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Safety and Health in Manufactured Structures

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Centers for Disease Control and Prevention

National Center for Environmental Health/Agency for Toxic Substances and Disease Registry
Division of Emergency and Environmental Health Services
Healthy Homes and Lead Poisoning Prevention Branch

U.S. Department of Health and Human Services, Public Health Service
Atlanta, GA

Preface

Millions of people in America live in manufactured structures—a range of units that includes manufactured homes, travel trailers, camping trailers, and park trailers. Manufactured structures are used for long-term residence; for temporary housing following disasters; for recreational and travel purposes; and also for classrooms, day care centers, and workplaces. Housing is a primary purpose of these structures, with manufactured homes accounting for 6.3% of the housing units in the U.S. and housing 17.2 million persons. Manufactured homes offer flexibility and affordability, and comprise an important part of the U.S. housing stock.

Whether used for long-term housing or for short-term shelter following a disaster, for classrooms or for offices, manufactured structures should be safe and healthy for the people who live, work, study, and play in them. With Americans spending the vast majority of their time indoors, it is vital that buildings protect occupants from the elements and provide privacy, comfort, and peace of mind. At the same time, these structures should not present risks to occupant's health and safety due to design, construction, or maintenance problems.

This report identifies and summarizes safety and health issues in manufactured structures based on a wide expanse of research. The end result is a thorough characterization of health and safety hazards in manufactured structures, along with mitigation strategies and discussions of opportunities for health/safety enhancements and at-risk populations.

Many of the hazards discussed in this report are not unique to manufactured structures, while other issues have been identified as particular problems for this form of housing. Further, when manufactured structures are used as interim housing following a disaster, additional health/safety issues can arise. The specific topics covered in this report are an introduction to manufactured structures, fire safety, moisture and mold, indoor air quality (IAQ), pests and pesticides, siting and installation, utilities, postdisaster housing, and potential opportunities for future enhancements.

The health and safety hazards related to fire safety, moisture and mold, IAQ, pests and pesticides, and other issues generally fall into the categories of design, construction, and maintenance. Thus, for an issue like effective moisture management to prevent mold and related problems, strategies range from good product selection in the design phase to proper grading of the site during construction all the way to regular maintenance of the building envelope after many years of service. Most other health and safety hazards are similar in nature, with multiple parties playing an important role in managing risks from the design of the manufactured home through its use as a home for years to come.

Fortunately, the challenges of managing health and safety risks in manufactured structures are well documented, along with appropriate strategies and solutions. This report documents and summarizes this information, with the intent of serving as a comprehensive resource to inform discussions and future decisions regarding the design, construction, maintenance, and deployment of manufactured structures in the United States.

I wish to thank the working group participants from the Centers for Disease Control and Prevention, U.S. Department of Housing and Urban Development, Federal Emergency Management Agency, U.S. Department of Education, New York City Office of Emergency Management, and Harvard School of Public Health; the expert consultants who reviewed the draft document during the Safe and Healthy Manufactured Structures meeting on October 17, 2008; and subject-matter experts who reviewed and commented on several drafts of the document. I believe that these recommendations provide essential guidance on the safe and healthy use of manufactured structures.

Christopher J. Portier, Ph.D.
Director, National Center for Environmental Health and Agency for Toxic Substances and Disease Registry

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Federal Agencies

- Access Board
- Centers for Disease Control and Prevention (CDC), U.S. Department of Health and Human Services
- Consumer Product Safety Commission
- Department of Education
- Department of Homeland Security (DHS)
- Department of Housing and Urban Development (HUD)
- Environmental Protection Agency (EPA)
- National Institute of Standards and Technology, Department of Commerce

State and Local Government

- California Air Resource Board
- New Orleans Department of Health
- New York City Department of Health and Mental Hygiene
- New York City Office of Emergency Management

Community and Environmental Entities

- Collaborative for High Performance Schools
- Environmental Working Group
- National Center for Environmental Health Strategies
- National Center for Healthy Housing
- National Environmental Health Association
- Sierra Club
- Southface

Industry Groups

- American Forest and Paper Association
- Composite Panel Association
- Formaldehyde Council
- Manufactured Housing Association for Regulatory Reform
- Manufactured Housing Institute
- Manufactured Housing Research Alliance
- Newport Partners, LLC
- Northeastern IPM Center
- Recreational Vehicle Industry Association

Professional Associations

- American Academy of Pediatrics
- American Institute of Architecture/New York
- American National Standards Institute
- American Planning Association
- American Public Health Association
- Architecture for Humanity New York
- Association of State and Territorial Health Officials
- Federation of American Scientists
- Healthy Schools Network
- Home Safety Council
- International Code Council
- National Association of County and City Health Officials
- National Fire Protection Association
- North Gulfport Community Land Trust
- Physicians for Social Responsibility

Academic Institutions

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- Washington State University

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Glossary

Air retarder: A material or system designed and installed to reduce air leakage into or through the exposed areas of a wall or other building components that enclose conditioned space.

Belly: The volume of a manufactured housing unit between the subfloor and the bottom board.

Bottom board: Most commonly a flexible sheet material used to enclose the bottom side of the floor system from the crawl space.

Building envelope: The entire outer shell of a structure that separates the internal environment from the external environment, providing structural integrity, temperature control, and air diffusion control.

Camping trailer: A form of travel trailer constructed with collapsible partial sidewalls that fold for towing by another vehicle and unfold at the campsite to provide temporary living quarters for recreational, camping, or travel use.

Daylighting: The use of natural light for illumination of a space. When used properly, daylighting is a technique that can save energy in buildings.

Dehumidification: The removal of water vapor from air by either cooling the air below the dew point and draining the resulting liquid away, or by absorbing it from the air through a repeatable chemical process.

Dew point: The temperature at which humid air becomes saturated and the water vapor begins to condense to liquid water.

Exfiltration: The uncontrolled flow of air out of a building through cracks, holes, doors, or other openings that allow air to escape. Air that leaks from a home is replaced by outdoor air brought in by fans or infiltration. (See Infiltration.)

Feedback systems: Energy monitoring devices with visual displays of factors affecting energy use in the home.

Infiltration: The uncontrolled flow of air into a building through cracks, holes, doors, or other openings that allows air to move in from the outside. (See Exfiltration.)

Insulation: A building layer that has a high resistance to heat flow in and out of buildings. Common insulation materials used in manufactured housing are cellulose, fiberglass, and rock wool.

Manufactured home: A home that is generally wider than 8 feet and longer than 40 feet (for an area greater than 320 square feet); built on a permanent chassis; contains plumbing, heating, air-conditioning, and electrical systems; and designed to be used as a dwelling with or without a permanent foundation when connected to the required utilities. It is assembled in a manufacturing plant and transported in one or more sections. At its final destination, the manufactured home is typically mounted and the wheels or axles, or both, are removed.

Manufactured structure: A range of units that includes manufactured homes, travel trailers, camping trailers, and park trailers. Some of this housing is used for long-term residence, some for recreational and travel purposes, and some as temporary housing following disasters.

Marriage line: The line of intersection through the floor, walls, ceiling, and roof that joins two home sections together.

MHCSS (Manufactured Home Construction and Safety Standards): A set of specifications to which manufactured housing manufacturers must build. This is a comprehensive national standard administered by HUD; it preempts all other building regulations. Also referred to as the "HUD Code."

Modular home: A home that is built in a factory in sections, transported to a building site, lifted from the transport by crane, and rested on a prebuilt foundation. These sections are then fastened together. Modular homes are beyond the scope of this document.

Moisture and vapor retarder: Materials used to slow the passage of water vapor or moisture into building assemblies through diffusion. (Also see Vapor Barrier.)

Motor home: Self-propelled vehicles that contain at least four of the following systems: cooking, refrigeration, toilet, heating and/or air conditioning, potable water, separate electrical power supply, and/or LP gas supply.

Park trailer: A larger version of a travel trailer (up to 400 square feet in area) that is used as temporary living quarters. Usually park trailers are regulated by transportation authorities.

Permeance: A measure of the ability of a material to transmit free water molecules by diffusion. The term "perm" refers to the rate of water movement through a material.

R-value: The measure of insulation's resistance to heat flow or its insulating effectiveness. R-value is calculated as the inverse of a material's U-factor. The higher the R-value, the higher the insulative properties of a material.

Recreational vehicle: A vehicle built on single chassis, under 400 square feet, self-propelled or towable by a light duty truck, and designed primarily to be used as temporary living quarters for recreational, camping, travel or season use, but not as a permanent dwelling. Recreational vehicles include camping trailers, motor homes, and travel trailers.

Relative humidity (RH): The ratio of water vapor in the air to the amount the air could potentially hold at a given temperature.

Site-built structure: A form of housing where the materials for the home, which may be detached or attached, are transported to the building site and assembled to form the structure. Site-built structures are built on permanent foundations and are not designed to be transported or moved. These structures are built in accordance with the locally applicable building codes and regulations.

Skirting: A perimeter enclosure that creates the crawl space area under a manufactured home. Skirting materials range from ventilated vinyl siding to brick walls.

Solar heat gain coefficient (SHGC): The rated portion of solar gain that passes through a window. Values of SHGC are between 0 and 1, with lower values representing less solar gain.

Thermal barrier: A continuous blanket of materials (such as fiberglass insulation) used to slow the flow of heat into building assemblies.

Travel trailer: A a wheel-mounted trailer designed to provide temporary living quarters during recreation, camping, or travel activities. Travel trailers generally have size limits, such as 8 feet in width and 40 feet in length, for an area of less than 320 square feet. When towed by a motor vehicle, a travel trailer does not require a special highway moving permit based on size or weight. Travel trailers are generally considered vehicles rather than structures and are regulated by state transportation authorities rather than housing authorities.

U-factor: The rated quantity of heat that passes through a material in a given time (Btu/hr X ft2 X °F), also known as conductance. The lower the U-factor, the higher the insulative properties of a material.

Vapor diffusion: The movement of water vapor from a region of high concentration to a region of low concentration.

Vapor retarder: Material used to slow the passage of water vapor into building assemblies; usually a sheet or coating with low permeance. Also referred to as "vapor diffusion retarder."

Ventilation: The introduction of outdoor air into a building. Passive ventilation takes place naturally through windows, doors, and air leakage sites. Mechanical ventilation uses a fan to move air. Mechanical systems that use exhaust fans depressurize a home, whereas systems that bring in ventilation air with the furnace fan pressurize a home. Spot ventilation is the temporary use of bath and stove exhaust fans to remove odors and water vapor.

Wall, ceiling, and floor cavities: Spaces between the outside sheathing and the inside surface treatment, usually containing insulation, ductwork plumbing, and electrical wiring.

CHAPTER 1: INTRODUCTION

PURPOSE

The purpose of this manual is to provide information that will help protect the health and safety of persons who use manufactured structures. This document should be useful to many audiences, including:

- Manufacturers of the various types of manufactured structures;
- Those who purchase, own and maintain manufactured structures;
- Federal, state and local emergency response agencies;
- Local government agencies involved in permitting and siting decisions;
- Public health officials; and
- Individuals who live, work, study, and play in manufactured structures.

This manual provides a consolidated source of information and an overview of health and safety issues associated with manufactured structures. This manual describes significant health and safety risks; highlights factors that distinguish manufactured structures from site-built structures; identifies causal and other risk factors for negative health/safety impacts on occupants; and presents advice about what steps manufacturers, purchasers, owners, and occupants of manufactured structures can take to prevent and control health and safety risks in manufactured structures. This manual identifies special challenges associated with manufactured structure's role in helping to meet emergency response needs after natural disasters as well as potential opportunities to further reduce health and safety risks in manufactured structures and contribute to other national objectives. This document has no regulatory force. In addition, this manual provides links to a multitude of sources for more detailed information and advice.

WHY FOCUS ON MANUFACTURED STRUCTURES?

Millions of people in America live in manufactured structures—a range of units that includes manufactured homes, travel trailers, camping trailers, and park trailers (see Glossary for definitions). Some of this housing is used for long-term residence, some for recreational and travel purposes, and some as temporary housing following disasters. After Hurricanes Katrina and Rita, for example, approximately 120,000 manufactured structures—including manufactured homes, park models, and travel trailers and camping trailers—housed individuals displaced by these storms.

According to the 2007 American Housing Survey (AHS) (U.S. Census Bureau 2008), 8.7 million manufactured homes account for 6.3% of the 128.3 million housing units in the United States and house 17.2 million persons (U.S. Census Bureau 2007). Manufactured homes offer flexibility and affordability and comprise an important part of the U.S. housing stock.

Manufactured structures are also used for classrooms, day care centers, and workplaces. For example, a 2005 U.S. Department of Education survey of public school principals found that 37% of all public schools use portable buildings (Chaney and Lewis 2007). In California, one in three students learns in a portable building (Shendell et al. 2004a, 2004b). The prevalence of portable buildings at schools rises with minority enrollment, from a low of 19% in schools with low minority enrollment to a high of 53% in schools with 50% or more minority enrollment (Chaney and Lewis 2007). No data are available on the number of manufactured structures used for offices, day care centers, construction site offices, and other purposes.

Whether used for long-term housing or for short-term shelter following a disaster, for classrooms or for offices, manufactured structures should be safe and healthy for the people who live, work, study, and play in them. In addition, manufactured structures should be aesthetically pleasing, environmentally friendly, and economical to construct and purchase. For effective emergency response to disasters, it is vital that manufactured housing be readily available, easily transported, and quickly deployable.

WHY WORRY ABOUT HEALTH AND SAFETY RISKS IN HOUSING, SCHOOLS, AND OFFICES?

Americans spend approximately 85%-95% of their time indoors (Lebowitz 1983). Our homes, schools, offices and other buildings protect us from the elements and disease and provide privacy, comfort, and peace of mind. At the same time, these structures can pose risks to our health and safety due to design, construction, or maintenance problems.

The direct connection between our housing and our health has been recognized for decades. In 1938, the American Public Health Association's Committee on the Hygiene of Housing published the *Basic Principles of Healthful Housing*, which remain relevant today. Both the public health and housing professions have long recognized the importance of healthy housing for good health (Howden-Chapman 2004; Krieger and Higgins 2002; Saegert et al. 2003). Similarly, the importance of healthy school environments (Frumkin et al. 2006) and of healthy workplaces (Levy et al. 2005) is widely recognized.

Every kind of structure has the potential to pose a variety of health and safety risks, including structural defects, risk of fire and electric shock, pests, moisture and mold problems, and exposure to toxic contaminants and explosive gases. This manual addresses a subset of structures called manufactured structures.

SCOPE OF MANUFACTURED STRUCTURES COVERED

This manual covers the following kinds of manufactured structures.

Manufactured homes: A manufactured home is generally wider than 8 feet and longer than 40 feet (for an area greater than 320 square feet); built on a permanent chassis; contains plumbing, heating, air-conditioning and electrical systems; and is designed to be used as a dwelling with or without a permanent foundation when connected to the required utilities. It is assembled in a manufacturing plant and transported in one or more sections. At its final destination, the manufactured home is typically mounted and its wheels or axles, or both, are removed. Manufactured homes are sometimes used as school classrooms, offices, and for other purposes unrelated to housing.

Travel trailers: A travel trailer is a wheel-mounted trailer designed to provide temporary living quarters during recreation, camping, or travel activities. Travel trailers generally have size limits, such as less than 8 feet in width and 40 feet in length, for an area of less than 320 square feet. A travel trailer when towed by a motor vehicle does not require a special highway moving permit based on size or weight.

Camping trailers: A camping trailer is a form of travel trailer constructed with collapsible partial sidewalls that fold for towing by another vehicle and unfold at the campsite to provide temporary living quarters for recreational, camping, or travel use.

Park trailers: A park trailer is a larger version of a travel trailer (up to 400 square feet in area), which is used as temporary living quarters.

This manual does not address "pop-up" camper trailers whose walls do not fold out. This manual also does not address manufactured or modular housing, which is built in a factory in sections, transported to a building site, lifted from the transport by crane, rested on a prebuilt foundation, and then fastened together.

When all four forms of housing are discussed, the term "manufactured structures" is used.

OVERVIEW OF HEALTH AND SAFETY CONCERNS

Many health and safety risks are common to both manufactured and traditional site-built structures. In other cases, health and safety risks associated with manufactured structures differ from traditional site-built structures by virtue of their transportability, more-confined spaces, use of different foundations and means of anchoring, and, in some cases, different utility connections and services than traditional site-built structures.

During 2006 and 2007, concerns arose about the presence of formaldehyde in the indoor air of trailers provided by the Federal Emergency Management Agency (FEMA) to some Gulf Coast residents as temporary housing following Hurricanes Katrina and Rita. FEMA, the Centers for Disease Control and Prevention (CDC), and other agencies collaborated in addressing these concerns. However, formaldehyde exposures are only one of a larger set of potential health and safety issues in manufactured structures. Importantly, many of these concerns apply to all buildings; they are not unique to manufactured structures.

Several populations may be especially vulnerable to health and safety risks associated with manufactured structures as well as other kinds of buildings. For example, fetuses, infants, and children are at special risk for toxic exposures due to their developing brains and nervous systems, and the elderly are at greater risk of slips and falls and may have more difficulty escaping fire. People with disabilities may have difficulty with access to and mobility within manufactured structures (as well as any structure with stairs and confined spaces). People with specific medical conditions, such as asthma or chronic obstructive lung disease, may be especially susceptible to indoor air contaminants. In postdisaster settings, when residents have been displaced, the risks of psychological distress, interrupted care for chronic diseases, and other medical problems may be high (Coker et al. 2006; Weisler et al. 2006). Persons living in poverty lack resources to maintain or make improvements to their homes. The needs of populations at special risk must be taken into account in protecting occupants from health and safety hazards. These needs are discussed in multiple sections of the report. Further, Chapter 8 contains a summary of housing-related risks to special populations living in manufactured structures following a disaster.

Structural Integrity and Building Performance

In contrast to traditional site-built structures, manufactured structures are built in a plant, transported to their point of use (in some cases, transported multiple times), and usually anchored in place. As a result, structural integrity and performance issues differ in manufactured structures from site-built structures. Structural integrity protects occupants from injury; controls pests and moisture; and affects utility and maintenance costs as well as the structure's reliability, durability, and long-term value.

The 2007 American Housing Survey reported that of 6.9 million occupied manufactured homes, 314,000 (4.5%) had sagging roofs, 209,000 (3.0%) had a visible hole in the roof, 171,000 (2.5%) had a visible hole in the floor, 180,000 (2.6%) had sloping outside walls, 467,000 (6.7%) had broken windows, and 98,000 (1.4%) had foundations with either visible crumbling or open cracks or holes (U.S. Census Bureau 2007). These percentages are comparable to site-built homes, as shown in Figure 1-1. No comparable data are available for other categories of manufactured structures. While inadequate maintenance is responsible for some structural deficiencies, additional considerations include design and construction standards as well as methods of transporting, storing, mounting, and tethering manufactured structures.

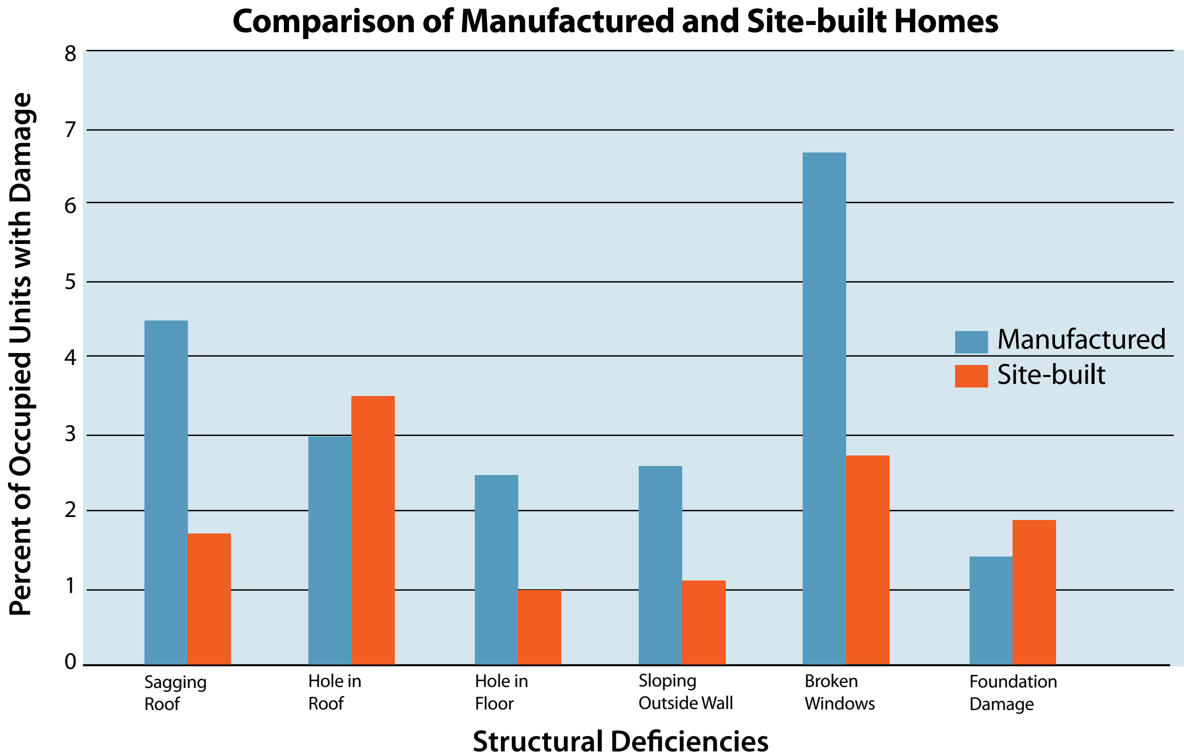


Figure 1-1: Damage assessment of occupied units of site-built and manufactured homes as reported by the 2007 American Housing Survey (U.S. Census Bureau 2007).

Access to Safe Utilities

Safe and reliable utility service is essential to minimize risk of injury from electrocution and protect health through safe drinking water and safe handling and treatment of wastewater. For some manufactured structures, the means of providing drinking water, wastewater treatment, gas, and electricity differ from site-built structures. For example, manufactured structures typically receive electricity from external hookups, although some units use on-site generators. The *2007 AHS* revealed that 48.3% of manufactured housing units were heated with electricity, 23.9% with piped gas, 17.6% with bottled gas, and smaller numbers with other sources such as fuel oil, kerosene, and wood. For cooking, 56.4% used electricity and 40.0% used gas. Municipal water and sewer service is provided in manufactured housing communities, but more localized services are used in some settings, including postdisaster situations. Access to safe utilities should be taken into account in siting manufactured housing communities as well as in the design, construction, installation, maintenance, and use of manufactured structures.

Fire Safety

In 2002, an estimated 17,200 structure fires in manufactured housing occurred in the United States, causing 210 deaths and $134 million in direct property damage. While fire safety has improved in manufactured housing since the Manufactured Home Construction and Safety Standards (MHCSS) took effect in 1976, manufactured homes have a higher rate of deaths per fire than other dwellings (Hall 2005). Like other residential settings, manufactured housing should have smoke alarms to protect residents against death and injury from fires (Istre et al. 2001). Other fire safety features include flame spread requirements for structural elements such as walls, for wall and floor covering, and for other materials.

Moisture and Mold

Moisture is a problem in many buildings, including manufactured structures. Climate (e.g., warm, wet conditions), building features (e.g., inadequate ventilation or air conditioning, or features that allow moisture to accumulate), and behavioral factors (e.g., failing to repair or clean up water leaks) are all factors. Moisture accumulation is likely to occur where humidity levels are high, such as in basements or bathrooms, and near leaks from rain water or plumbing. Some building materials and furnishings are prone to absorbing moisture. Indoor moisture accumulation, in turn, can facilitate the growth of mold, mildew and dust mites. These conditions can cause the development of asthma (dust mites) and also aggravate respiratory and allergic symptoms (Fisk et al. 2007, Institute of Medicine 2000).

Pests and Pesticides

Rats, mice, and invertebrates are problems in many kinds of buildings, including manufactured structures. Structures that are in substandard condition pose a special challenge. The *2007 AHS* reported that 70,000 occupied manufacturing housing units (1.0%) had signs of rats in the previous 3 months, and 692,000 (10.0%) had signs of mice. See Figure 1-2 for a comparison between site-built homes and manufactured homes. These pests may gnaw on electrical wires, causing a fire hazard, and they may damage structures and their contents by gnawing and burrowing. Rats and mice also may aggravate allergies (Institute of Medicine 2004); spread disease; bite (babies in cribs are especially vulnerable); transport fleas, lice, mites and ticks (which pose health threats) indoors; and contaminate food with urine, feces, and hair. Other pests, such as cockroaches, dust mites, and flies, also pose a health threat in buildings. For example, cockroaches exacerbate asthma, dust mites are a risk factor for asthma development and exacerbation (Institute of Medicine 2000; Platts-Mills and Chapman 1987; Rosenstreich et al. 1997), and flies

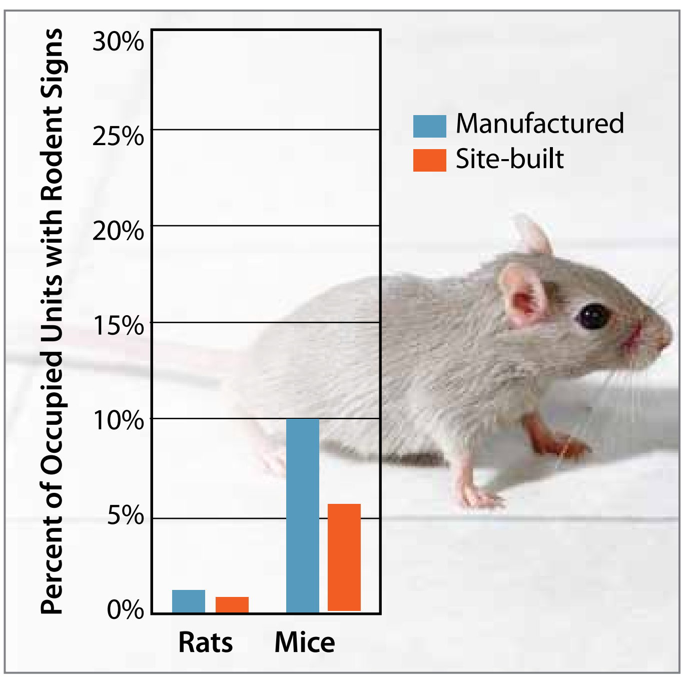


Figure 1-2: Signs of rats and mice in the last three months in occupied units of site-built and manufactured homes as reported by the *2005 American Housing Survey.*

can spread foodborne pathogens such as salmonella. An infestation of wood destroying insects may also jeopardize a structure's integrity.

Indoor Air Quality

Indoor air may contain a variety of contaminants that can cause respiratory disease, neurodevelopmental problems in children, and increased cancer risk. The confined spaces of manufactured structures, and in some cases lower ventilation and air exchange rates, make indoor air quality a concern in manufactured structures. Indoor air contaminants of concern include

- Volatile organic compounds emitted from cleaning products, personal care products, cooking fuel combustion, and other sources (Spengler et al. 2001), including formaldehyde "off-gassed" by manufactured wood products and building furnishings (Breysse 1977; Gold et al. 1993; Gupta et al. 1982; Hanrahan et al. 1984; Liu et al. 1991; Sexton et al. 1989; Stone et al. 1981; U.S. Environmental Protection Agency 1987).
- Nitrogen dioxide from gas stoves (Samet and Basu 1999).
- Carbon monoxide from combustion sources (Centers for Disease Control and Prevention 2005; Liu et al. 2000).
- Pollen and fungal spores (Sterling and Lewis 1998).
- Pet dander and other allergens (Pope et al. 1993).
- Smoke from tobacco use and woodstoves (Naeher et al. 2007).

Indoor air contaminants have been found in portable classrooms as well as manufactured homes (Shendell et al. 2004a, 2004b). In a 2002 study of 156 schools (with 180 portable classrooms) in Washington and Idaho, 18 portable classrooms had no mechanical ventilation system and systems were turned off in 46 others; and carbon dioxide levels exceeded 1,000 parts per million in 66% of portable classrooms (Prill et al. 2002).

Indoor air pollutants can be reduced both through source control and improved ventilation. For example, changes in manufacturing practices, ventilation, and similar practices can reduce formaldehyde emissions and formaldehyde levels inside homes (Godish and Rouch 1986).

Siting and Installation

The siting and installation of manufactured structures are also important to occupants' health, safety, and wellbeing. Some locations offer physical advantages such as low risk of flooding, good drainage of stormwater, and relative quiet from noise sources such as highways. In addition, access to public transportation, greenspace and recreational facilities, schools, shopping, and employment all improve residents' quality of life. For manufactured structures that are placed on foundations, it is vital that foundations be appropriately located, designed and constructed, and that the structure be properly anchored to protect against high winds.

