various surface treatments; it may require protective boards during construction. All types of rigid foam insulation gradually lose their insulating value over time, and the *R* values used in thermal analysis should be based on "aged" properties rather than on initial ones.

Polystyrene insulation is available in two types: expanded polystyrene ("bead boards"), an open-cell material sometimes specified for perimeter foundation protection, and extruded polystyrene used as wall and roof insulation. Extruded polystyrene, found among other things in disposable coffee cups, has a closed-cell composition with better vapor-retarding properties than an open-cell variety. Expanded polystyrene is water-permeable and for this reason is generally avoided in roof applications. However, water permeability makes it appropriate for some wall systems, such as EIFS.

Major advantages of extruded polystyrene include an *R* value of 5.0 or slightly higher and a compressive strength of 30 to 40 lb/in^2. Being combustible counts as its chief disadvantage.

Polyisocyanurate insulation, essentially a modified urethane foam, has a major advantage of being fire-resistant. It is more thermally efficient than polystyrene, with *R* values ranging from 5.8 to 7.2. However, it is also more compressible and friable than polystyrene and less water-resistant. Therefore, polyisocyanurates are normally covered with facing materials and are heavily dependent upon them for stability and moisture resistance. If the facers delaminate, the insulation is endangered. Unfortunately, this problem is far too common, especially with thicker boards.[5] There is also a question about the insulation's coefficient of thermal expansion and contraction, which apparently is quite high.

Polyiso insulation, as it is known, is less expensive to install than either extruded or expanded polystyrene and, also being more efficient, produces a much larger return on investment than polystyrene. This fact undoubtedly helps explain the fact that polyisocyanurate insulation is used in one-half of all new commercial construction.[6]

One of the most popular polyisocyanurate products is Thermax* by the Celotex Corporation. Thermax consists of a glass fiber-reinforced polyisocyanurate foam plastic core with aluminum foil facing on each side. The facings come in a variety of finishes: exposed facings often receive embossed white finish, while the concealed side normally has a reflective foil finish. The available insulation thicknesses range from 1/2 to 3 in; the standard panel width is 4 ft. Thermax was specifically designed to dampen the noise due to movement of standing-seam roofs.[7]

A new product called Nailboard, produced by NRG Barriers of Portland, Maine, uses polyiso insulation with bonded sheets of oriented-strand board 7/16 or 5/8 in thick. The product provides a nailable surface for roofing and eliminates damage to insulation during handling and erection.

Phenolic insulation boasts the highest *R* value of all foam boards, about 8.3 per inch,[5] as well as excellent fire resistance. It is more expensive than the other products and is reserved for the most demanding applications. Phenolic insulation may require an overlayment board for protection. Recently, phenolic foam insulation has been linked with accelerated corrosion of steel roof deck and should be specified with caution.

8.3.3 Foam-Core Sandwich Panels

Preinsulated panels discussed in Chap. 7 can incorporate either rigid or fiberglass insulation. Rigid-insulation foam is usually sprayed between the metal faces and allowed to "bubble" and expand, filling all the corrugations (Fig. 8.1*c*). The fiberglass is simply inserted between the sheets. Either way, the panels offer excellent *R* values but obviously lack the acoustical performance of exposed fiberglass. A typical panel with 2 in of urethane or isocyanurate foam core may have a *U* factor of 0.06 and weigh only 2 1/2 lb/ft^2; a 6-in-thick panel may have a *U* factor of about 0.02.[8]

8.3.4 Spray-on Cellulose

Cellulose, a paper product often treated with fire retardants, is brought to a sprayable form by addition of liquid binders (Fig. 8.1*d*). Low cost and good noise absorption are about the only advantages

*Thermax is a registered trademark of the Celotex Corporation.

of this material. Its disadvantages are many and include limited *R* value, lack of vapor retardance, and rough appearance; it can collect dust, absorb moisture and oily residues, and precipitate corrosion of metal surfaces.

Spray-on cellulose should conform to ASTM D 1042, type II, class (a)[9] and should not contain asbestos, crack, or lose bond with the substrate. The applicator's skill is critical for successful installation.

Recently, spray-in-place polyicynene foam insulation was introduced. This soft-foam insulation shows great promise, clearly outperforming cellulose. Spray-in-place foam can be trimmed after curing to provide a relatively flat interior surface.[8]

8.3.5 Choosing Type and Thickness

The process of insulation selection starts with determination of code-mandated *U* values and moves in concert with the wall and roof design. (A list of *U* values for several most popular wall assemblies is included in Sec. 8.6.) Apart from satisfying the minimum requirements, the insulation thickness should be substantial enough to prevent condensation on the facing by keeping its temperature above the dew point. The acoustical performance, appearance, and cost should also be considered. Fire-hazard classification rating determined by a flame-spread test could eliminate some insulation choices from the beginning. As already noted, polyisocyanurate insulation is heavily dependent on its facers for stability, and if the facers delaminate for some reason, it loses its dimensional stability. In contrast, the slightly more expensive extruded polystyrene retains its properties in wet condition.

Fiberglass blanket insulation with an appropriate facing often provides the best overall performance and is almost exclusively specified for metal building roofs. Selection of wall insulation is closely tied to wall system design and fire-rating requirements.

8.4 VAPOR RETARDERS

As mentioned above, the main function of a vapor retarder is to slow down the flow of moisture through a roof or wall assembly. (Another function is to reduce the flow of *air,* as explained below.) No known material is a true vapor barrier that completely stops passage of moisture, but some vapor retarders can slow the process better than others because of lower *permeability,* or permeance.

Permeability is measured in *perms* in the British system (a perm is 1 grain of water transmitted per hour per square foot for 1 inch of mercury vapor pressure differential) or in nanograms per pascal per second per square meter in SI. (One grain is $\frac{1}{7000}$ pound.) One perm equals 57.2 nanograms per pascal per second per square meter.

The rate of water vapor flow is equal to the vapor pressure difference on two sides of the material times its vapor permeance. The lower the permeance, the more effective the vapor retarder is. The perm ratings of commonly used vapor retarders range from 1.0 for a basic vinyl to 0.02 for such top-of-the-line composite materials as foil/scrim/kraft, metallized polypropylene/scrim/kraft, vinyl/scrim/foil, polypropylene/scrim/foil, and vinyl/scrim/metallized polyester.

In order to select an appropriate facing material, one needs to assess the amount of moisture likely to be generated within the building and compare it with the annual temperature and humidity conditions in the area. Factors like appearance, resistance to abuse, and cost are then considered. Some occupancies may impose additional requirements on vapor retarders such as noise reduction or low emissivity. Wherever chemical fumes are released—chemical plants, laboratories, poultry farms, steel mills, and the like—a special chemical analysis may be needed. Consulting a manufacturer is recommended for critical applications. Among the industry leaders in vapor retarders are Lamtec Corporation of Flanders, New Jersey; Vytech Industries, Inc., of Anderson, South Carolina; Thermal Design, Inc., of Madison, Nebraska; and Rexam Performance Products, Inc., of Stamford, Connecticut.

White-colored materials are popular because of their high light reflectance, a desirable quality for ceilings. Some abuse-resistant insulation facings such as those marketed by Lamtec Corp. tout their toughness; these products aim to compete with interior-wall panel liners and gypsum board.