne contaminants, making it an essential factor with respect to occupant comfort, indoor air quality and building durability.

There is one major downside to minimizing the flow of heat and air: a reduction in the rate at which building assemblies dry when they get wet. Although every effort should be made to prevent wetting of buildings, it is inevitable that some will occur. As such, building assemblies should be designed not just to minimize wetting, but also to maximize drying of the interior, exterior or both.

Recommended Crawl Space Construction

Local climate conditions should always influence decisions about design, materials and construction methods. From a building science perspective, the two fundamental ways to build a house over a crawl space are unconditioned and vented, with the thermal boundary and the pressure (air) boundary at the bottom of the floor of the living space; or conditioned and unvented, with the thermal and pressure boundaries at the perimeter of the crawl space. There are two major factors to consider when determining which design approach is appropriate. Is duct work or an air handler located in the crawl space, and can the floor of the crawl space be effectively air-sealed at the appropriate time? If under-floor duct work or an air handler is located in the crawl space then a conditioned, unvented crawl space is the preferred method. If no mechanical system is located in the crawl space, then either option will work.

The emphasis is on conditioning the crawl space because when conditioned, there is no need to vent them. Alternatively, when crawl spaces are vented there must be effective air-sealing between the crawl space and the conditioned space above.

Details for a Conditioned, Unvented Crawl Space

The easiest way to understand a conditioned, unvented crawl space is to think of it as a short basement. A crawl space that communicates with the living space should be inhabitable: dry, comfortable and with good air quality. The essential design characteristics, as illustrated in Figure 3, are:

- effective drainage of ground water,
- ground cover that is continuous and sealed to the perimeter walls and piers,
- the installation of insulation to the perimeter walls,
- minimal air leakage to the exterior (effective air-sealing of perimeter walls),
- sealed air-distribution ducts,
- conditioning of the air within the crawl space, and
- the installation of sealed combustion appliances only.

Different materials and methods can be used to accomplish these objectives. For example, a thin concrete slab can be cast over a polyethylene sheet to create a sealed ground

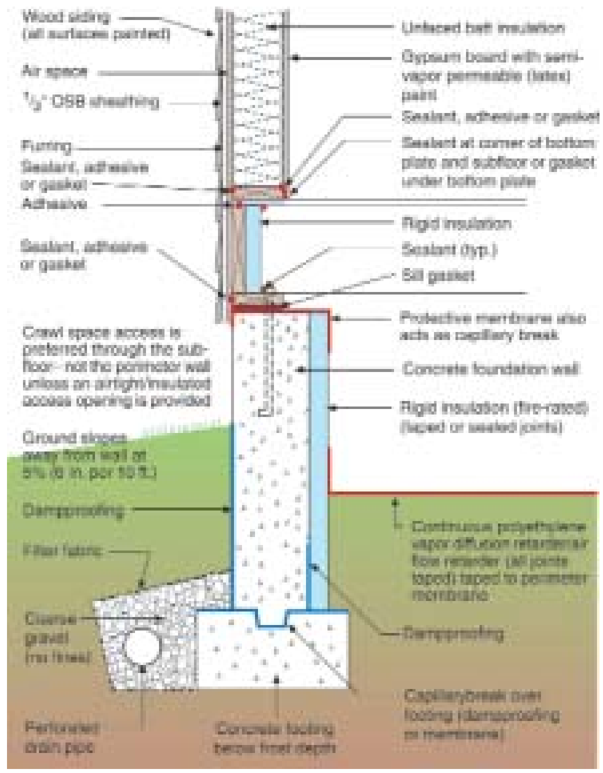


Figure 3: Conditioned, Unvented Crawl Space

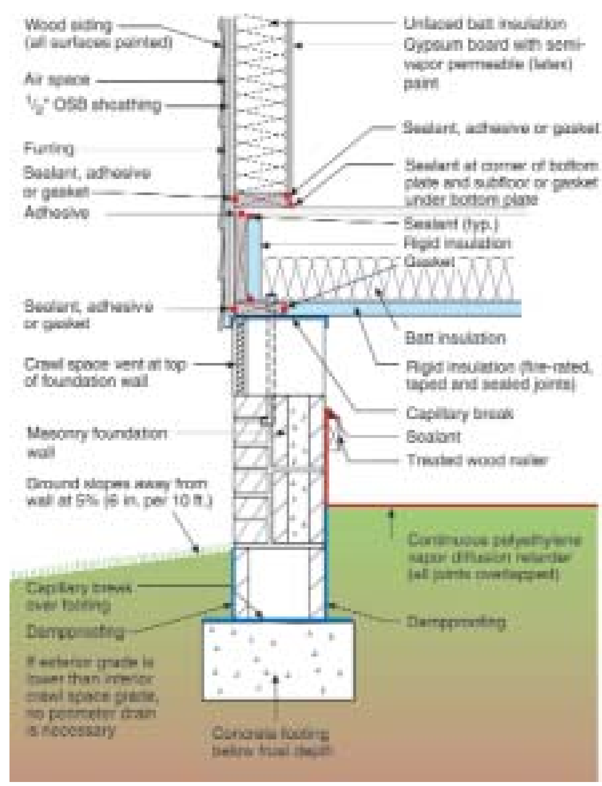


Figure 4: Vented, Unconditioned Crawl Space

cover. Water in construction materials can contribute to moisture problems in crawl spaces, so a low water-to-cement ratio (0.45 or less) is recommended. Concrete with higher water content may require supplemental dehumidification in the crawl space for 6 to 12 months to prevent fungal growth on wood framing.