Emergency Deployment

Special considerations arise when manufactured structures are deployed in emergency situations, such as after a disaster. In these situations, protecting health and safety may require weighing competing risks and benefits. For example, an otherwise excessive level of crowding may be considered acceptable in the short term to meet the urgent needs of displaced families. Emergency managers need to consider the condition of units that are deployed, since deterioration may occur during storage or emergency transport. The placement of postdisaster housing is a challenge, since ideal options may not exist for location, utility hook-ups, access to services, and other necessities to meet the urgent needs of displaced households.

RELEVANT STANDARDS AND REGULATIONS

This section explains the key standards and regulations that apply to

- Manufactured housing,
- Recreational vehicles and camping trailers, and
- Portable classrooms.

Manufactured Housing

The U.S. Department of Housing and Urban Development (HUD) regulates the construction of manufactured housing under the National Manufactured Housing Construction and Safety Standards Act of 1974. MHCSS (24 CFR Section 3280) and the companion Manufactured Home Procedural and Enforcement Regulations (24 CFR Section 3282) govern the construction of manufactured homes and outline regulatory and enforcement processes. This manual refers to these federal standards as the "HUD Code."

Manufactured homes are a minimum of 320 square feet with a permanent chassis to assure the initial and continued transportability of the structure. All sections of manufactured homes built in the United States after June 15, 1976, must be labeled, providing a manufacturer's certification that the section has been built in accordance with the HUD Code. The HUD Code covers structural integrity, energy performance, plumbing, electrical, fire and other requirements, and incorporates by reference more than two dozen industry standards issued by organizations listed at 24 CFR 3280.4.

The HUD Code for manufactured housing primarily contains performance-based requirements as compared to the typically more prescriptive housing codes that apply to site-built structures. Instead of mandating how the requirements must be met, the HUD Code allows manufacturers latitude in determining how to meet the established performance requirements. This gives manufactures maximum flexibility to demonstrate compliance through engineering analyses or physical tests that an assembly or component (e.g., wall, roof, etc.) meets the specified performance standard.

HUD is legally responsible for maintaining and periodically revising the Manufactured Home Construction and Safety Standards. Under federal law, the requirements of the HUD Code preempt state and local laws. HUD has broad investigatory authority to inspect factories, issue subpoenas and issue orders, and may bring administrative actions against manufacturers or inspection agencies for violations. HUD's program also provides a system for handling consumer complaints relating to failures to conform in the construction of homes.

Recreational Vehicles and Camping Trailers

The national MHCSS exempts recreation vehicles from MHCSS regulations for manufactured housing (24 CFR 3280) if the vehicle or trailer is built on a single chassis is under 400 square feet; self-propelled or permanently towable by a light duty truck; and designed primarily as temporary living quarters for recreational, camping, travel, or seasonal use and not as a permanent dwelling (24 CFR 3282.8). The National Highway Traffic Safety Administration considers motor homes to be vehicles and as such, motor homes can exceed 400 square feet and still be exempt from HUD regulation. Motor homes are self-propelled vehicles and contain at least four of the following systems: cooking, refrigeration, toilet, heating and/or air conditioning, potable water, separate electrical power supply, and/or LP gas supply.

The U.S. Department of Transportation (USDOT) sets vehicle safety standards for motor homes, recreational vehicles and travel trailers (49 CFR 571). These standards include bumper impact, seat belts, headlights and taillights, and trailer weight loads. In addition, USDOT has flammability standards for the interior materials of vehicles, which also apply to motor homes, recreational vehicles and travel trailers (49 CFR 571.302). On the other hand, travel trailers and park models are considered consumer products, which are subject to the jurisdiction of the Consumer Product Safety Commission.

The industry has adopted construction standards by consensus though the American National Standards Institute (ANSI) and the National Fire Protection Association (NFPA). The ANSI 119.2 Standard for Recreational Vehicles and ANSI A119.5 Standard for Recreational Park Trailers cover the correct installation of plumbing, fuel-burning, electrical, and other safety-related systems. Twenty states require compliance with these standards for the sale and registration of motor homes, recreational vehicles (RVs), and travel trailers. Camping trailers, travel trailers, and truck campers are all considered RVs. RVs also include recreational park trailers that meet the ANSI A119.5 standard and motor homes that meet the ANSI A119.2 standard.

Also, ANSI (A119.4) and NFPA (1194: Standard for Recreational Vehicle Parks and Campgrounds) have issued standards on minimum construction requirements for parks and campgrounds. These standards do not cover operational and maintenance practices for parks and campgrounds.

Portable Classrooms

Portable classrooms are used across the United States to provide temporary educational space to primary, secondary, and higher education institutions. In planning the construction of primary education facilities, California requires consideration of temporary classrooms if declines in enrollment are predicted. These classroom units are also referred to as temporary, portable, movable, modular or relocatable classrooms.

There are no federal construction or operation standards for portable classrooms. The MCHSS only applies to manufactured dwellings. Some states consider these classrooms as part of the school building and require the units to meet the same building codes and operation standards as other school facilities. Other states have separate standards for their construction, installation and use. California has specific standards for prefabricated relocatable classrooms that are used in the bidding process (http://www.chps.net/manual/documents/RelocatableClassroomSpec.pdf). In addition, California also has maintenance guidelines for relocatable classrooms (http://www.documents.dgs.ca.gov/opsc/Publications/Handbooks/RCP_Hdbk.pdf).

FEDERAL AGENCY ROLES AND RESPONSIBILITIES

In addition to HUD's responsibility for promulgating and enforcing health and safety standards for manufactured housing, the following federal agencies also play important roles in assessing or monitoring some aspect of manufactured structures:

- CDC bears responsibility for public health and safety, and CDC's agencywide goals include identifying and promoting healthy housing, healthy schools, and healthy workplaces.
- The Department of Education promotes safe, healthy school environments.
- The U.S. Environmental Protection Agency (EPA) regulates toxic chemicals and actively promotes healthy indoor air quality.
- FEMA purchases and provides manufactured housing that has played an important role in postdisaster recovery.
- The Occupational Safety and Health Administration is responsible for safeguarding workers' health and safety.

CHAPTER 2: FIRE SAFETY

THE DANGER OF FIRE

Fire is a serious risk to life and property in all kinds of structures. In fact, the United States ranks near the top of the industrialized world in fire death rates, reporting 13.0 deaths per million people per year from 2004-2006 (International Association for the Study of Insurance Economics 2009). In 2009, an estimated 515,000 structure fires were reported to U.S. fire departments, which resulted in 3,320 deaths and 16,075 injuries among civilians (Karter 2009). About four out of five fires occur in residential structures.

Residents of manufactured housing are at increased risk of fire-related injury and death (Parker et al. 1993; Runyan et al. 1992). The death rate from fires in manufactured homes is higher than in other kinds of home fires—an excess of 32% to 50% when measured as deaths per housing unit (U.S. Fire Administration 2006), and almost double in terms of deaths per fire (Hall 2005). Each year, fires in manufactured housing cause between 210 and 345 deaths, 765 injuries, and $134 million in direct property damage (Hall 2005, U.S. Fire Administration 2006).[1]

Children, people with disabilities and the elderly are especially at risk in home fires because they are less able to escape when fire strikes (Flynn 2008). Young children accounted for more than one-fifth of fire deaths in manufactured homes (U.S. Fire Administration 2006). Approximately 55% of children who were killed by fires in residential structures were asleep at the time of the fire, and 26% died while trying to escape (U.S. Fire Administration 2005).

[1]The fire safety data for manufactured housing do not cover other categories of manufactured structures.

LEADING CAUSES OF FIRE

Cigarette smoking is the leading cause of all fire-related deaths (Ahrens 2003). Alcohol use is another common risk factor, contributing to an estimated 40% of residential fire deaths (Smith et al. 1999). Home heating equipment, which includes portable and stationary space heaters, chimneys, fireplaces, heat transfer systems, central heating units, and water heaters, is another significant cause of fire in U.S. housing (Ahrens 2007). Only 2% of residential building heating fires involve portable heaters, but these fires account for 25% of the fatalities ih residential heating fires (U.S. Fire Administration 2010). Electrical systems, which include wiring, power switchgear or over-current protection devices, transformers, and meter boxes, are another cause of residential fires (Ahrens 2007).

According to the U.S. Fire Administration, many of the fires in manufactured homes result from cooking, heating and electrical system malfunctions, and improper storage of combustibles (U.S. Fire Administration 2006). Together, electrical system malfunctions and heating fires account for one-third of manufactured housing fires. The typically thinner insulation in manufactured structures may prompt greater use of supplemental room heaters, such as space heaters, to maintain a comfortable interior temperature (Manufactured Housing Research Alliance 2000). Heating fires in manufactured housing can be attributed to the increased use of a variety of supplemental room heaters, such as kerosene heaters, gas space heaters, and electrical heaters, especially when improperly installed, maintained, or used (Centers for Disease Control and Prevention and U.S. Department of Housing and Urban Development 2006).

According to the U.S. Fire Administration, fires due to electrical causes occur nearly twice as often in manufactured homes as in other one and two family dwellings (U.S. Fire Administration 2006). Additional considerations related to fire safety in manufactured structures include unit spacing and building materials (National Fire Protection Association 2009).

When fire occurs in manufactured structures, the damage may be more extensive than site-built structures, because manufactured structures are typically smaller than other kinds of housing and contain smaller sized rooms (Hall 2005), which can lead to increased fire spread due to flashover.

EFFECT OF HUD'S STANDARDS

HUD's Manufactured Housing Construction and Safety Standards (the HUD Code), which apply to manufactured structures built since 1976, address fire safety in several respects. Manufactured homes built between 1976 and 2002 were required to have at least two exterior doors, a smoke detector in the hallway or space communicating with each bedroom area, as well as an egress window in each bedroom that provides a secondary escape route for occupants. In addition, the HUD Code includes flame-spread rating requirements for interior finish materials and fire-stopping requirements to slow or limit the spread of fire. Manufactured homes built after 1976 that meet these construction and safety standards are issued a HUD certifying label.

There is some evidence that fire safety in manufactured homes has improved since HUD's standards took effect to require increased safety measures. The fire death rate in post-1976 manufactured homes (reported in the period from 1989 to 1998) was 54% lower than the death rate reported in older manufactured housing (Hall 2005). Additionally, heating fires have decreased in manufactured housing constructed after 1976 (Hall 2005). In addition, the percentage of fires (during 1989-1998) that were confined to the room of origin was 15% higher for manufactured homes built after 1976 than manufactured homes built before the HUD standards took effect (Hall 2005).

Although the number of fatalities and injuries caused by residential fires, including those in manufactured structures, has generally declined over time, many residential fire-related deaths remain preventable and continue to pose a significant public health problem.

THE IMPORTANCE OF SMOKE ALARMS

Given the number of fire fatalities associated with sleeping occupants, smoke alarms are a critical line of defense. In dwellings of all types, including manufactured homes, smoke alarms reduce the death rate per fire by 40%-50% (Ahrens 2004). In 1994-1998, the civilian death rate per fire in manufactured homes built after 1976 was 31% less if smoke alarms were present (Hall 2005). Since 2002 the HUD Code has required manufactured homes to have at least two exterior doors and have smoke alarms located in each bedroom, the kitchen/living area, stairwell and basement. The alarms must be hard-wired with a battery backup and interconnected unless they are listed for use and provided with a battery rated for a 10-year life [24 CFR 3280.208(d)(ii)]. In addition, an egress window is required to be installed in each bedroom that provides a secondary escape route for occupants. The flame-spread requirements were improved since 2002 to require lower flame-spread rating for the interior finish of ceiling materials.

In a study conducted by the Consumer Product Safety Commission (CPSC), hard-wired alarms were found to be functional a greater percentage of the time than battery-powered alarms when both types of alarms were powered (Smith 1995); however, HUD has permitted the use of battery-only alarms with long-life batteries to encourage the development of this technology (U.S. Department of Housing and Urban Development 2002).

Despite the HUD Code's requirements for smoke alarms, approximately half of all residential fire deaths occur in homes without smoke alarms (Ahrens 2004). In spite of the relevant standards and the apparent efficacy of smoke alarms, an assessment conducted in 1999-2002 found that 45% of manufactured homes built after 1976 were reported without smoke alarms (Hall 2005). Another recent study of rural fires showed that smoke alarms were less likely to be present or operating in manufactured homes than other types of housing (U.S. Fire Administration 2006).

TECHNOLOGIES TO CONSIDER FOR IMPROVED FIRE SAFETY

In 1975 the National Fire Protection Association (NFPA) introduced Standard 13D: Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Mobile Homes.[2] Since that time there have been approximately ten updates to the standard to reflect practical experience and to accommodate such things as nonmetallic piping and multipurpose systems. NFPA Standard 13D and related standard NFPA 13R: Standard for the Installation of Sprinkler Systems in Residential Occupancies up to and Including Four Stories in Height have evolved and been balanced to optimize system costs and fire safety for specific types of residential occupancy buildings (National Fire Protection Association 2009).

Although residential fire sprinkler systems are not a new technology, the International Residential Code (IRC) recently mandated installations in the 2009 edition of the code to take effect January 1, 2011. Currently, although the 13D standard can apply to manufactured homes, the HUD Code does not require the installation of sprinklers or other fire suppression systems in manufactured homes. Some manufacturers do include sprinklers systems within their manufactured homes or portable classrooms. There have been recent discussions about amending the HUD Code to incorporate a fire suppression system requirement.

Fire suppression systems are available for RV engine and generator compartments. A study conducted by National Institute of Standards and Technology (NIST) found the solid propellant generator system, in which gas/particulate effluent is rapidly delivered by pyrotechnical device, to be effective in extinguishing engine compartment fires. Powder, aerosol generator, and tubular suppression systems were ineffective due to insufficient discharge momentum (Hamins 2000). RV fire suppression systems typically contain a monitor to trigger the release of the suppression material (foam, powder, or gas compounds) from a limited number of nozzles, and a valve to shut off the propane. Such fire suppression systems can be installed by the manufacturer or after market (Cooperative Motor Works undated). Some insurance companies offer discounts for the installation of fire suppression devices.

Over 18% of fires start in a bedroom or the living room (U.S. Fire Administration 2008). CPSC has set national standards for the flammability of mattresses and carpets, but California is on the only state with standards for the flammability of home furnishings. The CPSC is considering new regulations to set a national residential furniture flammability standard. Upholstered furniture is easily ignited and frequently comprises the majority of a room's fuel load. There are a wide assortment of fire blocking barriers on the market for padding, batting, and fabrics that meet the California requirements. The use of inherent fire resistant fibers creates highly stable materials minimizing the breakdown into hazardous components, removing the health risks to consumers, and reducing the need for added fire retardant treatments (Zuniga 2008).

New innovations are being developed to incorporate flame retardants into the material. One of these improvements involves the use of nanoparticles with flame retardant properties and water or stain repellency. Another innovation is barrier materials that make polyester resin an integrated part of the fabric (Betts 2008).

Other retardants that have recently become commercially available are nanoclays. These naturally occurring montmorillonite clays, which are incorporated into the materials, result in a slower burn with a low

[2]"Mobile Homes" was replaced with "Manufactured Homes" in the 1994 edition.

flame temperature. Plastic manufacturers find nanoclays appealing since only a small amount is needed, they are inexpensive and they do not affect functionality (Betts 2008). NIST is conducting research on the use of carbon nanofibers, alone and in combination with nanoclays (National Institute of Standards and Technology 2008).

FIRE SAFETY TIPS

Make and practice a fire escape plan with your family. Make sure family members can identify two ways out of every room. Also, pick a safe meeting place away from your home for everyone to go to after escaping a fire. Practice the escape plan with your family every 6 months.

Smoke Alarms

- Follow HUD Code requiring smoke alarms to be located in each bedroom, kitchen/living area, stairwell, and basement (24 CFR 3280.208).
- For better protection, smoke alarms should be interconnected so when one sounds, they all sound (National Fire Protection Association 2009).
- If long-life alarms are not available, use regular alarms, and replace the batteries annually.
- Test all smoke alarms at least every month using the test button or an approved smoke substitute and clean the units, in accordance with the manufacturers' instructions.

In structures that are not regulated by HUD, follow the HUD code or if that is not possible:

- Install smoke alarms on every floor of the structure, and particularly in rooms in which people sleep.
- Use long-life smoke alarms with lithium-powered batteries and hush buttons, which allow persons to stop false alarms quickly. If long-life alarms are not available, use regular alarms and replace the batteries annually.

Cigarette Smoking

People who smoke should attempt to quit. The U.S. Department of Health and Human Services, National Institutes of Health, and National Cancer Institute provide a free helpline (1-800-Quit Now) for smokers who want to quit and need help doing so.

- Smokers should smoke outside the home.
- If someone does smoke in the home, large, nontip ashtrays on level surfaces and empty them frequently. When emptying cigarette butts, douse the butts with water before discarding.

Cooking

- Never leave cooking food unattended, and supervise older children who cook.
- Keep cooking surfaces clean and place anything that can burn well away from the range.

Electrical Circuits

- Ensure that electrical outlets, extension cords, and electrical circuits are never overloaded.
- Consult a professional electrician if electrical problems occur.

Home Heating

The increased likelihood of supplemental room heaters leading to fires in manufactured homes has prompted the USFA to offer a series of recommendations, which include the following:

- Use only the fuel designated by the manufacturer for the appliance
- Place vents and chimneys to allow 18 inches of air space between single-wall connector pipes and combustibles and 2 inches between insulated chimneys and combustibles
- If you use a space heater, read the manufacturer's instructions before using, and place it on a firm out-of-the-way surface to reduce tipping over and keep it at least 3 feet away from clothing, bedding, draperies, or other combustible material. When not in use, turn the space heater off and unplug it.
- Place noncombustible materials around the opening and hearth of fireplaces and store combustible materials away from heat sources.
- Place wood stoves on noncombustible surfaces or a code-specified or listed floor surface
- Have home heating systems serviced annually by a professional.

Other

- Install skirting materials around the exterior of manufactured structures to prevent leaves and other combustible material from blowing under the units.

CHAPTER 3: MOISTURE AND MOLD

INDOOR MOISTURE PROBLEMS

Excessive moisture in buildings is the root cause of multiple health and safety problems in all types of structures, including manufactured structures. The leading causes of moisture problems in buildings include the following:

- water leaks through faulty roofs, doors, and windows
- infiltration through cracked foundations and wet crawl spaces
- lack of ventilation to reduce excess humidity
- condensation of water vapor on cold surfaces when inside humidity reaches high levels
- catastrophic events, such as a flood.

The growth of mold in buildings is a direct result of moisture problems. Water damage, other moisture problems, and excessive humidity also can cause wood rot and deterioration of building materials, dust mites and other pests, and bacteria, such as *Legionella*. There are thousands of species of mold, which is a category of fungus that grows into multicellular filaments. Molds reproduce through spores, and these spores are common throughout the environment. Virtually everyone is exposed to mold spores on a daily basis, but whether an individual is affected by mold depends on a number of factors, including the intensity and duration of exposure, the species of mold, and individual susceptibility.

From time to time, mold spores encounter the three conditions they need to grow: moisture, warmth, and nutrients (i.e., organic materials such as starch and cellulose). When these conditions occur in buildings, then mold may grow on surfaces such as walls and floors. Many kinds of building products used in manufactured structures provide nutrients that support mold growth, including insulation, wallpaper, glues used to install carpeting, and the backing on drywall.

MOLD AND MANUFACTURED STRUCTURES

Although mold may grow in any building that develops warm, moist conditions, manufactured structures, especially those in hot, humid climates, may pose some special challenges. A study of manufactured houses in the Gulf Coast region (Manufactured Housing Research Alliance 2003) pointed to two kinds of problems: *pressure imbalances* and *vapor retarders and air barriers*. Moisture-related problems involving pressure imbalances occur when these pressure differences drive air (and water vapor in the air) to move to locations where moisture accumulates and/or condenses. These imbalances are caused by uneven distribution of conditioned air, duct air leakage, and air leakage through the building shell. Moisture-related problems involved vapor retarders and air barriers occur when the air/water vapor mixture encounters a poorly located vapor barrier (such as inside a wall assembly) where moisture condenses, or when an air barrier fails to adequately limit air flow and the air/water vapor mixture enters cavities where it condenses. Common locations for these problems include exterior wall assemblies, flooring (bottom board and ground cover), and ceilings.

A number of building materials and practices in manufactured structures warrant discussion for their potential role in mold and moisture issues, as described below.

Flooring

Some elements of flooring in manufactured structures can promote the growth of mold. For example, both the carpet and the padding for wall-to-wall carpeting, which is frequently used in new homes (including manufactured structures), readily absorb and hold excess moisture and also can collect dirt, dander, food crumbs, and a host of other nutrients that support the growth of microorganisms. A nutrient-rich carpet combined with a high level of moisture is an ideal environment for mold.

Under the carpeting pad is floor sheathing, which generally consists of a single structural layer, or, less commonly, a two-layer system with a structural layer beneath a separate underlayment. The most common floor sheathing is particleboard, followed by oriented strand board (OSB), and plywood. All wood products absorb moisture but OSB takes longer to absorb moisture and to dry out. In contrast, plywood both absorbs moisture and dries out more quickly (Fisette 2005). Materials that take longer to dry out are more likely to "telegraph," i.e., put pressure on neighboring walls or floors, because the wet materials remain in an expanded state longer than dry ones.

Fiberglass insulation, which is commonly used to insulate floor systems in manufactured structures, is highly porous and can hold a significant amount of moisture. If moisture infiltrates the floor system, condensation may form in the insulation, potentially leading to mold. This can dramatically reduce the insulating properties of the fiberglass (Manufactured Housing Research Alliance 2000).

Polyethylene membranes are commonly used in manufactured structures to wrap the floor system. If the floor system gets wet, the membrane can prevent water from draining away from the structural materials and slow the drying process. In the case of a significant plumbing leak, water spill, or condensation in the floor frame, it is not uncommon to find water pooling on top of the bottom board within the floor cavity (Manufactured Housing Research Alliance 2000).

Walls and Windows

Although HUD Code requires that exterior coverings be weather resistant, no clear prescriptions are provided for flashing and sealing around window and door openings (24 CFR 3280.307). Wall systems are susceptible to rain leakage at window and door flashings and at improperly sealed penetrations (openings where wires, pipes, or other structures enter, or external openings to compartments such as those that hold hot water heaters) (Manufactured Housing Research Alliance 2000). OSB, particleboard, and some panel products used on manufactured structures may be thinner than comparable products used on site-built structures. As when used in floors, these materials may absorb moisture and retain it for long periods.

Windows offer less resistance to the flow of heat than walls. In winter, the temperatures on interior glass surfaces can fall to near outdoor temperatures and below the dew point of the indoor air. This can cause water to condense and even freeze on interior surfaces. When the frozen water melts, it can pool on window ledges and run onto and pool on floors. Double-paned, low U-factor windows can help reduce the chance of condensation on windows.

In warm weather, moisture damage can occur within wall cavities through a similar process. When the indoor air is cooled by air conditioning, moisture condenses on the backside of the wallboard. As shown in Figure 3-1, using a vapor retarder on the inside of exterior walls can trap this moisture within wall cavities, setting up conditions for mold and structural damage (Manufactured Housing Research Alliance 2000).

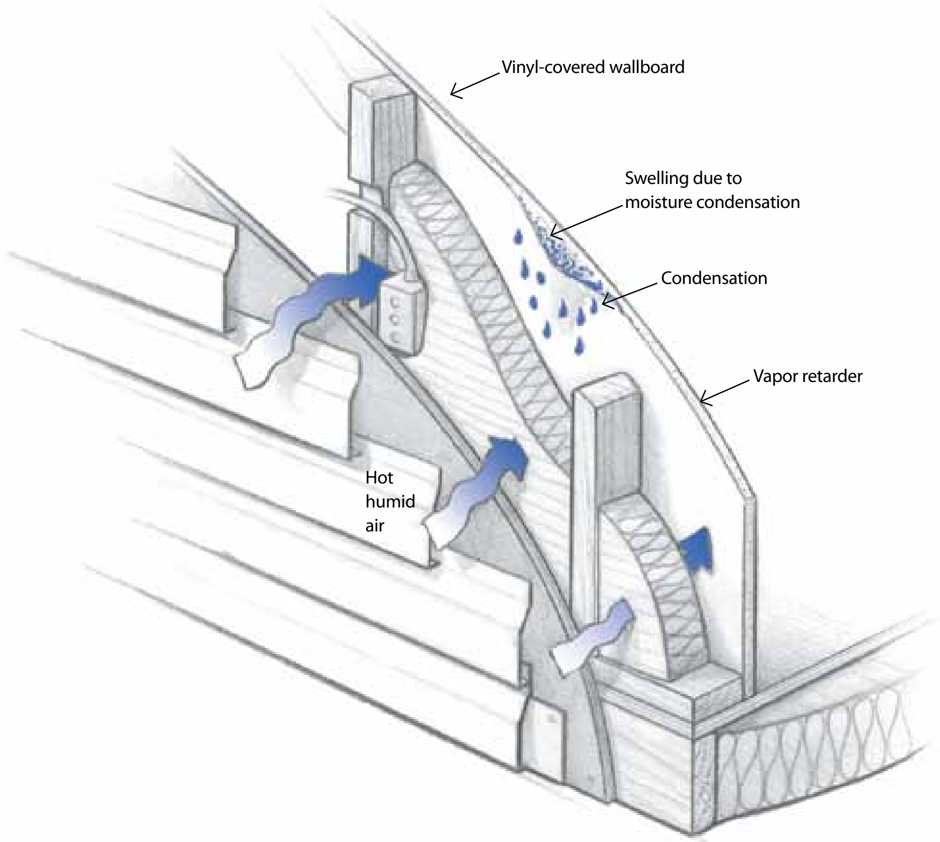


Figure 3-1: Moisture problems in manufactured homes (Manufactured Housing Research Alliance 2000, used by permission).

Roofs

The roof system is a home's primary weather barrier as well as its main thermal barrier. The roof assembly consists of shingles or other finish material typically nailed over a rain screen, sheathing, a roof truss frame that provides an attic cavity, the ceiling insulation layer, and, finally, the interior ceiling board. Leaks can develop around roof penetrations, such as vents and skylights. Moisture from the living space, e.g., from the kitchen or bathroom, also can infiltrate into the roof system, and condense or freeze. When this frozen water later melts, it drips onto the ceiling material.

Ice dams are common for manufactured homes and site-built homes in climates that get a lot of snow. They occur when either insulation is insufficient or warm home air enters the roof cavity through penetrations in the ceiling. In both cases, the roof sheathing is warmed enough to melt snow resting above it on the shingles. The melted water trickles down to the colder surfaces at the edge of the roof, where it refreezes and forms an ice dam on top of the shingles. Eventually, additional melt water backs up and seeps through the bottom edge of the shingles and into the roof cavity, then drips on the ceiling or wall surfaces and in cavities. Ice dams can be combated by providing adequate attic ventilation, adequate insulation (especially over the top plate of exterior walls), providing a double layer of roofing underlayment at the eaves to extend at least 24 inches horizontally from the inside surface of exterior walls, removing accumulated snow manually and ensuring that gutters are not blocked by ice, snow, or debris (Canadian Asphalt Shingle Manufacturers' Association 2001).

Heating, Ventilation, and Air Conditioning Systems

Controlling the relative humidity level in a home can minimize the growth of some biological contaminants. Standing water, water-damaged materials, or wet surfaces serve as a breeding ground for mold, mildew, bacteria and insects. House dust mites thrive in humid, warm environments. A relative humidity in the range of 30 to 50% is recommended to minimize the growth of mold and dust mites in the home. Reducing these two indoor air contaminants is essential to managing the negative health impacts they can have on occupants (discussed below).

Manufactured structures typically come with heating, ventilation and air conditioning (HVAC) system components. Typically, the evaporator is installed at the manufacturing plant inside the air handler, while the condenser is installed on site. Heated or cooled air is distributed through a duct system located in the floor or attic space. In most manufactured structures, air returns to the furnace through an intake grille in the door or wall of the equipment closet (Manufactured Housing Research Alliance 2000).

During the heating season, it is not uncommon to find manufactured structures with unvented propane or kerosene heaters used as auxiliary heat, despite nearly universal warnings by manufacturers against the practice. Unvented heaters can add 5–15 gallons of water a day to the air. A kerosene heater that burns 2 gallons of fuel per day can raise the relative humidity from 55% to 70%, which is sufficient to cause condensation on building surfaces (U.S. Department of Energy 2008, Manufactured Housing Research Alliance 2000).

Air conditioning equipment is often associated with moisture problems due to improper sizing. Air conditioners are designed to dehumidify inside air as well as cool it. Moisture problems can arise from oversized units that cycle on and off too quickly, cooling the air without reducing the humidity. Moisture problems can also arise if an air conditioning system cannot properly dispose of the condensate it removes from the air or if air that conditioned cools the surface of building materials enough to cause condensation.

