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A Systems Approach to Cold Climate Housing

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This publication provides a brief overview of a systems approach to housing construction. Numerous other publications that deal with understanding and preventing potential problems in houses are available from the Cold Climate Housing Information Center. For information on available titles, contact your local county extension office or the Cold Climate Center directly at the address given on the last page of this publication.

In the United States, extreme cold climates are restricted to the northwest tier of states, Alaska, and locations with high elevation. Throughout much of the northern half of the United States, however, winters are sufficiently cold to warrant special consideration in the design and construction of housing structures (see Figure 1).

A Systems Approach

It is increasingly recognized that buildings (particularly those located in cold climates) must be designed from a systems point of view. Experience with tight, highly energy-efficient buildings in recent years has heightened the awareness of the importance of indoor air quality, ventilation, moisture control, and quality of workmanship and materials in construction. Many leading builders and building designers now are aware that actions intended to influence one aspect of a building can significantly and broadly impact building operation and performance. This realization has led to a growing interest in the treatment of buildings and their components as integral systems.

A systems approach for houses in cold climate areas not only provides comfort, but can result in low maintenance and energy economy too. All of the features

listed below are present in a house designed to function as a total system. Figure 2 further illustrates these features.

- ☐ A ground moisture control system
- ☐ Full coverage, interior-side vapor retarder or vapor barrier
- ☐ An air-barrier or air-retarder system
- ☐ Carefully installed insulation
- ☐ Full coverage, exterior wind barrier
- ☐ Condensation-resistant windows and doors
- ☐ Fan-powered exhaust and supply ventilation
- ☐ Safe, efficient combustion systems

Owners of houses in cold climates that are not designed and built from a systems point of view frequently experience problems such as wet basements, cold drafts, high heating bills, excessive interior humidity, condensation on windows, wet insulation, and moisture damage to the structure. Moisture damage can include staining, peeling paint, mold growth, disintegrating plaster, warping and buckling siding, binding windows, rusting nails, dissolving resins and glues, and decaying wood. Maintenance and repair costs related to uncontrolled moisture can be particularly high. At the other extreme, some houses are very dry, causing discomfort for occupants and dimensional shrinkage in various types of wood products.

In houses that are well sealed to prevent air leakage, inattention to one or more features of the housing system can lead to further problems. For example, use of a natural draft (atmospheric) fuel-burning furnace, water heater, or fireplace in a tightly sealed house can result in poor chimney draft and incomplete combustion of fuel, causing release of dangerous fumes. In some cases, exhaust gases may be pulled back into the house as make-up air for combustion appliances. The relation between airtightness and problems with draft and combustion is extremely complex.

The Cold Climate Housing Information Center is a part of the Minnesota Cold Climate Building Research Center, and is administered through the Minnesota Extension Service.

