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ABSTRACT

In an on-going collaboration over the last ten years, researchers have worked with the manufactured housing industry offering building science advice and conducting diagnostic testing (Chandra et al 2002). This partnership resulted in the first two HUD code ENERGY STAR homes in 1997 and the development of standardized, in-plant Duct Blaster testing in 2001. One manufacturer is currently testing duct leakage on every home in 12 factories, representing over 8,000 homes per year.

In 2001, the U.S. Environmental Protection Agency (EPA) introduced the ENERGY STAR label for manufactured homes. Guidelines for this program focus on certification of the HUD-code plant and award the ENERGY STAR label to any homes manufactured to prescriptive design requirements. The primary hurdle to certification is consistent production of tight duct systems. Other important aspects of the program include verification of prescriptive design packages and energy related site installation details.

An outline of the certification process at 10 plants in six states is presented, including Blower Door and Duct Blaster test results from over 40 homes. Duct test data taken by researchers from site-installed homes is compared with corresponding, in-plant test data. Photos, specifications and cost data are used to illustrate certification with an emphasis on achieving targeted duct leakage. Duct system design and installation details are also presented along with in-plant testing protocols.

Background

The HUD Code

Since June 15, 1976, all Manufactured homes are constructed in accordance with the Federal Manufactured Homes Construction and Safety Standards, administered by the U.S. Department of Housing and Urban Development (HUD). Known as the HUD code, these standards regulate home design and construction including strength, durability, fire resistance and energy efficiency (Title 24 CFR 2001). The code was revised to enhance energy efficiency, ventilation standards and wind resistance in the early 1990's.

Manufactured homes are similar in many respects to modular homes. Both are built in a factory and transported to a site for installation. The difference is that manufactured homes are regulated by the HUD code, whereas modular homes must follow the building code enforced in the jurisdiction where the home will be located.

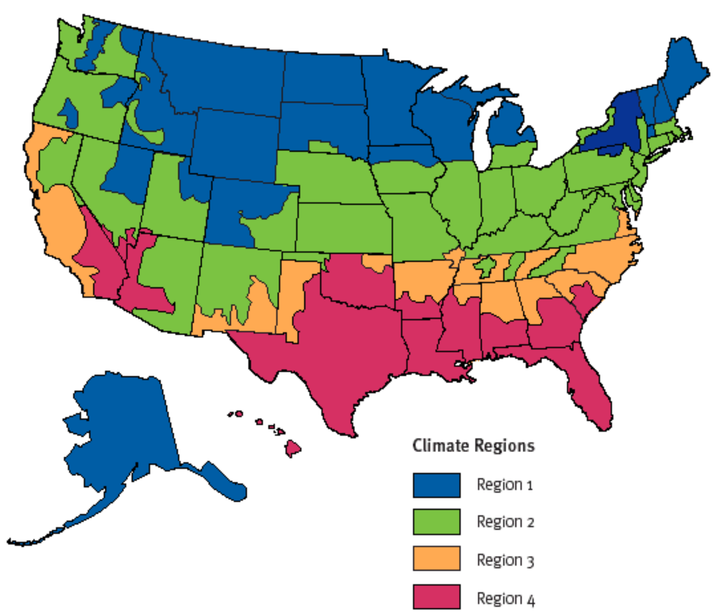
Energy Star Requirements

Prescriptive Design Packages

The Energy Star guidelines for manufactured homes (MHRA 2003) are very similar to the guidelines for site-built homes. As with a site-built home, an ENERGY STAR labeled manufactured home must be at least 30% more energy efficient in its heating, cooling and water heating than a comparable home built to the 1993 Model Energy Code (MEC). The 30% efficiency specification can be met either through prescriptive design packages or through the performance-based approach using approved software. While achieving Energy Star through software analysis is identical for both site-built and manufactured homes, there are a few differences in the prescriptive packages.

Pre-approved Energy Star packages for HUD code manufacturers diverge from the Builder Option Packages (BOPs) used by site-builders in several ways. Unlike BOPs, which are based on climate zones defined in the International Energy Conservation Code, HUD code packages are based on a four zone climate region map (Figure 1). Within each climate region, manufacturers can choose from maximum duct leakage targets of 3, 5 and 7%.[1] Once a duct leakage target is chosen, HUD code packages become increasingly similar to site-built BOPs, including trade-offs between heating, cooling and hot water equipment efficiency and window solar heat gain coefficient (SHGC).