When an air conditioner is operating properly, the condensed water produced drips into a collecting pan at the bottom of the coil and flows from there into a condensate line, a sloped pipe that drains water outside the home. On a hot, humid day, a central cooling system can discharge 10 gallons or more of condensate water through its drain line (Manufactured Housing Research Alliance 2000). For any type of home, if the condensate line becomes clogged, the water in the drain pan overflows into the furnace or onto the floor, or both. Materials such as dust, animal dander, sediment and mold growth can accumulate to block a condensate line. To drain properly, condensate lines also require a trap, similar to the trap under a sink. Condensate lines without a water-filled trap will suck in air, preventing water from draining while the fan is operating. This sets up conditions for condensate to overflow the collecting pan. Either of these situations can result in extensive soaking of interior building materials that is favorable for mold growth (Manufactured Housing Research Alliance 2000).

Filters clean the air taken up by heating and cooling equipment. In any type of home, if filters are not changed frequently enough, they will clog with dirt and restrict the volume of air reaching the heating or cooling elements. "Starved" for air, the fan may begin pulling air from around the edges of the coil and the condensate pan, preventing the water from running out of the condensate drain and causing it to spill over. Since an air handler is not watertight, the spilled water often makes the equipment closet floor wet. Such problems, particularly in equipment closets with difficult-to-access screw-on panels, may go unnoticed for long periods of time and contribute to mold growth (Manufactured Housing Research Alliance 2000).

Wet and damp ducts are linked to many building moisture problems, whether in site-built or manufactured homes. Ducts have dark interiors with high relative humidity and offer an ideal environment for mold growth. Water can get into ducts and collect at low spots through condensate pan overflows or other spills that find their way into the air distribution system. In addition, a flooded duct can readily overwhelm the dehumidification capacity of an air conditioner, thereby significantly raising the relative humidity and initiating mold growth throughout the interior (Manufactured Housing Research Alliance 2000). When located within a conditioned space (i.e., within the pressure and thermal boundary), specification of a mastic-sealed, insulated, metal duct system for both supply and return ducts represents the gold standard for healthy air distribution from a central system.

Moisture can also enter buildings through operation of mechanical ventilation systems during humid weather conditions. This is particularly a problem in humid climates for site-built or manufactured homes without supplemental dehumidification systems or independent dehumidification control. Without proper dehumidification, ventilation requirements (24 CFR 3280.103) intended to improve indoor air quality and remove moisture during cool dry periods can have the opposite effect during warm humid weather, with a resulting increase in humidity in the home and increased likelihood of mold growth (Manufactured Housing Research Alliance 2000).

Crawl Spaces

A crawl space is the space between a home's flooring and the ground. The ground in the crawl space should be completely covered with a polyethylene sheet or other vapor barrier and sloped to shed rainwater away from the home. Not all manufactured homes may be suited for gutters, but if a home is, installation of gutters and downspouts to direct water away from the home can be useful for keeping the foundation dry and sound (24 CFR 3285.203). Even with these precautions, crawl spaces can be a significant source of moisture (see Figure 3-2). Crawl space moisture comes from water vapor evaporating from the soil, infiltration of humid outdoor air through vented crawl space walls, rainwater runoff, and spills and other water leaks (Manufactured Housing Research Alliance 2000).

Crawl space foundations are typically ventilated to allow water vapor to escape from the area under the dwelling. In humid climates, however, crawl space ventilation can actually increase moisture levels in the crawl space because, during the hot/humid months of the year, the vents allow moist air to enter from outdoors. Humidity in the crawl space air then condenses on cool surfaces like air-conditioning ducts or the cool underside of the floor sheathing. This condensation can accumulate to cause mold, rot, and attract termites and other pests. Soaked insulation from the condensation may also fall out of the floor system, leaving the floor system both wet and uninsulated.

Besides humid ventilation from outdoors, other problematic sources of moisture in crawl space foundations include ground moisture that escapes when the plastic ground cover is missing or torn; water from plumbing leaks in the crawl space area; and clothes dryer vents that are terminated in the crawl space and thus dump their moisture there. These items are shown in Figure 3-2.

HEALTH EFFECTS OF MOLD

Mold can threaten a person's health in several ways (Bush et al. 2006; Institute of Medicine 2004; Seltzer and Fedoruk 2007). First, some molds produce volatile organic compounds, such as alcohols, ketones, and esters, which cause the musty odor often associated with mold growth. Approximately 6%-10% of the general population and 15%-50% of persons who are genetically prone to allergies are allergic to mold (Institute of Medicine 2000). The most common symptoms include runny nose, eye irritation, coughing, congestion, and exacerbation of asthma in persons who have the disease.

Second, mold can also adversely affect health by triggering immune responses. Some immune responses, such as allergies, are familiar and symptoms include sneezing, cough, runny nose, red eyes, and a skin rash. Asthma commonly has an immune component, and exposure to damp indoor spaces can aggravate this condition as can exposure to mold (Institute of Medicine 2000, 2004). More severe immune responses, such as a lung disease called hypersensitivity pneumonitis, are far less common.

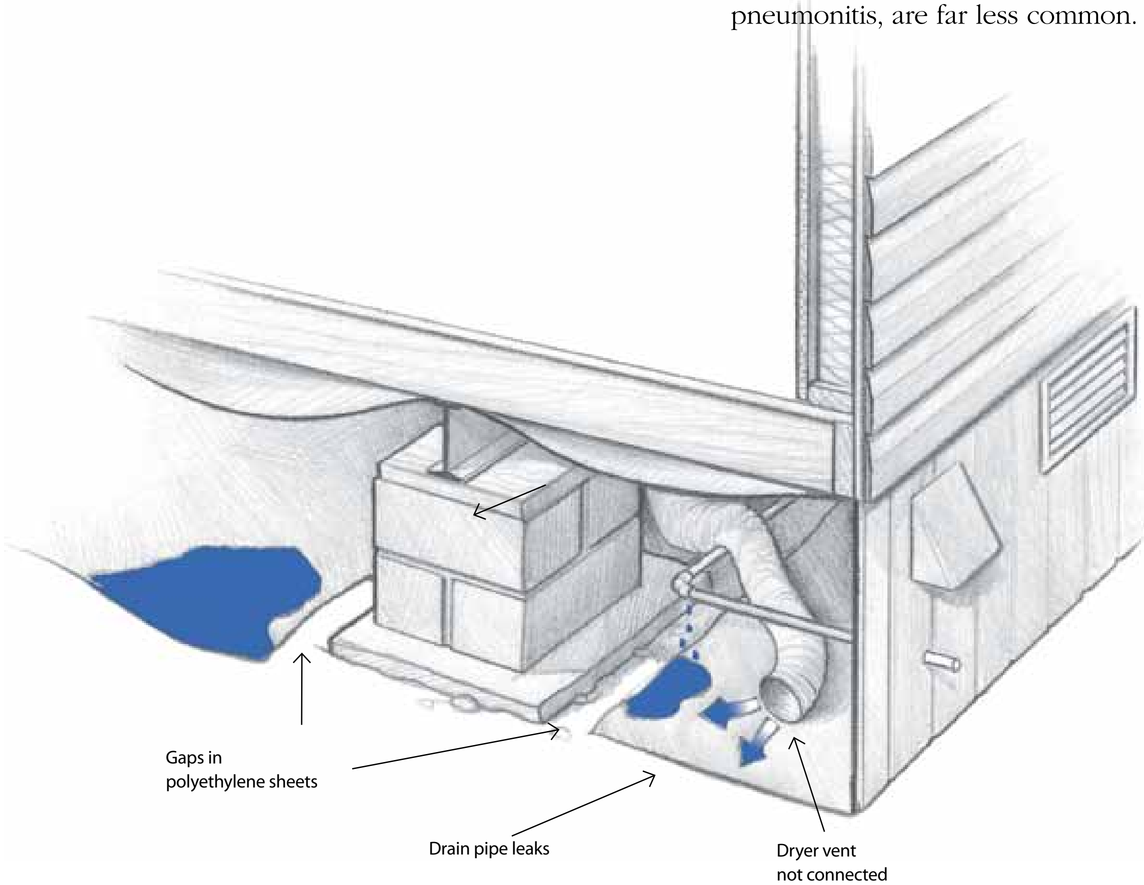


Figure 3-2: Moisture problems in the crawl space (Manufactured Housing Research Alliance 2000, used by permission).

Third, some molds can cause infections. The victims of such infections are typically people with compromised immune systems, such as transplant patients, chemotherapy patients, or people with infections such as HIV. Aspergillosis, which is caused by *Aspergillus*, is the best known such infection.

Finally, molds may also produce another class of chemicals, called mycotoxins. Mycotoxins are metabolic byproducts of molds and are toxic to humans and animals. Mycotoxins are suspected of causing disease from mold exposures in buildings, but scientists remain uncertain about the nature and extent of mycotoxin-related disease (Bennett and Klich 2003; Institute of Medicine 2004).

ASSESSING MOLD PROBLEMS

Methods for assessing the presence of mold include visual inspection and laboratory testing of air and dust (Institute of Medicine 2004; Macher 1999; New York City Department of Health 2000). Visual inspection by a knowledgeable person is the simplest, fastest, and least-expensive assessment method. Such an inspection includes looking for damp spots, evidence of water stains, mold growth, and the presence of musty odors (Macher 1999).

Because laboratory analysis is costly and produces results that often are difficult to interpret, current guidance discourages analysis of environmental samples for mold in most situations (Centers for Disease Control and Prevention 2006; Institute of Medicine 2004). However, such analysis may be appropriate if a mold-associated disease is suspected or if visual inspection cannot be done (a rare occurrence in a manufactured structure) (New York City Department of Health 2000). Guidelines to interpreting such test results are available (http://pollen.utulsa.edu/Rostrum.pdf) (Horner et al. 2008).

A portable moisture meter, which directly measures moisture levels in building materials, may help identify water leaks and areas of potential mold growth that are not obvious by visual inspection. A moisture meter also can be used to directly measure moisture content after water damage occurs. Finally, moisture meters can be used to monitor the drying of water damaged materials. Depending on the design, moisture meters may have a thin probe that is inserted into the material to be tested or may be pressed directly against the surface of the material for a noninvasive reading. Moisture meters can be used on materials such as carpeting, wallboard, wood, brick, and concrete (U.S. Environmental Protection Agency 2001).

CLEANING UP MOLD PROBLEMS

When mold is found in any structure, two responses are needed: clean up the mold and eliminate the moisture source that facilitated the mold growth. EPA's *Brief Guide to Mold, Moisture and Your Home* (http://www.epa.gov/mold/pdfs/moldguide.pdf) provides practical tips to occupants. The approach to a mold clean-up effort depends on site-specific factors such as the surface contaminated (porous or nonporous), extent of the contamination, and presence of highly susceptible occupants (Macher 1999, Morey 2000).

For relatively limited areas, such as superficial mold on the floor near a bathroom leak, individuals can perform the clean up themselves. For nonporous surfaces, such as hard surface floors and countertops, clean up is accomplished using a detergent. For contaminated porous materials, such as ceiling tiles, wallboard, carpet, or upholstered furniture, replacing the material rather than cleaning it is often the best mitigation option (New York City Department of Health 2000, U.S. Environmental Protection Agency 2001).

Different types of biocides are used to kill mold, including alcohols, aldehydes, halogens, hydrogen peroxide, phenolics and quaternary ammonium compounds (Foarde 1998). However, biocides can pose a potential hazard to human health (Foarde 1998; Macher 1999; U.S. Environmental Protection Agency 1997), and dead mold material often still retains allergenic or toxic properties (Institute of Medicine 2000; Foarde 1998). CDC recommends cleaning moldy areas with detergent and water; if that does not work, then CDC recommends using bleach, which does get rid of the allergenic and toxic properties of mold. Note: Ammonia and bleach should never be mixed, as this may produce chlorine and other poisonous gases, or lead to an explosion.

Because clean up, replacement work, or both—especially for larger jobs—might disturb mold and release fungal spores into the air (U.S. Department of Housing and Urban Development 2006), some authorities recommend hiring a contractor trained in mold remediation to do this kind of work.

Evaluating Health after Exposure to Indoor Mold

People who develop symptoms following exposure to mold should seek a proper medical evaluation. While some medical problems, such as wheezing, coughing and sneezing, have been associated with exposure to mold and moisture, these symptoms may also result from other causes, so a full evaluation is necessary.

PREVENTING AND CONTROLLING MOLD PROBLEMS

The two keys to controlling mold in buildings are keeping exterior moisture out of the building and controlling moisture from internal sources (U.S. Department of Housing and Urban Development 2005). Controlling moisture and mold problems in manufactured structures requires not only design and manufacturing strategies but also certain actions and behaviors by the occupants of manufactured structures.

Design and Construction Issues

First, ensuring the building envelope is weather tight is essential to avoid water leaks in the roof, windows, and doors. Exterior water intrusion can be prevented by good flashing techniques around windows, roof penetrations, and doors. This allows the building envelope to shed rain water down the building. Once this water reaches the ground, site drainage systems should channel water away from the dwelling and not let water collect or pool underneath the unit.

Second, manufacturers should consider enhancements in design and building materials to reduce the potential for mold and moisture problems in manufactured structures. A few examples are noted below. Additionally Chapter 9 discusses more opportunities for enhanced indoor air quality and durability of manufactured structures.

- Install moisture-resistant flooring for areas such as bathrooms, laundries, and utility rooms where floors are likely to get wet. Currently, HUD Code advocates for moisture resistant flooring in these areas (24 CFR 3280.305) but the code language leaves a loophole that permits manufacturers to install non-moisture-resistant floor coverings over moisture-resistant or sealed subfloors.
- While exhaust fans are generally required in bathrooms and kitchens by HUD Code (24 CFR 3280.103), performance can be enhanced by installing exhaust fans with field capacity that tracks closely with rated capacity (more often achieved by higher quality fans and/or fans with minimum 6-inch-diameter ducts). Exhaust fans controlled by a humidistat switch or a humidity sensor in the fan itself also help to reduce moisture and humidity indoors.
- Place HVAC ducts in the ceiling instead of the floor to reduce the risk of water collecting in ducts from leaks.

Third, differences in climate and humidity need to be taken into account in controlling condensation in manufactured structures. The HUD Code offers guidance to manufactured housing manufacturers for controlling condensation. One method is using a vapor barrier or vapor retarder. Vapor retarders are materials with a permeance of 1.0, meaning that these materials will slow the rate of moisture diffusion through the building envelope. Vapor retarders include common construction materials such as kraft paper facing on insulation batts and plastic sheeting, as well as products like special paints or a vinyl coating adhered to gypsum wallboard (Manufactured Housing Research Alliance 2000). Deployed properly, vapor retarders should minimize the amount of water vapor that diffuses into exterior wall assemblies, thereby preventing condensation and moisture problems.

Installation of vapor retarders like plastic sheeting on the living side of the building envelope (such as just behind the drywall) is well suited to prevent wintertime condensation problems in cold climates, because the plastic prevents humidity from the indoor air from getting into the colder parts of the wall cavity where it would condense. However, vapor retarders must be approached differently in air-conditioned homes in hot, humid climates. In these homes, moisture from humid outdoor air may diffuse into the wall cavity and eventually reach the plastic sheeting if it is still installed just behind the drywall. In this scenario, the plastic sheeting and the drywall it is next to will often be cool because they are adjacent to the cool, air-conditioned interior of the home. The cool surface of the plastic sheeting (the vapor retarder) will create a condensation point for the airborne moisture from outdoors. Since the vapor diffusion differential will continue to push humidity from the outdoors towards the dryer indoors, more and more condensation will take place and accumulate in the wall cavity. This accumulation of moisture and water in the wall will lead to mold, rot, and other problems. Seasonal drying of the wall may take place if the climate is mixed, and during the colder part of the year vapor diffuses back towards the outdoors.

This problem scenario is due to an inappropriate location of the vapor retarder in the wall considering the climate. HUD Code now permits, but does not require, a vapor retarder to be installed on the exterior of wall insulation in humid climates or mixed climates. Manufacturers who specify an exterior vapor retarder in lieu of an interior vapor retarder in these climates are expected to reduce moisture and mold problems in their units (24 CFR 3280.504).

Moisture in manufactured homes is also reduced if steps are taken to reduce the shell and duct air leakage levels. These steps, combined with a controlled ventilation system that provides the opportunity to condition (dehumidify) air drawn into the home before it reaches the living spaces, will decrease the chances of condensation (U.S. Department of Housing and Urban Development 2003).

HUD Code requires that ceilings be designed to control condensation and specify using a ceiling vapor retarder for homes in cold climates (24 CFR 3280.504). This vapor retarder is optional in warmer climates. These provisions, however, do not necessarily protect the roof system from moisture transported by air moving through holes in the ceiling made to accommodate lights, speakers, plumbing stacks, or other devices (Manufactured Housing Research Alliance 2000). As with site-built homes, it is important to reduce air infiltration/exfiltration across the ceiling plane to reduce the likelihood of moisture.

Preventing ice dams on manufactured structures is also related to controlling air leakage from the house to the attic area. To control the escape of heat from the home upward into the attic (which then triggers the ice dam), attic insulation should be the required thickness and evenly distributed, and a continuous air retarder should be used across the ceiling plane between house and attic. These two measures minimize the amount of home heat that can enter the attic cavity. A third measure is to properly ventilate the attic. Ventilating the attic cavity helps dissipate attic heat that contributes to ice damming (Manufactured Housing Research Alliance 2000).

Technologies to Prevent Moisture and Mold Problems

Drywall manufacturers have created gypsum board with cores that retard moisture absorption and are either covered with antimicrobial-treated paper or paper-free coverings. The American Society for Testing and Materials (ASTM) is considering revising ASTM C1396 / C1396M - 06a Standard Specification for Gypsum Board to include a standard definition for mold resistant gypsum board (http://www.astm.org/DATABASE.CART/WORKITEMS/WK17338.htm). To make the assembly truly mold resistant, the drywall should also be finished with inorganic tapes and glues.

The incorporation of antimicrobials in building materials seems to offer promise in reducing the potential for mold growth within a structure. Vinyl and rubber flooring has also recently become available with embedded antimicrobial properties to prevent the growth of mold and bacteria. An Environmental Protection Agency (EPA) study on the effectiveness of antimicrobial encapsulant paints to prevent the regrowth of mold on gypsum wallboard suggests that these paints offer a viable option when removal of contaminated wallboard is not feasible (Menetrez et al. 2008)

Tips to Reduce Moisture and Mold Problems

People who live, play, study, or work in structures of any type, including manufactured structures, can take the following steps to reduce and avoid moisture and mold problems (see http://www.epa.gov/mold/mold_remediation.html) (U.S. Environmental Protection Agency 2001).

- Check for and promptly correct any water leakage problems, including the roof, windows, doors, HVAC system, and plumbing.
- Watch for condensation and wet spots. Fix sources of moisture problems as soon as possible. Clean and dry wet or damp spots within 48 hours.
- Use dehumidifiers to reduce humidity to the range of 30%-50%.
- Ensure exhaust ventilation in kitchens and bathrooms that are vented to the outside are exhausting at rates required by HUD Code (24 CFR 3280.103, 50 cfm for bathrooms and 100 cfm for kitchen).
- Vent moisture-generating appliances, such as dryers, to the outside where possible (note dryers are required to be exhausted to the outside in 24 CFR 3280.708 and are not permitted to be exhausted beneath the home)
- Inspect and maintain HVAC systems, including the condensate line, which should drain outside to an appropriate place (and not into the crawl space) and drip pans, which should be clean and unobstructed.
- Maintain gutters and downspouts in good condition and slope soil away from building foundations (24 CFR 3285.203).
- Seal ducts with mastic, insulate, and cover with a continuous vapor barrier. Insulating the duct itself in addition to ensuring that the duct is within the conditioned thermal boundary and pressure boundary of the home will reduce the chance of condensation. HUD Code provides minimum requirements for installation of crossover ducts (24 CFR 3285.606) and supply and return ducts (24 CFR 3280.715).

CHAPTER 4: INDOOR AIR QUALITY

BACKGROUND

The air people breathe while indoors may contain many contaminants from many different sources (http://www.arb.ca.gov/research/indoor/indoor./htm). In many instances, contaminants reach higher levels in indoor air than outside. Accordingly, the quality of indoor air in homes, schools, and workplaces can have a significant impact on health (U.S. Environmental Protection Agency and U.S. Consumer Product Safety Commission 1993).

While many types of buildings may pose indoor air quality (IAQ) problems, some manufactured structures may raise special concerns. Those with small interior volumes, limited ventilation, and/or extensive use of components that emit volatile or semivolatile compounds that have health effects. Sterling and Lewis 1998) may expose occupants to higher le air contaminants. Lifestyle choices of persons living in these units also can have a significant effect on indoor air quality.

No comprehensive data are available on the quality of air in manufactured structures. However, several studies have addressed indoor air quality in manufactured structures in both home and school settings. While some studies assess overall air quality, most focus on specific contaminants. In general, manufactured structures with relatively less air circulation may develop higher levels of indoor contaminants.

The health effects of these contaminants vary depending on the contaminant, the level of exposure, individual susceptibility and other factors. Some people may be especially sensitive to indoor contaminants because of genetic factors, underlying allergies or other diseases, being very young or old, and other reasons. Note that Chapter 8 includes a summary of the health effects of many IAQ contaminants to Special Populations such as young children and people with asthma.

INDOOR AIR CONTAMINANTS OF CONCERN

A wide variety of contaminants are commonly found in indoor air in all types of structures. This manual addresses major contaminants of concern in the following categories:

- volatile chemicals emitted from building materials, cleaning products, furnishings, personal care products, cooking fuel combustion, and other sources
- biological contaminants, such as pollen and mold spores, pet dander, cockroach and dust mite particles, and other allergens
- combustion byproducts, such as carbon monoxide, nitrogen dioxide, and particulate matter
- pesticides used indoors to kill rodents, insects, and other pests and tracked in from outdoor applications
- smoke from tobacco use and wood stoves
- radon infiltration from the ground into living spaces

In addition to contaminants that are airborne, household dust and residues on indoor surfaces can also contain pollutants such as semivolatile chemicals and combustion by products that can be resuspended and inhaled. Pollutants in these reservoirs, including heavy metals such as lead, can also be ingested via hand-to-mouth activity.

Volatile Organic Compounds

Volatile organic compounds (VOCs) are emitted as gases from certain solids and liquids. Organic chemicals are widely used as ingredients in thousands of household products, including paints, varnishes, and wax as well as many cleaning, disinfecting, cosmetic, and hobby products. Carpeting and the padding and adhesives used to install them can also release VOCs into indoor air. All of these products can release organic compounds during use and, to varying degrees, during storage (U.S. Environmental Protection Agency and U.S. Consumer Product Safety Commission 1993). Other sources of indoor VOCs include cigarette smoke, dry-cleaned clothes, and room deodorizers (Torén and Hermansson 1999) (Table 4-1). Common organic pollutants can be 2 to 5 times higher inside homes than outside, regardless of whether the homes were located in rural or highly industrial areas (U.S. Environmental Protection Agency and U.S. Consumer Product Safety Commission 1993).

Indoor exposure to VOCs at low levels may cause symptoms (Hodgson et al. 2000; Wolkoff 1999). As with other pollutants, the health effects of VOCs depend on many factors, including level of exposure, adequacy of ventilation and length of time exposed. Immediate symptoms can include eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory loss (Mendell 2007; U.S. Consumer Product Safety Commission et al. 1998). For example, the use of aerosol cleaning products has been associated with an increased incidence of asthma symptoms over an average follow-up period of 9 years (Dales et al. 2008). In addition, some VOCs may increase the risk of chronic health effects. For example, the International Agency for Research on Cancer (IARC) classifies formaldehyde as a probable human carcinogen, although there are uncertainties in estimating formaldehyde's cancer risks.

Formaldehyde

One organic chemical that is used in many building materials and other household products is formaldehyde, a colorless, pungent-smelling gas. Formaldehyde is an irritant that may contribute to respiratory and allergic symptoms (Mendell 2007). In manufactured structures, the most significant sources of formaldehyde are typically composite wood products made using adhesives that contain urea-formaldehyde resins. Composite wood products include plywood, particleboard (used as subflooring and shelving and in cabinetry and furniture), hardwood paneling, and medium-density fiberboard (used for drawer fronts, cabinets, and furniture tops). The tight building envelopes and relatively low air exchange rates in some manufactured structures combined with formaldehyde off-gassing can cause indoor levels to rise. This effect has been recognized for decades (Breysse 1977; Gupta et al. 1982; Hanrahan et al. 1984; Liu et al. 1991; Stone et al. 1981). The rate at which products such as pressed wood or textiles release formaldehyde can change over time. For example, high indoor temperatures or humidity can increase release of formaldehyde. In general, formaldehyde emissions generally decrease as products age.

Reference	Study /Description	Location	Key Analyses	Summary
Hodgson et al. 2000	VOCs measured in four new manufactured houses over 2-9.5 months following installation; compared with seven new site built houses 1-2 months after completion.	Eastern and Southeastern United States	Concentrations of 54 volatile organic compounds (VOCs)	In both manufactured and site-built houses, the predominant airborne compounds were alpha-pinene, formaldehyde, hexanal, and acetic acid. Major identified sources included plywood flooring, latex paint and sheet vinyl flooring. Generally, the ratios of emission rates at the low and high ventilation rates decreased with decreasing compound volatility. Changes in VOC emission rates in the manufactured houses over 2-9.5 months after installation varied by compound. Only several compounds showed a consistent decrease in emission rate over this period.
Hodgson et al. 2002	Source identification study	Manufactured house in Florida	Formaldehyde, less volatile aldehydes, and terpene hydrocarbons	Several cabinetry materials, passage doors, and the plywood subfloor were the predominant sources of formaldehyde and other aldehydes. The plywood subfloor was the predominant terpene source.
Hodgson et al. 2004	Comparison between conventional and alternative products used in relocatable classrooms (RCs)	Newly constructed RCs in California	Fifteen target VOCs, including formaldehyde, acetaldehyde, vinyl acetate, phenol, toluene, and naphthalene	Concentrations of six of ten VOCs were significantly lower in modified RCs though average differences were mostly less than 1 part per billion (ppb). Only formaldehyde had average adjusted indoor concentrations above 5 ppb.

Table 4-1: Key Studies of Indoor Volatile Organic Compound (VOC) Concentrations in Manufactured Structures

Indoor combustion processes, such as gas stove use and tobacco smoking, can also produce formaldehyde (U.S. Environmental Protection Agency and U.S. Consumer Product Safety Commission 1993). Outdoor sources of formaldehyde, both from primary emissions and from photochemical reactions, can also contribute to indoor concentrations.

Studies in the 1980s showed formaldehyde levels in manufactured housing that were high by current standards. A 1981 study (Stone et al. 1981) of mobile homes in Washington, Wisconsin, and Minnesota distinguished between units less than 2 years old and those that were older. In newer homes whose residents had symptomatic complaints, mean levels ranged between 720 and 840 parts per billion (ppb), and in newer homes randomly selected without regard to owner complaints, the mean level was 530 ppb. In older homes with owner complaints, mean levels ranged between 280 and 470 ppb. Another 1981 study (Dally et al. 1981) of 65 Wisconsin mobile homes with owner complaints showed a median formaldehyde level of 480 ppb. In 1984 study of 430 mobile homes in Washington state (Breysse 1984), 4% had formaldehyde levels above 1,000 ppb, 18% had levels between 490 and 990 ppb, 64% had levels between 100 and 490 ppb, and 14% had levels below 100 ppb. And in a 1984 study of 65 mobile homes in Wisconsin, formaldehyde levels averaged 160 ppb, and ranged as high as 800 ppb (Hanrahan et al. 1984).

Later studies have shown substantially lower formaldehyde levels in manufactured housing built since HUD standards limiting formaldehyde emissions took effect in 1985. A 2000 study (Hodgson et al. 2000) of four new, unoccupied manufactured homes in the eastern and southeastern U.S. found geometric mean (GM) formaldehyde levels of 34 ppb in manufactured homes, with no measurements exceeding 50 ppb; these findings were close to levels seen in site-built homes. An Australian study found average formaldehyde levels of 100 ppb in unoccupied trailers and 29 ppb in occupied trailers, with older units having lower levels (Dingle et al. 2000). The U.S. Environmental Protection Agency's (EPA) National Human Exposure Assessment Survey found a median formaldehyde level of 17 ppb, with a maximum of 332 ppb, in 189 Arizona homes (Gordon et al. 1999). And the RIOPA study (Relationships of Indoor, Outdoor, and Personal Air) of 184 single-family homes in three metropolitan areas, including 31 mobile homes

(28 in Houston and 3 in Los Angeles County), found mean formaldehyde levels of 16–25 ppb in trailers, only slightly higher than levels found in conventional houses (Weisel et al. 2005).

