VENTILATION CHARACTERIZATION OF A NEW MANUFACTURED HOUSE

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ABSTRACT

A manufactured home has been installed on the NIST campus for ventilation, energy and indoor air quality studies. The primary purposes of the facility are to study mechanical ventilation requirements for U.S. manufactured homes and to investigate the systems used to meet these requirements. In addition, the building will be used to investigate moisture issues, indoor air quality impacts of combustion appliances, and VOC emissions from building materials and furnishings. The first phase of this multiyear effort has focused on airtightness, system airflows and air change rates. This paper describes the measurement results including envelope and duct airtightness, ventilation system airflow rates, and whole house air change rates under different ventilation configurations and weather conditions. In addition, a model of the building in the multizone airflow program CONTAMW is presented along with comparisons between model predictions and measurements of air change rates. The results indicate that the envelope and air distribution ductwork are fairly leaky, but not unusually high for U.S. manufactured homes, and that the predicted air change rates are in good agreement with the measured values.

KEYWORDS: manufactured homes, mechanical ventilation, modeling, residential

INTRODUCTION

The U.S. Department of Housing and Urban Development (HUD) Manufactured Home Construction and Safety Standards (HUD, 1994) contain requirements intended to provide adequate levels of outdoor air ventilation in manufactured homes. In the implementation of these standards, questions have arisen regarding the actual ventilation rates in homes built to the standards and the mechanical ventilation approaches used to meet the requirements. Questions also exist regarding how duct leakage, local exhaust fans and ventilation inlets affect ventilation rates, air movement patterns, and building pressures. In order to obtain insight into these issues, a modeling study was performed on a manufactured home using the multizone airflow and indoor air quality simulation program CONTAM (Dols and Walton 2002) to investigate different ventilation scenarios (Persily and Martin 2000). Simulations were performed to predict ventilation rates due to infiltration and mechanical ventilation, interzone airflow rates, building air pressures, and ventilation air distribution. The results of that previous modeling study showed that despite the assumption in the HUD standards that infiltration contributes 0.25 h^{-1}, the predicted infiltration rates were lower than this value under many conditions. The mechanical ventilation systems investigated provided ventilation rates that met or exceeded the HUD requirement of 0.35 h^{-1}, but the impacts of such systems were dependent on their operating schedules. In order to investigate these and other issues in the field, and to validate the conclusions of the modeling study, a double-wide manufactured home was constructed on the NIST campus. This paper presents the first phase of this field study, which focused on characterizing the building's airtightness and ventilation.

DESCRIPTION OF HOUSE AND INSTRUMENTATION

The house involved in this study is a double-wide manufactured home consisting of three levels: crawl space, living area and attic. The crawl space is divided into two sections by an insulated, plastic belly, with the region above the belly containing the HVAC ductwork and the volume below vented to the outdoors. The living area, shown in Figure 1, consists of three bedrooms, two bathrooms, and a combined family, kitchen, dining and living area. The attic comprises the volume above the vaulted ceiling, with five roof vents and eave vents spanning the perimeter of the house. Figure 2 provides a schematic of the house, showing the connections between the levels and the air distribution system.