Figure 1. Energy Star Climate Region Map for Manufactured Homes



Source: Energy Star Labeled Manufactured Homes Procedures, 2nd Ed. 2003

[1] Values based on cubic feet per minute of leakage to outside at 25 pascals divided by conditioned floor area.

Another difference between manufactured and site-built guidelines is use of the whole-house U_o (coefficient of heat transmission) as outlined in NFPA 501: Standard for Manufactured Housing (NFPA 2003). This property is routinely used by HUD code manufacturers and provides a single measure of heat conductance through the entire building envelope, including floor, walls, ceiling, doors and windows. Whereas BOPs specify individual R-values or U-values for walls, floors, attics and windows, manufactured housing packages specify only the whole-house $U_{o.}$

Site Installation Checklist

HUD code home construction takes place primarily in a controlled factory setting however an additional obstacle to ensuring Energy Star efficiency occurs when the completed home is installed at its final on-site destination. The advantages of building energy efficient homes in a factory environment are quickly undermined if certain critical tasks are not properly performed during setup. For this reason a home site installation checklist must be signed-off on every Energy Star manufactured home.

The checklist primarily focuses on field connections critical to building and duct airtightness but also ensures the installed HVAC equipment meet efficiency specifications. Most manufactured homes are composed of at least two sections that must be mated on site at the marriage line. The marriage line seal is crucial to achieving a tight envelope and must consist of a continuous, non-porous, insulating gasket where the ceiling, floor and end walls come together. Penetrations through the bottom board are routinely required for utility hook-ups and must be sealed with a durable patch to prevent air leakage.

Multi-section homes require a duct connection to join systems between floors. This is often done with a crossover duct, which are typically large (12-14 inch diameter) flex-ducts connected during setup and located either in the attic or crawlspace. The checklist specifies that crossover connections be secured in a permanent fashion with adequate insulation and a continuous vapor barrier to prevent condensation.

Sampling Protocol

A final distinction between manufactured and site-built Energy Star guidelines involves the random sampling of completed homes. Initial procedures are similar in that three consecutive homes must meet the guidelines as determined by a 3rd party verifier. Once it is determined that the builder or manufacturer can consistently produce homes that meet the guidelines, a sampling protocol is followed in which the 3rd party Energy Star certifier randomly selects and tests homes to verify envelope and duct leakage requirements. The sampling rate is set at 15% for site-builders and 2% for HUD code manufacturers.

Implementing Energy Star

Meeting Energy Star requirements, whether for manufactured or site-built homes, relies on a combination of a better performing envelope and higher efficiency equipment. Duct leakage however, is arguably the single most important factor in the home energy efficiency equation. Prevalence of duct leakage has been documented among site built homes (Cummings, et al, 1991, 1993, 2003) and new manufactured homes (Tyson, et al, 1996.

MHRA, 2003), as well as in manufactured homes in failure due to moisture and air flow control issues (Moyer, et al, 2001). Duct repair studies from the 80's and 90's show average savings of 15% cooling energy and 20% heating energy (Cummings 1991 and 1993; Davis 1991; Evans et al 1996; Manclark et al 1996.). Other benefits resulting from tight duct systems include first cost savings from smaller equipment sizes improved comfort, better indoor air quality and in many cases improved durability (Moyer 2001).