A CDC study of 519 travel trailers, park models, and mobile homes in the Gulf Region following Hurricane Katrina showed elevated formaldehyde levels. The geometric mean was 77 ppb, two or three times the typical level in conventional U.S. houses, and ranged as high as several hundred ppb. Certain factors predicted higher levels of formaldehyde, such as small size (travel trailers as opposed to manufactured homes), high temperatures, and closed windows. Because formaldehyde levels tend to be higher in newly constructed manufactured structures and during warmer weather, CDC cautioned that the levels observed likely underestimated long-term exposures; many of the units were approximately 2 years old when tested, and the study was conducted during the winter (Centers for Disease Control and Prevention 2008).

Other studies have focused on air quality in portable classrooms. The California Portable Classroom Study, completed in 2004 (http://www.arb.ca.gov/research/indoor/pcs/pcs.htm), showed that half of portable classrooms sampled had formaldehyde levels above 27 ppb, and 4% of portable classrooms had levels above 76 ppb. These levels were higher than those seen in traditional classrooms, but the elevated levels were seen only in newer portable classrooms. Other classroom factors linked with higher formaldehyde levels included warmer weather, the presence of pressed wood cabinets, new carpet, and flooring, and the presence of chemicals.

Since 1985, the Department of Housing and Urban Development (HUD) has limited the formaldehyde emission rate from plywood (0.2 ppm) and particleboard (0.3 ppm) used in the construction of manufactured housing (24 CFR 3280.308). Congress did not give HUD authority to regulate travel trailers in this way. In 2008, the California Air Resources Board (CARB) issued a final rule to further reduce formaldehyde emissions from hardwood plywood (0.05 ppm by 2012), particleboard (0.09 ppm by 2012), and medium density fiberboard (0.11-0.13 ppm by 2012) that are sold or supplied in California (California Air Resources Board 2008). The EPA is currently pursuing rulemaking to address formaldehyde emissions from pressed wood products on a national level (not limited to manufactured home applications) and is considering adopting the emissions limits imposed by CARB (U.S. Environmental Protection Agency 2008a). Among other groups, the Composite Panel Association has publicly endorsed nationalization of the CARB standards (Ehrlich 2008).

Manufactured homes subject to the Manufactured Home Standards and (MHSCC) are exempt from the CARB standard (http://www.arb.ca.gov/toxics/compwood/engfabricator.pdf). The Recreational Vehicle Industry Association (RVIA) members have agreed to build all units with wood products that comply with the CARB standard's emission limits by January 1, 2009, and, by July 1, 2010, all the wood they use will be certified by an appropriate third party as meeting the CARB standard.

Allergens

In manufactured structures as well as other kinds of structures, people may be exposed to a wide range of allergens from pets, dust mites, pests such as cockroaches and rodents, and mold. These biological agents can contribute to allergic symptoms, such as sneezing, runny eyes, and nose. Further dust mite allergen increases the risk of both asthma development and asthma symptoms (Institute of Medicine 2000).

Chapter 5 provides additional information on pests, pesticides and Integrated Pest Management (IPM). Chapter 3 provides additional information on mold and moisture.

Combustion Byproducts

Appliances that burn fuels such as natural gas, liquefied petroleum, kerosene, oil, coal and wood can also contribute to indoor air pollution. Common combustion appliances include space heaters, ovens, stoves, furnaces, water heaters, and clothes dryers, which are frequently used in manufactured housing as well as other types of housing. The types and amounts of pollutants these appliances produce depends upon the type of appliance; the kind of fuel it uses; and how well the appliance is installed, vented and maintained; (U.S. Consumer Product Safety Commission et al. 1998). Improper adjustment of burners, often indicated by a persistent yellow-tipped flame, causes increased pollutant exposure. Usage patterns and the physical characteristics of the home are also key determinants of indoor concentrations.

Combustion appliances commonly produce such indoor pollutants as carbon monoxide, nitrogen dioxide, particles, sulfur dioxide, unburned hydrocarbons and aldehydes (U.S. Consumer Product Safety Commission et al. 1998). Other important potential sources of combustion gases and particles include vehicles idling in attached garages, and portable generators, which should never be operated indoors, and, when operated outdoors, should never be placed near open doors and windows.

Some studies have examined the impact of combustion sources on indoor air quality in manufactured structures. For example, studies (Mumford et al. 1991; Williams et al. 1992) examined the role of kerosene heaters in eight mobile homes. Use of the heaters was associated with increased levels of carbon monoxide and organic matter, including polycyclic aromatic hydrocarbons.

Combustion products in indoor air may cause such health effects as headaches, dizziness, sleepiness, breathing difficulties, and even death (U.S. Consumer Product Safety Commission et al. 1998). Acute health effects may develop immediately, and chronic effects may occur after long-term exposure. The effects depend upon the level and duration of exposure.

Carbon Monoxide (CO)

CO is a colorless, odorless gas that interferes with the delivery of oxygen throughout the body. CO may come from gas furnaces, wood stoves, fireplaces, and portable generators (Dales et al. 2008) as well as outdoor sources such as cars and portable generators. In 2005 in the United States, there were an estimated 195 unintentional non-fire carbon monoxide deaths associated with consumer products (overall, not just in manufactured structures); the estimated annual average from 2003-2005 was 171 deaths (U.S. Consumer Product Safety Commission 2008). At high concentrations CO can cause unconsciousness and death. Lower concentrations can cause a range of symptoms—from headaches, nausea, shortness of breath, light-headedness, and weakness (Shimer et al. 2005) to episodes of chest pain in people with chronic heart disease. Vulnerable populations, such as infants, elderly, and those with chronic illnesses, are especially sensitive to carbon monoxide exposures (Centers for Disease Control and Prevention 1997; Ernst and Zibrak 1998; Raub 1999; Varon et al. 1999).

Nitrogen Dioxide (NO_2)

NO_2, a colorless, odorless gas, is another combustion byproduct (Brunekreef 2001; Willers et al. 2006). A study of nitrogen dioxide in mobile homes in California showed that levels were quite variable, but use of a gas stove, small size of the unit, and high outside NO_2 levels predicted higher levels within the units (Petreas et al. 1988). This work built on numerous studies of indoor nitrogen dioxide that have shown that identified indoor fuel combustion sources, particularly gas stoves, and tobacco smoking as principal sources. Modifying factors, such as the use of stoves for supplemental heating, dwelling size, ventilation rates, and ambient levels have been shown to contribute to indoor NO_2 levels (Gillespie-Bennett et al. 2008; Zota et al. 2005).

NO_2 can irritate the mucous membranes in the eye, nose, and throat and causes shortness of breath after exposure to high concentrations (U.S. Consumer Product Safety Commission et al. 1998). High concentrations or continued exposure to low levels of nitrogen dioxide may increase the risk for or exacerbate existing respiratory disease (Belanger and Triche 2008; Keller et al. 1979; Melia et al. 1977). People at particular risk from exposure to nitrogen dioxide include children and individuals with pre-existing respiratory disease such as asthma (U.S. Consumer Product Safety Commission et al. 1998; U.S. Environmental Protection Agency and U.S. Consumer Product Safety Commission 1993).

Particles or Particulate Matter (PM)

PM is released when fuels are incompletely burned. Key indoor sources are fuel-burning devices, including fireplaces and wood stoves, and tobacco smoking (Wallace 1996). Automobile emissions and other outdoor sources can contribute significantly to indoor particulate levels. Particulate matter that is inhaled may cause irritation or damage to lung tissue and negatively impact cardiopulmonary health (Pope and Dockery 2006). In addition, particles suspended in the air can cause eye, nose, and throat irritation. (Dockery 2009; Lebowitz 1996; Suh et al. 2000; U.S. Consumer Product Safety Commission et al. 1998; Wigle et al. 2007). Studies have shown indoor PM levels to be heavily affected by variations in outdoor automobile traffic congestion, so operation of mechanical ventilation systems in homes near congested areas could stand to benefit from filters and/or controls that take these levels into consideration (Diapouli et al. 2008).

Pesticides

A pesticide is any substance used to kill, repel, or control forms of plant or animal life that are considered to be pests. It is estimated that 75% of U.S. households use at least one pesticide product indoors over the course of a year, and 80% of most people's exposure to pesticides occurs indoors (U.S. Environmental Protection Agency and U.S. Consumer Product Safety Commission 1993). The amount of pesticides found in homes appears to be greater than can be explained by recent pesticide use in those households; other possible sources include contaminated soil or dust that floats or is tracked in from outside, stored pesticide containers, and household surfaces that collect and then release the pesticides (U.S. Environmental Protection Agency and U.S. Consumer Product Safety Commission 1993).

Pesticide exposure can result in eye, nose, and throat irritation; damage to the central nervous system and kidneys; and increased risk of cancer, reproductive damage, and other conditions (U.S. Environmental Protection Agency and U.S. Consumer Product Safety Commission 1993). Both active and inert agents in pesticides can cause negative health effects. Inert agents in pesticides are not toxic to the targeted pest; however, some inert agents are capable of causing health problems in people (U.S. Environmental Protection Agency and U.S. Consumer Product Safety Commission 1993). In addition to chronic effects of low-level exposures to pesticides, thousands of pesticide poisonings occur annually in the Unites States through accidental ingestion of large doses, especially in children.

Chapter 5 provides additional information on pests, pesticides, and integrated pest management (IPM).

Environmental Tobacco Smoke

Environmental tobacco smoke (ETS), which is a common indoor pollutant, is the mixture of smoke that comes from the burning end of a cigarette, pipe, or cigar, and smoke exhaled by the smoker. It is a complex mixture of over 4,000 compounds, many of which are known to be carcinogenic (Hackshaw et al. 1997). In 2006, the U.S. Surgeon General completed a major assessment of the respiratory health risks of ETS, which concluded that for nonsmoking children and adults, the predominant exposure to secondhand smoke occurs in the home, and this exposure can lead to premature disease and death (Centers for Disease Control and Prevention 2006).

Infants and young children whose parents smoke in their presence are at increased risk of childhood cough and wheeze, admission to hospital for respiratory illness, and sudden infant death syndrome (Dales et al. 2008). EPA estimates that passive smoking contributes to the occurrence of 150,000 and 300,000 lower respiratory tract infections annually in infants and children younger than 18 months of age, resulting in 7,500 to 15,000 hospitalizations each year (U.S. Environmental Protection Agency 1992). Asthmatic children are at increased risk. Research suggests that exposure to secondhand smoke can increase the number of episodes and the severity of symptoms in asthmatic children. Some estimates indicate that each year exposure to secondhand smoke worsens the condition of 200,000 to 1,000,000 asthmatic children (U.S. Environmental Protection Agency 1992).

Radon

Radon is a carcinogenic, naturally occurring radioactive gas that cannot be seen, smelled or tasted. It is the second leading cause of lung cancer in America and claims about 20,000 lives annually (U.S. Environmental Protection Agency 2003). Radon levels are found in dangerous concentrations in many areas of the U.S. due to infiltration of this soil gas into the home's living space.

Radon levels in homes should be measured with basic test kits from home improvement stores. If levels are too high, active mitigation systems use a fan and vent piping to exhaust soil gas from underneath the foundation slab to outdoors. In new construction, passive systems—which include the vent piping and vertical stack but not the fan—can be installed and later upgraded to an active system if necessary. In any home, cracks and joints in the slab or finish floor on the lowest level, like those around drain pipes, should be sealed to isolate the house air from soil gases beneath the unit.

CONTROLLING SOURCES OF INDOOR AIR CONTAMINANTS

Improving indoor air quality in manufactured structures, as in all kinds of buildings, is based on two general principles: controlling sources of indoor pollutants and ensuring adequate ventilation and moisture control. Significant opportunities exist to advance each of these strategies through changes in design and manufacturing, maintenance and occupants' day-to-day use.

Manufacturers can help reduce sources of indoor pollutants in many ways, including

- Ensuring the integrity of the structures to avoid cracks and crevices that can give pests access or lead to water damage and moisture problems.
- Choosing materials that are durable, cleanable and low- or non-emitting.
- Eliminating carpeting in kitchens and bathrooms to reduce allergen and mold reservoirs.
- Expanding the home owner manual to include information on controlling pollutants at the source (e.g., storage and use of chemicals and cleaners).
- Ensuring that all installed combustion appliances are properly vented.
- Using only composite wood products that meet the new CARB standards for reduced formaldehyde emissions.

For more information about improving indoor air quality, particularly in portable classrooms, see http://www.epa.gov/iaq/schooldesign/portables.html.

Design Changes to Improve Ventilation

Manufacturers can improve ventilation by ensuring that manufactured structures meet ANSI/ASHRAE Standard 62.2-2007, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings and the companion ASHRAE Guideline 24-2008, Ventilation and Indoor Air Quality in Low-Rise Residential Buildings (http://www.ashrae.org). These standards provide specific guidance for spot ventilation and whole-house ventilation. For example, it is important that exhaust fans in kitchens and bathrooms be properly sized and vented to the outside to reduce accumulations of pollutants, smoke and moisture.

In addition, California recommends following ASHRAE's Standard 62-1989 Ventilation for Acceptable Indoor Air Quality for designing HVAC systems for portable classrooms. Other design features recommended for portable classrooms (U.S. Environmental Protection Agency 2008b) include the following:

- Operable windows for user-controlled ventilation installed on different walls,
- At least one supply air outlet and return air inlet for each enclosed area with exhaust fans on opposite side of classroom than the fresh air supply,
- Local exhaust ventilation for special-use classrooms (e.g., for chemistry, biology, fine arts, etc.),
- Correctly calibrated carbon dioxide (CO_2) controlled ventilation systems to decrease operation during unoccupied periods and build up of CO_2,
- HVAC and air handler units located as far away as possible from teaching areas to reduce noise, and
- HVAC ducts and plenums accessible for inspection and cleaning.

Carpets typically have off-gassing issues that can release chemicals into the air for many years. The carpets can accumulate dust, insects, and possibly mold. An alternative to carpets could be laminated floors, which are easier to maintain and last longer. Many low-VOC laminates are becoming available, which can reduce indoor exposures. The floors themselves are easy to clean and, unlike a carpet, do not retain dust, mold, allergens or insects.

Paints used today release a variety of low-level volatile organic compounds (VOCs). Zero-VOC paints offer low odor during application and have no off gassing, allowing faster reoccupation of painted areas and reduced VOC exposures over time.

Decisions on mechanical ventilation systems that determine the home's overall air exchange rate and the use of spot ventilation should also take energy costs and comfort into account as well as indoor air quality concerns. Infiltration of outdoor pollutants should also be considered in areas with significant ambient sources.

More products that are VOC and formaldehyde free have recently become available. VOC free linoleum, urea formaldehyde free adhesives wood products, VOC-free paints and finishes are now readily obtainable and make a dramatic improvement in indoor air quality.

Air ventilation in a structure can be improved by reducing pressure differences between rooms by either opening doors or installing vents between rooms. These vents can increase the efficiency of the HVAC system. Products are available that allow the air to pass through them that reduce the light or noise between the rooms.

Chapter 2 on Fire Safety provides additional information about ensuring the safety of combustion appliances.

Tips to Occupants for Improving Indoor Air Quality

General:

- Read the Instruction manual provided by the manufacturer and keep it handy for ready reference.
- Give preference to "green" alternatives when buying cleaning and personal care products.
- When using household chemicals, ensure the unit is well ventilated by using exhaust fans or opening windows.
- Carefully read the labels containing health hazard information and cautions on the proper storage, use and disposal of these products and follow these instructions.
- Use dehumidifiers and air conditioning to control indoor relative humidity (in the range of 30%-50%)
- Maintain inside temperature at moderate levels.
- Air out structures prior to occupancy to remove excessive odors from inside the home caused from off gassing either through leaving screened windows and doors open or with two point exhaust fan system.

- Read the EPA, Washington State, and California recommendations and checklists for the commissioning of new portable classrooms.
  - http://www.epa.gov/iaq/schooldesign/commissioning.html
  - http://www.energy.wsu.edu/ftp-ep/pubs/building/project/final_portcls.pdf

Combustion appliances:

- Make sure that the burners on gas stoves and ranges are properly adjusted (producing a blue flame, as a yellow-tipped flame indicates a problem).
- Ensure that space heaters are well maintained.
- Have gas or oil-fueled furnaces are inspected annually.
- Always use kitchen exhaust fans when cooking and bathroom exhaust fans when showering to remove excess moisture from the home.
- If you suspect a carbon monoxide problem in your home, get fresh air immediately by opening windows and doors, turning off any combustion appliances and leaving the house (U.S. Consumer Product Safety Commission et al. 1998). To prevent this occurrence, install carbon monoxide detectors to provide early warning of elevated CO levels. Combination smoke-CO detectors are commonly available for protection against fire as well as CO.

Allergens:

- Keep the house clean, since regular cleaning reduces dust mites, pollens, animal dander, other allergens, and food that may attract pest insects (U.S. Consumer Product Safety Commission and American Lung Association 1990).
- Use dehumidifiers and air conditioning to control indoor relative humidity (in the range of 30%-50%)
- Clean and dry water-damaged carpets and building materials, ideally within 24 hours. Consider removal and replacement when complete drying may be difficult or delayed, or if visible mold growth has occurred, especially on soft materials.
- Regularly wash pets that are kept indoors, since this has been shown to decrease allergen levels for a few days (Avner et al. 1997).
- If residents have allergies to furry pets, consider options such as keeping the pet outside where possible, keeping the pet out of the allergic person's bedroom, or if necessary, finding the pet a new home (Dales et al. 2008).

Environmental tobacco smoke:

- Do not smoke in your home. Infants and toddlers, as well as asthmatics and others with respiratory problems, are especially vulnerable to the health risks from secondhand smoke. Trying to separate smokers from nonsmokers in different rooms is not effective at eliminating exposure to secondhand smoke, particularly in manufactured structures. The best approach to reduce exposure to tobacco smoke is for smokers to quit smoking. If you or others in your family smoke, do not smoke in your home or car, and do not allow family and visitors to do so. If smoking is permitted indoors, provide as much ventilation as possible, particularly in manufactured structures.

CHAPTER 5: PESTS AND PESTICIDES

OVERVIEW

A pest is an animal or insect that threatens human health and wellbeing or causes stress and discomfort. Animal and insect pests are common problems in all types of buildings, including manufactured structures, because people who live, work, and play in these spaces provide the food, water, and shelter that pests need to thrive.

Pesticides are substances used to kill and control pests. Pesticides can also be harmful or fatal to humans and can damage the environment and ecosystem. Human exposure to pesticides is increased by improper handling or application of insecticides and rodenticides, heavy reliance on aerosols, and widespread application of liquid sprays.

This chapter reviews several common pests and provides practical advice to owners and occupants of manufactured structures about pest control. Because these pests can cause different diseases and the methods to control their populations can differ, they are discussed separately. This chapter also describes integrated pest management (IPM), the recommended control approach that uses a variety of strategies to manage pests while minimizing the use of pesticides. IPM has been shown to effectively control cockroaches through reducing food sources in the kitchen, sealing cracks and crevices and using lower toxicity gels and baits (Wang and Bennett 2006).

HEALTH RISKS POSED BY PESTS

Dust Mites

Dust mites are microscopic pests that feed off human and animal dander and hair. Dust mites are particularly important to manage because exposure to house dust mite allergen is a risk factor for the development of asthma in susceptible children (Institute of Medicine 2000), and dust mites trigger asthma symptoms and respiratory irritation among some individuals.

Cockroaches

Many disease-causing organisms can grow in the gut of cockroaches and can be deposited on food and eating utensils (Mackerras and Pope 1948). For example, cockroaches can pick up disease-causing bacteria like Salmonella on their legs and deposit them on previously uncontaminated food products, possibly causing foodborne illnesses.

Cockroach allergens can cause allergic reactions or trigger asthma symptoms in some persons. The National Academy of Sciences found sufficient evidence to establish a causal association between cockroaches and several respiratory conditions, including asthma exacerbation. There is also limited evidence that links development of asthma in preschool-aged children to exposure to cockroach allergen.

Heavy cockroach infestations in manufactured structures may create reservoirs of allergens in carpets, rugs, and difficult-to-reach areas around appliances and furniture. Cockroaches are attracted to water and are often found near leaking plumbing or condensate drainpipes from air conditioners. High humidity in a home may also contribute to infestations of some cockroach species.

Daytime sightings of cockroaches may indicate a heavy infestation because they are primarily nocturnal. Live and dead cockroaches, cast skins, egg capsules, and droppings are evidence of infestation and can aid in species identification that will help one make targeted control decisions. For example, wood cockroaches, which are sometimes brought inside on firewood, will not infest and do not warrant pesticides. Nontoxic sticky trap monitors offer the best method of monitoring cockroach populations and evaluating the effectiveness of control strategies.

Rats and Mice

Commensal rodents—Norway rats, roof rats, and house mice—are a great concern in the United States. More than 9,000 persons are treated in emergency departments annually for rat or mouse bites (O'Neil et al. 2007). Rats and mice carry a variety of parasites that cause disease in humans. Rodents can transmit disease in two ways:

- Directly through food, water, and air contaminated by urine or feces (e.g., hantavirus, lymphocytic choriomeningitis, rat-bite fever, leptospirosis, and salmonellosis); and
- Indirectly through fleas, mites, and ticks that live on rodents (e.g., plague, murine typhus, scrub typhus, and tularemia) (Buchmeier et al. 1980; Lehmann-Grube 1975; Nowak 1999).

House mice can transmit lymphocytic choriomeningitis, which causes severe illness in people with compromised immune systems and can cause severe birth defects when contracted during pregnancy (Amman et al. 2007; Fischer et al. 2006). In addition, hantavirus-infected rodents have been identified throughout the United States.

Rodent urine and dander contain allergens that can cause allergic reactions or trigger asthma symptoms in sensitive persons. Several studies have shown that rodent allergens may affect inner-city and suburban children who have asthma (Matsui et al. 2004). High levels of allergens have been found consistently in homes that reported mice and cockroaches (Chew et al. 1998; Cohn et al. 2004; Matsui et al. 2003; Phipatanakul et al. 2000; Rauh et al. 2002). The allergens can be small particles that remain airborne for long periods. According to the 2005 American Housing Survey, more than 10% of mobile-home owners reported seeing rodents around their home within the last 3 months (U.S. Census Bureau 2008).

Indications of the presence of rodents—aside from seeing either live or dead ones—are rodent droppings, runways, rub marks, and tracks. Other signs include burrows, nests, gnawings, food scraps, rat hair, urine spots, rodent noises, insects that are associated with rodents, odors from urine, or dead rodents. Rats and mice are different animals and methods used to control them will differ. Proper identification is an important first step to any control program.

Mosquitoes

In the United States, mosquitoes transmit Eastern equine encephalitis, Western equine encephalitis, St. Louis encephalitis, and La Cross encephalitis. More than 21,000 persons are treated in emergency departments annually for rat or mouse bites (O'Neil et al. 2007). They also are carriers of west Nile virus, a sometimes deadly infection that can cause encephalitis in humans (Hayes et al. 2005). Although mosquitoborne diseases such as malaria and dengue are rare in the United States, mosquitoes found throughout the country are capable of transmitting them.

Standing water from lack of drainage; outside storage of buckets, tarps, plant pots, and tires around the home; and failing septic tank systems provide ready breeding sites for mosquitoes. Mosquitoes are found throughout the world and many transmit pathogens that cause disease. Disease carrying mosquito species are found throughout the United States, especially in urban areas and coastal or in inland areas where flooding of low lands frequently occurs (Centers for Disease Control and Prevention and U.S. Environmental Protection Agency 2007).

Assessing risks of mosquitoborne diseases requires routine monitoring of both disease frequencies and the distribution and abundance of mosquitoes. Standardized methods for surveillance exist (Service 1993) and consist primarily of larval sampling in breeding sites as well as adult trapping using dry ice, light, baited, gravid, and oviposition traps.

Ticks

Ticks are blood-feeding external parasites of mammals, birds, and reptiles. Ticks transmit a wide variety of pathogens, including bacteria, rickettsiae, protozoa, and viruses, and can infect humans with such debilitating illnesses as Lyme disease, ehrlichiosis, babesiosis, Rocky Mountain spotted fever, tularemia, and tickborne relapsing fever. More than 47,000 persons are treated in emergency departments annually for rat or mouse bites (O'Neil et al. 2007) Each year more than 16,000 Americans contract Lyme disease, the most common tickborne disease in North America. Deer ticks that are brought into the home on pets often carry Lyme disease.

Active surveillance for ticks requires purposeful sampling in their habitats; active surveillance for tick-borne diseases requires sampling of wild or domestic hosts or examination of humans (Lindenmayer et al. 1991; Nicholson and Mather 1996). Tickborne diseases that are reportable in the United States include Lyme disease, Rocky Mountain spotted fever, human monocytic ehrlichiosis, human granulocytic anaplasmosis, Q fever, and tularaemia (Groseclose et al. 2004).

Bed Bugs

Bed bugs rely entirely on blood for food, and seek shelter in cracks and crevices when not feeding. Infestations usually begin near where people sleep, but may spread as the infestation grows. Bed bug bites can affect individuals differently. Bite responses can range from an absence of any physical signs of the bite, to a small bite mark, to a serious allergic reaction. Bed bug bites are responsible for numerous secondary infections such as impetigo, ecthyma, and lymphanigitis (Anderson and Leffler 2008; Thomas et al. 2004). Bed bugs bites can cause welts, induce nervous and digestive disorders, and initiate allergic reactions. Allergic reactions can range from localized urticaria to in rare cases, anaphylaxis. Other reported health effects include anxiety, insomnia, and systemic reactions (Burnett et al. 1986).

Proper identification is the first step in controlling bed bugs. When bed bug infestation is identified, seek professional assistance and take steps to keep the infestation contained in one area until they are eliminated. It is important to note that while bed bugs have not been implicated as a disease vector, they are clearly a pest of public health importance.

PESTICIDE RISKS TO HUMAN HEALTH

Use of pesticides in manufactured structures and other buildings can pose significant risks to occupants' health. The three main routes of human exposure to pesticides are oral, dermal and inhalation. The oral route includes ingesting food or water that contains pesticides as well as smoking and other hand-to-mouth contacts. Inhalation exposure occurs by breathing air that contains pesticides as vapor, aerosol, or dust. Dermal exposure occurs when the skin or eyes come in contact with pesticides.

The U.S. Environmental Protection Agency (EPA) estimates that between 10,000 and 20,000 medically treated pesticide poisonings, including suicides, attempted suicides, and unintentional poisonings, occur each year in the United States (Blondell 1997). The early symptoms of acute poisoning include headache, hypersecretion, muscle twitching, nausea, and diarrhea. More severe poisoning can cause respiratory depression, loss of consciousness, and death. Persons who survive acute poisoning may develop weakness or paralysis of the arms and legs, or may exhibit an intermediate syndrome characterized by respiratory depression and muscular weakness.

The risks of chronic exposure to lower levels of pesticides is a growing concern as studies show pesticide exposure is associated with higher risk for several cancers, including non-Hodgkin's lymphoma, multiple myeloma, soft-tissue sarcoma, pancreatic cancer, lung cancer, ovarian cancer, breast cancer, testicular cancer, and Hodgkin's lymphoma. Chronic pesticide exposure may have long-term effects on the nervous system, which can be manifested by a range of symptoms that include deficits in neurobehavioral performance and abnormalities in nerve function. Neurotoxicity can result from high-level exposure to most types of pesticides. Chronic pesticide exposure is also associated with long-term neurodegenerative diseases, especially Parkinson's disease.

Exposure to pesticides during pregnancy can have potential adverse effects on fetal growth and childhood neurodevelopment (Landrigan et al. 1999). Children, especially in the first 6–12 months after birth, are at higher risk of toxic effects from pesticide exposure because their bodies are less able to metabolize and detoxify chemicals. In addition, exposure to pesticides can disrupt delicate developmental processes in infants and children.

Dermal and inhalation exposures are the most common routes of nonoccupational exposure to pesticides. Unintentional oral exposure occurs most often when toddlers crawl over treated surfaces or touch pets and then put their fingers in their mouths (Maroni et al. 2008). In 2000, EPA estimated that 80% of pesticide exposure occurred indoors and that 75% of U.S. households had used at least one pesticide indoors during the previous year. Pesticides can be found in indoor air, carpet dust, and settled dust on surfaces, and may persist in the indoor environment for years after use has stopped.

EXISTING CODES AND REGULATIONS

State and local governments have building codes that address pests. For example, most local codes specify requirements for refuse collection and storage, which can contribute to effective pest management by minimizing sources of food and shelter. Such codes are designed to meet local needs and vary by jurisdiction.

EPA has authority for regulating pesticides nationally under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). Under FIFRA, EPA reviews applications and registers pesticides for specified uses, can suspend or cancel the registration of a pesticide, develops new approaches to hazard and risk assessment, regulates pesticide use by consumers, and restricts certain pesticides to licensed applicators.