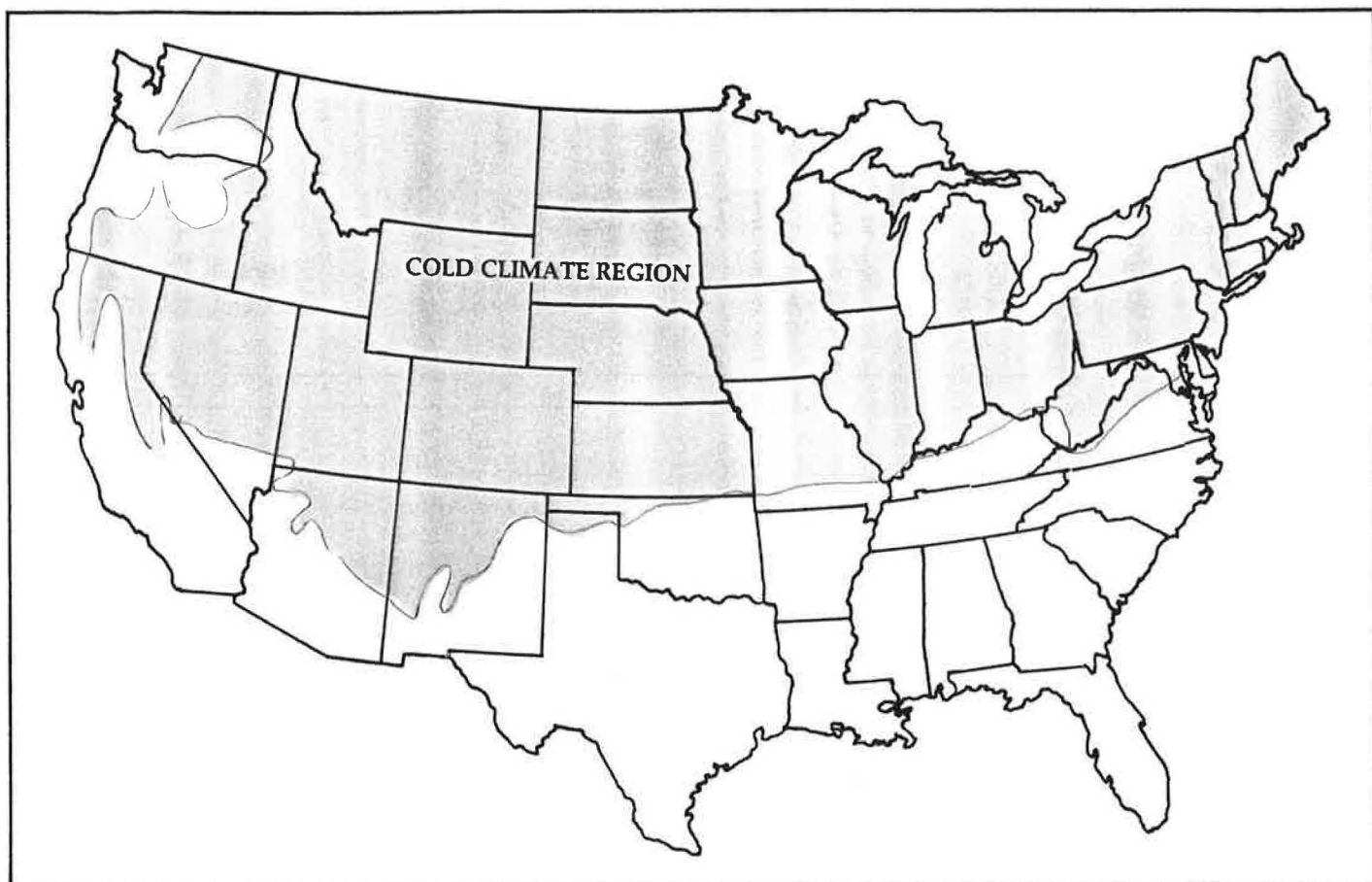


Figure 1 The cold climate region, where January temperatures average 35°F or lower. Winter condensation problems are common in houses located in this region.

The Evolution of Cold Climate Housing Problems

Prior to the energy crisis of the 1970s, most houses leaked air freely at random points throughout the structure. The continuous airflow dispersed interior moisture rapidly and kept indoor humidity at a relatively low level during the winter. Such houses tended to be uncomfortably dry and large amounts of heating fuel were consumed in maintaining warmth. In many of these houses homeowners frequently experienced problems such as cold drafts in living spaces and leakage of heated air into poorly ventilated attics. The latter problem then caused snow to melt on roofs, then refreeze at the eaves, which in turn caused water backup behind the ice and seepage through the roofs. In other houses, despite being uncomfortable and wasting heating fuel, few maintenance-related problems were experienced.

In the 1970s, heating fuel costs increased considerably and homeowners began to weatherize their houses more effectively to conserve fuel. Insulation was added, improved windows were installed, and leaks around windows and doors were sealed. Although fuel bills were

reduced, a side effect of improvements in some homes was an increase in the occurrence of maintenance-related problems. As homeowners methodically tightened their dwellings in order to save energy, they also systematically reduced the margin for error within their homes.