A small amount of conditioned air can be supplied to the crawl space with passive return through floor registers. Alternatively, air can be continuously exhausted from the crawl space, thus ensuring that soil gases or contaminants in the crawl space do not reach the living space. In this situation, the crawl space will be conditioned by air that moves from the living space because of the pressure differential created by the crawl space exhaust fan.

Details for a Vented, Unconditioned Crawl Space

The easiest way to envision a vented, unconditioned crawl space is to think of it as a house built up on piers, with the building envelope located at the underside of the floor deck. Essential design characteristics, as illustrated in Figure 4, are:

- effective drainage of ground water,
- ground cover that is continuous and sealed to the perimeter walls and piers,
- the installation of insulation under the floor,
- plumbing run within the floor cavity or well insulated,
- all air distribution ducts installed within the floor cavity or in the interior of the structure, and
- a continuous air barrier installed on the underside of the floor framing.

Note that effectively sealing the underside of the floor is difficult to accomplish unless there is adequate clearance between the floor and the ground.

Conclusion

A crawl space foundation is an excellent design when an above-grade floor is desired or when an under-floor space is needed for mechanical systems. The two basic strategies for constructing crawl spaces are to make them unconditioned, vented and effectively separated from the living space; or conditioned, in which case they should be unvented. Control of ground moisture is essential to both strategies, and can be accomplished through foundation drainage and properly installed ground cover.

A conditioned, unvented crawl space is recommended when mechanical systems and air distribution ducts are to be located within the underfloor area. This design minimizes the unintentional introduction of unconditioned air into the air distribution system and reduces the probability of condensation on cold surfaces. Conditioning such crawl spaces serves to provide an energy-efficient, durable foundation system; helps to maintain occupant comfort; and reduces the likelihood of moisture-related problems. ◆

References

Lstiburek, Joe and Betsy Pettit. *Builder’s Guide—Mixed-Humid Climates*. Energy and Environmental Building Association. Westford, MA. 2001.

Rose, W.B. “A Review of the Regulatory and Technical Literature Related to Crawl Space Moisture Control.” *Recommended Practices for Controlling Moisture in Crawl Spaces*. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Atlanta, GA. 1994.

***Dr. Nathan Yost, M.D.**, recently joined Building Science Corporation (BSC), a building and construction consulting firm, after an eclectic career in medicine and construction. He worked in general construction for several years between college and medical school, and has been involved in multiple renovations and additions to his own houses over the past 25 years, as well as periodically working with his brother's construction company. After leaving clinical medicine, he spent 18 months learning about current construction practices and failures and worked as a consultant to the American Lung Association of Ohio's Health House® program.*

Dr. Yost’s work for BSC includes investigating buildings, writing, researching, consulting and educating builders. He has written several articles on mold concerning both how to deal with its presence and, more importantly, how to build houses to prevent moisture and mold problems. His investigations of moisture-related problems in both residential and commercial buildings frequently involve analyzing the interaction between the building envelope and the mechanical systems. As part of the Building America team, he works with production builders to produce energy-efficient, durable, comfortable homes with good indoor air quality.

For more information about BSC, write to: Building Science Corporation, 70 Main Street, Westford, MA 01886; phone (978) 589-5100; fax (978) 589-5103; or direct your web browser to *www.buildingscience.com*.

GREEN ROOFS: A New American Building System

by Charles D. Miller, P.E.

Green roofs, sometimes also referred to as "living" or "vegetated" roofs, are composite systems that combine a waterproofing system with a vegetated-cover system. First popularized in Europe, vegetated roof covers offer a wide range in function and appearance. Green roofs are traditionally divided into two categories: "extensive"—6-inches (152 mm) thick or less, and "intensive"—10-inches (254 mm) thick or more.

Photos courtesy of Roofscapes, Inc.

Benefits

The benefits of green roofs include their capacity to:

- extend the service life of the underlying waterproofing system;
- improve the efficiency of roof insulation;
- reduce rainfall runoff impacts;
- reduce sound reflection and transmission;
- provide urban habitat for birds and plants, thereby improving air quality and the local ecology;
- reduce urban heat-island effects; and
- enhance property values.

Experience in Europe shows that uniformly vegetated extensive green roofs with 3 inches (76 mm) of media provide the highest benefit-to-cost ratio. Improvements associated with thicker and more intensively landscaped systems are marginal.

From a heat-flow perspective, the performance of green roofs as insulators depends greatly on a number of variables, including moisture content and temperature regimen. The physical processes producing the benefit are many and varied, but the general characteristic of green roof materials and foliage is a high capacity to absorb heat (i.e., thermal mass effect). Green roofs generally provide a greater benefit in summer than in the winter. Their capacity to virtually eliminate the daily variation in temperature on the roof deck, however, is a year-round phenomenon that serves to extend roof life by reducing thermal cycling. By way of comparison, green roofs are up to twice as efficient as white or reflective roof surfaces in reducing thermal gain, which is why jurisdictions like the City of Chicago are advancing green roofs for their potential to reduce interior temperatures during the summer.