Since 1993, the American Association of Poison Control Centers has received annual reports of 12,000–15,000 rodenticide exposures to children younger than 6 years. Secondary toxicity to wildlife, especially from second-generation anticoagulant rodenticides, poses a significant risk to wildlife throughout the United States, especially to birds of prey that feed on commensal rodents. Because of these risks, EPA has proposed banning the sale of loose baits (e.g., pellets and meal), greatly restricting the use of second-generation anticoagulant baits and limiting the amount of rodenticide that can be purchased by an unlicensed person.

Each of the 50 states registers pesticides at the state level, and states can impose more restrictive standards than EPA. State and local jurisdictions enforce pesticide regulations and pesticide applicator training and licensing. Less toxic and concentrated pesticides are approved for consumers to use in houses and yards. Only private firms that are registered as pest control businesses by the appropriate state agency are permitted to use more toxic and concentrated pesticides.

PREVENTING PEST PROBLEMS

Over the last century, pest control has increasingly involved chemicals. The ideal pesticide is safe in terms of both human and ecosystem health as well as effective at controlling the target species (Robson and Hamilton 2005).

The primary method of avoiding pesticide exposures in the home is to limit their use indoors and reduce the likelihood of transporting secondary sources indoors (e.g., contaminated shoes, soil, and clothing). This can be accomplished through the use of IPM, a system of pest control focused on changing the habitat that a building provides to pests by eliminating sources of food, water, and harborage; limiting access points and nesting areas; using pesticides judiciously to avoid unnecessary human exposure; and by denying pests access to homes by sealing cracks. IPM relies on targeted use of lower toxicity gels and bait instead of aerosol foggers and routine, widespread spraying of higher toxicity liquids. For more information about IPM, visit http://www.epa.gov/pesticides/factsheets/ipm.htm.

Current pest control seeks to move beyond exclusive reliance on pesticides by using IPM, a science-based, decision-making approach to managing pests. IPM combines biologic, cultural, physical, low-impact chemical tools and available technology to reduce pest populations in an effective, environmentally sensitive, and sustainable manner while minimizing economic, human health, and environmental risks.

Since many pest and rodent infestations in homes begin outdoors, the following prevention strategies are recommended for pest-proofing and sanitation:

- Removing abandoned manufactured homes, sheds, and vehicles.
- Reducing potential shelters such as piles of bricks or lumber and leaf litter.
- Keeping ground cover at least 18 inches from the structure's foundation.
- Trimming trees and shrubs so they do not touch the home.
- Avoiding shining exterior lights onto the building near doors or windows.
- Using exterior yellow bug lights to avoid attracting insects.
- Ensuring that garbage receptacles have tight-fitting covers.
- Ventilating spaces under decks and sheds.
- Keeping gutters unclogged and repairing any areas with poor drainage.
- Correcting water leaks and avoiding excess moisture and high humidity indoors.
- Denying pests access by sealing holes and cracks in the home's exterior and pipe and wiring entrances. Coarse copper wool, wire screen, and lightweight sheet metal are excellent materials for sealing gaps and holes.
- Screening windows adequately.
- Storing pet food in sealed containers and removing uneaten pet food.
- Eliminating potential breeding areas for mosquitoes by removing or modifying areas that can hold water such as gutters, tarps, empty cans, and used tires.

PEST CONTROL STRATEGIES

When pest infestation occurs, developing an effective control strategy requires assessing the population size and location of infestation in order to carefully design targeted control measures. When pesticides are needed to control infestation, the IPM approach, using the smallest amount of the least toxic pesticide is effective in the least dispersive manner possible. It is vital to understand that pesticide applications are almost never effective as a standalone strategy, because pests are likely to reinvade as long as a habitat suitable is available (i.e., food, water, and shelter). Changing the conditions that promoted the infestation is essential to avoid future infestations.

Dust Mites

Controlling dust mites is fairly straightforward. Control methods include regular cleaning using a HEPA vacuum, laundering bedding, use of pillow and mattress encasements, and keeping the relative humidity in the home below 50%.

Cockroaches

Control strategies for cockroaches include reducing sources of food, water, and shelter. Occupants should

- Wash and dry dishes nightly.
- Vacuum or clean floors and furniture where people eat.
- Keep stove tops, exhaust vents, and appliances clean.
- Minimize sources of water (e.g., drip pans, pipes with condensation, and puddles).
- Use a lidded trash can and empty it regularly.
- Keep food in resealable bags, lidded containers, or in the refrigerator.
- Not store empty cans, paper, or cardboard in the home.
- Minimize clutter in the home.
- Fill or fix cracks and crevices.
- If needed, supplement the above practices with least-toxic pesticides (ones with CAUTION on the label). Do not use foggers.

Commensal Rodents

Control strategies for rats and mice include reducing sources of food, water, and shelter. Occupants should

- Wash and dry dishes nightly.
- Vacuum or clean floors and furniture where people eat.
- Keep stove tops, exhaust vents, and appliances clean.
- Minimize sources of water (e.g., drip pans, pipes with condensation, and puddles).
- Use a lidded trash can and empty it regularly.
- Keep food in resealable bags, lidded containers, or in the refrigerator.

- Not store empty cans, paper, or cardboard in the home.
- Minimize clutter in the home.
- Fill or fix cracks and crevices (a mouse can fit through any space ¼ inch or larger).
- Install door sweeps on exterior doors.
- Fill gaps around pipes and wires that penetrate the building envelope.
- Avoid plants that offer rats places to hide (e.g., ground-hugging bushes).
- Use metal trash receptacles with a tightly-fitting cover outdoors.
- Keep piles of firewood at least 20 feet away from the structure.
- Use nontoxic traps (read the manufacturer's directions since trapping practices will differ for rats and mice).
- If needed, supplement the above practices with least-toxic rodenticides. Persons without a pesticide applicators license should only use bait in tamper-resistant stations to minimize the risk of poisoning non-target organisms.

Mosquitoes

The main control strategy for mosquitoes is reducing breeding sites. Occupants should minimize standing water from lack of drainage; outside storage of buckets, tarps, plant pots, and tires around the home; and failing septic tank systems. When spending time outdoors during mosquito season, use a repellant according to label instructions.

Ticks

Minimize the risk of tick exposure using habitat-reduction and clothing choice. Home owners should keep grass mowed and prune bushes that people are likely to brush against. When spending time outdoors—especially in woods or fields—wear light colored clothing (for easy detection of ticks), tuck shirt into pants and pants into socks, and avoid brushing against bushes. Launder clothes as soon as you come in from being outside being careful to inspect for ticks as you undress. For pets, consider using a topical flea and tick pesticide.

Bed Bugs

Regular laundering of bedding and cleaning around areas where people sleep will increase the chance of finding bed bugs before the infestation grows. If bed bugs are found, involve an experienced, licensed pest control professional before trying any control strategies.

Minimize the chance of bringing bed bugs home by inspecting beds when sleeping away from home, keeping belongings in luggage while traveling, laundering all clothes immediately upon return to home, and storing luggage away from the bed.

When using pesticides,

- Always read pesticide product labels and follow the instructions when purchasing, using, storing, and disposing of the product.
- Use pesticides only in the manufacturer's recommended quantities and mix or dilute pesticides outdoors.
- Take children or pets outside when applying pesticides.
- Never use pesticides labeled "Outdoor Use Only" indoors. Increase ventilation indoors during and after application of pesticides.
- Only use pesticides that list the target pest on the label.
- Do not store unneeded pesticides inside manufactured structures.
- Limit the use of chemical pesticides outdoors as well as indoors, to avoid unnecessary environmental contamination.

The following resources provide detailed advice on how to prevent and control various pests.

Cockroaches: http://nysipm.cornell.edu/publications/roach/default.asp

Mosquitoes: http://nysipm.cornell.edu/publications/mosquitobro/files/mosquito.pdfTicks

Dust mites: http://ohioline.osu.edu/hyg-fact/2000/2157.html

Bed bugs: http://nysipm.cornell.edu/publications/bed_bugs/files/bed_bug.pdf

CHAPTER 6: SITING AND INSTALLATION

Keeping safe and healthy in manufactured structures depends not only on how the units are built, maintained, and used but also on where the units are placed and how well they are installed and anchored. The Surgeon General defines healthy homes as those that are "sited, designed, built, renovated, and maintained in ways that support the health of residents" (U.S. Department of Health and Human Services 2009).

COMMUNITY SETTING

Manufactured housing units are often located together both for long-term residence and for temporary housing following disasters. When manufactured housing communities (MHCs) are designed with health in mind, they promote physical and mental health by encouraging healthy behaviors, enhancing quality of life, reducing crime, and building social connectedness.

Manufactured housing is commonly found in these three types of communities:

1. Recreational vehicle parks: While these parks are typically designed for use by travelers for short-term stays generally lasting days or weeks, residents may stay for longer periods in postdisaster settings, during poor economic conditions, or as a seasonal residence.
2. Long-term MHCs: These communities are designed for long-term residents and are sometimes informally referred to as "trailer parks."
3. Postdisaster MHCs: These communities, typically developed quickly after a disaster such as Hurricane Katrina, are designed for use measured in months but may be used for longer periods than originally intended.

DESIGN PRINCIPLES FOR MHCS

The design principles for healthy MHCs are similar to the Smart Growth principles used to design communities that consist of permanent site-built homes and other buildings (http://www.smartgrowth.org/about/principles/default.asp) (Ewing and Hodder 1998; International City/County Management Association and Smart Growth Network 2006; U.S. Environmental Protection Agency 2008). These principles are listed and discussed below in Figure 6-1.

Select a Healthy and Sustainable Site

Sites should not expose community residents to hazardous wastes and emissions from busy highways and industrial plants. Flood plains, swampy land, and sites with poor stormwater drainage also are not suitable for residential communities. Sites with good connectedness to existing communities allow MHC residents to access existing infrastructure, better goods and services, and local community activities. Final site selection, especially in a postdisaster setting, needs to balance multiple considerations including costs, land availability, accessibility to existing nearby communities, and zoning requirements and/or variances. Additional information about stormwater management is provided below.

Smart Growth Community Design Principles	
1.	Select a healthy and sustainable site
2.	Provide utility services
3.	Incorporate mixed land uses
4.	Create walkable neighborhoods
5.	Provide a variety of transportation choices
6.	Provide access to parks, greenspace, and recreational facilities
7.	Ensure safety and security
8.	Involve stakeholders in community design decisions
9.	Give residents a sense of place
10.	Provide a range of housing choices
11.	Provide post disaster social services as needed

Figure 6-1: Smart Growth Community Design Principles.

Local zoning requirements govern land-use types, building density, parking, and related requirements. Zoning also governs the size of the building permitted in relation to the size of the lot; the required open space for residential uses on the lot or the maximum amount of building coverage allowed on the lot; the number of dwelling units permitted on the lot; the distance between the building and the street; the distance between the building and the lot line; and the amount of parking required.

Provide Utility Services

Preferably, MHCs should be connected to existing municipal water and sewer systems and electric service if these are available within a practical distance and have sufficient capacity. Alternatively, small onsite water- and wastewater-handling systems may be built for a new MHC. Individual wells and septic systems are generally not appropriate for MHCs with a high density of dwelling units per acre. In a postdisaster setting, potable water may be trucked in and wastewater hauled away until more sustainable water and wastewater services can be established. If electrical service is not provided and generators are used, residents must install and use generators properly to avoid the risk of carbon monoxide inhalation (http://www.cdc.gov/co). Provision of training for residents in the use generators by builders and/or developers would be beneficial in this case. Chapter 7 provides additional information about safe access to utilities.

Incorporate Mixed Land Uses

An MHC that offers more than just homes—post office, stores, schools, libraries, places of worship, and other facilities in close proximity—provides residents with easy access to essential goods and services. Ready access to a neighborhood grocery store that sells fruits and vegetables facilitates improved nutrition for MHC residents. Nearby retail and office space may provide employment for some MHC residents. A resident who is self-employed or who telecommutes may benefit from having living and working space within the same manufactured housing unit.

Create Walkable Neighborhoods

Careful MHC layout and street and sidewalk design can help to ensure that important destinations, such as shopping, recreation, and schools, are within easy walking distance. Well-planned sidewalks and paths allow residents to visit friends, run errands, and reach many of their daily destinations by walking and bicycling. Such active transportation provides healthy physical activity, improves air quality, reduces the risk of motor vehicle crashes, and saves money by reducing the need to drive. Walkable neighborhoods also facilitate interaction among neighbors, which increases the community's social capital.

Provide a Variety of Transportation Choices

Locating MHCs near existing public transit is especially important for low-income residents who may not have cars for access to employment, health care, shopping, and other needs (Turner 2007). Similarly, residents who are unable to drive or who simply prefer to walk benefit from transportation alternatives such as walking and bicycling. An analysis of walking, biking, and transit routes to various destinations should be considered during the site selection and design phase of the MHC; improvements for sidewalks, pedestrian street crossings, bike lanes, and bus routes should be considered during the construction phase. For example, in many places, sidewalks are installed and turf areas can be monitored after occupancy for foot traffic to determine MHC needs for additional walking paths.

Provide Access to Parks, Greenspace, and Recreational Facilities

Parks, greenspace, and recreational facilities provide opportunities for physical activity and contribute to mental health. They also provide venues in which residents can get together and socialize. MHCs often are built with high-density layouts. One design option is to include small open spaces or playgrounds among the manufactured homes, and larger greenspaces within walking distance at the edges of the MHC. Another option is to have a large open space in the interior of the MHC. All of these options can be used within a single MHC. Community gathering places are particularly important for high-density residential areas. Such places are safer and more heavily used when they are highly visible and grouped with other community facilities. Inexpensive facilities that can increase quality of life for children and adults in MHCs include playgrounds with sandboxes, swing sets, and basketball hoops; picnic areas; community gardens; and open lawn space for informal recreation.

Ensure Safety and Security

Residents are not likely to take walks or socialize if they do not feel secure. MHCs can be designed to incorporate elements of Crime Prevention through Environmental Design (CPTED) (http://www.cptedtraining.net/cpted.htm). The goal of CPTED is to reduce opportunities for crime that may be inherent in the design of structures or neighborhoods. CPTED strategies include natural surveillance ("eyes on the street"), territorial reinforcement to clearly separate public and private space, effective lighting, natural access control, and target hardening. For more information on these strategies, visit the CPTED Web site (http://www.cpted-watch.com/).

Involve Stakeholders in Community Design Decisions

While MHCs may be built before many of its future residents have been identified, design decisions once the community has been established should include active input from affected residents. The process of involving stakeholders may begin earlier where many of the residents (or likely residents) are known, such as in disaster relief MHCs, possibly even before residents have moved into the MHC. Establishing an MHC residents' association facilitates such input.

Give Residents a Sense of Place

Instead of residents feeling disconnected and as if they are living in a temporary location, they may feel more invested in maintaining the quality of their community if it has distinctive characteristics and attractive features. It is desirable that there be design variation within an MHC and design differentiation from other MHCs.

Provide a Range of Housing Choices

MHCs often must accommodate households ranging from single individuals to extended families. While manufactured homes may be available in a limited number of sizes and models, they can be assembled and configured to accommodate households of varying sizes. MHCs that can accommodate a wide range of tenants encourage broader social interactions and may help increase the community's social capital.

Provide Postdisaster Social Services as Needed

Persons moving into an MHC after a recent disaster may need more services than usual such as physical and mental health care, employment assistance, child care for their younger children, and activities for their older children. Making these services available in proximity to the MHC will help provide stability to residents (Turner 2007). In addition, assistance to help residents return to their homes or to move into new permanent housing should be provided as promptly as possible.

Stormwater Management

Good stormwater management and drainage are important for MHCs. If stormwater is not properly drained away from a structure, it can cause a range of problems, including

- Erosion around structures leading to structural instability,
- Flooding or moisture infiltration in homes contributing to mold concerns,

- Increased risk of contaminating drinking water through stormwater contact with well-heads or through infiltration and inflow into pipes, and
- Increased loading on the wastewater disposal system and potential for wastewater treatment failure.

Precipitation runs off impervious surfaces toward lower elevations until it slows to permeate into the ground or encounters a body of water. Therefore, if wells, water pipes, wastewater leach fields, roads, or manufactured structures are at low positions in the surrounding landscape, they are likely to collect standing water or experience erosion at sensitive points.

The foundations of manufactured structures often can be more vulnerable to soil erosion and flooding than other structures, which can undermine structural stability. In coastal regions, flooding and high winds from hurricanes have a propensity to damage and destroy manufactured structures, sometimes requiring recommendations for evacuation of manufactured structures before other structures in coastal areas during tropical storms. Manufactured structures are also more susceptible than site-built housing to damage from other natural destructive forces, such as tornadoes.

Avoiding Stormwater Problems

There is no one-size-fits-all approach to stormwater management and drainage. The optimal approach depends on local conditions, including topography, soil, adjacent structures, and the availability of stormwater management facilities. The greater the extent of impervious surfaces nearby, such as buildings, roads, and parking lots, the greater the need for stormwater management. EPA's stormwater guidance (http://cfpub.epa.gov/npdes/home.cfm?program_id=6) provides guidelines to protect local waterways under the Clean Water Act, and many states and localities require newly constructed structures to meet stormwater management regulations. Because some manufactured structures are not considered permanent structures with foundations, they may not receive full scrutiny with regard to stormwater management.

In general, stormwater should be directed away from structures, as well as from wells, leachfields, and roads or sidewalks. Gutters should drain into a gravel area first to prevent soil erosion and channeling in the yard, and landscaping should be used to avoid low spots in the yard that can collect standing water.

Visual inspection of the area around the structure, especially during severe weather, can reveal a range of stormwater management and drainage problems, including erosion; clogged gutters, downspouts, and drains; and standing pools of water; cracks in the foundation; and binding doors and other signs of settling that may indicate more serious structural problems.

Stormwater and drainage problems that may be affecting the structural stability of a home should be evaluated by a local building inspector or engineer. Lesser issues with drainage can be addressed simply by redirecting water away from structures, wells, and leach fields.

CDC's west Nile guidelines (http://www.cdc.gov/WestNile/) provide detailed information about a range of strategies to prevent mosquito production from stormwater and other sources of standing water.

FOUNDATION OPTIONS FOR SITING UNITS

The foundation system plays a vital role in the structural integrity of every building, including manufactured structures. The ability of a structure to maintain its integrity is affected by forces due to winds, snow loads, and seismic activity, as well as the prevalence of termites and other structurally damaging pests. Foundation types differ and choosing the correct one depends on many factors, including budget, installation times, site location, soil conditions, and use of the structure.

Soil Conditions

Certain soil types have little ability to support weight (bearing capacity); other soil types may become more or less supportive when wet or dry. Some soils compact well and others do not, while some soils expand when water is present and others shrink. Soil conditions and classifications should be taken into account in selecting a foundation system to provide adequate support for the structure.

Seismic Activity

Earthquakes can pose a serious risk to the structure's integrity. The risk of earthquake should be taken into account in selecting the type of foundation, since some foundation systems withstand seismic activity better than others.

Wind Zones

High wind areas affect how a home is supported and anchored. Overturning, uplift, and sliding forces should be calculated to determine if a foundation system is able to withstand expected wind speeds. Building foundations, roofs, walls, and floors should all be designed to withstand these forces.

Snow Loads

Snowfall can impose a heavy load on a roof, transferring the force of the weight through the walls to the foundation. The roof selected must be able to support the increased load due to snow and ice. Similarly, the foundation selected must be able to support the structure with the increased weight of snow and ice on the roof.

Frost Heave

Frost depth is the depth in the ground to which water in the soil is known to freeze. When the water in the soil freezes, it expands and may cause the structure above to shift or "heave." There are various ways to avoid frost heave, such as extending the footing below the frost line, replacing problematic soil below the footings with coarse sand and/or gravel, and using an insulated slab or building crawl space that does not extend below the frost line.

Termites

Termites represent a threat to wood and therefore are an important consideration when selecting a foundation that has wood as its main building material. Concrete, steel, and pressure-treated woods can be used to minimize the impact of termites, and can act as the cornerstone to an integrated pest management solution for pest control (see Chapter 5 for more information). In areas deemed "termite-prone," the foundation design should ensure that there is no contact between untreated wood and the ground.

Foundations for HUD Code manufactured homes are subject to a federal preemptive regulation, but other building structures may be subject to requirements imposed by local or state building officials. Local, state, or national requirements for foundation designs should be considered when selecting and designing a foundation system.

TYPES OF FOUNDATIONS AND ANCHORING SYSTEMS

Pier-anchor Systems

Pier-anchor systems are the most commonly used foundation systems for manufactured structures. The pier-anchor system uses piers to support the structure and anchors with straps to hold the structure down and resist the force of wind uplift. The two most common types of piers are hollow core masonry blocks stacked vertically and pyramid-shaped steel jack stands. Piers are placed on footers that are made of concrete to spread the load. The design and weight of the structure and the type of soil and site characteristics will determine the required spacing and positioning of the piers and footers. Auger-type anchors or screw-in soil anchors are most commonly used, and straps attach the anchors to the building supports. The size, number, and configuration of anchors are based on the wind zone and soil characteristics of the construction site.

Manufactured homes are vulnerable during high winds, especially tornadoes or hurricanes. Foundation systems that can be placed quickly with little preparation time are ideal in holding semipermanent structures in place. This tie-down system can be anchored to the structure and act as both the foundation and a solid point of contact between the ground and the structure.

Helical piles are a tie-down system with a series of pitched steel plates welded to steel shafts. The piles are screwed into the ground and can support up to 25 tons. A series of piles will support a manufactured home and offers stability during high wind events.

Slabs-on-grade

Slabs-on-grade are continuous concrete platforms or pads that support a structure. Unlike slab-on-grade foundations for site-built homes that provide both the structural support and serve as the subfloor surface within the living space, slab foundations under a manufactured home do not serve as the unit's floor and only act as the structural platform under the home. With manufactured homes, the dwelling unit with its own finished floor is typically *elevated above* this slab, creating what is more like a crawl space around between the slab-on-grade and the dwelling unit above. What distinguishes this foundation system from a crawl space, however, is the presence of the slab-on-grade and the fact that this slab will sit above the frost line even in cold climates.

The fact that the slabs underneath manufactured structures do not go below frost depth allows them to be shallower and cheaper, but raises the possibility of slab movement due to frost heave. For this reason slab foundations for manufactured structures may be insulated or uninsulated. Insulated designs incorporate insulation around the slab's perimeter to keep the ground under the slab warmer, essentially capturing heat loss from the house to the ground and keeping this heat under the unit. To help capture this heat effectively, vents that ventilate the area underneath the dwelling (and above the slab) should be thermostatically controlled so that they close during the winter, helping to keep any heat loss from the unit from escaping to the outdoor air. By keeping the space under the dwelling warmer, the soil is warmer and will not experience frost heave. This design is often called a frost-protected shallow foundation, and is more advantageous in colder areas where building-to-frost depth requires a deeper foundation.

On the other hand, uninsulated slab foundations for manufactured homes do not try to keep the ground under the unit warmer to prevent frost heave. This design relies on proper drainage around the unit (e.g., drain tiles, sump pump) to avoid excess moisture levels in the soil. Reducing soil moisture helps to reduce the extent of any frost heave that does occur, which in turn minimizes or eliminates movement of the slab itself.

Proprietary Systems

Proprietary systems use techniques similar to those described in the pier-anchor system for which the manufacturer has patented a unique feature. Some of these systems are listed and preapproved for use in manufactured homes. Those that are not listed may need to be verified by a local or state building official for use with a manufactured structure. Most of these systems are good alternatives to the traditional pier-anchor systems that are widely used in the manufacture of home foundation designs.

Additional information and details on foundations for manufactured homes can be found in the *Guide to Foundation and Support Systems for Manufactured Homes* (Manufactured Housing Research Alliance 2002).

RELOCATING MANUFACTURED HOMES

Manufactured homes are unique from other forms of housing in that they may be moved from one location to another. For the small number of house moves that do occur, these moves tend to involve single-wide units as opposed to homes with two or more units. And while moving a manufactured housing unit is technically feasible, there are several important issues to consider to make the move reasonably efficient and to maintain the ability of the dwelling to provide a safe and healthy home to the residents. Several key issues are discussed below.

Transporting the Manufactured Home

When planning to move a manufactured home, use a transport company that is familiar with the laws and necessary permitting for moving manufactured homes. The transport firm should also evaluate the proposed route for moving the structure, checking for adequate road width, overhead clearance, sharp turns or dips in the road, steep grades, time-of-use restrictions, and adequate access to the site. There may also be requirements for pilot cars and pole cars to check whether homes are going to fit under overpasses.

When transporting the unit, follow the transport firm's directions regarding preparing the unit for travel. It is particularly important for utilities to be properly disconnected at the old site and that any hazardous or explosive materials be handled appropriately prior to the move.

Once the home is sited at the new location, all installation steps should be carefully followed such as utility hook-ups and duct connections. The home should also be thoroughly inspected to check for damages incurred from transport or any problems with the new installation measures. Cracks or openings in the building shell, for example, should be repaired or sealed immediately. This helps to prevent intrusion of water leakage from outdoors and can also prevent the infiltration of airborne contaminants into the living space.

Ensuring the Adequacy of the Dwelling for Its New Location

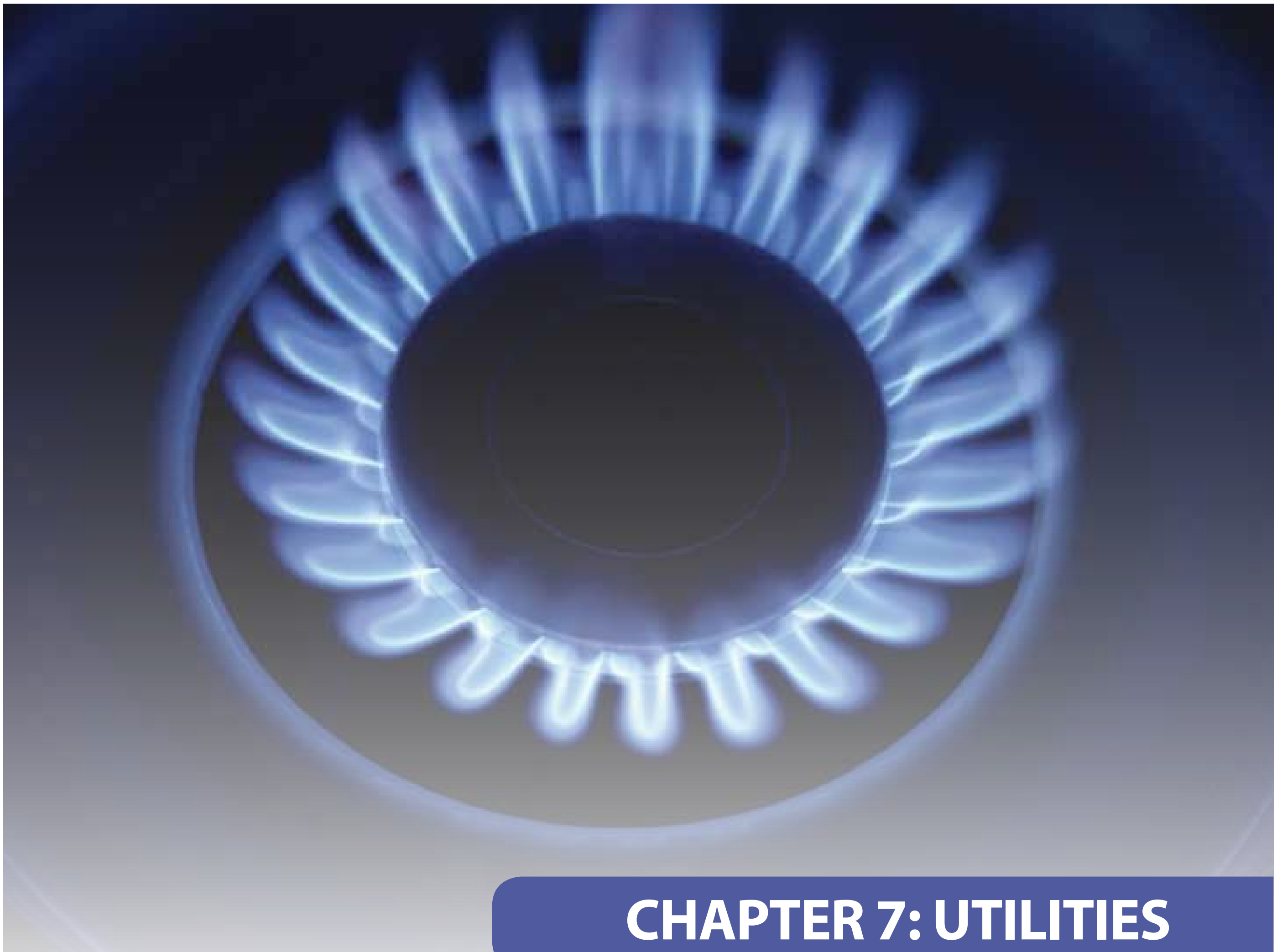
Manufactured homes are designed for specific locations in terms of structural systems (wind, seismic, snow loads), moisture management (vapor retarders, dehumidification), and energy (insulating values of assemblies, furnace capacity). When a manufactured home is going to be moved to a new location, it is essential that these parameters be reviewed to ensure that the dwelling is adequate for the new location. Generally, a unit should not be moved to a more restrictive zone in terms of wind, thermal, or roof load requirements. The dwelling's data plate can be checked for zone information.