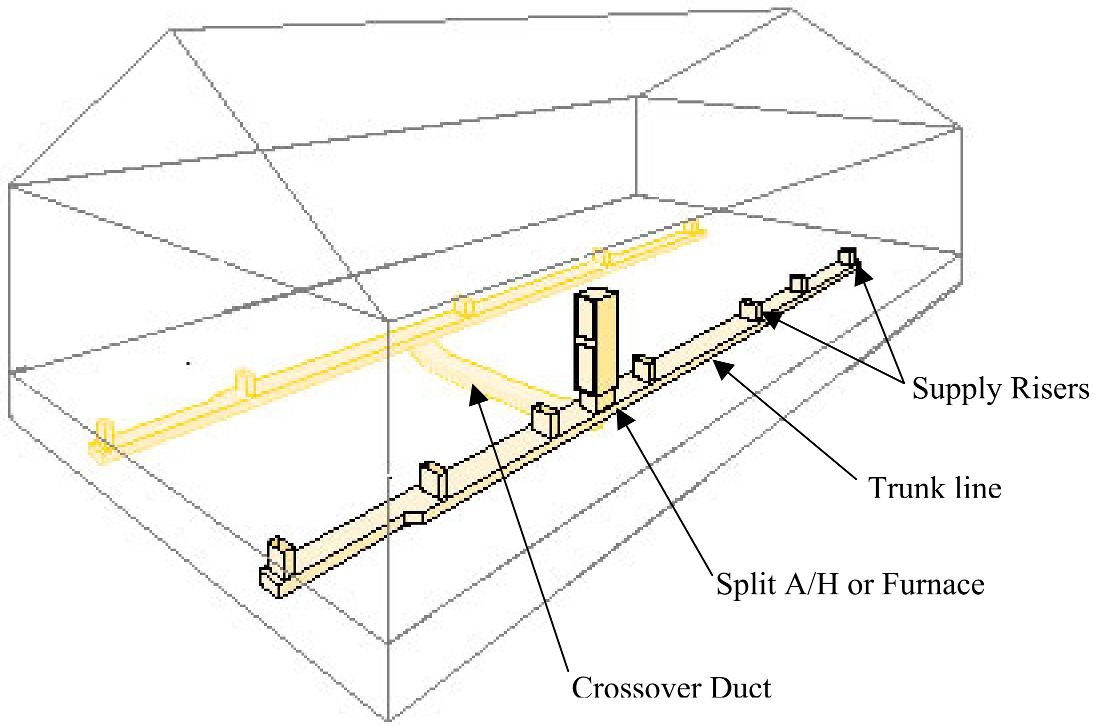
While the potential for energy loss is great, preventing leakage is relatively simple and inexpensive when approached in a systematic manner. The problem however, is that air leakage is difficult to determine without sophisticated testing equipment. Unlike other aspects of home energy efficiency, air leakage represents the only performance test currently required for Energy Star certification. All other characteristics that differentiate an Energy Star home from a standard home such as equipment efficiency and insulation levels are verified by visual inspection.

Duct System Design

Duct systems in manufactured homes are, by nature, very simply designed. The two basic types are overhead systems installed in the attic space and under-floor systems installed in the belly space between the floor deck and the bottom board. Floor duct systems are composed of rectangular sheet metal or fiberglass duct board, which runs down the center of each home segment. The simplest floor system is the inline type that has metal supply risers tied directly to the trunk line as shown in Figure 2. The perimeter floor duct system takes this design one step further with flex duct supply branches emanating from the trunk line and terminating at points near the exterior walls. Ceiling duct systems on the other hand are constructed entirely of flex duct with distribution boxes built of fiberglass duct board.

Multi-section homes have an additional section of ductwork that is connected during the setup operation. A flexible duct is used to connect the supply sections together in the attic or in the crawlspace. Also called the crossover duct, this connection is usually made with a tie strap.

Figure 2. Inline Duct System in a Two-section Manufactured Home



Source: Improving Air Distribution System Performance in Manufactured Homes. 2003

Sealing with Mastic versus Tape

Researchers collected duct leakage data during factory visits to 24 different plants on behalf of 6 HUD-code manufacturers. The data, dating back to 1996, illustrates the advantages of duct systems sealed with mastic over those sealed with tape (McIlvaine et al 2003). Duct leakage was measured in 101 houses representing 190 floors (single wide equals one floor, double wide equals two floors, etc.) and includes more recent data taken during factory certification for Energy Star. Throughout this testing the duct leakage goal was Qnout ≤ 3%.[2] Researchers tested homes at sales lots and home sites, as well as partially constructed homes in the factory setting, however home sections in the factory cannot be sealed enough to perform a CFM25out test. Past field tests suggest that CFM25out will be roughly 50% of total leakage (CFM25total). Thus, to achieve a Qnout of less than 3%, it was recommended that manufacturers strive for a CFM25total of less than 6% of the conditioned area (Qntot). Duct leakage data gathered from 1996 to 2003 is summarized in Table 1 and Figure 3.

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[2] Qnout is the ratio of duct leakage to outside at 25 pascals (CFM25) to conditioned floor area (square feet).

