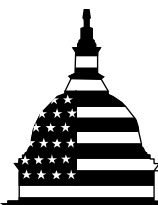


October 2012

# MANUFACTURED HOUSING STANDARDS

## Testing and Performance Evaluation Could Better Ensure Safe Indoor Air Quality



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## Why GAO Did This Study

Since 1976, HUD has been responsible for developing construction and safety standards (the HUD Code) for manufactured homes. Concerns have been raised by Congress and others about existing HUD code requirements that are intended to ensure proper indoor air quality, including protecting occupants from potential carbon monoxide exposure. As requested, GAO examined 1) existing standards for separating air intakes and exhaust vents in both manufactured and site-built homes; 2) reasons for differences in ventilation standards for manufactured and site-built homes; and 3) the number of manufactured homes built, the distances between their air intakes and exhaust vents, and the performance of their ventilation systems. GAO reviewed documentation from HUD and building standards organizations to determine differences in requirements tied to ventilation and air quality, reviewed the rulemaking process and status of proposed updates to manufactured housing standards related to ventilation and air quality, analyzed data on the occupancy of manufactured houses subject to HUD's standards, assessed HUD's efforts to ensure compliance with certain standards, and interviewed agency officials and indoor air quality experts.

## What GAO Recommends

GAO recommends that HUD test the performance of installed ventilation systems and reassess its ventilation standards. HUD generally agreed with both recommendations and stated that it would bring them before the MHCC for consideration.

View [GAO-13-52](#). For more information, contact Mathew J. Scire` at (202) 512-8678 or [sciremj@gao.gov](mailto:sciremj@gao.gov).

# MANUFACTURED HOUSING STANDARDS

## Testing and Performance Evaluation Could Better Ensure Safe Indoor Air Quality

## What GAO Found

Key standards for manufactured homes provide a lower margin of safety against a carbon monoxide exposure incident than those for site-built homes, which are constructed at their permanent locations. For instance, the Department of Housing and Urban Development (HUD) Code requires a minimum 3-foot separation between air intakes and exhaust vents, while industry standards for site-built homes have required a greater distance for many years. The industry standards call for a greater separation between air intakes and exhaust vents to help reduce the risk that contaminants such as carbon monoxide will re-enter the home. Indoor air quality experts whom GAO interviewed stated that the exhaust of an improperly operating furnace combined with unique wind conditions could, in rare cases, present a risk of carbon monoxide exposure. GAO analysis shows that increasing the separation between an air intake and exhaust vents, using industry standards, can significantly dilute concentrations of contaminants.

The primary reason for the differences in ventilation standards for manufactured homes and site-built homes is the HUD Code has not been updated since 2005 and has not kept pace with standards tied to ventilation and air quality for site-built homes. For example, updates to standards for site-built homes made in 2003 requiring a greater separation between intakes and exhaust vents are only now being considered by HUD for manufactured homes. This update was recommended to HUD in 2010 by the Manufactured Housing Consensus Committee (MHCC), which is responsible for recommending proposed rule changes to HUD. Similarly, requirements for carbon monoxide detectors adopted in industry standards for site-built homes and recommended by the MHCC in 2009 have yet to be incorporated in the HUD Code. HUD did publish a proposed rule in the *Federal Register* in 2010 to update aspects of the HUD Code but has not issued a final rule because the rulemaking process is ongoing. Additional proposals, including the two above related to indoor air quality, are under consideration by HUD, but have not yet been published as proposed rules.

An estimated 5.5 million occupied manufactured homes were built under the HUD Code, according to 2009 American Housing Survey data. Although HUD retains copies of approved designs of manufactured homes, the agency does not maintain data on the actual distances between the air intakes and exhaust vents of each home. Further, once ventilation systems are installed in manufactured homes, HUD does not require manufacturers to test their performance. For example, manufacturers are not required to determine if the systems meet the requirements for the whole-house ventilation airflow rate, which quantifies the volume of air exchanged in the home over time. Without performance testing of the installed ventilation systems, HUD cannot fully ensure that the systems installed in manufactured homes are meeting performance specifications. In addition, HUD's standard for the whole-house airflow rate provided by mechanical ventilation was initially established assuming a certain level of natural air infiltration. This whole-house airflow rate standard has not changed since 1993. Air quality experts and research suggest that homes are increasingly being built with less air leakage, reducing the expected level of natural air infiltration. However, HUD has not reassessed the whole-house ventilation airflow rate standard to determine whether it continues to be sufficient to assure adequate air quality.

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# Contents

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Letter		1
	Scope and Methodology	2
	Background	3
	Ventilation and Air Quality Standards Differ between Manufactured and Site-Built Homes	7
	Updates to the HUD Code on Key Standards Related to Ventilation and Air Quality Lag behind Industry Standards for Site-Built Homes	11
	Millions of Manufactured Homes Have Been Built under the HUD Code but HUD Has Not Tested the Performance of Installed Ventilation Systems	15
	Conclusions	18
	Recommendations for Executive Action	20
	Agency Comments and Our Evaluation	20
Appendix I	Comparison of Different Separation Distances Between Air Intakes and Exhaust Vents and Impacts on Potential Carbon Monoxide Exposure	23
Appendix II	Comments from the Department of Housing and Urban Development	27
Appendix III	GAO Contact and Staff Acknowledgements	29
Table		
	Table 1: Parameters Used in Our Analysis	25
Figures		
	Figure 1: HUD Label	5
	Figure 2: HUD Code's Separation Requirement for Fresh Air Intakes and Exhaust Vents, 2012	7
	Figure 3: Air Intake Contaminant Concentration at Different Wind Speeds for Various Exhaust Vent to Air Intake Separations	9
	Figure 4: GAO Analysis of HUD Processes for Updating the HUD Code	12

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Figure 5: Contaminant Concentration at Air Intake for Different  
Wind Speeds and Various Exhaust Vent to Air Intake  
Separations

26

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United States Government Accountability Office  
Washington, DC 20548

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October 24, 2012

The Honorable James P. Moran  
Ranking Member  
Subcommittee on Interior, Environment, and Related Agencies  
Committee on Appropriations  
House of Representatives

The Honorable John W. Olver  
Ranking Member  
Subcommittee on Transportation, Housing, and Urban Development,  
and Related Agencies  
Committee on Appropriations  
House of Representatives

The Department of Housing and Urban Development (HUD) certified manufactured homes offer a lower-cost option to traditional site-built homes. In 2010, an estimated 18 million individuals lived in manufactured homes, which are defined as transportable structures of at least 320 square feet built on permanent chassis structures.<sup>1</sup> Since 1976, all manufactured homes (formerly called “mobile homes”) have been required to meet HUD’s Manufactured Home Construction and Safety Standards (the HUD Code), the only building code that preempts state and local building codes. The HUD Code covers body and frame requirements, thermal protection, plumbing, electrical, ventilation, and other aspects of the home. Every home built to the HUD Code is identified with a red metal tag, known as the HUD certification label.

In your request, you raised concerns that the HUD Code’s ventilation standards, particularly the separation distance between fresh air intakes and exhaust vents that is intended to assure that contaminants do not reenter a home, may not be keeping pace with standards for site-built homes. For this review, we examined 1) existing standards for separating air intakes and exhaust vents in both manufactured and site-built homes; 2) reasons for differences in ventilation standards for manufactured and site-built homes; and 3) the number of HUD manufactured homes built,

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<sup>1</sup>This estimate is from the U.S. Census Bureau’s 2010 American Community Survey (ACS). The margins of error for these estimates are +/- 87,000.

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including the distances between their air intakes and exhaust vents, and the performance of their ventilation systems.