In some houses, moisture problems increased following weatherization efforts because of inattention to control of humidity and condensation; molds developed on the interior side of the outside walls and corners, and condensed moisture caused deterioration within walls whose ability to dry out was severely reduced by loss of air circulation from added insulation. In a few homes, furnaces that had always had sufficient make-up air as a result of leaks in the structure, now drew air from less desired sources (such as chimneys). In still other homes, a number of steps were taken to conserve energy, with no apparent effect on other aspects of building performance. Then, following one or two additional, and relatively minor, weatherizing steps, a host of problems began to show up. In these homes the margin for error was reduced gradually with each action to tighten them, until one or two final changes tipped the balance. As reports of problems increased, it became obvious that steps to

tighten a house should include consideration of a number of factors.

Before going further, it is important for the reader to understand that the types of problems already discussed have occurred in only some houses following weatherization improvements. In most houses, few or no problems have been experienced as a result of weatherization.

Home Improvements and Moisture Management

It is now recognized that a new "tight house" must have such improvements as a ground moisture control system, full coverage vapor retarders for insulated areas

and an air-barrier system, well-insulated window units, and mechanical ventilation to remove excess moisture and/or indoor air pollutants. On the other hand, a tightened "older house" may need only some of these improvements. These improvements are generally discussed in the text that follows.

Weather-Driven Air Supply versus Fan-Powered Ventilation

Both weather-driven air infiltration and fan-powered ventilation provide air movement through a house, but which is most efficient? In cold weather, all air passing through a house must be heated. Passage of unneeded or excessive air only adds to heating costs. Weather-driven infiltration depends on the randomness of the wind and outside temperatures, and it occurs at randomly located