Table 1. Number of Home Sections Tested by Sealing Method, Duct Location and Duct Material (1996-2003) 39 factory visits to 24 plants run by 6 different manufacturers			
	Tape	**Mastic**	**Total**
Duct System Location			
Undocumented	1	0	1
Overhead Systems	25	44	69
Floor Systems	32	88	120
Total	**58**	**132**	**190**
Duct Materials			
Undocumented	5	0	5
Sheet Metal with Flex	24	22	46
Duct Board with Flex	29	110	139
Total	**58**	**132**	**190**

Figure 3. Average Duct Leakage: Tape vs Mastic Sealed Ducts

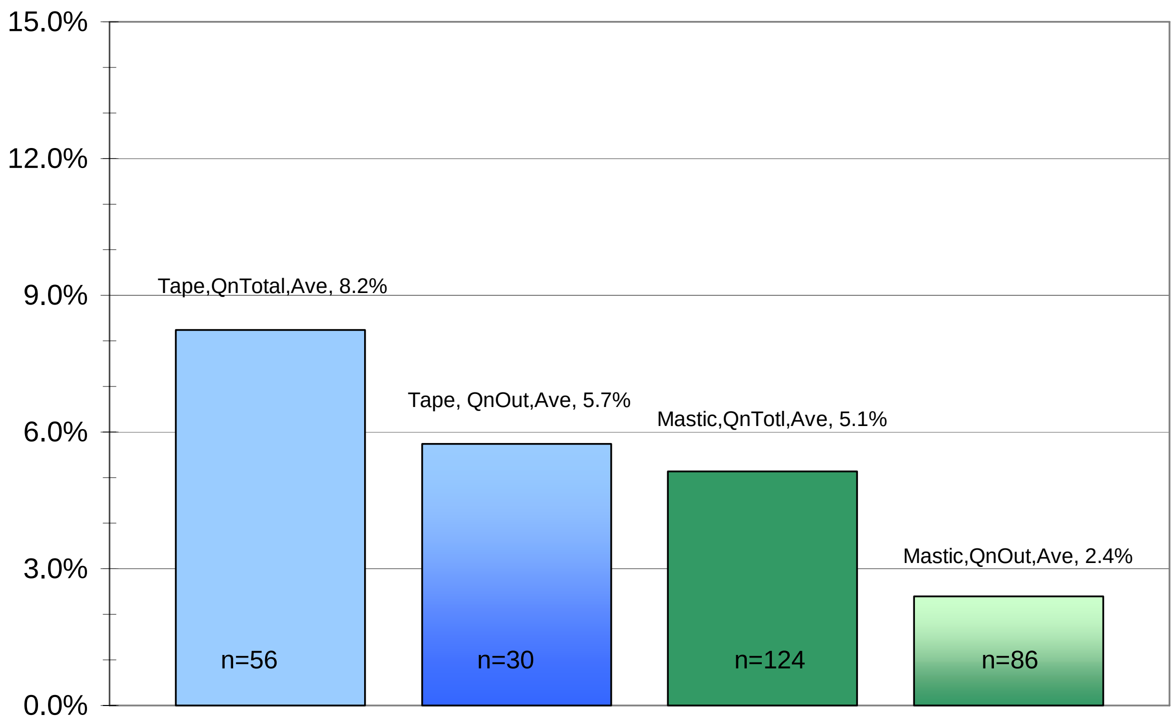

Figure 3 indicates that mastic provides a superior seal over what can be accomplished with tape. The average taped system did not meet either of the duct leakage targets, Qntot $\leq$ 6% and Qnout $\leq$ 3%, while the average mastic system met both. Cost information from two manufacturers indicates that the added cost of implementing a duct sealing program using mastic ranges from $4 to $8 per floor, including in-plant quality control procedures (testing) critical to meeting duct tightness goals.

Energy Star Plant Certification Data

Researchers, acting as third party verifiers, visited 10 HUD-code plants for a single manufacturer in 2002 and 2003 to certify them for Energy Star production. Energy Star procedures call for three consecutive homes under production to be tested at the plant to determine whether duct leakage requirements are being met (in this case Qnout ≤ 3%). Prior to these visits, the manufacturer began voluntarily testing all duct systems in all homes throughout the company.

In-plant Duct Blaster Testing

During 2001, plant personnel at 10 facilities were outfitted with a duct blaster and digital manometer and trained in their use with assistance from researchers. Training focused only on those points essential to completing a reliable leakage test and avoided in-depth instruction to keep the test as uncomplicated as possible. Basic duct testing such as this typically adds only a few minutes of time to the production process unless excessive leakage is detected.