Green roofs also produce a dramatic reduction in both the quantity of rainfall runoff and the rate of runoff.[1] This benefit has spurred the widespread implementation of green roofs in Germany. On an annual basis, rainfall runoff quantity will be reduced by 60 percent or more in most regions, with a similar reduction in runoff rate. To the extent that green roofs can reduce runoff rate, other devices like stormwater basins, below-grade detention storage, etc., can be reduced in size or eliminated. In urbanized areas the potential savings are three-fold: reduced site-development costs, increased commercial space (which would otherwise be consumed by stormwater detention basins) and lower public infrastructure demands for stormwater mitigation strategies.

Standards and Guidelines

Because the market in the U.S. for green roofs is in its infancy, most Americans are unfamiliar with them. The combination of few companies with extensive installation experience and the large number of different systems now entering the market can make it difficult to obtain good information about green roof systems. Evaluating the claims of different providers and making meaningful comparisons between products can be challenging, especially since there are not yet any accepted standards or measures of performance to reference.

In the absence of American standards, many green roof customers rely on the guidelines and standards developed in Germany. In particular, the detailed standards and guidelines published by FLL[2] cover most aspects of green roof design. These include tests and standards for assessing the root resistance of waterproofing materials, determining the water retention properties of growing media, predicting the maximum weight of green roof systems, ensuring adequate drainage capacity, etc. These standards are most appropriately applied in northern temperate areas of North American. Several groups, most notably ASTM International, are working to adopt standards that will be more broadly applicable throughout the U.S. (see sidebar).

Weight Considerations

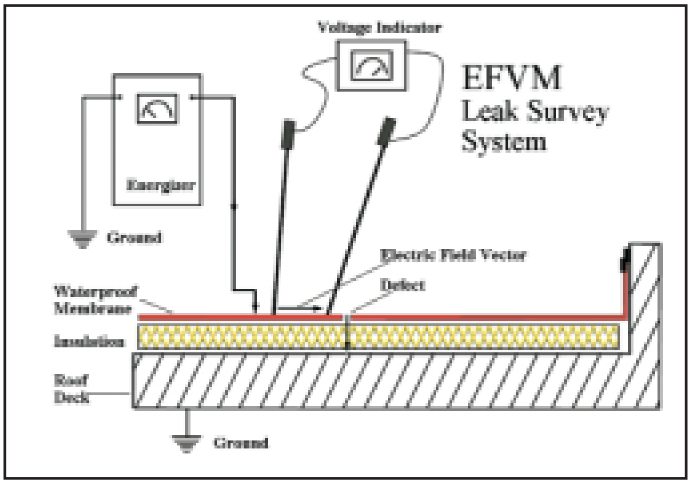
It is not difficult to design green roof systems that have a maximum weight of less than 13 pounds per square foot (36.5 kg/m^2). However, green roofs weighing 18 pounds per square foot (87.9 kg/m^2) or more are most common. Many buildings constructed prior to 1960 incorporated conventional roofing systems that included layers of felt and asphalt topped with stone ballast. Depending on the locality, these roofing systems weigh 10–15 pounds per square foot (48.8–73.2 kg/m^2). As a result, it is often possible to remove existing waterproofing systems and replace them with green roofs without having to resort to structural reinforcement of the roof deck.

The weight of a green roof system includes the weight of all its components. In order of decreasing contribution to overall load, they include the growing medium, plants, water retention, waterproofing, and synthetic components such as fabrics and membranes

The guidelines set forth in the *International Codes*™ treat the weight of a green roof, including all retained moisture, as a dead load. How should this weight be determined in the absence of an American standard procedure? The FLL specifies a laboratory test to assess the maximum weight contributed by the media. The test involves compressing the material into a mold with a 10-pound Proctor hammer, immersing the sample for 24 hours and then draining it briefly before measuring its weight. Due to the conservative nature of this test, I recommend using it to evaluate the structural adequacy of roof structures.

In extensive green roofs the weight of plant foliage, laden with moisture, rarely exceeds 2 pounds per square foot (9.8 kg/m^2). However, when designing intensive green roofs with large shrubs and trees, careful consideration must be given to the mature weight of such plants. During and immediately following rainfall, water will accumulate in the drainage layers of green roofs. This temporary increase in weight might be more appropriately addressed as a live load. However, in green roof design it is usually included in the calculation of dead load. This load factor may vary widely among different green roof systems and should be specified by the system provider. The dead load associated with the green roofs must be added to appropriate live loads such as snow, wind and human foot traffic to evaluate the feasibility of a green roof design. The *International Codes* provide guidelines for assigning these loads appropriately.

(continued)



International Leak Detection Ltd.

Preventing and Detecting Leakage

The issue of leakage involves two separate factors: compatibility between the overlying vegetated cover and the underlying waterproofing materials; and the ability to detect, isolate and repair any problem areas.

Materials used in conjunction with green roofs should be certified for use in waterproofing, as opposed to dampproofing or weatherproofing. Many conventional waterproofing materials are suitable for use in combination with green roof installations. In most instances, however, green roof waterproofing systems will incorporate thicker membranes or multiple layers, and the level of quality control in the installation and testing of the completed waterproofing will generally also be at a higher level. The additional up-front cost is offset by the fact that, once protected with a vegetated cover, the waterproofing system will last for a very long time. How long? No one can be sure, since the oldest examples in Germany and Switzerland are now only about 35 years old. However, when uncovered after 35 years, the underlying waterproofing materials have been found to be in excellent condition. Experienced green roof installers speculate that these systems will last for 50 years or more.