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## Scope and Methodology

To examine standards associated with the separation distance between air intakes and exhaust vents in homes, we collected and analyzed information on existing standards for home ventilation systems. Specifically, we collected and analyzed documentary information on construction and safety standards for manufactured homes and interviewed representatives from HUD to ascertain how such standards were developed. Likewise, we collected information on commonly-accepted industry standards for site-built homes and the evolution of those standards. We also interviewed subject area experts performing research on ventilation and air quality issues for manufactured homes to understand factors affecting the indoor air quality of manufactured and site-built homes. Further, we contacted state administrative agency officials in 5 of the 37 states that administer manufactured housing consumer programs for information on indoor air quality complaints. We chose administrative agencies in New York, Pennsylvania, Tennessee and Texas based on different climate zones and numbers of placed manufactured homes. We added Utah because carbon monoxide poisoning had allegedly occurred in a manufactured home. We selected states with relatively high numbers of manufactured homes, using data from the Census Bureau's 2010 Manufactured Homes Survey. Additionally, we compared different separation distances between air intakes and exhaust vents and the potential for carbon monoxide exposure using modeling methods from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). Appendix I contains a more detailed description of our comparison.

To assess the rationale for having different ventilation standards for manufactured and site-built homes, we collected documentary information and contacted officials from HUD, industry associations, and organizations that set building standards. Specifically, we identified the reasons behind the differences in ventilation standards for manufactured versus site-built homes, the evolution of these standards over time, and the current status of new or revised standards that have been proposed for manufactured homes.

To determine the number of manufactured homes that have been built to HUD standards, we analyzed U.S. Census Bureau estimates on the number of occupied manufactured homes built since 1975 and relevant characteristics of the homes. We assessed the reliability of the Census

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Bureau's 2009 American Housing Survey and 2010 American Community Survey by reviewing information on the data and interviewing knowledgeable officials on the quality of the data. We determined the data were sufficiently reliable for the purposes of this report. To identify and obtain available data on the design and performance of ventilation systems in manufactured homes, we sought information from HUD on the distances between intake and exhaust vents and the performance of the ventilation systems. We also contacted officials from industry associations, researchers, and companies in the manufactured home industry to identify common design and performance specifications that they used for manufactured homes. Further, we collected information from organizations that conduct testing and certify ventilation systems for manufactured homes.

We conducted this performance audit from December 2011 through October 2012 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

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## Background

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### HUD Oversight and Standards for Manufactured Homes

HUD is responsible for enforcing the federal manufactured home construction and safety standards that it established under The National Manufactured Housing Construction and Safety Standards Act of 1974.<sup>2</sup> The act authorized HUD to develop construction and safety standards for manufactured homes and to oversee the enforcement of the standards through inspections and review of building plans. HUD developed the Manufactured Housing Construction and Safety Standards, commonly known as the HUD Code, basing them in substantial part on the National

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<sup>2</sup>Pub. L. No. 93-383, Title VI.

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Fire Protection Association (NFPA) standards for manufactured homes (NFPA 501).<sup>3</sup> The HUD Code was implemented in 1976.<sup>4</sup>

Because a manufactured home can be moved from one state to another, the HUD Code is applied nationwide and preempts state and local codes. As a result, state and local building authorities may not apply their own codes to manufactured homes for components covered by the HUD Code, such as ventilation systems. Unlike site-built homes, which are constructed at their permanent locations, manufactured homes are constructed in factories and must have a permanent chassis so that they can be moved on wheels to retailers or consumers in different states and localities, where they are placed on temporary or permanent foundations. Manufactured homes differ from modular homes, which are another type of prefabricated home and are often designed and constructed by the same manufacturers that construct manufactured homes. Like site-built homes, modular homes are built to state and local building codes. But unlike manufactured homes that are required to be moved to the site and remain on wheeled chassis, modular home sections or modules are transported on truck beds and assembled on site.

The 1974 act was amended by the Manufactured Housing Improvement Act of 2000 to create a balanced consensus process for establishing and revising manufactured home building standards.<sup>5</sup> The amendment established the Manufactured Housing Consensus Committee (MHCC), a federal advisory committee established to provide recommendations to the HUD Secretary on new standards and revisions of current standards.

The MHCC consists of voting members representing seven producers or retailers of manufactured housing; seven representatives of consumer interests, such as owners of manufactured homes; and seven general interest and public official members. In addition to construction and safety standards, the MHCC also develops proposed model installation

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<sup>3</sup>NFPA is a nonprofit organization that focuses on the prevention of fire and other hazards through codes and standards, research, training, and education. First published in 1940, NFPA 501 Standard for Manufactured Housing establishes minimum criteria for manufactured homes and is updated periodically. The NFPA has a HUD contract to provide administrative, managerial, and technical support to the MHCC.

<sup>4</sup>24 C.F.R. Part 3280.

<sup>5</sup>Pub. L. No. 106-569, Title VI.



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standards for the manufactured housing industry. Two-thirds of MHCC members must approve a proposal before the committee recommends it to HUD.

As part of the oversight of manufactured homes, HUD approves certain state agencies and private third-party entities to inspect manufactured housing plants and determine whether manufacturers are complying with the HUD Code. Each manufacturer contracts with two types of third-party entities, a Design Approval Primary Inspection Agency (DAPIA) and In-plant Production Primary Inspection Agency (IPIA). DAPIAs review and approve all home designs, design changes, and each plant's quality assurance manuals. To ensure that homes comply with the HUD Code, manufacturers contract with IPIAs to approve and monitor their quality control programs by inspecting each home at some stage of production in the plant. IPIAs issue the HUD label that is attached to each section of the home upon completion (see fig. 1).

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**Figure 1: HUD Label**



Source: HUD.

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## Ventilation Standards Used for Manufactured Homes

Builders of manufactured homes, as well as site-built and modular homes, are designing more tightly constructed homes that have less natural air infiltration in order to reduce energy costs for consumers. Without proper ventilation, a home's occupants may be exposed to a buildup of harmful contaminants, such as carbon monoxide,

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**Federal Efforts to Improve Indoor Air Quality**



**HUD's Healthy Homes Program**

Promotes research, assessment and intervention methods, and public education of housing-related health hazards, such as mold, dampness, and poor indoor air quality.



**Department of Energy's Indoor Air Quality Project**

Aims to reduce ventilation energy demands without compromising indoor air quality, improve ventilation standards, and enable energy-efficient building practices.



**Environmental Protection Agency**

Regulates toxic chemicals and promotes healthy indoor air quality in homes, schools, and large buildings.



**Centers for Disease Control**

Promotes public health in homes, schools, and workplaces and monitors carbon monoxide-related illness and death.



**Consumer Product Safety Commission**

Works to ensure the safety of consumer products, including furnaces and carbon monoxide detectors, through voluntary and mandatory standards, recalling products, and researching potential product hazards.



**National Institute of Standards and Standards**

Researches indoor air quality in buildings, including the ventilation of manufactured homes.



**Occupational Safety and Health Administration**

Publishes guidance on indoor air quality in commercial and institutional buildings.

formaldehyde, and mold.<sup>6</sup> In addition to the HUD Code, multiple federal agencies have an interest in and have made efforts to improve indoor air quality in buildings.

To prevent indoor contamination and compensate for less natural air in manufactured homes, the HUD Code requires a whole-house ventilation system consisting of either mechanical ventilation or systems combining mechanical and passive ventilation.<sup>7</sup> Mechanical ventilation uses fans and ducts to bring fresh air into the home or draw contaminated air to the outdoors. Passive ventilation takes place naturally through windows, doors, and other air leakage sites. One common mechanical ventilation approach uses an outdoor air intake that is connected to the air distribution system return duct and that carries fresh air into the home whenever the furnace fan operates. Another approach uses a whole-house exhaust fan, which draws contaminants from the home to the outdoors. In both cases, the system releases air to the outdoors through an exhaust vent, preventing the build-up of contaminants indoors. Although mechanical ventilation is becoming more common, most older site-built homes have relied on passive ventilation.