Duct leakage guidelines were set at Qnout ≤ 3% company-wide but beyond that each plant was allowed to develop its own duct testing protocol. In most plants the preference was toward early testing, soon after the ductwork was installed. Three such strategies are shown in Figure 4, each of which takes place on the production line while the home is being constructed. The first two photos of Figure 4 (left and center images) show inline and ceiling systems being tested by depressurizing the ducts. In the last photo (right image) a perimeter system is tested by pressurization. The duct blaster is taped to the air handler plenum with the fan blowing into the ducts, which allows for a simple, compact test setup without the need for a flex connection.

Figure 4. In-plant Duct Blaster Testing – Incorporated into Production Line

Inline Floor Ducts | Ceiling Ducts | Perimeter Floor Ducts

A few factories performed duct testing at the end of production as shown at two plants in Figure 5. All plants perform function testing on HVAC, electrical and plumbing systems upon completion of construction, at which time a temporary crossover duct is installed offering an ideal time to test duct leakage for the home as a unit. While duct leaks are more difficult to correct at this stage, the testing conditions are far more controlled and less apt to cause damage to sensitive test equipment.

Figure 5. In-plant Duct Blaster Testing – Performed upon Product Completion

During factory certification, researchers observed duct testing by line workers to ensure proper technique and offered advice on possible improvements to test methodology. Tests were sometimes repeated with researcher equipment.

Field Testing

Energy Star factory certification procedures also call for duct leakage and blower door testing of at least three site-installed homes per plant. Researchers tested 42 homes as part of this effort. Some of these homes were completely installed and occupied, but more often they were located at sales lots where setup was only partially completed. All tested homes were produced after implementation of in-plant duct blaster testing, which offered an opportunity to compare field test results with those recorded in the plant as shown in Table 2.

Table 2. Field-Measured Duct Leakage as Part of Manufactured Home Energy Star Plant Certification Results from 42 homes built in 10 factories					
	Area (ft^2)	**ACH50**	**Qntot**	**Qnout**	**Qnfactory[3,4]**
38 Homes Passed					
Average	1,774	5.66	4.62%	1.39%	2.28%[3]
Maximum	3,116[1]	8.14	9.60%	3.00%	3.48%
Minimum	1,093[2]	3.94	2.44%	0.00%	0.78%
4 Homes Failed					
Average	1,465	5.65	10.30%	4.59%	N/A[4]
Maximum	2,052	6.38	11.50%	5.86%	N/A
Minimum	1,140	4.32	9.05%	3.77%	N/A

Notes: 1. Largest homes were triple-wide models (3 included in data set)
2. Smallest homes were single-wide models (2 included in data set)
3. Factory duct leakage records were available for only 30 of 38 passing homes
4. Not applicable as only 2 of 5 failing homes had factory duct leakage data available

Similar to the other Qn quantities, Qnfactory represents the ratio of duct leakage measured at 25 pascals with respect to floor area. Technically this is a measure of total duct leakage as duct testing is performed on detached home sections that cannot be tested for leakage to out. Depending on the point during production that the test is performed however, the Qnfactory quantity can nearly achieve the same measure as leakage to out. The majority of factory test data collected for this report was done early in the production process when supply and return outlets are easily accessed and can be sealed relatively tightly and is reflected in the data showing factory leakage as being much closer to the field-measured leakage to out than to total leakage. This goes contrary to past studies that estimate duct leakage to out to be 50% of total leakage (MHRA 2003). In this case the manufacturer requires Qnfactory ≤ 3%.

Details on the four field-tested homes that failed the Qnout ≤ 3% duct leakage requirement are provided in Table 3. These homes originated from one of two factories and missed the leakage target by only 1% to 3%. In all but one case, leakage was concentrated on side A, which has additional sealing requirements as that is where the air handler is mounted. These four homes were on average 17% smaller than the typical home that passed and 3 out of 4 were nearly 30% smaller, one being a singlewide unit. This illustrates the increasing difficulty of meeting Energy Star duct leakage criteria as unit size shrinks.