Protection against root penetration is a critical concern. Many otherwise excellent waterproofing materials will not stand up to years of root attack, so a supplemental root-barrier system is essential. Such systems fall into three categories: thermoplastic membranes (e.g., polyethylene), roofing membranes impregnated with root-inhibiting chemicals and copper foils.

Thermoplastic membranes certified for use in Germany as root-barriers are typically about 30 mils thick and have hot-air welded seams. Some American companies offer waterproofing membranes or supplemental root-barriers that have been certified by FLL for root resistance. Copper foils are relatively new in the green roof industry so, once again, since no American standards exist it is a good idea to look to the FLL guidelines.

Should a problem develop, effective methods have been established for locating the source of leakage, even under feet of cover. Electric field vector mapping (EFVM) is a new and powerful tool for improving quality control on waterproofing systems, and is now available in the U.S. Although unfamiliar to most Americans, it has achieved a long record of success in Europe. Unlike most other leak detection methods, EFVM can quickly and accurately locate the point of water entry. Alternative approaches like infrared surveys can determine where water has accumulated in the insulation, but may not be as useful in actually finding the waterproofing defect. The benefits of EFVM can be summarized as follows:

- it can be used after the vegetated cover systems are installed;
- it can be used, to locate defects precisely, enabling efficient repairs;
- because ponding water is not part of the procedure, there is no hazard of overloading structural decks during testing;
- it can be used on steeply sloping roof surfaces where flood testing is impossible; and
- repairs can be tested immediately.

Once the source of leakage has been detected, thin vegetated covers can be removed locally to expose the damaged area and make repairs.

Conclusion

When appropriately designed and constructed, green roofs are extremely durable roofing systems. Hopefully, we will see more widespread acceptance of these systems in the U.S. and the development of appropriate American standards in the near future. Until these systems become more familiar to American builders, however, it is prudent to rely on the standards and guidelines which have been developed in Europe over the past 40 years. ◆

Notes

1. Miller, C, and Pyke, G., *Methodology for the Design of Vegetated Roof Covers*, Proceedings of the 1999 International Water Resource Engineering Conference, American Society of Civil Engineers.
2. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (Landscaping and Landscape Development and Research Society), Richtlinien für die Plannung, Ausführung und Pflege von Dachbegrünung (Guidelines for the Planning, Installation and Maintenance of Green Roofs), 1995.

***Charles D. Miller, P.E.**, is a member of the Technical Advisory Committees for the Center for Green Roof Research at the Pennsylvania State University and the Green Roofs for Healthy Cities Coalition, a Toronto-based research and public policy organization. He is also a member of the ASTM Subcommittee E06.71 on Sustainability, Buildings; and the German Roof-Gardening Association.*

Miller is the founder and president of Roofscapes, Inc., which offers the Roofmeadow® family of green roof systems through its national network of licensed green roof installers. For more information, write to Roofscapes, Inc., at 7114 McCallum Street, Philadelphia, PA 19119; phone (215) 247-8784; fax (215) 247-4659; e-mail cmiller@roofmeadow.com*; or go to* www.roofmeadow.com.

In 2001, ASTM International added a Green Roof Task Group to its Subcommittee E06.71 on Performance of Buildings, Sustainability. The group is charged with the development of a Standard Practice of the Assessment of Green Roofs. The resulting standard is intended to address both technical requirements and considerations for sustainable development.

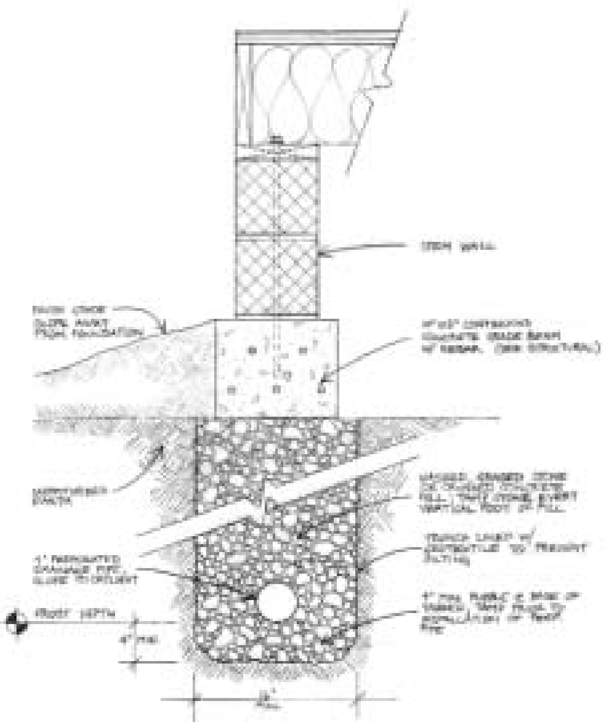
The members of the task group include a cross-section of the green roof industry roofing material specialists, horticulturists and engineers. The group has been using the well-established German FLL guidelines as the foundation for its work, which has recently focused on establishing a technical basis for assessing the performance characteristics of drainage layers and growth media in green roof systems. Particularly challenging is the problem of extending the European knowledge base to encompass the diverse regional conditions across North America. ◆

A 2.5-inch (63.5 mm) deep green roof system installation for The Fencing Academy of Philadelphia. The installation was a retrofit on a modified bituminous membrane waterproofing system.