To help ensure that contaminants that accumulate indoors are adequately vented out of the home and replaced with fresh outside air, the HUD Code requires a certain whole-house ventilation airflow rate. This rate specifies the volume of air that should be "replaced" over time—that is, fresh air drawn into the ventilation system as contaminated air is expelled. HUD requires an airflow rate of least 0.035 cubic feet per minute for each square foot of interior floor space or its hourly average equivalent. The ventilation system is required to produce between 50 and 90 cubic feet per minute to achieve this whole-house airflow rate.<sup>8</sup>

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<sup>6</sup>Carbon monoxide is particularly hazardous because it is colorless, odorless, and tasteless. According to Centers for Disease Control (CDC) estimates, from 1999 to 2004 an average of 439 persons died annually from unintentional, non-fire-related carbon monoxide poisoning. CDC estimates from 2000 to 2009 show that about 78 percent (53,039) of carbon monoxide exposure-related incidents occurred in the home.

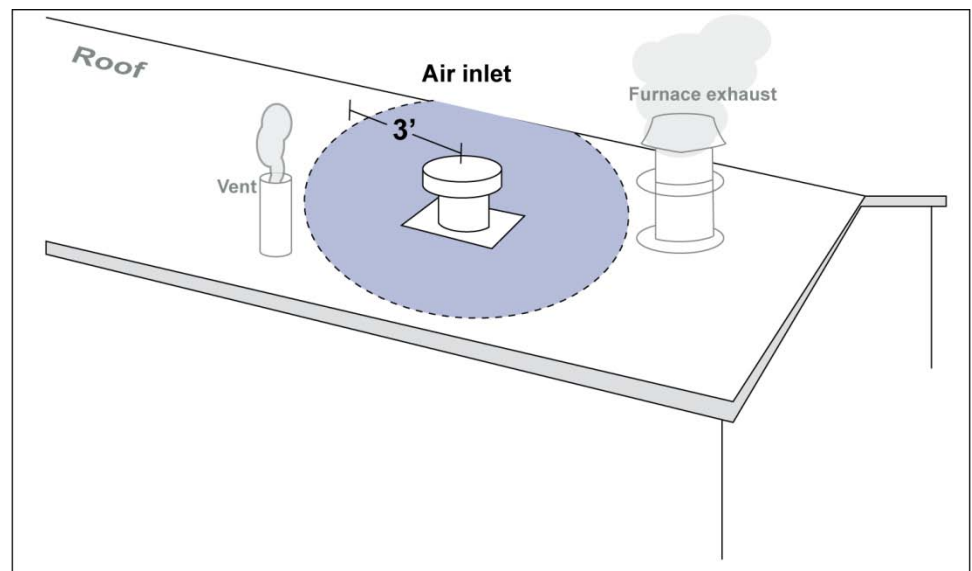
<sup>7</sup>24 C.F.R. § 3280.103(b)

<sup>8</sup>24 C.F.R. § 3280.103(b).

## Ventilation and Air Quality Standards Differ between Manufactured and Site-Built Homes

Standards exist for separating air intakes and exhaust vents in both manufactured and site-built homes, but standards for the two types of homes differ. Since 1976, HUD's ventilation system specifications for manufactured homes have required that any fresh air intake be at least 3 feet from any exhaust vent—for example, from a gas furnace exhaust or plumbing system vent. (See fig. 2.)

**Figure 2: HUD Code's Separation Requirement for Fresh Air Intakes and Exhaust Vents, 2012**



Source: GAO.

Compared with the HUD Code, industry standards commonly used for site-built homes recommend a greater distance between air intakes and exhaust vents. State and local building codes commonly cite generally accepted ventilation standards from ASHRAE and the International Residential Code (IRC). Specifically, ASHRAE requires a 10-foot horizontal separation between any air intake and exhaust vent. Additionally, IRC requires either a 10-foot horizontal separation or a minimum vertical separation of 3 feet if the horizontal separation is less than 10 feet.

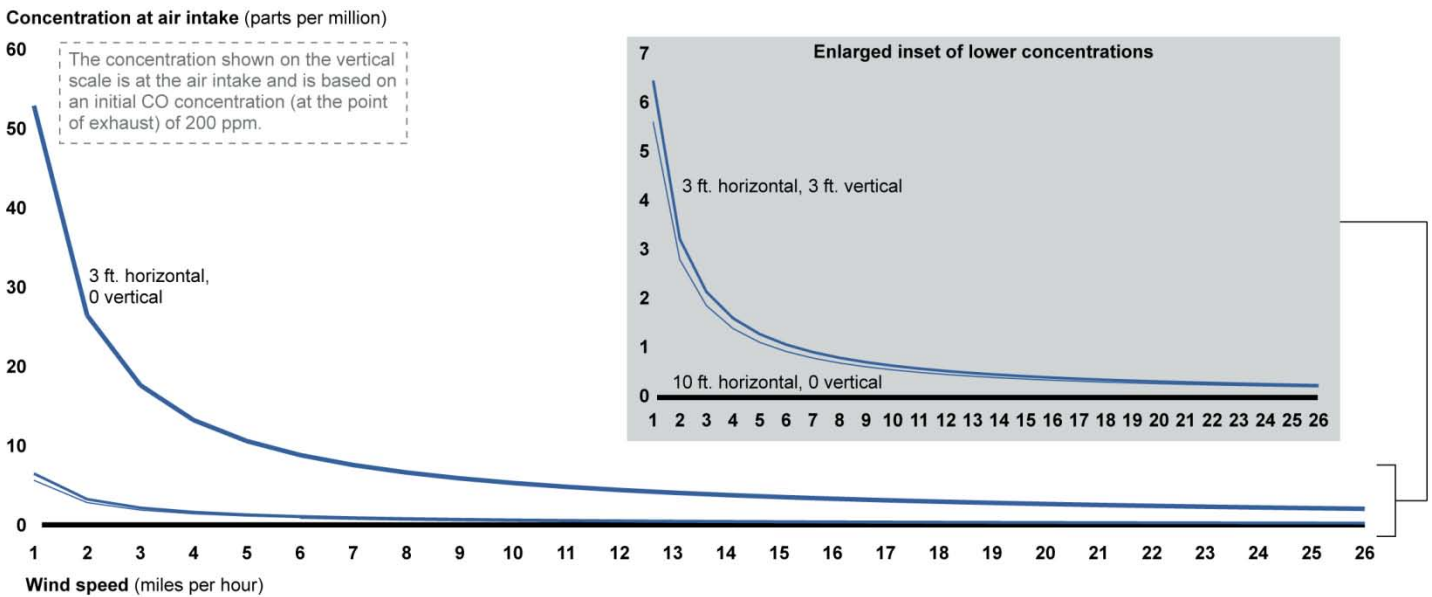
Industry standards that address the separation distance between air intakes and exhaust vents were created to reduce the possibility that contaminants in the exhaust, such as carbon monoxide, would reenter the building. Experts associated with testing and establishing ventilation

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standards said that increasing the distance between the air intakes and exhaust vents would improve the margin of safety, making it less likely that contaminants, such as carbon monoxide, could reenter the home. Experts explained, however, that such an event would occur rarely and would require a combination of several factors. They noted that the exhaust of a properly functioning furnace would contain relatively low levels of carbon monoxide (e.g. less than 4 parts per million (ppm)). They also noted an improperly functioning furnace, however, could produce hazardous carbon monoxide levels that, coupled with unique wind conditions, could result in carbon monoxide gas reentering a home through a fresh air intake. Because carbon monoxide is produced by incomplete combustion in fuel-burning devices such as gas furnaces, contamination is most likely in homes utilizing combustible fuels for heating and with an outdoor air intake connected to the air distribution duct system.