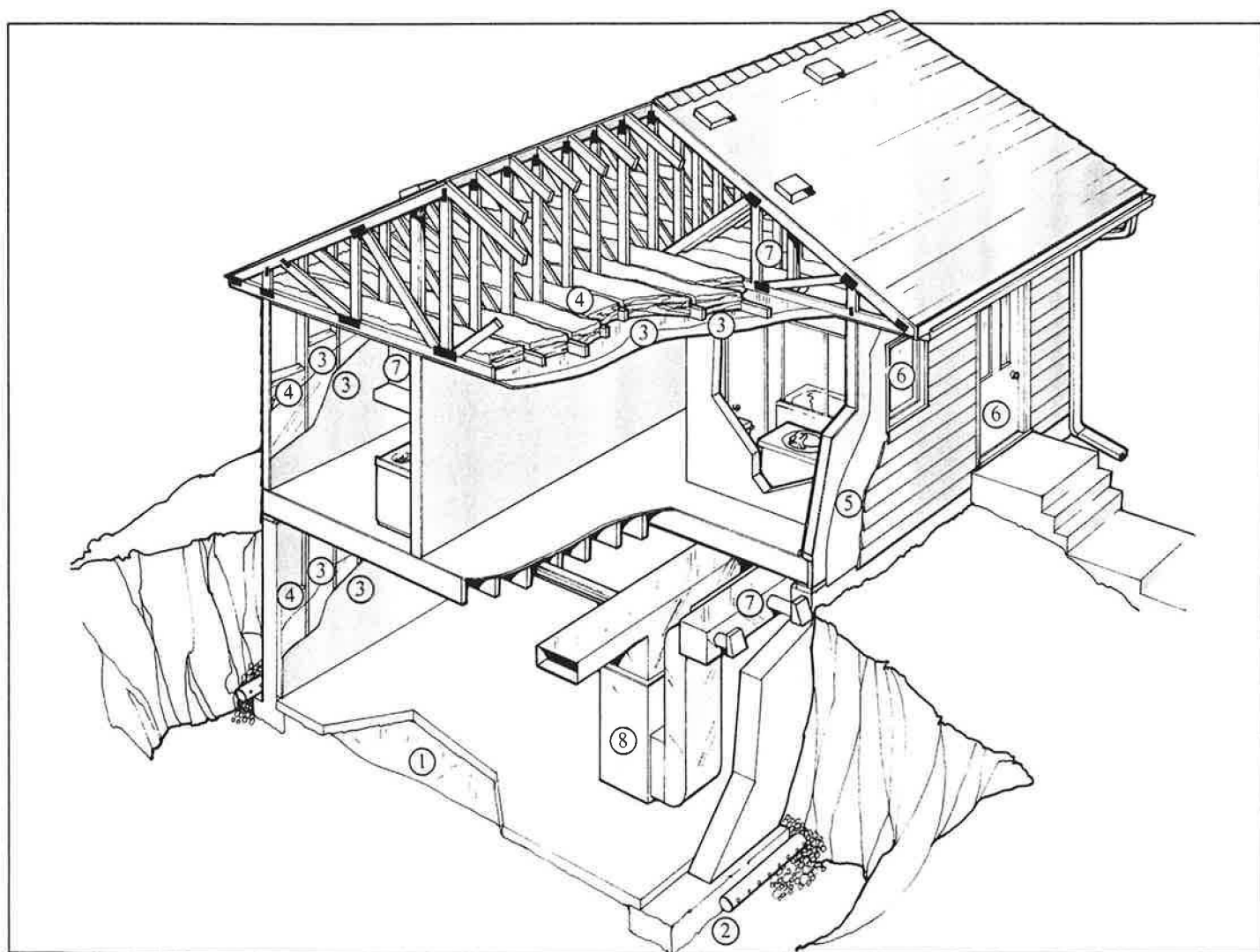


Figure 2 A house designed to function as an energy-efficient system in cold climates includes a ground moisture control system (1,2), full coverage, interior-side vapor retarder and air-barrier system (3), carefully installed insulation (4), a full coverage wind barrier (5), condensation-resistant doors and windows (6), fan-powered exhaust and supply ventilation (7), and a safe, efficient heat source (8).

cracks and holes. Infiltration is not reliable or controllable—the amount of air change is often too much or too little. Weather-driven infiltration can vary by a factor of 20 depending on the severity of the weather. Cold drafts near the floor or near windows and doors may be uncomfortable. Exfiltration of humidified air into cold attics or wall cavities can cause wet insulation. Warm air leakage into attics causes the snow melt/ice buildup problem already noted previously.

Fan-powered ventilation can be controlled to provide airflow in the right amount as needed to remove excess moisture or odors with minimal waste of heat. Even with electrical costs in running the fan included, fan-powered ventilation has an economical advantage over weather-driven infiltration. This is true because the quantity of air can be regulated with fan-powered ventilation. The cost of operating a bathroom exhaust fan four hours per day, for example, is less than \$5 per month (assuming a gas-heated home, a 100-cubic-feet-per-minute fan, and 1988 fuel and electricity prices). Four hours per day of fan usage is normally more than adequate to remove excess humidity. Caulking and weatherstripping to eliminate air leaks and proper use of fan-powered ventilation insures that air change is always sufficient without being excessive. Exhaust pickup points can be located for effective pickup of moisture and odors in bathrooms and kitchens. Ideally fresh air is brought in at a controlled intake point where it can be filtered and heated. Unfortunately, this concept is not available in the market. More commonly, exhaust ventilators will be installed without air supply, and chimney safety tests will need to be conducted to safeguard against sustained backdrafting.

Lifestyle, Moisture Production, and Ventilation Management

People and household activities in most cases produce the major share of moisture in houses (see Angell and Olson 1988). Moisture production largely determines ventilation needs, and ventilation volume, in turn, is a major determinant of heating costs. For example, if no one is at home during the day, generation of household moisture production will be minimal in the day hours, decreasing the need for ventilation and reducing heating fuel consumption. Reducing moisture production when people are in the house can also help to conserve energy by controlling humidity with less ventilation. However, a minimal continual ventilation rate is recommended, even when no one is home and the humidity levels are low. This controls the nonmoisture pollutants in the home, preventing them from building up concentrations which may be damaging.