Table 3. Duct Leakage Details on Four Failed Homes						
	Total Duct Leakage			Duct Leakage to Out		
Area (ft^2)	Side A[1]	Side B	Qntot	Side A	Side B	Qnout
1,370	100	24	9.05%	44	10	3.94%
1,296	125	24	11.50%	62	14	5.86%
2,052	145	66	10.28%	50	48	4.78%
1,140[2]	118	N/A	10.35%	43	N/A	3.77%
Notes: 1. Side A has air handler installed 2. singlewide unit						

Conclusion

Ten years of collaboration with the manufactured housing industry has yielded useful information on how this important housing sector can continue to improve the quality and efficiency of its product. HVAC systems in general and ducts in particular have proven to be a key element in providing a safe, durable and energy efficient manufactured home. The Energy Star label for manufactured homes provides individual recognition for this housing type, offering building packages tailored specifically for HUD-code construction and allowing certification at the factory level.

Sealing duct systems in manufactured housing comes at a relatively low cost with the proper use of mastic. Duct Blaster test data taken since 1996 on 190 manufactured home sections show the superiority of mastic over tape for sealing ductwork, with the average mastic-sealed system allowing only 2.4% leakage to out at 25 pascals compared to 5.7% for the average taped system. Use of mastic has proven to be very cost effective as the added cost of implementing a duct-sealing program using mastic ranges from $4 to $8 per floor according to two manufacturers.

One manufacturer has incorporated Duct Blaster testing into its daily operations at 12 plants in six states representing over 8,000 HUD-code homes in fiscal year 2003 (SEC 2004). The testing has proved cost effective toward efforts to consistently provide an energy efficient home that meets Energy Star requirements. Researchers collected duct leakage data during factory certification for Energy Star on 42 homes and found field measurements consistent with leakage measurements obtained by factory personnel.

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References

Chandra, S., K. Fonorow, M. McCloud, N. Moyer, D. Beal, D. Chasar, J. McIlvaine, D. Parker, J. Sherwin, E. Martin, M. Mullens, M. Lubliner, M. McSorley, 2002. *The Building America Industrialized Housing Partnership*. Symposium on Improving Building Systems in Hot, Humid Climates. Houston, Tex.

Cummings, J., C. Withers, L. Gu, J. McIlvaine, J. Sonne, P. Fairey, M. Lombardi, 2002. *Field Testing and Computer Modeling to Characterize the Energy Impacts of Air Handler Leakage*. FSEC-CR-1357-02, Florida Solar Energy Center, Cocoa, Florida.

Cummings, J., J. Tooley, N. Moyer, 1993. *Duct Doctoring: Diagnosis and Repair of Duct System Leaks*, DRAFT. Florida Solar Energy Center, Cocoa, FL.

Cummings, J., J. Tooley, N. Moyer, 1991. *Investigation of Air Distribution System Leakage and Its Impact in Central Florida Homes*. Contract Report, Florida Solar Energy Center, Cocoa, FL, FSEC-CR-397-91.

Davis, B., 1991. *The Impacts of Air Distribution System Leakage on Heating Energy Consumption in Arkansas Homes*. Arkansas Energy Office, Littlerock, Arkansas.

Manclark, Bruce, and Bob Davis. *Duct Improvement in the Northwest, Part II: Mobile Homes*. Home Energy Magazine. Jan/Feb, 1996.

McIlvaine, J., D. Beal, N. Moyer, D. Chasar, S. Chandra, 2003. *Achieving Airtight Ducts in Manufactured Housing*. DRAFT. Florida Solar Energy Center, Cocoa, FL.

MHRA, 2003. *Energy Star Labeled Manufactured Homes: Design, Manufacturing, Installation and Certification Procedures, 2nd Ed*. Manufactured Housing Research Alliance. New York, NY.

MHRA, 2003. *Improving Air Distribution System (ADS) Performance in Manufactured Homes*. Manufactured Housing Research Alliance, New York, N.Y.

Moyer, N., D. Beal, D. Chasar, J. McIlvaine, C. Withers, S. Chandra, 2001. *Moisture Problems in Manufactured Housing: Probable Causes and Cures*. ASHRAE Conference Proceedings IAQ2001. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, Georgia.

NFPA. 2003. NFPA 501: *Standard for Manufactured Housing*. Quincy, Mass.

SEC. Form 10-K, Filed March 26, 2004. Securities and Exchange Commission, Washington, D.C. (http://moneycentral.msn.com/investor/sec/filing.asp?Symbol=US%3aPHHM)

Title 24, Code of Federal Regulations Part 3280, 2001 Department Of Housing And Urban Development [Docket No. FR-4376-P-01] Manufactured Home Construction and Safety Standards