Our analysis of scenarios involving the dispersion of exhaust containing carbon monoxide demonstrated that the contaminant was less likely to reenter a building when the separation distance between an air intake and exhaust vent was increased. Using calculations recommended by ASHRAE, we quantified the difference in contaminant concentrations at the air intake as a function of wind speeds for various exhaust vent to air intake separations. As shown in figure 3, across a range of wind speeds, contaminant concentrations at air intakes placed either 10 feet horizontally or 3 feet horizontally and 3 feet vertically from an exhaust vent are less than contaminant concentrations that would be expected at an air intake separated just 3 feet horizontally (HUD Code requirement) from an exhaust vent. The figure also shows that the effect of separation distance on concentration levels is particularly evident at low wind speeds. For example, in a light 1 mph wind, exhaust with a carbon monoxide concentration of 200 parts per million (ppm) would be diluted to approximately 50 ppm at an air intake separated 3 feet horizontally from the exhaust vent. Increasing the separation between the exhaust vent and air intake to either 10 feet horizontally or 3 feet horizontally and 3 feet vertically in a 1 mph wind results in carbon monoxide concentrations of less than 10 ppm at the air intake.

**Figure 3: Air Intake Contaminant Concentration at Different Wind Speds for Various Exhaust Vent to Air Intake Separations**



Source: GAO analysis based on the ASHRAE Handbook of Fundamentals.

Note: The lines shown in the figure were generated using an exhaust-to-intake dilution calculation, based on recommendations from ASHRAE members, with parameters typically found in manufactured housing. Among the parameters used in our scenario, we assumed a capped exhaust vent with a diameter of 4 inches, which emitted exhaust at a speed of 1000 feet per minute, and which contained a CO concentration of 200 parts per million (ppm). The dilution levels determined by use of the calculation will vary based on changing these and other parameters. See Appendix I for a more detailed discussion of our use of the ASHRAE dilution equations.

These results were consistent with statements made by indoor air quality experts that increasing the distance between air intakes and exhaust vents reduces the concentration of contaminants such as carbon monoxide from reentering a home.

Concerns about the risk of carbon monoxide reentering the fresh air intake of a manufactured home were presented to the MHCC in July 2009, including an explanation of the differences between current industry standards and the HUD Code. That is, the MHCC viewed a presentation prepared by an individual who claimed an incident of carbon monoxide reentering a home built to the existing HUD Code requiring a separation distance of 3 feet.

HUD officials told us that the agency, in its oversight capacity for the Manufactured Housing Program, had not received any reports, other than the incident described above, either directly or from state administrative

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agencies, on cases of carbon monoxide reentering manufactured homes through fresh air intakes. We also contacted several state administrative agencies in the five states we reviewed, all of which stated that they had not received reports from consumers of any incidents of carbon monoxide reentering a home through a fresh air intake. HUD has not conducted or sponsored research to determine an appropriate separation distance between the fresh air intakes and exhaust vents since the HUD Code was established in 1976, according to HUD officials. However, HUD has sponsored research related to whole-house ventilation that discusses airflow rate issues.

Industry standards also call for carbon monoxide detectors in all site-built and modular homes. These detectors are not intended to be used as a measure of, or to test for, adequate indoor air quality but are a safety device to warn occupants in the event of a dangerous build-up of carbon monoxide gasses in the air. IRC and ASHRAE have required carbon monoxide detectors for residential site-built and modular homes since 2009 and 2010, respectively. While the MHCC has recommended this standard be required for all new manufactured homes, it is not yet a requirement in the HUD Code.

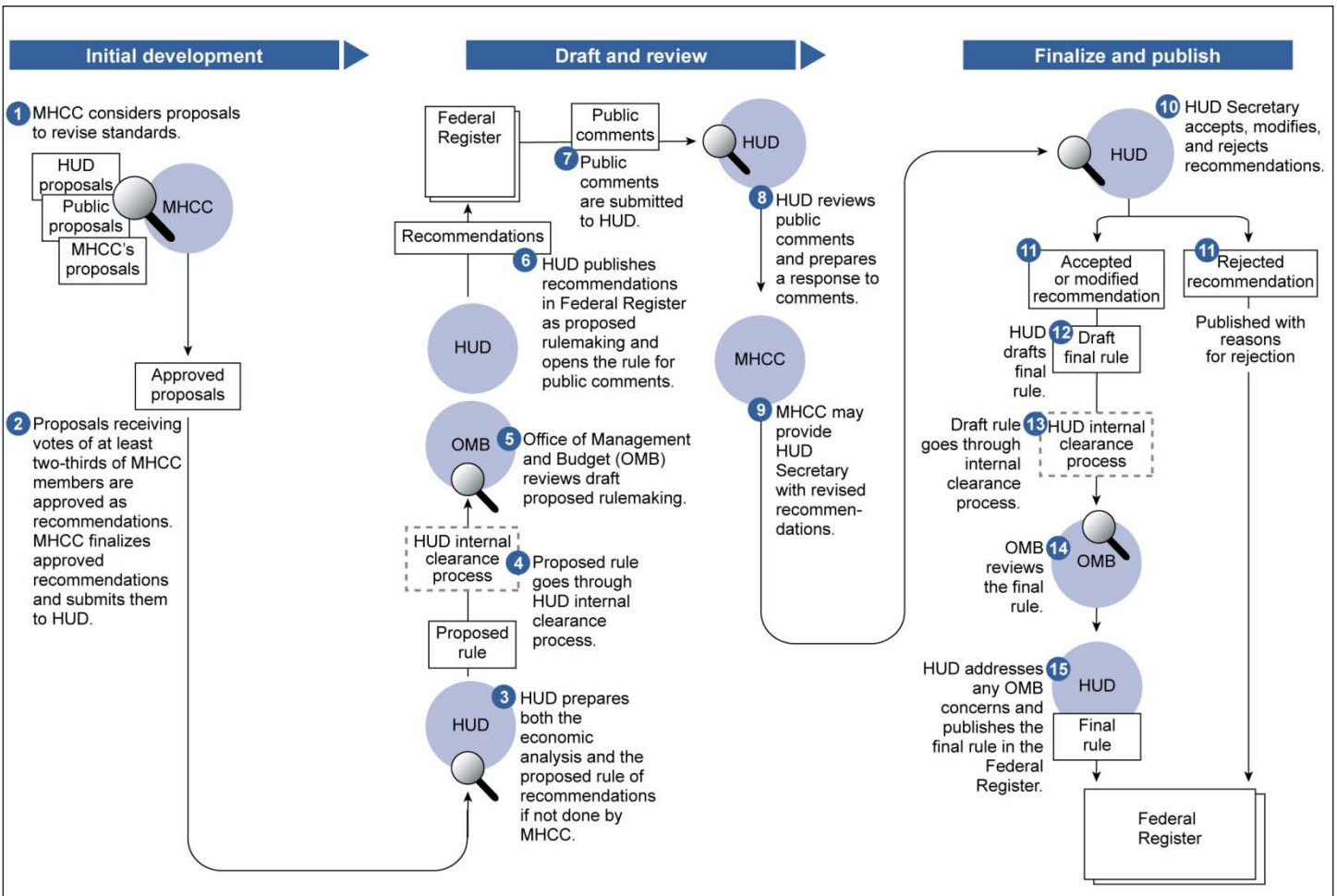
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## Updates to the HUD Code on Key Standards Related to Ventilation and Air Quality Lag behind Industry Standards for Site-Built Homes

As of April 2012, HUD officials stated they were reviewing 84 MHCC recommendations on changes to the HUD Code. However, time delays associated with considering updates to the HUD Code continue to exacerbate differences between standards for manufactured and site-built homes. These include MHCC recommendations and proposed changes related to ventilation and indoor air quality that HUD has begun considering to bring the HUD Code in line with industry standards. However, HUD's process for considering and approving proposed changes, which includes development and consideration of proposed changes by the MHCC, can take many years (see fig. 4). Despite the outstanding proposed changes that are being considered, HUD has not adopted any changes to the HUD Code since 2005. Another set of proposed updates to the HUD Code were published in the *Federal Register* in 2010, and a final rule is currently under review at HUD, according to HUD officials. Further, other proposed updates being considered by HUD have not yet been published in the *Federal Register* as proposed updates to the HUD Code. These include MHCC safety designated items related to air quality and ventilation.