Rubble Trench Foundations—A Brief Overview

by Sigi Koko

Various forms of rubble trench foundations have been used for thousands of years. For example, earthen walls in the Middle East and Africa are built on top of shallow ditches filled with loose rock. Frank Lloyd Wright came across the rubble trench foundation system around the turn of the 20th Century. He observed the structures to be "perfectly static" with no signs of heaving, and thereafter built consistently with what he termed "dry wall footing." Many time-tested structures stand as testimony to the longevity of the rubble trench.



The Basics

A rubble trench foundation, as its name suggests, is comprised of a continuous trench filled with crushed stone and topped with a grade beam. It is unique in that it provides structural bearing as well as water drainage in one system. The result is a resource-efficient, high-quality, low-cost foundation system.

The trench is typically dug with a backhoe bucket several inches below frost depth and sloped to daylight (or a dry well) for drainage. The trench should have straight sides and a minimum width of 16 inches (406 mm); a wider trench provides additional bearing area if soils do not have adequate bearing capacity. The bottom of the trench is tamped flat and lined with several inches of gravel, on which a standard 4-inch (102 mm) perforated drainpipe is laid. The trench is then filled to grade with gravel, tamping every vertical foot (305 mm) to ensure compaction. The steel-reinforced grade beam is cast directly on the stone fill, and can either support a stem wall and crawl space (see illustration) or become the turned-down edge of a slab-on-grade. The "rubble" fill may be stone or crushed concrete, but in either case it must be washed and should provide a variety of sizes with an average rough diameter of 1.5 inches (38 mm). Where silting-in is of concern, the trench may be lined with a geotextile filter fabric prior to being filled.

Why It Works

The compacted gravel acts both as a "French drain" system as well as a spread footer that provides bearing capacity for the grade beam. The required width of the trench is determined in the same way as that for a standard footing: according to the building loads and bearing capacity of the soil. The reinforced concrete grade beam distributes the building load evenly across the gravel footer. The size of the grade beam and placement of rebar depends on building loads and should be designed by an engineer. For reference, however, a typical single-story residential structure requires approximately a 16-inch wide by 8-inch (203 mm) high grade beam with three continuous lengths of 2-inch (51 mm) rebar. Because the footer itself is literally a drainage way, water cannot settle in or around the structure of the foundation. In the absence of water, there is no opportunity for freeze/thaw cycles to cause detrimental heaving of the grade beam.

Permitting Points

A rubble trench foundation meets the requirements and the intent of U.S. building codes. However, since such systems

BENEFITS

- lower cost than a concrete footing
- uses much less concrete (production of concrete requires a great deal of energy and generates greenhouse gases)
- can use recycled crushed concrete fill
- provides excellent drainage, and thus a "static" foundation system

are not specifically addressed in the current codes, acceptance must be provided on a case-by-case basis. Since this puts permit approval at the discretion of the individual building official, it is recommended that builders initiate a dialogue with the building department prior to applying for a permit. Doing so will provide an opportunity to inform and educate permitting staff as needed and provide adequate information to satisfy their desire to ensure a safe structure. It is further recommended that stamped structural drawings be provided so that the burden of proof is not purely conceptual.

Personal Experiences

My experiences with rubble trench foundations have been generally positive. I typically interact with the permitting office well ahead of time, and have not encountered rejection or delays. In one case, the building inspector required that the structural engineer be present to verify tamping. I met skepticism from only one contractor, but the building permit ultimately appeased him. I have needed to increase the trench width to 24 inches (610 mm) when a 16-inch backhoe bucket proved too difficult to find. (The only impact was the need for additional gravel mix to fill the trench; even with additional gravel, the cost of the foundation was lower than a standard concrete footer would have been.) ◆

Additional Resources

Rob, Tom. “Rocks In Your Shoes,” *The Last Straw Journal*, Issue #16, Fall 1996.

Velonis, Elias. “Rubble Trench Foundations: A Simple, Effective Foundation System for Residential Structures,” *The Best of Fine Homebuilding*. Taunton Press: Newtown, CT, 1997.

***Sigi Koko** is the founding principal of Down to Earth, a design and consulting firm specializing in natural building techniques. She has a Masters of architecture, several years of in-the-field construction experience and has been designing sustainable structures for over 10 years. She has worked to obtain permit approval, write specifications and generate architectural details for strawbale and other "alternate" methods of construction. For more information about Down to Earth, phone (610) 868-6350, e-mail* sigikoko@eartlink.net *or visit the website at* www.buildnaturally.com.

LIMITATIONS

- soils with low bearing capacity may require an extremely wide trench (or some other footing alternative) to achieve adequate bearing area
- not specifically addressed in building codes; requires additional dialogue with permitting officials

STEP-BY-STEP PROCESS FOR RUBBLE TRENCH FOUNDATIO1.