It may be tempting to assume that a relatively short move—perhaps 100 miles—would not introduce any new design conditions significant enough to have an impact. However, wind, seismic, and thermal design conditions can change dramatically across distances of much less than 100 miles.

Health and safety risks that could be introduced by moving a manufactured home to a new location for which it is not adequately designed include the following:

- Structural failures (e.g., roof tear off) due to wind, seismic, or snow loads;
- Moisture problems due to improper vapor retarder design or insufficient insulation, which can then lead to mold, dust mites, and pest infestations and their associated health risks to residents; and
- Uncomfortable indoor conditions, such as excessive humidity or cold temperatures, because the unit's energy systems (e.g., HVAC, insulation) are not appropriate for the new location.

In some cases, proposed relocations of manufactured homes are changed due to the location-related complications and the expense of transporting the home. In these situations it is sometimes more practical to sell the existing home and purchase another unit at the new location.



CHAPTER 7: UTILITIES

UTILITY SERVICES FOR MANUFACTURED STRUCTURES

Manufactured structures, like other types of buildings, require several kinds of utility service, typically including drinking water, sewage service, electricity and gas. Many issues associated with utilities affect manufactured structures in the same way as site-built structures. However, in many cases, utility connections and services for manufactured structures differ from typical site-built structures. For example, some manufactured structures access electric service differently than site-built structures and rely on propane instead of natural gas.

As a group, manufactured structures may be at increased risk of water and wastewater problems because these structures are more likely to depend on small, unregulated drinking water systems such as private wells and on onsite wastewater disposal systems, which are more prone to problems compared to public utilities. In addition, temporary dwellings and vehicles, such as travel trailers or recreational vehicles, may use water and wastewater tanks serviced by water and wastewater stations or trucks, which can present tank-based health risks, similar to cruise ships.

Hot Water

Scalds, which are burns attributed to hot liquids or steam, account for 33%–58% of all patients hospitalized for burns (American Burn Association 2006; Centers for Disease Control and Prevention 2009; Ehrlich et al. 2005). Younger children are more likely to sustain injuries from scald burns that are caused by hot liquids or steam, while older children are more likely to sustain injuries from flame burns that are caused by direct contact with fire. Adults aged ≥65 years have a worse prognosis than younger patients after scald burns because of age-related factors and comorbid medical conditions (Alden et al. 2007). During 2001–2006, there were an estimated 51,700 visits for nonfatal scald-related burns by persons aged ≥65 years (Hunderford et al. 2009).

The water heater thermostat should be set to 120°F or lower. Other ways to prevent burns and scalds include installing hot water temperature limiters at the faucet; using roll-up cords for electric coffee pots; and using pots, pans, and kettles designed to be less likely to tip and spill hot liquids.

Drinking Water

Manufactured structures may draw drinking water from an onsite well, a small community system, a large regulated water system, or a municipal or other publicly owned water system. Small water systems such as private wells are not subject to the requirements of the Safe Drinking Water Act (SWDA) and therefore are not regulated. Approximately 45 million people, or about 15% of the U.S. population, are served by such water systems, and the proportion of manufactured homes served by an unregulated water system is likely to be higher than site-built structures. These small water systems are often not sampled and can expose residents to microbial and chemical contamination (Rhode Island Department of Health and University of Rhode Island Cooperative Extension Water Quality Program 2003).

Sources of Drinking Water Contamination

Water contamination has many sources, including naturally occurring chemicals and minerals (e.g., arsenic, radon, uranium), local land-use practices (fertilizers, nitrates, pesticides, concentrated animal feeding operations), manufacturing processes, sewer overflow, and malfunctioning wastewater treatment systems (e.g., septic systems). Heavy rainfall exacerbates contamination routes and is an established risk factor for waterborne disease outbreaks (Curriero et al. 2001). Wells can be contaminated by chemicals, some of which can threaten human health. For example, pesticides can cause reproductive problems (Casarett and Doull 1991), polychlorinated biphenyls (PCBs) and lead can cause neurological disorders (Chevrier et al. 2007), and nitrates can cause methemoglobinemia or "blue baby syndrome" (Greer and Shannon 2005). Wells also can be contaminated with microbial agents such as *Cryptosporidium*, E. coli O157:H7, and noroviruses, all of which cause gastrointestinal illness. The U.S. Environmental Protection Agency (EPA) estimates that 168,000 viral illnesses and 34,000 bacterial illnesses occur from consuming drinking water from untreated groundwater (U.S. Environmental Protection Agency 2002). Continuing studies are evaluating exposure to cryptosporidium for people served by private wells and onsite wastewater disposal systems. Preliminary evidence suggests that cryptosporidium exposure rates may be higher among people who use wells and onsite wastewater systems.

Because water may become contaminated at any point from its source to the faucet, assuring safe drinking water requires attention to the source, the method of extracting water from the source, the distribution system, and plumbing fixtures.

Water quality initially depends on the water's source. Surface water (lakes, reservoirs, streams, and rivers), the drinking water source for approximately 50% of our population, is generally of poor quality and requires extensive treatment. Groundwater, the source of the other 50%, is typically of better quality. However, groundwater may be contaminated by agricultural runoff or surface and subsurface disposal of liquid waste, including leachate from solid waste landfills. Other sources, such as spring water and rain water, are of varying levels of quality, but can be treated to render water potable.

Various types of drinking water wells exist throughout the United States. Well construction types include drilled, bored, driven, or dug. The most common type of well used in the United States today is the drilled well. These types of wells typically draw water from deeper sources and are the most protective type of well from external contamination sources. Wells that are bored, driven, or dug usually receive water from shallower sources and do not offer the protective benefits of a properly constructed drilled well. Although states and localities generally have well construction standards, lax enforcement and infrequent inspection leaves most well construction essentially unregulated in many states. More information regarding private wells can be found on the EPA Web site (U.S. Environmental Protection Agency 2006).

Wells may become contaminated through several routes: surface water entering directly into the top of the well, surface water entering the space between the well casing and surrounding soil, and groundwater entering below ground level. Each contamination route can be controlled by proper design and maintenance. Frequently, onsite wells or small community systems do not disinfect water before it is consumed. In addition to any microbial risk associated with the source, failure to use an acceptable disinfectant leaves water vulnerable to further contamination during storage or distribution.

Bacterial contamination in the absence of disinfection may result in bacterial growth in pipes and water tanks and exacerbate biofilm development.

In addition to contamination at its source, water can become contaminated as it flows through the water distribution system in the yard and home. Such contamination can occur from biologic materials, toxic debris from construction, or unsuitable materials used in water pipe joints. Disruptions in flow or loss of pressure in water lines can contaminate drinking water through infiltration and inflow into the plumbing system. These contamination risks are exacerbated by running drinking water and wastewater lines in the same trench, poor maintenance or cracked pipes, flooding events, or periodic standing water problems. Water flowing backwards (backflow) in the pipes can suck potentially harmful materials back (back-siphonage) into the water distribution system, creating serious health hazards.

Finally, plumbing fixtures may contain lead or copper, and corrosive water may leach (pick up) lead and copper from household plumbing pipes. This issue is a bigger problem in older structures (i.e., those built before 1981 that have original plumbing systems). Water utilities add corrosion inhibitors to minimize corrosion of pipes in the distribution system and avoid undue exposure to lead and copper. The EPA Lead and Copper Rule (40 CFR Part 141) requires all regulated water systems to periodically monitor for lead and copper.

Protecting Drinking Water

Problems with publicly supplied water should be handled by local municipalities. Concerns should be addressed to the municipality, local health department, or state environmental protection agency. Private wells and small community water supplies are the responsibility of the well owner; however, the environmental health division of the local health department should be able to assist and offer site-appropriate advice. More detailed information can be found in the EPA guide to private wells (http://www.epa.gov/safewater/privatewells/pdfs/household_wells.pdf).

Wells should be drilled into an aquifer free of contamination, located at a depth sufficient to prevent surface water interactions, and outfitted with casing and well-head protection to prevent infiltration from runoff. Because groundwater contamination is usually localized, the best way to identify potential contaminants is to consult a local expert or the environmental health division of the local public health agency. Because the potential for pollution to enter a well is affected by its placement and construction, local agricultural and industrial activities as well as the area's geology and climate should be taken into account. Wells should always be located to provide access for maintenance, inspection, and pump or pipe replacement.

Tips to Help Protect Groundwater Quality

- Hire a certified well driller for new well construction, modification, or abandonment and closure.
- Slope the area around wells to drain surface runoff away from the well.
- Install a well cap or sanitary seal to prevent unauthorized use or entry into a well.
- Periodically inspect exposed parts of wells for cracked, corroded, or damaged well casings; broken or missing well caps; and settling and cracking of surface seals.
- Test well water at least once a year and after flooding events for coliform bacteria, nitrates, and other contaminants, such as pesticides, organics, and metals.
- Keep accurate records of any well maintenance, such as disinfection or sediment removal, that require the use of chemicals in the well.
- Avoid mixing or using pesticides, fertilizers, herbicides, degreasers, fuels, and other pollutants near wells.
- Do not dispose of waste in dry or abandoned wells.

Changes in the odor, taste, or color of tap water may indicate contamination. EPA's guide to private wells provides additional information (http://www.epa.gov/safewater/privatewells/pdfs/household_wells.pdf).

Responding to Drinking Water Contamination

Cleaning up water contamination requires thorough understanding of the source and route of contamination. Once an aquifer is compromised, restoring its quality is extremely difficult; usually, another source of water must be found. If components of the well construction fail and allow contaminates into the system, fixing or even drilling a new well may be appropriate. Shock chlorination of the well is not considered a permanent solution to microbial contamination but may help reduce exposure during an outbreak or acute situation. Onsite water treatment such as ultraviolet (UV) or chlorination can address specific contamination concerns, but is not widely recommended for routine use as an effective protective measure because of significant maintenance requirements. For additional information, contact the Environmental Health Division of your local health department and consult EPA's guide to private wells (http://www.epa.gov/safewater/privatewells/pdfs/household_wells.pdf).

Sewage Service

Background

Safe, sanitary, nuisance-free disposal of wastewater is a public health priority in all settings, small and large, rural or urban. Several methods of managing wastewater exist, both in traditional site-built structures and in manufactured structures. Wastewater can be piped away from the structure to a community treatment system, treated onsite using septic tank systems, or stored in tanks or compost toilets for later disposal. One-third of new homes use onsite wastewater treatment and disposal, while more than half of all manufactured homes are connected to onsite septic systems (U.S. Environmental Protection Agency 2002).

In any event, wastewater should be disposed of in a manner to ensure that

- Community or private drinking water supplies are not threatened;
- Direct human exposure is not possible;
- Waste is inaccessible to vectors, insects, rodents, or other possible carriers;
- Odor or aesthetic nuisances are not created; and
- All environmental laws and regulations are complied with.

Too often, these goals are not met. Septic tank systems are the second greatest threat to groundwater (after leaking underground fuel tanks). According to EPA's *Onsite Wastewater Treatment Systems Manual* (U.S. Environmental Protection Agency 2002), approximately 10%–20% of onsite wastewater systems are failing. The failure rate is probably higher for manufactured housing because only 17 states regulate these systems as they do other structures.

Septic System Problems

The most common method of onsite waste disposal is the septic tank system. These systems are generally composed of a septic tank, distribution box, and absorption field (also known as the drain field or leach field). The septic tank serves three purposes: it allows for sedimentation of solids in the wastewater, storage of solids, and anaerobic breakdown of organic materials. The absorption field is where final treatment and disposal of wastewater occurs.

Septic tank systems can fail in a number of ways. The actual septic tank can fill with solids (because of inadequate maintenance and pumping), resulting in failure when solids are discharged into the absorption field. This damages soil porosity and can result in surface failure. Failures can also be caused by flushing hazardous household chemicals like drain cleaners into the tank that destroy anaerobic bacteria needed for digestion of solids in the tank. This can result in inadequate primary treatment in the septic tank and causes soil damage. Most critically, many sites are simply unsuitable for any type of onsite wastewater disposal system because of severe topographic limitations, a high groundwater table, overly porous soil that allows sewage to reach groundwater without adequate treatment, or impervious soil that will not allow wastewater to percolate through the soil and results in surfacing of sewage effluent.

Following are signs of serious septic system problems:

- Sewage backup in drains or toilets (often a black liquid with a disagreeable odor).
- Slow flushing of toilets. Many drains will clear much slower than usual, despite using plungers or drain-cleaning products. This slow movement may also result from a clogged plumbing vent or a nonvented fixture.
- Surface flow of wastewater with liquid ranging in color from clear to black seeping along the ground near septic systems with a disagreeable odor.
- Lush green grass over the absorption field, even during dry weather, may indicate that an excessive amount of liquid from the system is moving up through the soil, instead of down, as it should. Although some upward movement of liquid from the absorption field is good, too much could indicate major problems.
- The presence of nitrates or bacteria in a nearby drinking water well may indicate that liquid from the septic tank system may be flowing into the well through the ground or over the surface. Water tests available from the local health department will indicate whether nitrates or bacteria are present in the drinking water.
- Buildup of aquatic weeds or algae in nearby lakes or ponds may indicate that nutrient-rich septic waste is leaching into the surface water, possibly creating health risks.
- Unpleasant odors around the house. Often, an improperly vented plumbing system or a failing septic system causes a buildup of disagreeable odors.

More information can be found in the EPA *Homeowner's Guide to Septic Systems* (U.S. Environmental Protection Agency 2005).

Avoiding Health Risks from Septic Systems

EPA's *Homeowner's Guide to Septic Systems* provides detailed information about locating, installing, and maintaining septic systems (U.S. Environmental Protection Agency 2005).

Siting Septic Systems

Septic tanks and absorption fields must be located to avoid contaminating water wells, groundwater, or streams. At a minimum, the system should be 10 feet from the house and other structures, 5 feet from property lines, 50 feet from water wells, and 25 feet from streams. To take into account soil porosity and groundwater issues, local health or code authorities should be consulted.

Drinking water and wastewater lines should be laid in separate trenches leading to the structure. Regulations vary by state but typically require between 3 and 10 feet of horizontal separation. Drinking water and wastewater lines should be placed above the water table, away from areas of drainage or standing water.

Connections and Piping

There are many techniques and devices for preventing backflow, back-siphonage, and cross-contamination between water and wastewater, including vacuum breakers (nonpressure and pressure); backflow preventers; surge tanks; and color coding lines to avoid cross-connecting drinking water and sewage systems.

Inspection

Septic tanks need to be inspected from time to time, as described in the EPA *Homeowner's Guide to Septic Systems* (U.S. Environmental Protection Agency 2005).

Addressing Septic System Failures

Failure of onsite wastewater systems may be addressed through pumping and maintenance of the septic system by trained contractors. Where soils or terrain are insufficient to handle wastewater loads, extension of leach fields, or other acceptable septic tank system repairs may be appropriate where land is available. Ultimately, providing the structure access to a publicly owned wastewater treatment system is the best way to address wastewater problems.

Electricity

Manufactured structures share many potential electrical safety concerns in common with traditional site-built structures. Some manufactured structures may pose special electrical safety issues. Electric shocks can cause burns, and severe shocks can disrupt the heart, potentially causing death. An occupant may experience such shocks when coming in contact with faulty wiring, appliances, or short circuits or when connecting some kinds of manufactured structures to a power source. Electrical problems can also start fires (see Chapter 3 on Fire Safety). The 2007 American Housing Survey reported 40,000 manufactured housing units (0.6%) have exposed electrical wiring (U.S. Census Bureau 2008).

Electrical Safety

The safety requirements for outdoor, countertop, and bathroom electrical receptacles (outlets) are the same for manufactured structures as site-built structures, although the safety requirements for hooking to electrical service may differ depending on the type and use of manufactured structures. Manufactured housing must meet Title 24 Sec. 3280 and part A of Article 550 of the National Electrical Code (NEC) (NFPA No. 70-1993). These regulations cover the electrical conductors and equipment installed within or on manufactured homes and the conductors that connect manufactured homes to a supply of electricity. Local electrical codes may also apply, and the authority having jurisdiction may enforce specific editions of the NEC or International Residential Code (IRC). In general, external electrical feed connections must be within 30 feet of the manufactured home and provide grounding and insulated conductors, and the distribution panel must be located within the home. Installing the power hookup may be hazardous and should be performed by trained personnel.

For recreational vehicles using RV parks, electrical service is provided through a power pedestal. Installation and maintenance of these pedestals must be performed by a licensed electrician and are regulated by local or state electrical codes (Trout 2001).

Residential electrical wiring system studies performed or sponsored by the Fire Protection Research Foundation, the U.S. Consumer Product Safety Commission (CPSC), the National Institute of Standards and Technology, and the U.S. Fire Administration have found three contributing factors to electrical wiring fires: the effect of natural aging over time on the electrical system wiring and equipment; misuse or abuse of the electrical system components in the home by the occupants; and non-code-compliant installations, upgrades, or repairs (Dini 2008). These studies indicate that there would be a significant reduction in the number of electrical wiring home fires if electrical systems are installed and maintained in accordance with NFPA 70 (the *National*

Electrical Code) and inspected in accordance with NFPA 73 (*Electrical Inspection Code for Existing Dwellings*).

Electrical Safety Tips Inside the Home

- Use arc fault circuit interrupters (AFCIs), ground fault circuit interrupters (GFCIs), and TROs (tamper-resistant outlets) to help protect against fire and shock hazards. These devices should be installed where required by codes and where additional safety is desired (See http://www.esfi.org/cms/homesafety). For additional information on AFCIs or GFCIs, see http://www.cpsc.gov/volstd/afci/afci.html or http://www.cpsc.gov/volstd/gfci/gfci.html.
- Use only appliances and equipment approved by Underwriters Laboratories (look for the UL listing on the label) or other recognized testing laboratories.
- Make sure appliances are in good condition and that there are no breaks or cracks in power cords, plugs, or connectors.
- Keep appliances such as hair dryers, radios, and curling irons away from water-filled tubs and sinks.
- Do not overload outlets with cords. Use multiple plug outlets (devices with three to six receptacles, a circuit breaker, and a surge protector) as a more permanent solution when there are too few electrical outlets.
- Use extension cords as a temporary solution. If the television picture shrinks or flickers when major appliances go on, or if fuses or circuit breakers blow frequently, have your circuits and wiring checked.
- Use extension cords as a temporary solution, and do not run cords under carpets or furniture because the cords can overheat and cause a fire.
- Unplug small appliances when not in use. Always unplug appliances before cleaning. Never unplug or carry anything by its cord. Unplug and do not use an appliance that has given you an electrical shock.
- Use all three prongs of electric plugs. Never force a plug into an outlet if it doesn't fit, and never nail or tack cords to walls or floors.
- Use plug covers or safety caps. Teach children not to poke things into electrical outlets, toasters, or other appliances. Keep electrical cords out of children's reach.

Electrical Safety Tips Outside Manufactured Structures

- If you have overhead electrical service, watch out for the drop line from the utility pole. Keep ladders, tools, and children away from the electrical service equipment. Be particularly careful when you are unloading materials from your car or truck.
- Keep television and radio antennas away from power lines. Antennas should be far enough away so if blown over they remain clear of the lines.
- If work must be done near power lines, contact the local electrical utility first for specific advice or to de-energize the lines.
- Place outdoor outlets on a circuit protected by a GFCI. GFCIs can be added as a temporary plug-in adapter, added as a replacement outlet, or even installed as a circuit breaker. Electricians can provide options. For additional information on GFCIs, see http://www.cpsc.gov/volstd/gfci.html.
- Make sure that any electrical products used outside are intended for outside use.
- Teach children to recognize "Danger" signs, to avoid climbing in trees close to power lines, and to avoid playing around pad-mounted transformers (metal cabinets on concrete pads).

The Electrical Safety Foundation International, the Fire Protection Research Foundation and CPSC Web sites have more tips for using electrical appliances and space heaters for indentifying potential electrical hazards both inside and outside. For more information, see the following:

- http://esfi.org/cms/node/184
- http://www.cpsc.gov/cpscpub/pubs/463.pdf
- http://www.cpsc.gov/cpscpub/pubs/513.pdf
- http://www.cpsc.gov/cpscpub/pubs/elec_sfy.html
- http://www.usfa.dhs.gov/downloads/pdf/fswy5.pdf
- Electrical Safety in Manufactured Homes. USFA, HUD, NIST, 2000 (http://www.usfa.dhs.gov/downloads/pdf/electrical-mh.pdf).

Gas

Many manufactured structures use propane (also known as liquefied petroleum gas or LPG), for cooking, water heating and/or interior heating. When used properly, propane appliances are safe.

Health Risks Associated with Propane

Three kinds of hazards arise with the use of propane. First, propane is a flammable gas, so fire and explosion may occur if it builds up and is ignited. Second, propane can displace oxygen in enclosed spaces, causing a risk of asphyxiation. Third, if furnaces or other gas-powered appliances malfunction or burn without adequate ventilation, they can generate carbon monoxide (CO), a poisonous gas, which can build up within structures.

Tips for Safe Use of Propane (LPG)

Ventilation

- Ventilate well. Proper ventilation is a key to safe propane use. Make sure that adequate ventilation is provided in accordance with the appliance manufacturer's installation instructions.
- Never block ventilation, combustion air openings, or return air ducts.

Know your system

- Know where your gas service line and shutoff valve are located and how to shut off the gas.
- Recognize the smell of propane, which is treated to smell like sulfur (rotten eggs).
- Keep your owner's manual near your appliance.
- Ensure that overfill protection devices are installed on all propane containers.

Maintain your appliances

- Make sure appliances are installed and operated according to the manufacturer's instructions and local building codes. Most appliances should be installed by qualified professionals.
- Have the heating system professionally inspected and serviced annually to ensure proper operation. The inspector should also check chimneys and flues for blockages, corrosion, partial and complete disconnections, and loose connections.
- Never service fuel-burning appliances without proper knowledge, skill, and tools. Always refer to the owner's manual when performing minor adjustments or servicing fuel-burning equipment.
- Clean appliances regularly to removed lint and dirt. Contact your local propane supplier for tips on proper cleaning and follow the manufacturer's instructions.
- Do not cover the bottom of natural gas or propane ovens with aluminum foil. Doing so blocks the combustion air flow through the appliance and can produce CO.
- During home renovations, ensure that appliance vents and chimneys are not blocked by tarps or debris. Make sure appliances are in proper working order when renovations are complete.
- Have your cooking range serviced if the burner flame is not blue. The blue flame indicates complete combustion. A yellow flame indicates air inlets are clogged or burners need adjustment. Contact your propane supplier's service department immediately.
- Water can damage the internal safety mechanism in the gas controls of an appliance. If you suspect that your appliance gas controls may have gotten wet (because of flooding, for example), have a trained technician replace them immediately.

General safety practices

- Never store propane cylinders inside your home.
- Install and maintain a CO alarm that meets the requirements of the current UL 2034 or CSA 6.19 safety standards. A CO alarm can provide some added protection, but it is no substitute for proper use and upkeep of appliances that can produce CO. Install a CO alarm in the hallway near every separate sleeping area of the home, and make sure the alarm cannot be covered up by furniture or draperies.
- Install and maintain a residential propane gas detector that meets the requirements of the current version of UL 1484, Standard for Residential Gas Detectors. A propane gas detector can provide added protection, but it is no substitute for proper use and upkeep of propane-fueled appliances that can malfunction and allow unburned propane to leak into the dwelling. Install a propane gas detector in accordance with the manufacturers' installation instructions. Make sure the detector cannot be covered up by furniture or draperies.
- Never operate a portable generator or any other gasoline engine-powered tool either in or near an enclosed space such as a garage, house, or other building. Even with open doors and windows, these spaces can trap CO and allow it to quickly build to lethal levels.

- Never use portable fuel-burning camping equipment inside a home, garage, vehicle, or tent unless it is specifically designed for use in an enclosed space and provides instructions for safe use in an enclosed area.
- Never operate unvented fuel-burning appliances in any room where people are sleeping.
- Keep flammable and combustible materials away from open flames and appliances.
- Keep children and pets away from all heaters to avoid accidental burns.
- Never use gas ranges or dryers for home heating.
- Never place your head near or directly over the valves on your storage tank.
- Never leave a car running in an attached garage, even with the garage door open.

In case of trouble: If you smell gas, assume there is a serious problem and respond immediately. Instead of attempting to identify the source of the leak,

- Make sure that everyone leaves the structure immediately, and leave the door open.
- Do not touch any electrical appliances (including lights).
- Shut off the gas at the propane tank.
- Call the local fire department or the local propane dealer for assistance, but make the call from outside the house.

CHAPTER 8: POSTDISASTER HOUSING: KEEPING SAFE AND HEALTHY

In the wake of a disaster, manufactured structures will provide interim housing for many displaced people. The housing environment for people in this situation is very unsettled because they find themselves in unfamiliar housing after losing the ability to live in their home with their normal furnishings and possessions. Besides the absence of many possessions that people are used to, the housing unit itself will introduce major differences to residents. The manufactured structure may have just been recently sited at its location near the disaster. The building systems in the dwelling might be new or different for the occupants. Living spaces may be smaller and may include more people. And the pattern of how to operate a home to best provide for the safety and health of the residents must often be relearned to some extent in this new environment.

With this scenario in mind, this chapter provides practical, action-oriented guidance for people living in a manufactured structure in the aftermath of a disaster. The information is intended to provide simple, direct guidance on how to stay safe and healthy in the emergency housing during the time people are living there. While many of these recommendations are similar to health and safety guidance for *permanent* residents of manufactured structures, there are some key differences for temporarily housed residents following a disaster. This is due to the fact that these temporary residents are living in a very unsettled and unfamiliar environment, trying to cope with the aftermath of the disaster while also establishing a safe home environment.

The recommendations generally fall into the same categories covered in the rest of this report, including a separate discussion on risks and hazards for special populations like pregnant women and asthmatics. The recommendations below are stated in brief terms, so that they can serve as a checklist for people to consider as they temporarily adapt to living in a manufactured structure.

FIRE AND ELECTRICAL SAFETY

Smoke Alarms

Make sure the dwelling has working smoke alarms:

- Follow HUD Code requiring smoke alarms to be located in each bedroom, kitchen/living area, stairwell, and basement (24 CFR 3280.208).
- Use interconnected smoke alarms for better protection so when one sounds, they all sound. Combination smoke-carbon monoxide (CO) detectors are commonly available for protection against fire as well as CO.
- Use regular alarms if long-life alarms are not available—and replace the batteries annually.
- Test all smoke alarms at least every month using the test button or an approved smoke substitute and clean the units, both in accordance with the manufacturers' instructions.

Cigarette Smoking

People who smoke should attempt to quit. The U.S. Department of Health and Human Services, National Institutes of Health, and National Cancer Institute provide a free helpline (1-800-Quit Now) for smokers who want to quit and need help doing so.

- Smokers should smoke outside the home.
- If someone does smoke in the home, provide large nontip ashtrays on level surfaces and empty them frequently. When emptying cigarette butts, douse the butts with water before discarding them.

Cooking

- Never leave cooking food unattended. Supervise older children who cook.
- Never use an outdoor grill/BBQ unit inside.
- Keep cooking surfaces clean and place anything that can burn well away from the range.
- Have gas stoves or ranges checked if the flame has yellow tips: a yellow-tipped flame on a gas stove or range indicates a problem.

Candles

- Avoid the use of candles for lighting during blackout situations. Use battery- or crank-powered flashlights or lanterns instead.

Electrical Circuits

- Avoid overloading electrical circuits. If breakers are frequently tripping, try taking major loads off that circuit.
- Keep appliances such as hair dryers, radios, and curling irons away from water-filled tubs and sinks.
- Use extension cords as a temporary solution, and don't run cords under carpets or furniture as the cords can overheat and cause a fire.
- Unplug small appliances when not in use. Always unplug appliances before cleaning. Never unplug or carry anything by its cord. Unplug and do not use an appliance that has given you an electrical shock.
- Use all three prongs of electric plugs. Never force a plug into an outlet if it doesn't fit, and never nail or tack cords to walls or floors.
- Use outlet covers to keep young children from playing with outlets.
- Stay clear of any loose electrical connections or wires that appear to have come loose from a connection, and consult an electrician.

Burns/Scalds

- Set the water heater thermostat to 120°F or lower.
- Install hot water temperature limiters at the faucet.