**Figure 4: GAO Analysis of HUD Processes for Updating the HUD Code**



Source: GAO analysis of HUD information.

MHCC recommended in 2010 that HUD increase the separation distance between air intakes and exhaust vents. HUD officials said that HUD is now considering this recommendation to increase the separation distance toward industry standards, which were modified in 2003. The requirements for this separation distance in the HUD Code have remained unchanged since 1976, when HUD first established the HUD Code. We found that IRC and ASHRAE standards on ventilation were periodically updated about every 3 years.



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Specifically, in the 2003 version of its residential ventilation standards, ASHRAE stated several reasons for the need to update the standards, including:

- recognition by government agencies on ties between indoor air quality and health effects;
- increasingly more energy-efficient, air-tight homes being constructed;
- increased concerns over residential indoor air quality and ventilation; and
- the importance of adequate whole-house ventilation to improve air quality.

According to HUD officials, HUD is currently considering the MHCC recommendation to increase the distance between the air intakes and exhaust vents to a 3-foot vertical separation if the horizontal distance is less than 10 feet. MHCC developed the proposal after hearing the public testimony in July 2009 alleging that exhaust from a vent reentered a manufactured home through the air intake and caused carbon monoxide poisoning. MHCC made the recommendation to HUD in April 2010, but as of August 2012, HUD had not published a proposed rule in the *Federal Register*. A HUD official explained that HUD had received and is considering the MHCC recommendation to revise the current separation distance required between air intakes and exhaust vents. That is, HUD has not completed its internal clearance process – step 4 in figure 4.

HUD is also considering an MHCC recommendation to require installation of carbon monoxide detectors for all new manufactured homes. MHCC made this recommendation in December 2009. Similarly, HUD officials stated that HUD has not completed the economic analysis or drafted the proposed rule for this recommendation. As we have seen, other organizations that set industry standards already have this requirement—the IRC since 2009 and ASHRAE since 2010.

The Manufactured Housing Improvement Act of 2000 established a 1-year time limit for HUD to publish decisions on MHCC recommendations in the *Federal Register*.<sup>9</sup> HUD's website states that statutory language

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<sup>9</sup>Pub. L. No. 106-569 requires the Secretary of HUD to either accept, reject, or modify proposed changes to the HUD Code within 1 year and publishing the decisions for notification or further comment in the *Federal Register*.

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requiring the MHCC to submit recommendations to HUD in the form of a proposed rule, including an economic analysis, is impractical.

HUD explains that the MHCC does not have the technical expertise to present HUD with a rule package that meets the requirements of the *Federal Register* and the Administrative Procedure Act. HUD collects the necessary supporting information and then prepares the proposed rule. According to HUD, proposals that the MHCC recommends are then subject to a review and clearance process—which can be lengthy—first within HUD and then are subject to review and approval by the Office of Management and Budget. We plan to assess these rulemaking issues, including options for accelerating the process, in future work.

We also observed several administrative challenges facing the Manufactured Housing Program. For example, NFPA temporarily suspended its administration of the MHCC in May 2012, citing that HUD had not yet paid invoices supporting the committee. Later, NFPA officials stated they had resumed the function for administering the MHCC after HUD paid the outstanding funds due. Further, MHCC members we spoke to told us that HUD's Office of Manufactured Housing was understaffed and lacking in resources, possibly contributing to delays in updating the standards. HUD officials stated that the Manufactured Housing Program and its processes can be labor intensive. The program has 10 authorized staff positions. The office has been run by an Acting Deputy Administrator since July 2011. The Administrator position has been vacant since 2010.

Industry officials also told us that the federal rulemaking process for manufactured housing was slow because manufactured housing was not a priority for HUD. We found the priority given the program is unclear. HUD's strategic plan does not include the manufactured housing program among those contributing to HUD's priority goal of promoting healthy, energy-efficient, and affordable buildings.

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## Millions of Manufactured Homes Have Been Built under the HUD Code but HUD Has Not Tested the Performance of Installed Ventilation Systems

HUD does not maintain data on the number of manufactured houses built or the distances between vents and air intakes of homes designed with an outdoor air intake connected to the air distribution system. American Housing Survey estimates showed that in 2009 many of the approximately 6.8 million occupied manufactured homes had been built under the HUD Code. Specifically, about 5.5 million of these units had been built after 1975.<sup>10</sup> The 3-foot separation requirement between air intakes and exhaust vents has been in effect since 1976 and thus applied to these homes. According to the American Housing Survey, about half (52 percent) of occupied manufactured homes used electricity as their main heating source, and most of the remaining 48 percent used a combustible fuel source.<sup>11</sup> As we have mentioned, experts said carbon monoxide exposure—although rare—is most likely in homes that use a combustible fuel source, or nearly half of the manufactured homes identified in the survey.

According to HUD officials, although it does not have data on the actual distances between vents and air intakes of constructed homes, HUD retains copies of all DAPIA approved design packages, which include requirements for this separation. As validated by DAPIAs, designs of manufactured homes are developed with the intent of meeting the HUD Code. Two large manufacturers we spoke to, which accounted for about 60 percent of the market, stated that they did not track the distances between vents and air intakes of each home, but that their homes met HUD standards—that is, the distances were at least 3 feet for homes with air intakes.

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## Data on the As-Installed Performance of Ventilation Systems in Manufactured Homes are Limited

Furthermore, we found that the HUD Code does not require testing of the performance of the ventilation system, including the resulting whole-house airflow rate of homes, either at the plants or once the homes are put in place. HUD officials told us that the DAPIAs review designs to help ensure the performance of ventilation systems meets the HUD Code. In particular, DAPIAs ensure that designs include the required exhaust fans to move a certain volume of air that should achieve the specified whole-

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<sup>10</sup>The relative margins of error for these estimates are between 4.41 and 13.70 percent.

<sup>11</sup>Estimates are from the Census Bureau's 2009 American Housing Survey. The margins of error are between 1.40 and 4.70 percent.

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house airflow rate.<sup>12</sup> HUD officials stated that IPIAs are not required to test the whole-house airflow rate either in the plant or in the field because the HUD Code does not require it. In contrast, the HUD Code does require the inspection and testing of other specified features, such as gas lines, smoke alarms installed at the factory, and plumbing systems.<sup>13</sup>

Air quality experts we spoke with emphasized that a variety of factors could impact the whole-house airflow rate. For example, one expert said duct leakage and friction could result in airflow losses. Therefore, an approved design may assume a certain airflow rate for an exhaust fan, but the quality of construction could reduce the whole-house airflow rate upon installation. Additionally, several studies by the Department of Commerce's National Institute of Standards and Technology (NIST) indicated that the whole-house airflow rate of manufactured homes depended on how often the fans were operated, as well as weather and climate factors. In 2008 and 2010 NIST reported that some airflow rates in a test home were below levels specified in the HUD Code. Because HUD does not require testing to validate the performance of ventilation systems, specifically the resulting whole-house airflow rates, it does not know how the systems are performing or whether they meet HUD specifications.