1. Dig 16-inch (406 mm) wide minimum trench to frost depth plus 4 inches (102 mm) and slope to daylight or dry well—1/8 inch (3.175 mm) per foot minimum. Note: centerline of trench aligns with centerline of grade beam.
2. Tamp any disturbed earth in the bottom and line trench with filter fabric geotextile (optional).
3. Layer in 4 inches of stone and tamp. Ensure that surface of gravel fill maintains drainage slope and is at or below frost line.
4. Lay continuous 4-inch perforated drainage pipe.
5. Fill remainder of trench flush to grade with 1½-inch (38 mm) gravel, tamping after every vertical foot (305 mm) of fill.
6. Lay formwork for grade beam and pour, adding steel reinforcing as required.

Integrating Green Building Practices Into the Building Regulatory Process

by Anthony Floyd, AIA, C.B.O., and Edward Peaser, C.B.O.

"Green building," "sustainable architecture" and "environmentally responsible building" are terms we hear when a building is designed and built to reduce energy consumption, improve indoor air quality and limit environmental impacts. Such designs may cause anxiety for building officials due to nonconventional building techniques and potential code-compliance issues, but is important to bear in mind that the alternatives represent a growing recognition of the impact of building design and practices on our health and physical environment. However trite such terms as "green" may threaten to become, the fundamental underlying principle is a comprehensive attempt to address public welfare.

The issue of green building practices addresses a small piece of a large picture, yet it gives us a chance to promote the idea that nothing we do happens in isolation. Connecting building to the local, regional and global environment allows other elements to fall into place within the broader context of energy, resource conservation and environmental impacts.

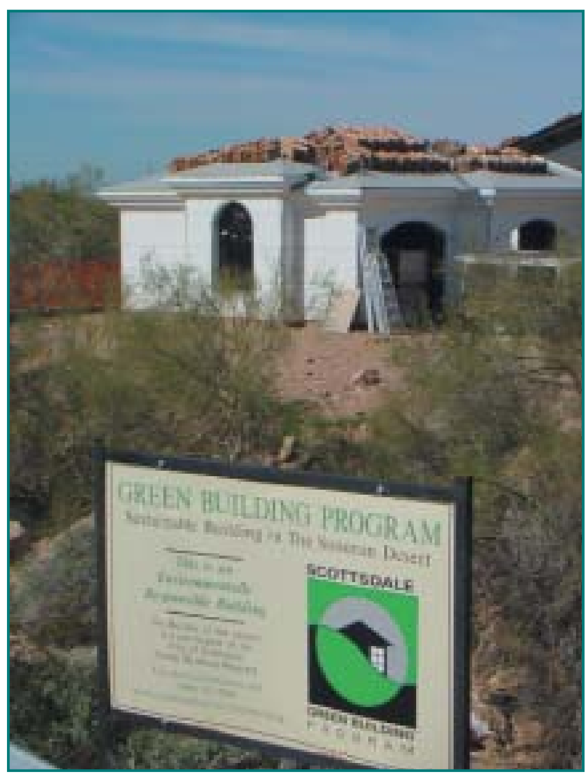
Over the past decade, green building has taken an integrative approach to design and building by addressing energy-efficiency, water conservation, the use of low-impact materials, waste reduction and indoor air quality. Its goal is to provide healthy, durable and environmentally responsible buildings in which to live and work. Regulatory agencies have a vested interest and public obligation to ensure that buildings are designed and built to safeguard life, health, property and public welfare. With continued growth and development, the scope of public welfare is broadening to encompass the welfare of our natural environment, and market incentives—in conjunction with performance standards and certifications—have evolved to substantiate these efforts.

The City of Scottsdale, Arizona, recognizes the environmental implications of natural resource depletion and energy consumption. These issues will increasingly influence the way buildings are built now and into the future, and Scottsdale has made a conscious decision to jump-start the green building regulatory process. The City fully supports and promotes green building, and encourages others to follow suit. This article addresses how the City is integrating green building into its building code regulatory process.

Voluntary Programs in a Regulatory Setting

The City of Austin, Texas, established the first green building program in 1991. There are now close to 20 municipal residential green building programs in the U.S., with at least a dozen more under development. Such programs are designed to reduce the environmental impacts involving energy, water, materials, waste and indoor air quality. The programs are usually voluntary and rely on rating checklists to qualify projects. Incentives are typically offered to attract builder participation, often including some type of development incentive and builder recognition through various marketing tools.

The City of Scottsdale initiated Arizona's first Green Building Program in 1998. It was developed to encourage



environmentally responsible building in the Sonoran Desert region by incorporating healthy, resource- and energy-efficient materials and methods in the design and construction of homes. The program's goals are to reduce the environmental impact of building; achieve both short and long-term savings of energy, water and other natural resources; and encourage a healthier indoor environment.

Scottsdale's program is strictly voluntary and uses incentives in the forms of builder recognition and expedited plan review to entice builder/developer participation. A conscious effort has been made to promote the program to the construction and home-buying communities through publications and public activities. Promotional materials include brochures, building-strategy handouts, job site signs, a directory of participating builders and designers, green building home certificates, and a homeowner's manual. A monthly lecture series is provided covering such topics as energy conservation, alternative materials, water conservation and indoor air quality. With the help of the City Green Building Advisory Committee the program also hosts other events, including an Annual Green Building Expo and Home Tour. The City also has a green building website (*www.scottsdaleaz.gov/greenbuilding*) that contains program criteria, builder profiles, upcoming events and links to other environmental building resources.