Full Coverage, Interior-Side Vapor Retarders

To protect the building structure from water vapor (which can condense into water), a full coverage, vapor-retarder¹ system is an important part of cold climate

construction. In cold climates, the retarder must be installed on the interior side of walls and ceilings to resist penetration of water vapor from the living space into the insulation or wall cavities. The principal function of the vapor retarder is to retard or control the passage of moisture as it diffuses through the assembly of materials in a wall.

A recent publication produced by the National Research Council of Canada stated that, "Contrary to popular belief, a vapor retarder does not need to be perfectly continuous. Unsealed laps and pin holes, minor cuts, etc. do not increase the overall moisture diffusion rate into a wall or roof cavity appreciably. It is worthwhile, however, to avoid these imperfections if possible" (National Research Council of Canada 1985).

A combination of materials can be used to complete the vapor-retarder system, provided that each material is vapor-resistant and that adequate connections are made between materials. All parts of the retarder must be on the interior (warm side) of the building envelope. New techniques and materials are available to install a vapor-retarder system at a reasonable cost. *Note:* In using the systems approach to cold climate housing, the use of *both* the vapor retarder and the air retarder (barrier) in the design of the house is advocated.

An Air-Barrier or Air-Retarder System

Vapor retarders/vapor barriers are not to be confused with air barriers. A well-constructed vapor-retarder system, using high quality materials that are uniform in thickness and resistant to degradation in use, *can* serve as an air barrier or air retarder. However, construction practices currently in use in the United States generally lack the quality control required for vapor retarders to also serve as air barriers.

Why the need for an air-barrier or air-retarder system? It is generally conceded that considerably more moisture is lost in a home through convection than through diffusion. Convection losses occur when water vapor escapes the house through open windows, the chimney, cracks, and other air leaks (TenWolde and Suleski 1984). Air-barrier systems are designed to reduce air leaks through the building envelope. They may be inside, outside, or within the envelope. There are several materials that may be used as an air barrier or air retarder if they meet the following requirements (Lstiburek 1987a):

- ☐ They are continuous.
- ☐ They are sufficiently impermeable to air (0.1 liters of air or less passing through the system per second per square meter at 75 Pascals).
- ☐ They withstand the air pressure loads on them—including the local minimum wind design loads, the influence of mechanical systems, and stack effects.
- ☐ They are stiff enough to maintain pressure equalization behind exterior cladding.
- ☐ They are durable and easy to maintain over the service life of the building.

Although polyethylene film has been promoted as an air barrier (and generally meets the first two requirements of continuity and impermeability), most poly materials used in this country do not meet the last three requirements. Gypsum board², stress-skin panels, and sprayed-in-place foams can meet all five requirements (Lstiburek 1987b).

It is important to note that the installation of an air-barrier system within a house creates a very tight structure. Consequently, controlled ventilation systems must also be installed in conjunction with air-barrier systems. In Figure 2, both a poly sheet and a drywall configuration are shown at point 3. If the drywall is installed using the ADA* system, the poly may be unnecessary.

Insulation and Wind-Barrier Installation

Adequate insulation is needed to keep the vapor retarder warm enough so that condensation will not occur on the retarder itself. Cold spots, where insulation is missing or inadequate, must be avoided. Framing at corners, headers, floor perimeters, overhangs, etc. must be designed and built to hold adequate insulation. Otherwise, insulating sheathing must be used. On the exterior side of the framing, use of a full coverage, windproof building paper is recommended to prevent cold wind and wind-driven moisture from blowing into the insulation.