Cooperative research in 2003 involving HUD and the Manufactured Housing Research Alliance concluded that it was unclear how well whole-house ventilation systems in manufactured homes performed with respect to the HUD Code's whole-house airflow rate performance specification.<sup>14</sup> According to the study and HUD officials, identifying a typical airflow rate for manufactured homes is challenging because factors such as temperature, wind, location of the home, and construction type have varying impacts on the natural infiltration in similar homes. The study recommended that HUD:

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<sup>12</sup>24 C.F.R. § 3280.103 (b). The HUD Code also requires mechanical ventilation systems to have a manual control and for the instructions to encourage consumers to operate the system whenever the home is occupied. 24 C.F.R. § 103(b)(4), (6).

<sup>13</sup>24 C.F.R. § 3280.706(l)(8), 3280.208(f), 3280.612.

<sup>14</sup>The Manufactured Housing Research Alliance is now named the Systems Building Research Alliance. The mission of this nonprofit organization is to develop new technologies to enhance the value, quality, and performance of both manufactured and modular homes.

- 
- conduct further research to develop a testing method to determine whether specifications for ventilation design and performance were being met, and
  - publish guidelines for achieving the required airflow rate in manufactured homes in a best practices manual to be created for the industry.

As of August 2012, MHCC was considering a proposal to adopt an industry standard for residential ventilation that includes testing to ensure that ventilation systems meet performance specifications. Requirements for testing the ventilation system after installation were incorporated in ASHRAE's ventilation standards for residential homes in 2003. The current proposal with the MHCC includes testing the delivered airflow of the system, using an airflow measuring device to confirm the airflow of the system.

HUD officials acknowledged that the recommendations from the 2003 study had not been implemented and cited funding issues as reasons for not implementing them. According to HUD officials, HUD has not received negative reports on indoor air quality in manufactured homes that occurred as a direct result of the whole-house ventilation systems. However, without testing of the actual whole-house airflow rates of recently manufactured homes, HUD cannot know whether these homes, as built, meet HUD's requirement of 0.035 cubic feet per minute for each square foot of interior floor space. Still, the ventilation standards establish standards for airflow, not air quality, although the required airflows are intended to enhance air quality in the home.

Measuring the actual airflow achieved by installed ventilation systems would not only permit HUD to know whether its standards are being met, but also permit HUD to better understand the potential impact ventilation systems may have on indoor air quality. In the next section we discuss limitations in HUD's standard.

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## The HUD Code Airflow Rate Is Based on Standards and Research from 1993

We found that the performance specifications for the whole-house airflow rate in the HUD Code were based on industry standards and assumptions from nearly 20 years ago. As we stated earlier, HUD has not tested these performance specifications as manufactured homes are built and installed. In 1993, HUD first set a standard for the whole-house airflow

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rate, basing it on the ASHRAE standards from 1989 and ventilation research by NIST and the U.S. Department of Agriculture's Forest Products Laboratory.<sup>15</sup> The original whole-house airflow rate requirement aimed at replacing about one-third of the air in a manufactured home with fresh air each hour (that is, 0.35 total air changes per hour). As part of this requirement, HUD also assumed natural infiltration would account for 0.25 air changes per hour and required mechanical ventilation to provide the remaining 0.1 air changes per hour. Therefore, the HUD Code in 1993 specified that each manufactured home shall be provided with mechanical whole-house ventilation having a minimum capacity of 0.035 cubic feet per minute for each square foot of interior space in order to achieve a minimum rate of 0.1 air changes per hour. In 2005, HUD removed the natural infiltration assumption but kept the same rate for mechanical ventilation.

Since 1993, HUD has continued to specify a mechanical whole-house ventilation airflow rate of least 0.035 cubic feet per minute for each square foot of interior floor space or its hourly average equivalent.<sup>16</sup> Air quality experts emphasized that homes have continued to be built with less leakage and greater energy efficiency. Thus, a home built in 1993 and a home built in 2012 may both meet the HUD whole-house airflow rate standard (that relates only to ventilation achieved through mechanical means) but may not achieve the same level of air quality. Nonetheless, HUD has not reconsidered the appropriateness of its standard in achieving an acceptable level of air quality, nor specified an acceptable level of air quality. Without further research and testing of its whole-house airflow rate standard, HUD may not know the effect of new design and construction practices on the overall ventilation performance and air quality of manufactured homes.

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## Conclusions

Current standards used for site-built and modular homes offer a greater margin of safety against carbon monoxide exposure than the HUD Code standards used for manufactured homes. While carbon monoxide

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<sup>15</sup>As of 2010, ASHRAE requires specific fan flow rates depending on the floor area, the number of bedrooms, and the number of occupants rather than the fixed airflow rate of 0.35 air changes per hour.

<sup>16</sup>24 C.F.R. § 3280.103(b). In 2005 the HUD Code also first required exhaust fans to produce between 50 and 90 cubic feet per minute to achieve this airflow rate.

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exposure resulting from exhaust reentering the home through an air intake is unlikely, air quality experts we spoke to maintain that industry standards already required for site-built homes offered a greater margin of safety to prevent carbon monoxide from reentering a home than the HUD Code does for manufactured homes. Our analysis also confirmed that increasing the separation distance between air intakes and exhaust vents to industry standards decreased the likelihood of carbon monoxide reentering the home. Further, industry standards for site-built homes call for the use of a carbon monoxide detector whereas the HUD Code does not. In response, the MHCC has forwarded safety-designated recommendations to HUD to update the HUD Code to address concerns over the separation distance between air intakes and exhaust vents and the lack of a requirement for carbon monoxide detectors in manufactured homes.

The differences between the HUD Code and industry standards related to home ventilation and indoor air quality are due to the regulatory procedures and time it takes HUD to consider and implement proposed updates. Although we observed proposals aimed at maintaining similar standards for manufactured and site-built homes, proposed updates for manufactured homes lagged behind those made by industry for site-built and modular homes. HUD's process for adopting changes to the HUD Code involving considerable time for proposals to be considered by the MHCC and HUD has resulted in a lack of action even on safety-related proposals that the MHCC has put forth, including increasing the separation requirement for air intakes and exhaust vents and requiring carbon monoxide detectors. Although MHCC has submitted several recommendations to HUD, HUD has not implemented any changes to the HUD Code since 2005, so actual implementation of recent updates may be years away. We will explore rulemaking and other issues with the Manufactured Housing Program in further work.

HUD does not maintain data on the actual separation distances between the fresh air intakes and exhaust vents, but does retain copies of designs with DAPIA approval, indicating they comply with the HUD Code. We noted that 5.5 million occupied manufactured homes were built since the HUD Code took effect with a 3-foot separation requirement, and almost half of manufactured homes built use combustible furnace fuels. However, we found limited data available related to the installed performance of the ventilation systems of manufactured homes constructed and placed. HUD does not require manufacturers to test the performance of the ventilation systems installed in manufactured homes to determine whether the systems actually meet their performance

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specifications. Further, while the HUD Code specifies certain inspections and tests to validate many other features of manufactured homes, HUD does not require manufacturers to conduct performance testing of the ventilation system, specifically the required whole-house ventilation airflow rate. Other research efforts have previously voiced similar concerns over uncertainties as to whether the performance specifications of the ventilation system were being met in manufactured homes. Ultimately, without testing the whole-house airflow rate for constructed manufactured homes, either in the factory or the field, HUD and others cannot be assured as to whether the airflow is ventilating the home as specified.

We also found that the current HUD code performance specification for the whole-house ventilation airflow rate is based on standards and research from nearly 20 years ago. Since then, air quality experts and research suggest that the industry has improved the construction of manufactured homes. To the extent that manufactured homes continue to be built tighter and more energy efficient, mechanical ventilation of homes becomes more important for ensuring indoor air quality. HUD's whole-house airflow rate standard for mechanical ventilation of 0.035 cubic feet per minute per square foot of living space has remained unchanged. Without further assessment of the impact that potential changes in natural air infiltration have on whole-house ventilation, HUD cannot be certain of the air quality in manufactured homes.