To qualify, a project must meet a set number of prerequisites and score a minimum number of points from a rating worksheet. The worksheet was developed by the City Green Building Advisory Committee, which consists of representatives from the building community, utility companies, product manufacturers and Arizona State University. The worksheet rates homes in the areas of site use, water and energy consumption, building materials, solid waste production, and indoor air quality. The designer or builder can select from a checklist of green building options to achieve a rating of either "entry level" or "advanced level."

By the end of 2002, 79 builders had submitted 183 projects for building permits under Scottsdale's program. The projects exhibited a wide range of construction strategies and materials, ranging from standard wood construction to hybrid systems, using innovative products such as insulated concrete form systems, masonry walls with integral insulation, foam structural panels, pumice concrete, cast-earth, straw bale and super-insulated frame construction.

The decision to integrate green building into the plan review and inspection process was initiated as a result of limited staff resources. The green building program previously functioned with two staff members devoted exclusively to green building. As the success of the program grew, it became increasingly difficult to keep up with project qualifications, inspections and outreach. When general building permit activity slowed as the result of a generally sluggish economy, a window of opportunity opened to involve plan review and inspection in the green building process. Recognizing the growing interest of staff, the building official and inspection manager embraced the idea of integrating green building and making it a tool for learning about building trends.

In fall of 2002, Scottsdale's building plan review and inspection units began reviewing and inspecting projects for conformance to the City's green building guidelines. The program is still voluntary, but requires that participating builders adhere to program guidelines from start to finish. This protects the benefits and interests of both the homeowner and builder, while supporting the credibility and long-term goals of the program.

Integration into the Regulatory Process

Why integrate a non-regulatory program into a legislative infrastructure? First, the City of Scottsdale believes that green building is a growing trend and wants to be prepared for the inevitable. From our experience, we have noticed that many builders decide to participate in the green building program because they are already implementing many of its energy conservation strategies as a result of the competitive building market. Because of the City's program incentives, most of these builders are willing to go even further by incorporating the additional criteria involving water conservation, the use of low-impact materials, waste reduction and indoor environmental quality.

Plan review and inspections are key. Without oversight, builders are not always consistent in their applications of the program criteria. Integrating green building into the plan review and inspection process also educates plan reviewers and inspectors on trends involving building strategies and alternate materials and methods of construction. It also serves to build the confidence of the citizens of Scottsdale in the City's concern for the long-term health and viability of the community.

Project Qualification and Plan Review

Once an owner or builder decides to participate in the Scottsdale Green Building Program, a project qualification meeting is required prior to making a formal application for plan review permitting. Applicants complete a green building checklist and enrollment form prior to the meeting. The checklist is used to rate the project based on accumulated point values from 161 options. In addition, the project must include 26 mandatory items. Either the green building manager or one of two designated building plan reviewers can conduct the meeting.

The meeting not only qualifies a project into the program but also helps to resolve potential code-compliance issues. This in turn helps streamline the expedited plan review process offered as an incentive for participation in the program.

Once the project is submitted for review at the Plan Review/Permit Services counter, it is given a “green building designation” as part of the plan review/permit tracking system. This puts the project on the expedited plan review track, which means that the plans will go through the initial building, planning, fire and civil engineering review process in about half the time (two weeks) as a regular project. As part of the process, the plans are reviewed for conformance with the 26 mandatory green building checklist items. These requirements must be fully integrated into the notes and details of the plans. The green building checklist options must also be listed in the plan set.

Inspections

In 1999, the City of Scottsdale hired Arizona’s first green building inspector. This position was dedicated exclusively to green building and did not involve code inspections. By 2002, the building inspection unit took over the responsibility of inspecting green buildings for compliance with program guidelines. A lead building inspector was selected from a recruitment list of four inspectors who applied for the special assignment. After training over a six-month period, the lead inspector became responsible for training Scottsdale’s remaining inspectors. Once training is complete, each inspector is responsible for green building projects in his or her respective inspection area.

Green Building Inspectors on a job site.

The Building Inspection Manager identified key green building categories and subcategories for integration into the City’s automated inspection request system. The 26 mandatory green building requirements and 14 optional categories were then assigned inspection numbers (see Table 1). A total of 40 green building inspection types were identified and aligned with the code compliance inspection types. This system allows the builder to request the necessary green building inspection at the appropriate stage of construction.

When a green building permit is issued, a census code is used to notify the responsible inspector, allowing him or her to establish contact with the builder regarding the inspection process and procedures. This has proven extremely beneficial for both the builders and the inspectors, fostering a level of comfort on the part of builders with the knowledge that they can contact their inspector whenever necessary.

(continued)

Table 1. Green Building Inspection Categories.

Insp. No.	Category
121-199	Mandatory Requirements
205	Site Use Options
225	Structural Element Options
240	Building Envelope Options
265	Insulation Content Options
275	HVAC Options
290	Indoor Air Quality Options
305	Electrical Power, Lighting & Appliances Options
325	Plumbing System Options
340	Roofing Options
350	Exterior Finish Options
365	Interior Finish Options
375	Doors, Cabinetry & Trim Options
390	Finish Floor Options
405	Pool & Spa Options
415	Solid Waste Options
425	Special Options

The inspectors also have the ability to make field changes if it becomes apparent that a chosen green building option cannot be met. The inspector reviews the checklist of available options with the builder in order to find another item of similar point value and makes the necessary changes to the green building documents. This allows the builder to continue construction under program guidelines without the need to go through the plan review process again.