Escape Plan

- Make and practice a fire escape plan with your family. Make sure family members can identify two ways out of every room. Also, pick a safe meeting place away from your home for everyone to go to after escaping a fire.

HEATING, COOLING, AND VENTILATION

Operating Your Heating/Cooling System

- Keep the indoor temperature at reasonable levels. Keeping it too cold in the winter or too warm in the summer can actually create moisture and indoor air quality (IAQ) problems.
- Inspect and replace air filters in the system regularly. Inexpensive fiberglass filters (which are common) should be changed monthly, especially if there are pets in the home.
- If normal operation of your air-conditioning system cannot keep indoor humidity below 50%, use a separate standalone dehumidifier also to reduce indoor moisture. Simple digital temperature and

relative humidity monitors are available for $10 or less at home improvement and department stores.

- Make sure that water from the indoor air-conditioner unit drains outside the home, and not into the crawl space below the house.

Space Heaters

- Read the product instructions before using a space heater, and place it on a firm, out-of-the-way surface to reduce tipping over. Keep it at least 3 feet away from clothing, bedding, draperies, or other combustible material. When it's not being used, turn the space heater off and unplug it.
- Do not run space heaters using propane or kerosene for longer than the instructions specify. Longer run times can release too much water vapor and harmful combustion gases into the home.
- Avoid the use of unvented propane or kerosene heaters—they add lots of moisture to the indoor air and can create other IAQ problems. If such heaters must be used, be sure to use the proper fuel for the unit, follow the time limits on how long the unit should run, and provide ventilation to the indoor space where it is used.

Ventilating the Building

- Ventilate your dwelling when outside conditions are mild and dry by opening up windows. This is especially helpful if the dwelling is new; has been closed up for a long period of time; or has new furnishings like carpet, furniture, or cabinets.
- Use kitchen exhaust fans when boiling things on the stove.
- Turn on bathroom exhaust fans whenever showering and for a few minutes afterwards.
- Both kitchen and bath exhaust fans can be used more frequently to help reduce general odors and pollutants from the home. As these fans pull air and odors out of the home, fresh air from outdoors will make its way inside, helping to dilute remaining odors.
- Use the home's ventilation systems as much as needed to achieve comfortable indoor air conditions. Postdisaster housing is often overcrowded, which requires higher levels of ventilation.
- Do not block ventilation, combustion air openings, or return air ducts.

COMBUSTION SAFETY

- Never operate a portable generator or any other gasoline engine-powered tool either in or near an enclosed space such as a garage, house, or other building. Even with open doors and windows, these spaces can trap CO and allow it to quickly build to lethal levels.
- Never use portable fuel-burning camping equipment inside a home, garage, vehicle, or tent unless it is specifically designed for use in an enclosed space and provides instructions for safe use in an enclosed area.
- Make sure the dwelling has CO detectors to provide early warning of elevated CO levels. Combination smoke-CO detectors are commonly available for protection against fire as well as CO. If a CO problem is suspected, get fresh air immediately by opening windows and doors. Turn off any combustion appliances and leave the house immediately.
- Make sure the vent piping for furnaces and water heaters is connected and carries the exhaust gases from this equipment to outdoors.
- Do not store propane cylinders inside the home.
- Learn the location of gas shutoff valves and be familiar with how to use them. Also learn to recognize the smell of propane and natural gas so you can recognize a leak by smell.
- If you smell gas, assume there is a serious problem and respond immediately. Instead of attempting to identify the source of the leak,
  - Make sure that everyone leaves the structure immediately, and leave the door open.
  - Do not touch any electrical appliances—including lights.
  - Shut off the gas at the propane tank.
  - Call the local fire department or the local propane dealer for assistance, but make the call from outside the house.

INDOOR AIR QUALITY AND MOISTURE CONTROL

Keep an eye out for these signs of water problems:

- Drips or puddles anywhere in the house.
- Water stains on drywall or ceiling tiles.
- Blistering or bubbling paint on walls or ceilings.
- Damp or musty smells.
- Mold growth on surfaces.
- Excessive condensation on windows or other surfaces. "Excessive" means condensation that is there continuously or enough condensation so that it accumulates and pools.
- Pooling water or puddles near the interior unit of an air-conditioning system.
- Rotting wood or materials that are damp to the touch.
- Water-soaked building insulation.
- Sagging drywall or ceiling tiles.

If you see a sign of a water problem, the source of the problem needs to be identified and fixed.

Managing Indoor Humidity Levels

- Use dehumidifiers and/or air-conditioning to reduce indoor humidity to the range of 30%-50%. An indoor digital temperature and relative humidity (RH) monitor costs less than $10 from department or home improvement stores.
- Use kitchen exhaust fans when boiling things and bathroom exhaust fans while showering.
- Make sure dryer vent ducts go to the outdoors, not inside or underneath the unit.

Household Cleaning Products

- Try to use household cleaning products that are listed as solvent-free. If using a product made of harmful chemicals, provide ample ventilation (at least as much as the product instructions recommend) using your home's exhaust fans and opening windows.
- Be mindful of what you bring into the home. New furnishings, pets, cleaning products, and stored chemicals can all negatively impact the home's IAQ.

Allergens

- Keep the house clean by sweeping, vacuuming, and dusting. This reduces dust mites, pollens, animal dander, and other allergens.
- Keep indoor relative humidity levels below 50% with air-conditioning and/or dehumidifiers. This reduces dust mites.
- If residents are allergic to pets kept in the home, try to keep the pets outdoors as much as possible or find a temporary home for them.
- Limit the use of carpeting or rugs in areas that are damp or moist—like bathrooms and kitchens.

MOLD

Most of the guidance for IAQ, moisture control, and HVAC also will help to prevent mold problems in homes. In general there are two key steps to dealing with mold: 1) clean up the mold, and 2) eliminate the moisture source that allowed the mold to grow in the first place.

Mold Clean Up

- For small areas of mold like a few square feet, many residents can often handle the clean up. In cases where porous materials (e.g., carpet, ceiling tiles) have significant mold growth, they often must be replaced. Nonporous materials like tile can typically be cleaned with a detergent and water. If that is not effective, a bleach solution can be used.
- Contractors with training in mold remediation should be consulted for larger problems or if residents have health issues (e.g., a suppressed immune system or asthma) that make mold exposure risky.
- Important safety note: Ammonia and bleach should never be mixed because it may produce chlorine and other poisonous gases or it may lead to an explosion.

Mold Testing

- Testing for mold generally is not recommended or needed. In most cases the main goals are to find and fix the moisture problem and clean up the mold.

PESTS AND RODENTS

Prevention and "Pest-proofing" Tips

- Remove debris piles from around the home like piles of lumber, leaves, and rotting firewood.
- Place household garbage in receptacles without holes and with tight-fitting lids.
- Keep plants, shrubs, and trees back from the home's foundation at least 18 inches.
- Use exterior yellow bug lights to avoid attracting insects.
- Keep roof gutters unclogged and direct downspouts away from the building.
- Deny pests access by sealing holes and cracks in the home's exterior at pipe and wiring penetrations. Expanding spray foam in a can and wire screen make good materials for plugging up these holes.
- Use window screens when windows are open, and patch holes in the screens.
- Store pet food in sealed containers and remove uneaten pet food before pests find it.
- Eliminate potential breeding areas for mosquitoes by removing or modifying areas that can hold water such as gutters, tarps, empty cans, and used tires.

Before Using Pesticides In/Around the Home

- Just applying a pesticide normally does not solve a pest problem. First, try to figure out why the pests are there to begin with and fix it. Look for the pest's target (like food scraps on the counter) and how they're getting in (a hole in the exterior wall by a water line).
- Purchase only a small amount of pesticide, and buy more later if it is needed.
- Follow all pesticide product labels and instructions.
- Use pesticides only in the recommended quantities, and mix or dilute pesticides outdoors.
- Take children and pets outside when applying pesticides indoors.
- Never use pesticides labeled "Outdoor Use Only" indoors.
- Increase ventilation indoors during and after application of pesticides.
- Only use pesticides that list the target pest on the label.
- Do not store unneeded pesticides inside manufactured structures.
- Limit the use of chemical pesticides outdoors as well as indoors, to avoid unnecessary environmental contamination. Pesticides can cause negative health effects in people.

STRUCTURAL INTEGRITY

Potential signs of a structural problem with a manufactured structure are listed below. Residents will not be equipped to address these types of problems, but can recognize and alert authorities that there is a potential structural issue.

- Look for foundation problems including crumbling or leaning foundation piers, cracked or settling foundation walls, or uneven (not level) foundations.
- Look for stormwater management problems like pooling water underneath the unit or near its foundation, soil erosion near the home's foundation, and clogged gutters or downspouts.
- Look for roof problems including sagging roof lines, holes of any type (look around roof penetrations), or missing roof shingles.
- Look for exterior wall problems including cracks or gaps in the walls, sloped walls, walls with rot or bug infestations, or walls that do not sit on top of the foundation.
- When windows or doors will not open/close correctly, look for cracks in the walls around them for signs of structural movement.

BUILDING ACCESSIBILITY

The ability to walk up stairs outside a manufactured structure or to maneuver inside the dwelling can be difficult and hazardous for some residents. In most instances, residents will not be able to fix such issues on their own but can at least notify the appropriate people that a health/safety issue exists.

- For elderly, disabled, or any other occupant who has difficulty with stairs or maneuvering in the dwelling (due to a wheelchair, for example), inquire about manufactured housing units with enhanced accessibility features.

SPECIAL POPULATIONS

All of the tips and guidance listed above can help make manufactured structures safer and healthier homes for residents in the wake of a disaster. But for some special populations, dealing with hazards in the home environment is even more critical for their wellbeing. Pregnant women, infants and young children, the elderly, the disabled, people with asthma, and those with suppressed immune systems are major groups—representing millions of Americans—who demand special attention. For these populations, the risk presented by different household hazards can be much greater and result in very serious consequences.

Table 8-1 below highlights particular areas where these populations may be at greater risk. The goal of this chart is to highlight where these increased risks exist so that residents can be aware of them and place extra emphasis where it is needed. For example, in looking at the table below a mother of a young child with asthma might note that there are several allergens—including dust mites—that can worsen asthma symptoms in her child. This would indicate that keeping indoor humidity levels below 50%, regular cleaning, and avoiding the use of carpeting in damp areas are very important practices for controlling dust mites and managing her child's asthma. Residents should also consult health care providers on how to best manage different health conditions with respect to their temporary homes.

In addition to raising the awareness of manufactured structures residents, this overview of special populations and risk categories should also serve to inform emergency response decision makers.

Health/Safety Issue	RISKS TO SPECIAL POPULATIONS					
	Pregnant Women & Fetuses	Infants & Young Children	Elderly People	Physically Disabled People	People with Asthma or Other Chronic Respiratory Illness	People with Suppressed Immune Systemse
Fire Safety - Home Fires		Increased likelihood of accidents involving fire Reduced ability to escape a fire	Reduced ability to escape a fire	Reduced ability to escape a fire	Especially sensitive to smoke exposure	
Electrical Accidents		Increased likelihood of accidents				
Combustion Safety - CO in the House		Especially sensitive to CO exposures	Especially sensitive to CO exposures		Especially sensitive to CO exposure	
IAQ -- High Indoor Humidity		Increases dust mites, which can contribute to the development of asthma in susceptible children			Increases dust mites that trigger breathing difficulties and makes symptoms more severe	
Mold		Potential allergy symptoms and irratiation	Reduced ability to escape a fire	Reduced ability to escape a fire	Can trigger breathing difficulties and make symptoms more severe	Potential for serious infections
Indoor Chemical Agents such as – VOCs from cleaning products – NO_2 from cigarettes or gas stoves		Potential allergy symptoms and irratiation May increase risk for developing or worsen existing respiratory disease			Can trigger breathing difficulties and make symptoms more severe	

(Continued)

Health/Safety Issue	RISKS TO SPECIAL POPULATIONS					
	Pregnant Women & Fetuses	Infants & Young Children	Elderly People	Physically Disabled People	People with Asthma or Other Chronic Respiratory Illness	People with Suppressed Immune Systemse
Allergens from pets, dust mites, pollens, and pests including cockroaches and rodents		Increased risk for developing asthma (in the case of dust mites) or worsening existing respiratory disease Possible increase in risk for developing asthma in preschool aged children (cockroaches)			Can trigger breathing difficulties and make symptoms more severe	
Environmental tobacco smoke	Low birth weight and overall smallness in fetus size (Office of the Surgeon General, 2006)	Increased risk for asthma development Increased risk for Sudden Infant Death Syndrome (SIDS) Increased risk for lower respiratory tract infections such as pneumonia and bronchitis			Can trigger breathing difficulties and make symptoms more severe	
Mice	Virus transmitted by common house mice can cause birth defects					Virus transmitted by common house mice can cause severe illness
Pesticides	Exposure during pregnancy has potential adverse effects on fetal growth and childhood neuro development	At risk for accidental ingestion. At greater risk for exposure due to crawling, sticking fingers in mouth. Infants are at higher risk of toxic effects from pesticide exposure due to their immature metabolisms				
Building Accessibility			Exterior building access and maneuverability within units may be difficult. Units with accessibility features should be sought out.	Exterior building access and maneuverability within units may be difficult. Units with accessibility features should be sought out.		

Table 8-1: Risks to Special Populations. Centers for Disease Control and Prevention. 2006. The health consequences of involuntary exposure to tobacco smoke: a report of the Surgeon General. Atlanta, GA: U.S. Department of Health and Human Services.

CHAPTER 9: POTENTIAL OPPORTUNITIES

Since the construction of manufactured homes was first federally regulated over 35 years ago, great strides have been made in improving the sustainability, durability, and safety of manufactured homes. While the process of updating regulations and building practices can be lengthy, the development and transfer of new technology, progress in site-built construction, and feedback from research and home owners continue to present more opportunities for improving manufactured homes. This chapter discusses a wide range of potential design improvement opportunities, as well as discussing health/safety considerations associated with potential changes to manufactured homes.

SUSTAINABLE BUILDING AND HEALTH/SAFETY

Construction of manufactured homes in a controlled factory environment has resulted in inherent efficiencies in material use and reduction of construction waste. While manufactured homes have been heralded for their material and resource efficiencies, there are now opportunities in other areas of green and sustainable building applications as well. Current opportunities for technological advancements and pending updates to the HUD Code point towards the beginning of a "greener" era for manufactured homes. However, the use of any new material or technique can result in benefits and sometimes in unforeseen adverse consequences. Thus it is important that health and safety concerns be considered as new technologies are developed and deployed.

The discussion in this chapter covers a range of opportunities for manufactured homes in the areas of energy performance, water conservation, and indoor air quality.

Energy Efficiency and Conservation

Regulations and Voluntary Beyond-Code Programs

HUD Code

Beginning in 1974, the U.S. Department of Housing and Urban Development Federal Manufactured Home Construction and Safety Standards Act, known as the "HUD Code," regulated the construction of all manufactured homes in the United States. The energy conservation components of the HUD Code were last updated in 1992.

The opportunity to upgrade the energy conservation components of the HUD Code was recognized by the Energy Independence and Security Act of 2007, which places the responsibility for establishing updated energy conservation standards for manufactured homes with the U.S. Department of Energy (DOE). DOE's standards will be based on the 2009 International Energy Conservation Code (IECC) and are scheduled to be released in 2011. Thereafter, DOE is required to update the standards within 1 year of each update to the IECC, which currently occurs in 3-year cycles. These updates are expected to result in more stringent requirements for manufactured homes than are currently required, reflecting the new, more stringent energy efficiency requirements for site-built homes. Along with these updated building practices and technologies, consideration of unintended impacts on resident health and safety will also be essential. Several examples of these issues are noted in the discussion below.

Energy Star

Energy Star was created in 1992 by the U.S. Environmental Protection Agency (EPA) as a voluntary labeling program to identify and promote energy-efficient products. The Energy Star program has expanded into the construction of manufactured homes that are built to be 30% more energy efficient than the 1993 Model Energy Code. The EPA offers guidelines on the design, production, sales, and installation of these energy-efficient manufactured homes. A certified plant must produce homes that meet the Energy Star design criteria, integrate these into their quality control and inspection procedures, ensure duct tightness, and ensure proper installation.

Energy Star's requirements can result in significant energy efficiency improvements compared to a standard HUD Code home—improvements that are expected to result in a manufactured home that is 15% more efficient than the same home built to the 2004 International Residential Code. These improvements are realized through changes in the building envelope (effective insulation, air sealing of holes and joints, and high-performance windows), air distribution (air-sealed and well-insulated ducts), and equipment (appliances, HVAC, and hot-water heating). As of 2009, over 30,000 Energy Star manufactured homes had been built.

A significant crossover area between energy efficiency and occupant health/safety lies in the air exchange between indoors and outdoors. Improving energy performance often involves air-sealing of the building envelope with spray foam or caulk to seal up leakage points. This reduces the flow of cold or hot outdoor air, which in turn reduces the need to heat or cool this air and saves energy. The Energy Star requirements for manufactured homes contain a limit for envelope air leakage (≤7 air changes per hour at 50 pascals of pressure differential) in the preapproved Energy Star design packages.

However, reducing infiltration of outdoor air also limits the ability of outdoor air to dilute indoor air contaminants like chemicals, odors, and moisture. This can create IAQ problems and adverse impacts on occupants. Therefore, aggressive air sealing of the building envelope should also be accompanied by the use of a whole-building mechanical ventilation system for the dwelling. The mechanical ventilation system uses one or more fans to exchange indoor air with outdoor air in a controlled manner because natural infiltration is no longer serving this role.

The current set of Energy Star design packages contains some requirements for mechanical ventilation in certain scenarios. It is also worth noting that the underlying HUD Code already contains mechanical ventilation requirements for all manufactured homes (regardless of participation in Energy Star), so ventilation is being provided in these homes. Future updates to the HUD Code will likely contain refinements of the mechanical ventilation provisions as well, as this area of building performance benefits from increased research.

Manufactured Zero-energy Homes

Although Energy Star manufactured homes represent significant energy improvements from baseline HUD Code homes, efforts have been pursued through the Department of Energy's Building America Industrialized

Housing Partnership to go beyond Energy Star in demonstrating a "zero-energy manufactured home" in Cherry Lane, Idaho. Zero-energy homes are designed to produce as much energy as they consume, which results in net zero energy consumed for the home over the course of a year.

The Idaho home was designed to reduce heating, cooling, lighting, and water heating energy use and to offset a portion of the energy use through onsite renewable energy. Because of budget restrictions, the home was not designed to be a true zero-energy home, but to demonstrate interim measures in ultimately reaching net zero energy goals. Energy conservation and generation measures included spray foam insulation for walls, floors, and roof; R8 ducts with mastic; 100% fluorescent lighting package; Energy Star appliances; a marriage line gasket; solar water heating; solar photovoltaic panels for electricity generation; reduced infiltration (2.0 ACH 50); and a heat recovery ventilator (HRV) for whole house mechanical ventilation.

The HRV is an example of a mechanical ventilation system, which becomes a vital component with infiltration reduced to the levels seen in this home. HRVs and other mechanical ventilation systems make up for reduced natural air exchange by using a fan(s) to move air between indoors and outdoors. Mechanical ventilation systems can help support IAQ and occupant health by reducing indoor moisture levels and exhausting chemical contaminants and odors. Reducing indoor moisture levels helps manage dust mites and their role in asthma development and exacerbation. Similarly, removing VOCs and other airborne contaminants also helps reduce respiratory irritants from the home.

Most mechanical ventilation systems can also filter incoming fresh air to remove dust, allergens, and other particulates. This is an advantage of controlled mechanical ventilation over a leaky building envelope, where outdoor air randomly enters the structure through different openings.

Building Envelope

Designing for the Climate Zone

Heating and cooling loads of manufactured homes are strongly driven by the climate zone where the home is ultimately located. Selecting building envelope components that are climate appropriate is crucial in specifying a manufactured home that will perform efficiently and comfortably, while not negatively impacting indoor air quality. Consideration should be given to climatic impacts when specifying building envelope components such as insulation, windows, and vapor retarders.

Insulation

HUD Code requirements for building energy performance are limited to an overall prescription for the "coefficient of heat transmission" of the building envelope. This coefficient takes into account the area-weighted insulating value of windows, floors, walls, ceilings, and doors to arrive at an overall rating for a structure. While the use of this coefficient may have meaning for engineers and scientists, its meaning can be very difficult for average homebuyers to interpret.

A study by the Pacific Northwest National Laboratory (PNNL) converted the HUD coefficients into typical R-values by building envelope component. Based on PNNL's analysis, the current requirements show great opportunities for energy conservation by increasing insulation. As a first step in improving the insulation of a manufactured home, manufacturers can look to the prescriptive requirements of the most recent model energy code for single family homes for guidance: the 2009 International Energy Conservation Code (IECC). As an example, Table 9-1 shows HUD Code typical R-values versus IECC prescriptive R-values for the state of Nebraska.

The R-values in Table 9-1 for the 2009 IECC can mostly be met with traditional insulation materials (e.g., fiberglass batts, rigid foam insulating panels) in many assemblies. Advanced insulation technologies such as spray polyurethane foam (SPF), structural integrated panels (SIPs), rigid foam exterior insulation, and even aerogel insulation have also been demonstrated on manufactured homes with success. SPF offers a high R-value per inch, helps to create a tighter building envelope, and may even reduce the frequency of nail-pops and drywall cracks that typically occur during transportation of the unit to the site. Factory-friendly SIPs have been used with success in manufactured homes, with favorable results from road tests and energy performance monitoring (U.S. Department of Energy 2002).

	HUD Code	2009 IECC
Walls	R-11	R-20
Ceiling	R-22	R-38
Floors	R-22	R-30
Windows	U=0.49	U=0.35

Table 9-1: A comparison between typical HUD Code insulation levels and 2009 IECC prescriptive insulation levels for a home located in the state of Nebraska

Fire safety is a common concern about using SIPs. Foam insulation is relatively hard to ignite, but when it is ignited, it burns readily and emits a dense smoke containing many toxic gases. However, when the interior of the SIP is covered with a fire-rated material, such as gypsum board, it protects the SIP facing and foam long enough to give building occupants a good measure of escape time (U.S. Department of Energy 2005, 2009a). Insects and rodents, as in any structure, can become a problem for SIPs as well. Any foam insulation product can provide a good environment for these pests to dwell. Some manufacturers issue guidelines for preventing these problems, including the following:

- Applying insecticides to the panels,
- Treating the ground with insecticides both before and after initial construction and backfilling,
- Maintaining indoor humidity levels below 50%,
- Locating outdoor plantings at least two feet away from the walls, and
- Trimming any overhanging tree limbs.

Boric acid-treated insulation panels are also available. These panels keep insects away while remaining relatively harmless to humans and pets (U.S. Department of Energy 2009a). EPA has classified boric acid as showing "evidence of non-carcinogenicity" for humans. Further, residents in homes with such panels will have very limited exposure to these materials since they will be situated in exterior walls/ceilings and separated from the living space by an air barrier of drywall.

Aerogel insulation can have R-values of over 10 per inch, and has been demonstrated as an energy efficiency retrofit option for manufactured homes (Emerging Technologies Coordinating Council 2008). Though currently cost prohibitive for many applications, aerogels are expected to decrease in cost by 30%-50% over the next few years. Any potential IAQ impacts from the materials used in aerogel insulation are likely minimal due to the fact that the insulation is likely to be used in a location with little air communication with indoor spaces.

Windows

Window thermal performance is not specifically addressed in HUD Code, so manufacturers are free to specify any type of window desired, as long as they still meet the requirements for the overall heat transfer coefficient of the home. In hot climates, the most important performance metric for windows is the solar heat gain coefficient (SHGC), with lower values representing better window performance. Selection of a SHGC below 0.3 generally represents a good value for hot climates.

In cold climates, a higher SHGC can actually help with supplying free solar heat in winter, and so model energy codes have no requirements related to SHGC in these climates. Instead, the U-factor of a window is a more important indicator of its effect on home energy efficiency. Windows with U-factors of 0.35 or lower (e.g., a vinyl, double-paned, low-e window) provide a good balance between performance and cost in cold climates. Higher performance options include windows with Heat Mirror technology, which can exceed R-values of 12. For windows specified for daylighting function only (e.g., bathroom or portable classroom applications), products incorporating aerogel are now available that transmit up to 20% of visible light while reaching R-values of 20.

Vapor Retarders

Vapor retarders are useful in reducing the transport of water vapor across the building envelope. Where vapor retarders do not exist, condensation can occur within wall, floor, or ceiling assemblies when warm, moist air encounters surfaces below its dew point. In cold climates, the likelihood of condensation increases in the winter, when warm air carrying moisture could seep into walls and condense on cold surfaces near the outside of the wall assembly. In hot climates, condensation in wall cavities is more likely to occur in summer, when warm, humid outdoor air can seep into walls and then condense on cold interior wall coverings (near the air-conditioned building interior).

Placing a vapor retarder on the interior of wall studs in cold climates reduces the chance of vapor transport (and condensation) in wall cavities in winter. However, placing a vapor retarder on the interior of wall studs in warm, humid climates can encourage condensation and reduce the ability of the wall to dry after condensation events. For this reason, a vapor retarder should not be used on the interior of studs in warm, humid climates.

Prior versions of the HUD Code required exterior walls to have a vapor retarder on the living space side of the wall, regardless of climate zone. This requirement was typically met by installing wallboard with a vinyl facing, a specification that has been noted as contributing to moisture accumulation, wall deterioration, and an environment conducive to mold growth (Lstiburek 2007; Moyer et al. 2001). However, the latest version of the HUD Code exempts "homes manufactured to be sited in 'humid climates' or 'fringe climates'" from this requirement, in which case a vapor retarder must be installed on the exterior of the wall. This improvement should help to alleviate many of the moisture problems previously experienced in wall cavities in these regions.

In cold climates, the specification of vapor-barrier interior paint can also serve to limit the diffusion of interior water vapor into the exterior wall assembly (U.S. Department of Energy 2009b). This method, as illustrated in Figure 9-1, can provide first-cost savings and is most effective in tightly sealed manufactured homes. The figure also illustrates the climatically appropriate installation of vapor retarders on the interior side of wall studs.

Reduced Infiltration

Infiltration rates of manufactured homes generally range from 6-12 air changes per hour at 50 Pascals (6-12 ACH 50) (Lubliner and Hadley 2007). For buildings with mechanical ventilation, the lower the infiltration, the less energy is lost across the building envelope. Efforts at air sealing for energy-efficient manufactured homes have included the use of spray foam insulation at walls, ceiling, windows frames, and floors; and the use of improved marriage gaskets at seams between units (Lubliner and Hadley 2007). Such efforts have resulted in infiltration levels as low as 2.0 ACH 50. Low infiltration rates may also be achieved in homes built with fiberglass insulation without using spray foam through extensive caulking and sealing efforts. Further research is needed to identify the durability of various air infiltration methods over time (especially as related to forces applied during transportation of the manufactured home).

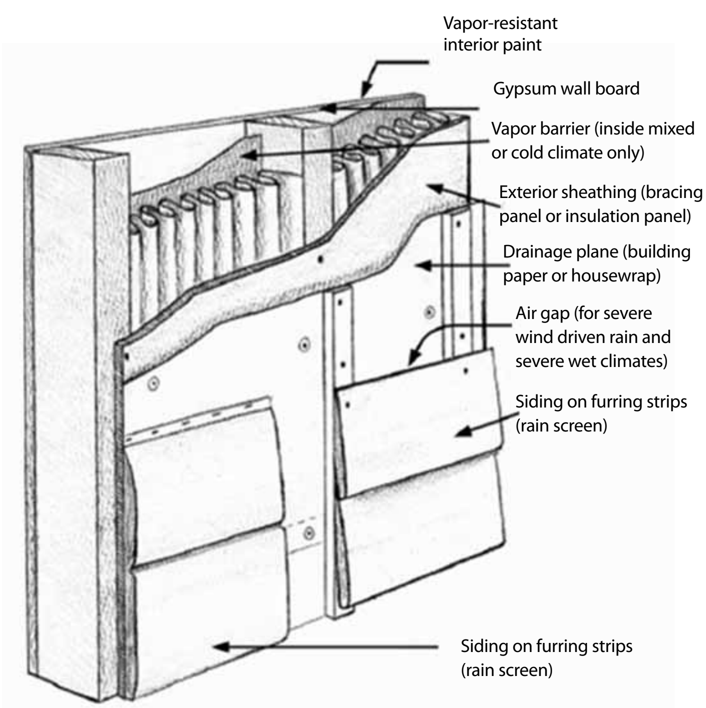


Figure 9-1: Wall design for enhanced durability and energy efficiency. (U.S. Department of Housing and Urban Development 2002).

The air tightness of a well built structure requires controlled fresh-air ventilation for safety, health, and performance, and to meet many building codes. A well designed, installed, and properly operated mechanical ventilation system can also help prevent indoor moisture problems, which is important for achieving the energy saving benefits (U.S. Department of Energy 2009a). Mechanical ventilation and IAQ is discussed in more detail below.