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## Recommendations for Executive Action

To better ensure that air ventilation systems in manufactured homes perform as specified and meet the HUD Code, we recommend that HUD develop an appropriate method to test and validate the performance of the ventilation system as part of the HUD certification process.

To ensure that its specification for airflow continues to be appropriate, we recommend that HUD reassess the assumptions for the whole-house ventilation specification, working with the MHCC, to determine the appropriate rates, taking into consideration current natural air infiltration, to achieve the whole-house ventilation performance, considering the expected impact such ventilation would have on indoor air quality.

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## Agency Comments and Our Evaluation

We provided a draft of this report to HUD for review and comment. HUD's Acting Assistant Secretary for Housing-Federal Housing Commissioner provided written comments that are discussed below and presented in



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Appendix II. HUD also provided technical comments that were incorporated as appropriate.

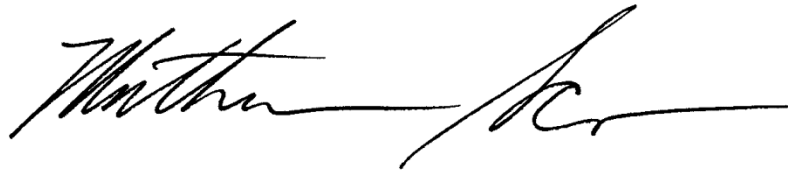
HUD agreed with both recommendations, noting that it would bring them before the MHCC for consideration. HUD also said, however, that it would require additional funding and resources. Specific to our recommendation that HUD develop an appropriate method to test and validate the performance of the ventilation system as part of the HUD certification process, HUD agreed that such testing and validation could improve the accuracy of system performance. But HUD also questioned the need for such testing, given that the current systems were designed and approved by private design professionals. HUD further noted that no documentation existed showing that ventilation systems in manufactured homes did not meet current standards. But as our report points out, HUD lacks such documentation because it does not systematically test the systems. HUD also stated that it would be impractical to conduct testing at the factory for multi-section units. However, testing of the whole-house airflow rate could occur in the field as well as at factories, when practicable.

We also recommended reassessing the assumptions for the existing whole-house ventilation airflow rate specification. HUD agreed that a reassessment of the assumptions used to determine the appropriate rate could have a positive impact on indoor air quality. HUD also said that it would need to balance changes in these requirements against costs incurred by manufacturers and consumers. As we noted in the report, the existing whole-house ventilation airflow rate requirement (0.035 cubic feet per minute per square foot of living space) is based on assumptions for natural air infiltration dating back to 1993. HUD noted in its technical comments that no evidence existed to support the argument that the ventilation standards for manufactured homes were less effective than industry standards. Further, HUD said that its standards provide rates of mechanical ventilation that are comparable to those provided by industry standards. However, without further assessment of the impact that potential changes in natural air infiltration have on whole-house ventilation, HUD cannot be certain of the air quality in manufactured homes. Reassessing assumptions made nearly 20 years ago would help determine whether HUD's required whole-house ventilation airflow rate continues to ensure that manufactured homes are properly ventilated.

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We are sending copies of this report to appropriate congressional committees and the Secretary of Housing and Urban Development. The report also is available at no charge on the GAO website at <http://www.gao.gov>.

If you or your staff have any questions about this report, please contact me at (202) 512-8678 or [sciremj@gao.gov](mailto:sciremj@gao.gov). Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made major contributions to this report are listed in appendix III.

A handwritten signature in black ink, appearing to read "Mathew J. Scire". The signature is fluid and cursive, with a long horizontal stroke extending to the right.

Mathew J. Scire  
Director,  
Financial Markets and Community Investment

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# Appendix I: Comparison of Different Separation Distances Between Air Intakes and Exhaust Vents and Impacts on Potential Carbon Monoxide Exposure

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Reentry of exhaust occurs when exhaust leaving its vent finds its way to an air intake and gets pulled back into the home. The common mitigation practice is to provide adequate horizontal or vertical separation between the exhaust vent and the air intake such that any reentered air is diluted to a greater extent by the time it reaches habitable areas of the home.

In their Handbook of Fundamentals, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) provides methods for modeling the diluting effect of an exhaust stream mixing with open air. ASHRAE officials we spoke with told us that these methods can be used to assess solutions to various ventilation problems including exhaust air reentry scenarios. Therefore, we used these techniques on a simple model of a manufactured home to analyze how much carbon monoxide in the exhaust stream of the furnace in the home could be diluted by the time it reached an air intake of the home. We analyzed different scenarios involving various separation distances between the exhaust vent and the air intake to see what effect separation distance produced on the amount of dilution provided by open air mixing.

Dilution of contaminants occurs through mixing of the exhaust stream with fresh air as the stream leaves its vent, enters open air, is affected by the wind, and spreads away from the vent, dispersing contaminants in the stream as it progresses. In general, dilution increases with increasing wind speed, as might be expected, because a stronger airflow will aid in dispersing contaminant particles, and is inversely proportional to both the speed with which the exhaust stream is coming out of the vent, as well as the size of the vent opening. This makes sense because increasing exhaust speed and increasing vent size, naturally, competes against dilution by putting more contaminant into the air.

However, the mixing is not straightforward, as many factors can influence how much dilution takes place. For example, the airflow closer to the ground can be disrupted by obstacles such as trees and buildings, inducing turbulence in the flow. At roof level, vents and even the pitch of the roof can further complicate the flow, creating a mix of eddies and zones where the air might get recirculated and trapped near the roof, thus restricting the dilution effect. This is sometimes the case at lower exhaust speeds and lower wind speeds, where the exhaust plume will not have the momentum to rise very high or get dispersed very quickly by the wind and may get pushed down and remain near roof level and the air intake.

In implementing their model, ASHRAE assumes the air intake is positioned directly downwind of the exhaust vent and then allows for a

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**Appendix I: Comparison of Different Separation Distances Between Air Intakes and Exhaust Vents and Impacts on Potential Carbon Monoxide Exposure**

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variety of parameters to specify the geometries involved; for example the height of the roof, the horizontal and vertical separation distances between the exhaust vent and the air intake, and the size of the exhaust vent opening. In addition, ASHRAE allows for specifying characteristics of the exhaust stream, such as the speed with which the exhaust is exiting the vent, and the initial concentration of a contaminant within the stream at the vent opening. Finally, ASHRAE models the flow of the air through a number of factors that include the wind speed, the downwind, cross-wind, and vertical spread of the plume as it progresses downstream, and the turbulence intensity of the air, which is controlled by a factor that allows for specifying the roughness of the terrain over which the air will be flowing.

In our analysis, we used three different scenarios for separation distances between the air intake and exhaust vent—3 foot horizontal, 10 foot horizontal, and 3 foot horizontal with a 3 foot vertical separation. Table 1 also shows the specific parameters we used in our analysis. These included a manufactured home with a roof height of 10 feet and an exhaust vent diameter of 4 inches. We used an initial carbon monoxide concentration in the exhaust stream of 200 ppm, which experts have told us could occur in the exhaust stream of a malfunctioning furnace.