Unfortunately, some participating builders have used the green building program to get expedited plan review and permitting, only to fail to comply with program guidelines during construction. In order to resolve this type of situation, the building inspector has the authority to issue a Stop Construction Notice until the construction plans are revised to remove green building checklist items. This requires that the plans be resubmitted for review, which can take up to three additional weeks. As an added deterrent, a double-hourly plan review fee is assessed. Thanks to this policy and the continued education of builders by City staff, the withdrawal rate has fallen dramatically.

By integrating green building into the automated inspection system, paperwork is reduced by 80 percent and a complete history of both code compliance and green building inspections are recorded. In addition, all requested inspections for both green building and code compliance are able to be performed within 24 hours. Finally, when all of the required inspections are approved, a Certificate of Occupancy is issued stating that the building complies with Scottsdale's Green Building Program standards.

Plan Review

Once an applicant qualifies, the plans and required documents are submitted to the Plan Review/Permit Services counter.

- Plans are reviewed for mandatory green building checklist items.
- The full checklist is required to be listed on the construction plans.

Project Qualification/Pre-application Meeting

Prior to completion of construction documents, applicants must schedule a meeting with green building staff. The following documents must be completed for each project:

- Enrollment form and builder's agreement.
- Rating worksheet (checklist required on plans).
- A green building inspection manual is created and filed.

Building Permit and Inspections

Upon approval of plans, a building permit is issued with a green building inspection manual and designation.

- The project must follow the green building inspection sequence.
- Projects not able to maintain qualification as a green building will be forced to stop work until plans are resubmitted with revisions as non-participating projects. Plan revisions are also subject to additional review fees.

Certificate of Occupancy

After successful final inspection, a Certificate of Occupancy is issued with green building designation.

- The green building inspection manual is returned to administrative staff.
- Builder and project owner packets are compiled and mailed.

Figure 1. The Green Building process.

To our knowledge, no other city in the U.S. has an automated green building inspection request program with a full staff of building inspectors performing green building inspections. Nor are we aware of any jurisdiction that issues a Certificate of Occupancy with a green building designation.

Summary

Arizona does not currently have an energy code but as a "home rule" State, local jurisdictions maintain a significant amount of autonomy. Scottsdale attempted to adopt an energy code in the early 1990s, but was unsuccessful due to the political climate of the building industry at the time. Fortunately, the situation has improved and the City is now preparing for the adoption of the 2003 *International Energy Conservation Code®* (IECC®). Integrating the provisions of the IECC into the existing building code will result in mandating most of the energy provisions that are now part of the voluntary green building program. It is expected that this will create a greater synergy for the integration of other green building standards into the regulatory process.

As we continue the process of integration, we will face some challenges. The first will be to maintain a proactive and open-minded attitude toward alternate building practices. Meeting this challenge will require a thorough understanding of the intents of both the building code and specific green building guidelines in order to minimize conflicts. Having a green building specialist on staff will certainly help in this area. The second challenge involves the prescriptive nature of the green building rating checklist. As with any checklist, the intended effect could be compromised if careful consideration is not given to how one component may affect another. For instance, selecting strategies for well-insulated walls in conjunction with low-performance windows will minimize overall energy performance. The adoption of energy and performance-based codes can be of significant benefit, but a good understanding of the integrative approach is paramount.

Building departments are often reluctant to embrace unconventional materials and methods of construction. However, by undertaking a comprehensive view of the built environment, proposed projects can be evaluated within the context of sustainability without sacrificing health- and life-safety standards. Fortunately, there is an ever-increasing number of sources for information regarding environmentally responsible building systems, materials and products. Green building programs around the country have certainly helped lay the foundation, and the next-generation building codes are helping bridge the sustainability gap by taking a life-cycle approach. Moving forward, we must also look to utilize historically proven solutions exhibited in indigenous building systems around the world.

Building codes and standards are a critical part of the technical framework by which the built environment takes its form. Code agencies and standards bodies can help clarify the scope of building regulation as sustainability becomes a reality in the development process by improving provisions for health- and life-safety in the broader context of public welfare. The intent of specific code provisions and standards may vary, but they must ultimately be in alignment with principles that encompass a comprehensive and integrative approach in the design and construction of the built environment. Today, this stands as perhaps the greatest challenge, and opportunity, for every building regulatory agency and jurisdiction in the U.S. and around the globe. ◆

Acknowledgments

The authors would like to thank the following individuals who have been vital to Scottsdale's green building integration process: Dave Potter, Building Official; Pedro Anzures, Building Inspector; Darrell Morrison, Plans Examiner; Michelle Dalton, Systems Integrator; and Sara Uribe, Green Building Assistant.

***Anthony Floyd, AIA, C.B.O.**, is a registered architect and former building official for the City of Scottsdale. As Scottsdale's Sustainable Building Manager, he oversees its Green Building Program and serves as resident authority on sustainable building practices. Floyd is a past President of the Arizona Chapter of ICBO and serves on the Board of Governors of the World Organization of Building Officials.*

***Edward Peaser, C.B.O.**, is a certified building official and has served as Building Inspection Manager for the City of Scottsdale since 1997. He has worked for the City in several capacities since 1984, including as a building inspector and building inspector supervisor. Peaser is a certified building, electrical, mechanical, plumbing and combination inspector. He is also an instructor of the* International Codes™ *at Scottsdale Community College.*