Heating and Cooling

Ducts in Conditioned Space

Typically, manufactured homes have space conditioning ducts either in the belly of the home or in the attic. Studies have shown that these configurations often result in large inefficiencies in air distribution and can contribute to moisture problems and poor indoor air quality. Between 10% and 30% of supply air can be lost to the belly of the manufactured home (Moyer et al. 2001). Field tests of manufactured homes with ducts in conditioned space have demonstrated savings of 7%-10% in whole-house annual energy use (Moyer et al. 2008). Regardless of location, ducts should be tightly sealed with duct mastic to maintain both occupant comfort and indoor air quality. Some negative IAQ consequences of ducts that are not well sealed include creating a reservoir of nutrients that favor mold growth and other allergens, allowing build-ups of toxic chemicals resulting from cooking, smoking, and other indoor sources, and providing a safe haven for pests.

If located within an unconditioned attic, ducts should be insulated to at least R-8, or to R-6 if anywhere else outside of conditioned space. These levels are in step with current IECC requirements, and represent a slight improvement over current HUD Code. If ducts are located in attics in hot-humid climates, providing a conditioned and sealed attic can increase efficiency and improve comfort. Further, a conditioned and sealed attic can provide greater uplift resistance during high wind events while resisting the intrusion of wind-driven rain.

Higher Performance Space Cooling and Heating Equipment

Increasing the efficiency of mechanical equipment represents one of the most cost effective improvements. Combined, space heating and cooling can account for 48% of the energy use of a manufactured home, so specification of high efficiency equipment can have significant impacts on energy and utility bill savings (U.S. Department of Energy 2005). Selection of an affordable, high efficiency system should be based on location of the home. For example, specifying a 95% gas fired furnace in Massachusetts will result in a shorter payback for the higher cost equipment compared to specifying the same furnace in Florida (where it will run less and take longer to deliver energy/cost savings). Similarly, specifying a 15 SEER air-conditioning (A/C) system in Texas will result in a much higher return on investment than specifying the same A/C in Vermont.

Because manufactured home mechanical equipment is usually located in tight spaces, federal efficiency standards do not require it to perform on par with equipment in site-built homes, which can often achieve higher efficiencies using equipment with larger components (e.g., split system central air conditioners with oversized evaporator and condenser coils). Rules developed by DOE require "space-constrained" air conditioners to have a SEER of 12, which is about 8% less efficient than the SEER 13 minimum required for site-built homes.

Some manufacturers of split system central A/Cs now manufacture 13 SEER units that can be used in manufactured homes. Even higher efficiencies can be achieved with duct-free split systems. These systems achieve SEER ratings up to 58% higher than federal minimum (i.e., SEER 19 versus SEER 12), and also provide the advantage of completely avoiding the need for ducts in some climates, which can greatly improve indoor air quality while reducing distribution losses. The main barrier to integration of duct-free split systems, which are used extensively in Europe and Asia, is their typically higher first costs. Ground source heat pumps (GSHPs) can also provide a high efficiency alternative to traditional forms of heating and cooling systems, but their use in manufactured homes is also limited by their high first costs. GSHPs also rely upon a ground loop installed on-site, which would not move with the dwelling if it was relocated.

Excellent opportunities are developing for high efficiency gas- or propane-fired heating equipment as well. Although manufactured homes' forced-air gas furnaces are only required to rate at 75 AFUE, forced-air furnaces of up to 95 AFUE are available. Additionally, gas-fired, condensing and modulating, tankless, combination water and space heating equipment is now available with AFUEs over 90. Such technologies improve energy efficiency and can also save space in the case of tankless systems and combination systems.

In terms of occupant health/safety, high efficiency gas- or propane-fired systems are direct-vented or power-vented. This means that the combustion gases are exhausted directly to outdoors through a fan-powered duct or pipe. This is a reliable way to ensure that combustion gases, which can potentially contain carbon monoxide, are exhausted from the home.

Additional Technologies

This section contains brief descriptions of several additional technologies/systems that can provide additional energy savings in manufactured homes. From a safety and health perspective, these systems are notable for their ability to lower the environmental and energy impact of manufactured structures overall. By allowing these homes to use less energy, the associated health impacts of energy generation (e.g., mercury emissions) are also reduced—which improves health/safety for society at large. Also, since these technologies can reduce energy use and energy costs for residents, they help to provide residents of manufactured homes with additional money that can be spent on health care and wellness.

Programmable Thermostats

By setting back a thermostat's heating set point 10°-15° for an 8-hour period each day, a home owner can save 5%-15% on their annual heating energy bill (U.S. Department of Energy 2009c). Specification and use of a programmable thermostat can be one of the most affordable energy conservation measures that a resident can pursue.

Advanced Water Heaters: Tankless Water Heaters and Solar Water Heaters

Ideal for their fast response, small footprint, and high efficiencies, on-demand or "tankless" water heaters can provide significant energy savings over their life. Tankless water heaters are available as gas- or propane-fired or electric units, have a life expectancy of around 20 years, and provide significant savings over tank-based models that have inefficiencies associated with standby losses—which occur in between demands for hot water. Specification of a tankless water heater can save 24%-34% of the water heating energy consumed by homes using up to 41 gallons of hot water per day (U.S. Department of Energy 2009d).

Solar water heaters have been demonstrated to provide nearly 100% of the water heating demands of manufactured homes in summer months (Lubliner et al. 2004), and are capable of reducing water heating bills 50%-80% over the course of a year (U.S. Department of

Energy 2009e). There are several types of solar water heaters available, with variations in the type of collector (flat plate, batch, or evacuated tube) and system configuration (passive or active). The type of solar water heater specified should be based on considerations of climate, maintenance, and project budget.

Lighting, Appliances, and Plug Loads

Lighting, appliances, and all products that a home owner might plug into an electric socket account for 35% of annual energy use of a typical manufactured home (U.S. Department of Energy 2005). The most affordable high efficiency measure to pursue in this area is high efficacy lighting. Using compact fluorescent lighting in lieu of traditional incandescent lighting typically has a payback of less than a year, and can save up to 50%-75% of lighting energy use in a home (U.S. Department of Energy 2009f).

Energy Star appliances are at least 10% more efficient than standard appliances, with savings up to 70% possible in some product categories. Table 9-2, sourced from the EPA (U.S. Environmental Protection Agency 2008a), provides anticipated savings based on standard products. For instance, Energy Star clothes washers are advertised to reduce electricity use by 30% as well as reduce water consumption by 50%. Energy Star exhaust fans can be used to provide mechanical ventilation requirements for manufactured homes (may not be appropriate for hot-humid climates), while operating at very low noise ratings and up to 70% higher efficiencies than standard exhaust fans.

Energy Star Product	Average Energy Savings Above Standard Product
Lighting	
Compact fluorescent light bulbs and residential light fixtures	75%
Residential Appliances	
Room air conditioners	10%
Dehumidifiers	15%
Exhaust fans	70%
Ceiling fans	45%
Dishwashers	20%
Refrigerators	15%
Clothes washers	30%
Televisions	30%

Table 9-2: Energy Star products' energy savings over standard products.

Advanced Controls

Advanced controls for lighting and plug loads include whole-house switches, occupancy sensors, and wireless switches. Whole-house switches are convenient in that they can enable the home owner to shut off all nonessential circuits with one flick of a switch before leaving the home. HVAC, water heating, security systems, and kitchen and laundry appliances operate independently from whole-house switches to ensure that they can continue to operate as needed. By using a whole-house switch or plugging electronics into power strips that are switched off when not in use (sometimes called "smart strips"), home owners can reduce whole-house electricity use by up to 10% (Lawrence Berkeley National Laboratory 2009). Power strips that are also equipped with occupancy sensors are now available as well.

Manual-on, automatic-off occupancy sensors (also known as vacancy sensors) are used to turn lights or other items off when a room is unoccupied. Turning the devices on requires the occupant to manually turn the switch on. The potential savings using occupancy or vacancy sensors is highly dependent on the usage patterns of the home owner.

Similar sensors with an automatic-on feature can also provide additional health/safety benefits to residents in manufactured structures. For example, lighting controls that automatically turn on lights near a staircase can help young children or older residents navigate stairs more safely and prevent injuries.

Wireless switches are another advanced system that allows for very flexible on/off control of lighting and other plug loads. One or more switches can be programmed with very little wiring work (and no fishing of wires through walls or ceilings). Wireless controls can easily allow wheelchair-bound or shorter residents to have switches in convenient locations. They can also easily create three-way or four-way switches on lights that need to be controlled from multiple locations, like stairway lighting. Wireless switches can even be kept in a car, allowing residents to turn on an exterior or hall light as they enter the homes at night. By providing for such flexible control of lights and other plug loads, this technology lets the home adapt to resident needs and helps to improve safety and security.

Feedback Systems

The adage that "you can't manage what you don't measure" applies equally to residential energy loads. After scanning their monthly electricity or gas bill, home owners are typically left with little information on exactly how they consumed their energy. Studies have shown that energy savings of 5%-15% are possible with direct feedback systems that provide the home owner with real-time feedback on energy use in the home (Darby 2006). These feedback systems, sometimes referred to as dashboards, are able to provide information on such items as instantaneous whole-house electricity use, demand, and pricing; individual appliance electricity consumption; and even recommendations on ways to reduce energy consumption.

Water Conservation

Low-flow Toilets and Fixtures

Conserving water also conserves energy that would otherwise be used to treat and pump water to homes. Toilets account for approximately 30% of water used in a home and represent an excellent opportunity for water savings (U.S. Environmental Protection Agency 2008b). Federal regulations currently limit the volume of water used per flush to 1.6 gallons, and products are now available "with a water flushing device capable of adequately flushing and cleaning the bowl" (per HUD Code) that use far less water than this. Toilets with EPA's WaterSense label use 1.28 gallons per flush (gpf) or less, saving at least 25% of the water used per flush. WaterSense labeled dual flush toilets, which have a full volume flush for solids and a reduced volume flush for liquids, use 1.6 gpf or less at full volume and 1.1 gpf or less at reduced volume. Flushless urinals and flushless composting toilets are also available, but are prohibited by HUD Code, which requires water flushing devices be installed.

Low-flow devices can also be specified at sinks and shower heads. Water used in sinks accounts for about 15% of water used in a home, and faucets with the WaterSense label can reduce flow by 30% or more while delivering comparable performance (U.S. Environmental Protection Agency 2008c). Showers account for approximately 17% of indoor water use, and showerhead flow is capped by federal mandate at 2.5 gpm at 80 psi. The EPA is currently developing a specification for a WaterSense showerhead that will consider such input as consumer perception, safety, and performance while achieving lower flow rates. In the meantime, low-flow showerheads are available, as well as showerheads that slow to a trickle when hot water reaches them, assuring that no extra water is wasted as home owners wait for a shower to warm.

Plumbing Improvements: Centralized, Home Runs with Polyethylene (PEX)

Shortened plumbing runs save water and energy by reducing the amount of water wasted while waiting for hot water to arrive at the intended destination. Because of the relatively small footprint of manufactured homes, there are inherent water use efficiencies built into the homes. Today, cross-linked PEX tubing is specified in most manufactured homes, and the small cross-diameter of this tubing reduces the amount of water wasted in waiting for hot water to arrive. Where not common practice, central location of the water heater and specification of a central manifold with individual or "home" runs to each water fixture can further reduce water heating demands and water consumption.

Water Catchment

Recently, manufactured home designs have begun to incorporate water-catchment systems. For instance, a model green manufactured home collects rain water with a metal roof that is sloped from both ends to the center. Currently, water harvested from the catchment system can be used for meeting landscaping needs, but future modifications to the system could also enable the water to be used for flushing toilets.

Optimizing Indoor Air Quality and Mechanical Ventilation

Significant strides have been made to improve indoor air quality in manufactured homes. Changes have been made in the HUD Code to control pollutants at the source as well as to ensure that whole-house ventilation is provided to facilitate a healthy indoor environment. Providing good indoor air quality has been and will continue to be an iterative process as manufacturers and regulators respond to the evolving body of science on this topic as well as the introduction of new materials and consumer products that may compromise air quality.

Controlling Pollutants and Potential Problems at the Source

While HUD Code has a history of being proactive in addressing indoor air quality (e.g., incorporating regulations related to formaldehyde, requiring mechanical ventilation), further opportunities exist to go beyond code in providing a healthier indoor environment. By attention to detail during construction and careful selection of such items as building materials and adhesives, manufacturers can greatly influence indoor air quality of homes. Opportunities for improving indoor air quality that can be achieved during the manufacturing process include the following:

- Providing for passive radon mitigation systems (piping, presence of electrical outlet for a fan installation if necessary) in the built units. Radon mitigation, which is not covered in the HUD Code, is especially important for units on basements and/or units that will be situated in high radon areas. Appendix F of the International Residential Code has guidance on radon control methods.

- Ensuring that separation between exhaust terminations and ventilation intakes is at least 10 feet (minimum permitted by ASHRAE 62.2, which is more restrictive than HUD Code's 3-foot allowance)
- Location of tightly sealed ducts within conditioned space.
- Ensuring that composite wood products (including products used in floors, walls, and cabinets) conform to CARB standards, which are more stringent than HUD Code (Composite Panel Association 2008).
- Installing low- or no-VOC carpets.
- Using no-VOC paints for interior finish.
- Use of soy adhesives and resins as an alternative to urea-formaldehyde and phenol-formaldehyde adhesives.
- Avoiding interior vapor retarders in hot-humid climates.
- Following model building code prescriptions for flashing of building openings, intersections, and penetrations (e.g., 2009 IRC Section R703.8).

Optimizing Mechanical Ventilation

All HUD Code homes are required to specify mechanical ventilation systems, including whole-house, kitchen exhaust, and bathroom exhaust systems. While the ventilation specifications of the HUD Code are more progressive than those of most site-built building codes, there is still room for improvement. For example, HUD Code does not address the use of intermittent whole-house ventilation or permissible sound levels for ventilation equipment. Maintaining low sound levels for supply and exhaust fans increases the likelihood that occupants will not override the operation of specified mechanical ventilation systems.

Manufacturers that desire to provide indoor air quality in accordance with the latest consensus-based specifications may look to ASHRAE 62.2 for guidance on these and other indoor air quality concerns not addressed within HUD Code. ASHRAE 62.2 has now been adopted by reference in the state residential building codes of California and Maine and is also a prerequisite of the LEED for Homes green building rating system. Adoption of ASHRAE 62.2 is currently being considered by the Manufactured Housing Consensus Committee, which is responsible for maintaining and updating the HUD Code. It should be mentioned that while ASHRAE 62.2 provides a more thorough ventilation specification reference, its minimum ventilation rates can be lower than HUD Code rates, depending on the number of bedrooms and conditioned floor area. Assuming that outdoor air contains lower pollution concentrations than indoor air, higher ventilation rates should result in better air quality. A notable exception to this premise is when introduction of outdoor air increases the humidity level of the indoor air to levels that are conducive for condensation and mold growth.

While providing higher ventilation rates generally results in better indoor air quality, it can also carry a severe energy penalty associated with ventilation fan energy use as well as energy required to condition the outdoor air to indoor set points. Neither ASHRAE 62.2 nor the HUD Code address the energy use of ventilation equipment, which is an important consideration given that ventilation distribution systems alone can consume as much as 3100 kWh annually in manufactured homes (assuming 350-watt central blower operates continuously for ventilation distribution) (Lubliner et al. 2005). Manufacturers have multiple options for specifying energy efficient mechanical ventilation systems. If specifying a whole-house exhaust-based ventilation system, specification of Energy Star exhaust fans can be a very economical choice (e.g., payback of 1.2 years and savings of 580 kWh per year when operated continuously versus a builder-grade exhaust fan, assuming $0.11/kWh). "Smart" versions of this system ventilate only as much as needed to meet a certain target air exchange rate, and "take credit" for time periods when exhaust fans are run for bath exhaust too.

Specification of heat and energy recovery ventilators (HRVs and ERVs), which precondition outdoor air with exhausted indoor air before introducing it into the space, can provide another energy efficient option for mechanical ventilation. A recent DOE study used building energy simulations to show that total heating and cooling energy savings of HRVs over other mechanical ventilation systems in a cold climate manufactured home can range between 500 and 2000 kWh (Lubliner et al. 2005). The energy efficiency of central fan integrated systems, which introduce fresh outdoor air into the return plenum of the central duct system, can be improved by ensuring that the central fan is powered by an electronically commutating motor (ECM). An ECM operates at a higher efficiency than a traditional permanent split capacitor motor, offering up to 70% savings when operated continuously (Canada Mortgage and Housing Corporation 2005).

As mentioned above, mechanical ventilation for homes that undergo air sealing and lack sufficient natural ventilation is critical. Providing for outdoor air exchange with indoors can help control indoor humidity and exhaust airborne chemicals and pollutants. Fresh ventilation air is also filtered in many systems to remove dust and other particulates. These essential health/safety benefits of mechanical ventilation will only be realized, however, if the systems are allowed to run by the residents. Therefore, systems that are reasonably quiet and energy efficient to operate, as well as automated, are important for occupant health and safety.

DESIGNING FOR DURABILITY AND DISASTER

Manufactured homes, park trailers, and travel trailers are often used to provide emergency and short-term housing in the wake of natural disasters that have destroyed or damaged housing units. Because manufactured homes and trailers are sited in areas where natural disasters occur, it is prudent to ensure that their construction is sufficient to withstand the recurrence of the natural disasters, within reason. HUD Code and state regulations have responded to natural disasters by increasing their stringency, with favorable results (Grosskopf and Cutlip 2006). Nevertheless, opportunities still exist for improving the durability and disaster resistance of manufactured homes, and thereby improving occupant health and safety.

Floods

Protecting Manufactured Homes from Floods and Other Hazards (Federal Emergency Management Agency 2009), provides guidance for installation of manufactured homes in flood hazard areas. This resource may be supplemented by state-specific requirements, and provides foundation specifications that will help in avoiding a complete structural loss from flooding. In addition to thoughtful siting and providing an adequate foundation to resist flood forces, manufactured homes can be built with flood-resistant materials that will permit them to weather flood events more successfully. When building for flood resistance, assemblies and materials should be selected that can withstand water immersion, do not provide a food source for mold, and dry easily. For example, a wall assembly consisting of the following materials (in order from exterior to interior) would serve this purpose (Louisiana State University Agricultural Center 2008a):

- Cladding: vinyl or fiber cement siding, furred out from sub layers.
- Insulation: rigid foam insulation.
- Building wrap.
- Sheathing: non-paper-faced gypsum.
- Framing: steel studs with empty cavity that can be opened at top and bottom to allow drying.
- Interior finish: non-paper-faced gypsum and latex paint.

Similarly, the insulation, structure, and finishes of the floor system may be selected to permit faster drying and decrease the chance of permanent damage from flooding events. Placing ducts in conditioned space instead of the underbelly of the manufactured home should also permit a faster and less costly recovery from flood damage. Locating ducts in the conditioned envelope also helps keep them free of pests, which aids in maintaining a healthy indoor environment.

Termites

Inspections of manufactured homes after the Florida hurricanes of 2004 revealed that many of the damaged homes had sustained termite damage and wood rot that compromised their structural integrity (Jordan 2004). When locating a manufactured home in a location with high termite pressure (generally coincident with hot-humid climates), specification of termite-resistant materials for structural framing and sheathing is a good choice. In fact, Hawaii now requires that termite-resistant materials (e.g., light-gauge steel framing, pressure-treated lumber, or masonry) are used for all structural members in site-built homes.

Insulation materials treated with borates (which are nontoxic to humans) are now available that provide further termite resistance in the walls. If a borate-treated rigid foam insulation is specified for the flood resistant wall described previously, this wall would also function as a termite-resistant assembly.

Termites thrive in warm, moist conditions where a cellulosic food source is available. Removal of cellulosic debris from around the foundation will minimize food sources. Ensuring that foundations stay dry by addressing any plumbing leaks and installing gutters and drain spout extensions of at least three feet in length can help to remove sources of moisture. Regular inspection is also an important component of combating termites.

In terms of health/safety benefits of these termite prevention measures, keeping the home's structure intact is the main benefit. Preventing termites from compromising the home's structural integrity is crucial for the home to withstand strong external forces (e.g., hurricanes) and keep the residents safe.

High Winds

Changes made to the HUD Code in 1994 greatly increased the wind resistance of manufactured homes. A survey of over 4,000 manufactured homes built after 1994 that were also in the path of the 2004 Florida hurricanes (Charley, Frances, Ivan, and Jeanne) revealed that none of these homes were “seriously damaged.” Additionally, the performance of some of these units was likely enhanced by the manufactured home installation requirements of Florida’s Administrative Code Chapter 15C-1 (Florida Department of Highway Safety and Motor Vehicles, undated). Manufactured homes built prior to 1994 will likely require retrofitting of uplift-resistant hardware and other wind-resistant measures to provide acceptable performance in high wind events. Manufactured homes built prior to the HUD Code have a poor performance record in high wind events.

Several opportunities exist in going beyond code requirements to enhance the performance of manufactured homes during high wind events. These performance enhancements address not only strength of the structure, but also resistance to intrusion of wind-driven rain, which can result in a total loss of the home even if the structure remains intact. Opportunities include the following:

- Following the prescriptive requirements of the Institute for Building and Home Safety’s “Fortified …for safer living” specifications for hurricane, high-wind, tornado, and hail hazards (Institute for Business and Home Safety 2009). Modular homes have been certified under this program, but no manufactured homes have been certified to date.
- Specification of roofing, windows, doors, vents, and cladding that is approved for high wind events (e.g., Miami-Dade County approved) (Miami Dade Building Code Compliance Office 2009).
- Install a sealed, conditioned roof in a hot-humid climate. The lack of soffit and eave vents will keep out wind-driven rain and can improve the energy performance of the home.
- Ensure that any carport, shed, awning, or other addition is rated for high wind events. A survey of manufactured homes after the 2004 hurricane season showed that up to 75% of these structures were destroyed in storms and were often turned into projectiles by the winds.
- Attach roof sheathing with ring shank nails for greater resistance to uplift, at 3 inches to 6 inches on center
- Seal roof sheathing joints with roofing tape or apply a peel and stick membrane underlayment over the entire roof (Louisiana State University Agricultural Center 2008b).

Further guidance for increasing the wind resistance of homes can be found from sources such as the Institute for Building and Home Safety (http://www.ibhs.org) and the Louisiana State University Agricultural Center (http://www.lsuagcenter.com/en/family_home/home/la_house/index.htm).

Hardening a manufactured home against high wind events carries multiple health/safety benefits for residents. Foremost, the residents are more likely to be kept safe inside the structure during high wind events. This provides an immediate safety benefit through reduced likelihood of structural failure, windborne debris, etc. Secondly, by making homes more resistant to water intrusion during storms, residents are less likely to live in a postflooding living environment, which is typically characterized by respiratory hazards such as mold, rodents, and dust mites. All of these hazards can trigger asthma episodes and create respiratory irritation. Finally, a home that can withstand high wind events will help residents financially (allowing more resources for health care and wellness) and also reduce the likelihood of being displaced by a disaster (and the associated mental and physical stresses).

Fire

More than 17,000 fires in manufactured homes result in the death of approximately 300 Americans on an annual basis (U.S. Fire Administration 2006a). Prevention, detection, and suppression of fire are all important components of a holistic fire safety approach for manufactured homes.

Prevention

Electrical distribution fires accounted for 23% of the fire damage in HUD Code homes from 1989-1998, the largest share reported (Hall 2005). HUD Code requires ground fault circuit interrupters for many outlets within manufactured homes. Although these units can limit the number of fires, their primary function is to protect against shock and electrocution. By interrupting current supply when there is an unintentional jump of current, arc fault circuit interrupters (AFCIs) can be much more effective at preventing fires. Since 1999, the National Electric Code has required AFCIs for circuits serving bedrooms, and by 2008, the list of required rooms expanded to virtually every other room in the home.

Besides installing AFCIs, the fire safety of manufactured homes can be improved by specifying materials with a low in-class flame spread index. In wildfire-prone areas, sealed and conditioned attics and noncombustible roofing and siding can also improve the fire resistance of manufactured homes.

Detection

Installing hard-wired smoke alarms with battery backup can provide a greater margin of safety for manufactured home occupants. Carbon monoxide sensors are required in the 2009 IRC and are now required by some states and municipalities to be installed in new and existing site-built and manufactured homes at the point of sale or resale (Colorado House 2009). The Consumer Product Safety Commission recommends that at least one carbon monoxide sensor be installed in the hallway immediately adjacent to each separate sleeping area in the home. Occupants of trailers and manufactured homes with generators, attached garages, gas-fired furnaces, and other forms of combustion equipment, would be provided with a greater margin of combustion safety by the installation of carbon monoxide sensors.

Suppression

Sprinkler systems are now a requirement for all site-built homes under the 2009 IRC. This requirement is expected to provide both home occupants and first responders with increased safety in the event of a fire. In fact, the U.S. Fire Administration claims that installation of fire sprinklers alone in a residence reduce the chances of death by fire in that residence by 69%. When installed in conjunction with smoke alarms, the risk of death by fire in the residence is decreased by 82% (U.S. Fire Administration 2008).

Installation of sprinkler systems is addressed in NFPA 13D, Standard for the Installation of Sprinkler Systems in One- and Two-Family Dwellings and Manufactured Homes (National Fire Protection Association 2010). Independently operating sprinklers can be used if a municipal water supply or an on-site tank (at least 100 gallons) and pump are available (U.S. Fire Administration 2006b). Affordability of sprinkler systems is expected to continue to improve as they become more common place. A recent study found that the average cost for residential sprinkler systems was $1.61 per sprinklered square foot, with costs as low as $0.38 per sprinklered square foot (National Fire Protection Association 2008). Regardless of costs, the life safety benefit of these systems provides a strong argument for their specification.

All of these opportunities in fire prevention, detection, and suppression serve to directly keep manufactured home residents safer from fire risks in their home. In addition, reducing the likelihood of a fire in a manufactured structure also carries other health/safety-related benefits beyond lower risk of fire-related injury or death. For instance, lower risk of fire in a home also means a lower risk of the financial burden that is experienced by residents of a home where a fire occurs. Avoiding this financial burden allows more resources for health care and wellness. Lower fire risk also means lower risk of residents being displaced from their homes, along with the health stresses created by such displacement.

EVALUATING NEW TECHNOLOGIES FOR HEALTH/SAFETY

Many consequences of changes to home building have occurred in an unexpected manner in the past, where the implications of a new method or technology would gradually become apparent after many homes had undergone the change. Under this mode of technology development, unfortunately, many residents could be subject to health/safety risks until the implications of a change are fully understood. Having learned from these lessons, the manufactured housing industry today can take more proactive approaches to fully understanding all the implications of making a change to construction methods or materials.

U.S. DOE Building America Program

Research, development, and demonstration programs such as U.S. DOE's Building America program (http://www.buildingamerica.gov) offer an excellent opportunity to evaluate new methods/materials. Programs like Building America involve builders, product manufacturers, building code officials, contractors, and others who collectively will evaluate a new system from many different perspectives such as constructability, IAQ implications, and impacts on the home's ability to manage moisture. A key benefit of research of this type is that it evaluates systems in ways which are not possible in lab settings. Items like impacts on other building systems and constructability are evaluated, for example.

Further, the researchers under this program will actively test and evaluate new systems to characterize their performance. New materials/techniques, or even commercialized products that may not be ready for large-scale market introduction yet, benefit greatly from participation in credible research and development programs of this nature. It is also worth noting that DOE's Building America program has a distinct set of projects that focus on manufactured housing.

Green and Sustainability Ratings and Programs

Rating the energy and environmental performance of particular building products or systems is typically a complex exercise. However, given the steady increase in emphasis on such evaluations, more rating criteria are being developed and the credibility and usefulness of ratings is steadily growing. For example, the Green Spec Product Guide provides descriptions for over 2,000 environmentally preferable products (Building Green 2010). These products are evaluated for numerous criteria depending on the product type, with established controls to limit manufacturer influence in the process.

At the whole-house level, green/sustainable building programs represent a type of proving ground for many emerging practices and technologies. Programs such as LEED for Homes (http://www.usgbc.org) and the National Green Building Standard (http://www.nahbgreen.org) incorporate the viewpoints from a wide group of stakeholders connected with construction, technology, and codes/standards/safety. The current versions of residential rating programs under these and similar programs reference numerous product and design specifications in areas such an indoor environmental quality. Thus, such programs can be looked at as potential models or sources for new/emerging products. They can also serve as sources to identify products that are not viewed as green (e.g., LEED prohibits unvented combustion appliances under its Indoor Environmental Quality section).

Given the regular updating of these standards/rating systems, they also reflect changes in the industry as new research is performed and new technologies and issues develop.

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