**Appendix I: Comparison of Different Separation Distances Between Air Intakes and Exhaust Vents and Impacts on Potential Carbon Monoxide Exposure**

**Table 1: Parameters Used in Our Analysis**

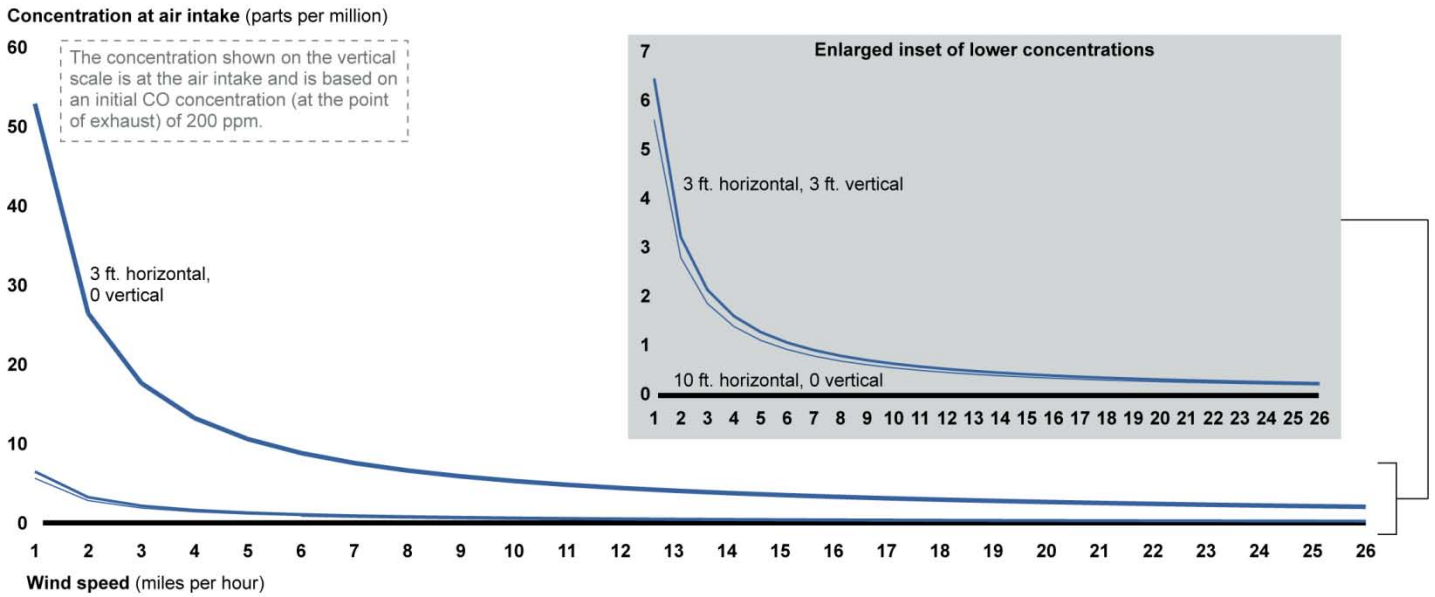
<b>Parameter</b>	<b>Value</b>	<b>Notes</b>
Height of the roof	10 ft	Height of the roof off the ground at the gutter.
Horizontal distance between the exhaust vent and the air intake	Variable	We assessed cases with horizontal separation distances of 3 feet and 10 ft.
Vertical separation distance between the exhaust vent and the air intake	Variable	We assessed cases of no separation (0) and a separation of 3 feet.
Diameter of the exhaust vent opening	4 inches	Diameter of the exhaust vent opening. We considered the exhaust vent to be capped.
Exhaust stream speed	1000 feet per minute (fpm)	ASHRAE representatives mentioned 100-2000 fpm are typical values for residential furnaces.
Initial carbon monoxide concentration	200 ppm	Concentration at the exhaust vent opening of an assumed carbon monoxide component in the exhaust stream.
Wind speed	Variable	We assessed scenarios varying the wind speed from 1 to 26 mph (about 88 to 2288 fpm).
Roughness factor	2.132	Characterizes airflow over the terrain. This is the value ASHRAE specifies for a suburban setting. For comparison purposes, a flat desert would have a value of 0.03 while an urban setting would have a value of 6.0.

Source: GAO analysis based on the ASHRAE Handbook of Fundamentals.

Figure 5 represents the results of our analysis and illustrates contaminant concentration at the air intake as a function of wind speeds for various exhaust vent to air intake separations. Here it can be seen that increasing the horizontal separation to 10 feet or adding a 3 foot vertical separation to the 3 foot horizontal separation reduces the concentration at the air intake more than the 3 foot horizontal separation alone does. For example, in a light 1 mph wind, exhaust with a carbon monoxide concentration of 200 ppm would be diluted to approximately 50 ppm at an air intake separated 3 feet horizontally from the exhaust vent. Increasing the separation between the exhaust vent and air intake to either 10 feet horizontally or 3 feet horizontally and 3 feet vertically in a 1 mph wind results in carbon monoxide concentrations of less than 10 ppm at the air intake.

**Appendix I: Comparison of Different Separation Distances Between Air Intakes and Exhaust Vents and Impacts on Potential Carbon Monoxide Exposure**

**Figure 5: Contaminant Concentration at Air Intake for Different Wind Speeds and Various Exhaust Vent to Air Intake Separations**



Source: GAO analysis based on the ASHRAE Handbook of Fundamentals.

# Appendix II: Comments from the Department of Housing and Urban Development



U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT  
WASHINGTON, DC 20410-8000

ASSISTANT SECRETARY FOR HOUSING-  
FEDERAL HOUSING COMMISSIONER

SEP 28 2012

Mr. Mathew J. Scire  
Director  
Financial Markets and Community Investment  
Government Accountability Office  
441 G Street, NW  
Washington, DC 20548-0001

Dear Mr. Scire:

Thank you for the opportunity to respond to the Government Accountability Office (GAO) draft report GAO-13-52 of September 17, 2012, entitled, "Manufactured Housing Standards: Testing and Performance Evaluation Could Better Ensure Safe Indoor Air Quality,"(GAO-13-52). This letter conveys the Department of Housing and Urban Development (HUD) response to the audit.

**Recommendation:**

HUD develops an appropriate method to test and validate the performance of the ventilation system as part of the HUD certification process.

**HUD Response:**

HUD agrees that the development of new methods to test and validate performance of ventilation systems could improve the accuracy of system performance; however, current systems are designed and approved by private design professionals to meet existing standards for each home design and HUD has no documentation to support that ventilation systems do not meet current standards. The development of new methods to test and validate the performance of ventilation systems by HUD will require additional funding and resources to accomplish and would be impractical to conduct at the factory for multiple section units. However, the Department is agreeable to bringing the recommendation before the Manufactured Housing Consensus Committee (MHCC) for consideration.

**Recommendation:**

HUD reassesses the assumptions for the whole-house ventilation specification, working with the MHCC, to determine the appropriate rates, taking into consideration current natural air infiltration, to achieve the whole-house ventilation performance, considering the expected impact such ventilation would have on indoor air quality.

[www.hud.gov](http://www.hud.gov)

[espanol.hud.gov](http://espanol.hud.gov)

**HUD Response:**

HUD agrees that a re-assessment of the assumptions for whole-house ventilation specification to determine appropriate rates could benefit the impact on indoor air quality. However, HUD notes that the current range of rates for whole-house ventilation of 50 cfm minimum to 90 cfm maximum is already comparable to those recommended by the Industry Standard, ASHRAE 62.2, for residential buildings of similar size and area. Any potential benefits obtained by changes to the current requirements for whole-house ventilation would need to be balanced against the costs incurred by the manufacturers and the consumers. HUD would require additional funding and resources to adopt GAO's recommendations. The Department is agreeable to bringing the recommendation before the MHCC for consideration.

We appreciate the efforts of the GAO to review testing and performance evaluation to ensure safe indoor air quality.

Sincerely,



Carol J. Galante  
Acting Assistant Secretary for Housing-  
Federal Housing Commissioner



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# Appendix III: GAO Contact and Staff Acknowledgements

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## GAO Contact

Mathew J. Scirè, (202) 512-8678 or [sciremj@gao.gov](mailto:sciremj@gao.gov)

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## Staff Acknowledgments

In addition to the contact named above, Andy Finkel (Assistant Director), Mike Armes, James Ashley, Tim Bober, Bill Carrigg, Emily Chalmers, Pamela Davidson, Juliann Gorse, Barry Kirby, John McGrail, Marc Molino, and Nadine Garrick Raidbard, made key contributions to this report.

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