Effects of Wet Basements

Houses with wet basements tend to have excess interior humidity and related condensation problems, which may become more serious when the house is weatherized to conserve fuel. Wet basements result from seepage of ground water through the foundation due to inadequate slope of ground away from the house, incorrectly installed or plugged foundation drainage systems, and the lack of damp-proofing and effective rain-gutter systems. Steps to insure that the basement remains dry are essential to long-term building performance.

Effects of Weatherization on Existing Houses

Caulking and weatherstripping restrict random air leakage, which reduces drafts, saves heating fuel, and helps to hold a comfortable humidity level in a house. Sometimes a side effect of weatherization is that indoor humidity becomes too high. Formation of condensation on the inside of windows usually is the first sign that humidity is too high. In such a case, exhaust-supply ventilation fans may be needed to remove excess moisture from wet rooms such as bathrooms, kitchen, and laundry rooms. Measures to reduce the amount of

ground water entering the basement and/or to control other excessive sources of moisture in the house may also be needed.

Failure to recognize excessively high humidity can allow serious damage to occur. Thus, it is important to monitor the humidity and moisture effects in a home and to use control measures before damage occurs. It may be advisable to weatherize and insulate in stages, beginning with improvements to windows, walls, and doors so these parts can better resist condensation and conserve heat. The next step should be to install quiet, humidistatically-controlled exhaust fans in bathrooms and a code-approved fresh air supply. After the ventilation and air-supply system is working satisfactorily, further caulking, weatherstripping, and insulating can be done. Special attention should be given to attic bypasses that allow large amounts of air to pass upward through the structure.

In a tightly sealed house, the natural draft (chimney action) of furnaces, water heaters, and fireplaces may not be strong enough to vent properly, particularly if exhaust fans are competing for a limited air supply and creating low pressure in the house. If fuel-burning equipment does not receive enough fresh air, dangerous gases can be produced through incomplete combustion of fuels. Intakes that supply fresh outdoor air to fuel-burning appliances are needed. Consult with your local building official for more information. If new heating equipment is installed, whether in old or new houses, induced-draft or sealed combustion with direct outside air is recommended for safe and reliable operation.

A New Era in Residential Construction

Airtight homes with controlled mechanical ventilation are a relatively new development. When such houses are built, extra attention to both detail and coordination in construction is needed. To achieve the expected performance, the full system must be installed with careful attention to system design, correct details, and quality workmanship. Clear specifications on blueprints and specific agreements between designer, builder, subcontractors, and the buyer-owner are needed to spell out responsibility for each part of the system.

Many of the features that make the cold climate house system work are hidden in a finished house (see Figure 2). For example, carefully installed vapor retarders, air barriers, and insulation are not readily observable in the finished house. Yet, these characteristics are essential for effective performance of a cold climate house system.

*Airtight Drywall Approach.

Thus, the buyer-owner may want to inspect work at key stages, verifying that insulation, vapor-retarder and air-barrier materials are of specified quality and that they are properly installed. After a house is built, an infrared viewer scan can be made to determine whether any insulation is missing or has been improperly installed. Testing air leakage, ventilation system operation, and heating equipment safety also is important. Private inspection and testing services are available in some areas. Check the Yellow Pages of your phone directory, under "Building Inspection Services" or write to the associations listed as resources at the end of this publication.

State and Local Building Codes and Inspections

Any house built today in Minnesota should meet or exceed the standards of the Minnesota State Building Code (SBC). Building permits, plan review, plan approval, inspections, and occupancy approval are administered through a municipal or county building authority³. Scheduling inspections at all required stages in construction is the responsibility of the permit holder.

In most communities requiring licensing, permits will be issued only to licensed contractors for contracted or subcontracted work. A final inspection and issuance of a certificate of occupancy is required before occupants can move into a new house, and may also be necessary for finalizing a mortgage. Licensing, permits, inspections, and approvals are important services to assure sound construction practice, consumer protection and safety.

It is essential that homes be built to standards as specified in state and local building codes. Certification that codes have been met helps to insure that the dwelling is constructed in accordance with widely recognized minimum standards. It is important to realize, however, that all the features in the systems approach are not yet covered by codes. If you are planning a house, shopping for a house, or evaluating your existing house, use the list of features from page one as a checklist. In some areas, inspections that go beyond the requirements of the building code, including air-leakage testing, infrared viewer scans, and ventilation system performance testing, may be provided by municipal programs or by private services (check the Yellow Pages).

Special Programs Regarding Energy Performance

As fuel prices increased during 1975-83, states, utilities, and insulation manufacturers developed programs with specific guidelines for energy efficiency. Energy efficiency certifications, energy performance ratings, and energy use calculation methods have been developed to guide builders and consumers toward effective features for conserving energy and for comparing performance.

Recommendations for insulation, airtightness, and moisture and air control vary by regional climates and by fuel prices. It is essential, therefore, to be aware of regional factors in design and construction, and to obtain regionally specific information. Finally, it is important to realize that housing technology is progressing rapidly and making use of up-to-date information should be a priority for all persons involved in housing construction.

Warranties

Various types of warranties may be offered for new houses or certain types of remodeling. There are some warranties that are even required by law. Unfortunately, such warranties usually do not cover vapor-retarder installation, mechanical ventilating systems, or other moisture control features, and may even exempt the builder from liability for moisture problems. If a home warranty does not include coverage of important features or important aspects of building performance, a buyer may request a supplementary warranty.

Summary

An efficient cold climate house has a full system of features that result in comfort, safety, low maintenance, and heating economy. Proper foundation drainage and damp-proofing provide a dry basement and help prevent excessive humidity. A full coverage vapor-retarder and air-barrier system protects the structure from moisture while the occupants enjoy a comfortable indoor humidity level. Carefully installed insulation and wind barriers provide consistently warm walls with no cold corners or drafts that might cause chills and condensation, mold, or mildew. Exhaust-supply ventilation fans remove excess moisture and odors, and provide fresh air efficiently as needed with minimal waste of heat. Ventilation can be turned down during unoccupied or low activity periods to further conserve energy. The systems approach applies equally to construction of new energy-efficient homes, or to improvement of older dwellings.

Resources

The following are two sources of inspection and test services associations.

American Society for Home Inspectors
1629 K St. N.W., Suite 520
Washington, DC 20006
202/842-3096

Infraspection Institute (infrared viewer scans)
Juniper Ridge
P.O. Box 2643
Shelburne, VT 05482
802/985-2500

Endnotes

1. Vapor retarders are also commonly referred to as "vapor barriers." It is generally recognized, however, that materials such as 6 mil polyethylene film do not act as a total barrier to water vapor movement. Instead, they "retard" the rate of diffusion which is a function of vapor pressure difference, material permeability to water vapor, and surface area. For more information on vapor retarders, refer to the extension publication entitled *Insulation Basics*, CD-FO-3400 (see references).
2. Often associated with the "Airtight Drywall Approach" (ADA). For more information on this system, please refer to Lstiburek 1987a and Lstiburek 1987b in the references.
3. Building permits, plan review, and inspections are required in municipalities and counties that have adopted the State Building Code. In some areas, electrical code inspections may be handled by an inspector for the State Board of Electricity.

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Acknowledgments

This publication was improved with critical comments provided by Michael Noble, president, Natural Resources Corporation, Minneapolis; Bruce Nelson, engineer, Minnesota Department of Public Service; and Tim Larson, forest products extension specialist, University of Minnesota Cold Climate Building Research Center (MnBRC) — Minnesota Extension Service's Cold Climate Housing Information Center.

The financial support of Exxon Oil Overcharge funds administered by the U.S. Department of Energy and Minnesota Department of Public Service, Grant number DE-F602-76CS60014 is acknowledged, but the authors assume complete responsibility for the contents herein.

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