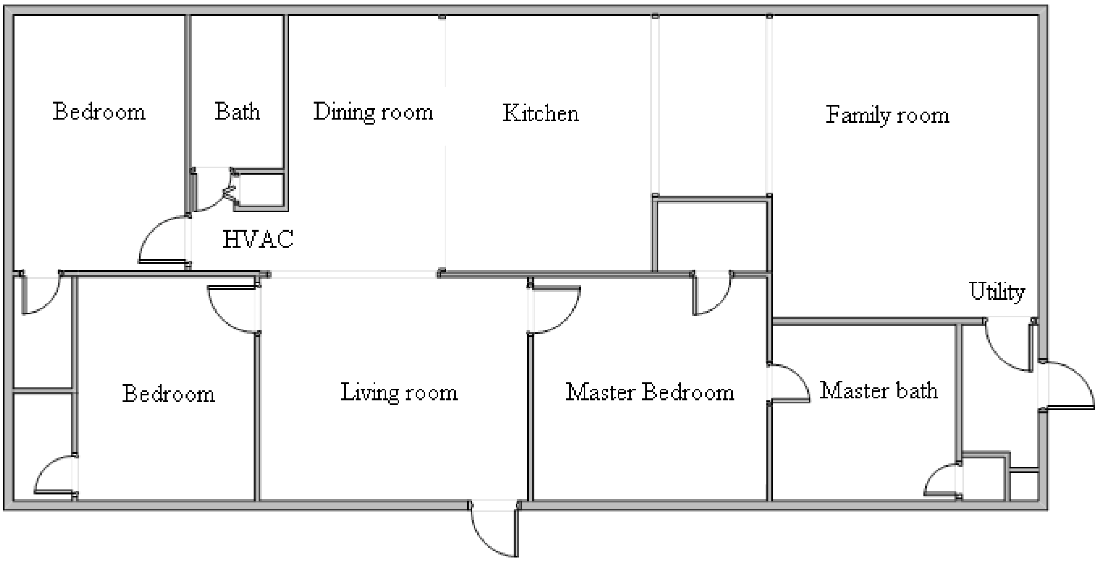

Figure 1: Floor plan of house

The house has a forced air heating and cooling system located off the dining area, with the supply air distribution ductwork located in the belly space and a single return grille located in a panel of the HVAC system closet. There are local exhaust fans in both bathrooms and in the kitchen, as required by the HUD standard. In order to investigate different approaches to meeting the HUD ventilation requirements, there are multiple options for ventilating the building. One is an outdoor air intake duct connected to the return side of the forced air system, which draws in outdoor air whenever the system operates. There is also a whole house exhaust fan located in the ceiling outside the bathroom near the HVAC closet. In addition, every window is fitted with a small vent that can be opened from the inside.

The building is instrumented with an automated data acquisition system for monitoring air temperatures, building pressures, outdoor weather and HVAC operation. In addition, the instrumentation system has an automated tracer gas system for continuous monitoring of building air change rates. The tracer gas system injects sulfur hexafluoride into the house every 4 h to 6 h, allows it to mix to a uniform concentration and then monitors the concentration decay in all the major zones of the building. Air change rates are then calculated based on the tracer gas decay rate in the living space.

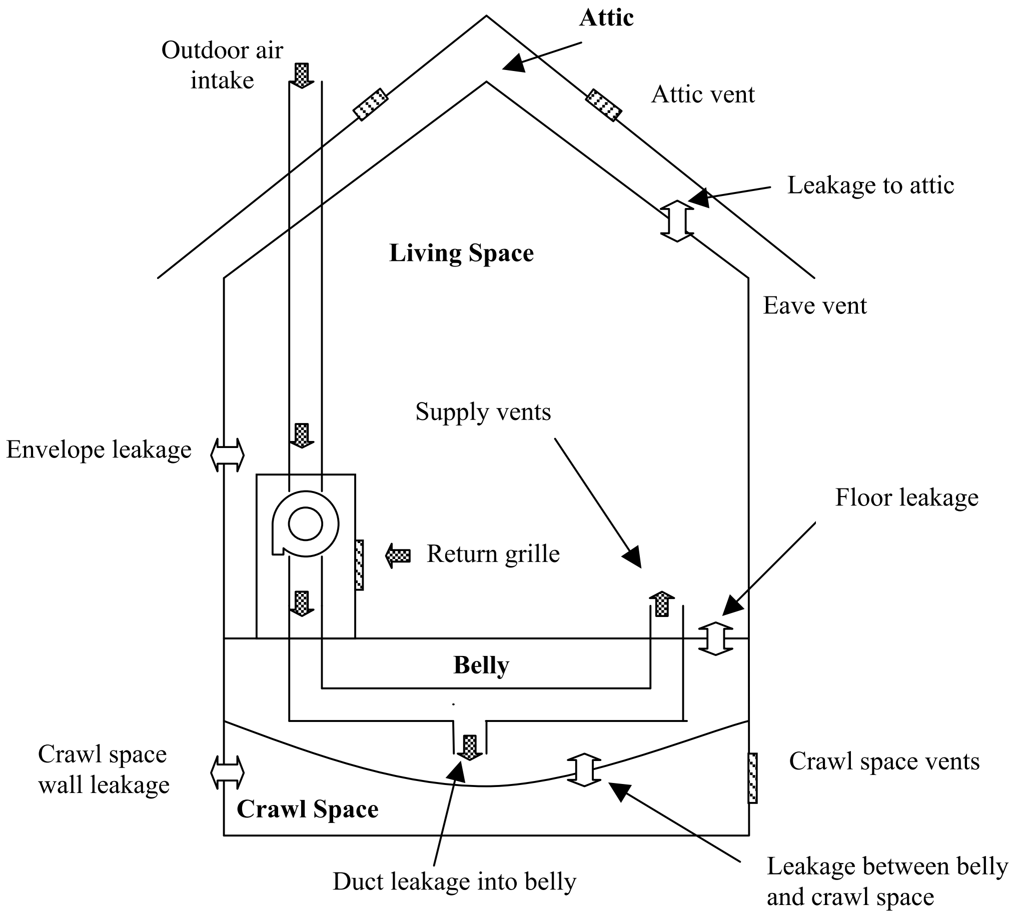

Figure 2: Schematic of House

BUILDING TIGHTNESS MEASUREMENTS

Measurements were made to determine the exterior envelope leakage, the leakage between the living space and the crawl space, and the leakage of the ductwork. Whole building pressurization testing per ASTM E779 (ASTM 1999) was used to determine the whole building airtightness, yielding an air change rate of 11.8 h^{-1} at 50 Pa and an ELA of 728 cm^2 at 4 Pa with the ventilation system unsealed. Tests with the supply vents and return grille sealed yielded an air change rate of 10.1 h^{-1}at 50 Pa and an ELA of 636 cm^2 at 4 Pa. A series of pressurization tests using two blower doors were used to determine the leakage from the living space to the belly, from the belly to the crawl space, and from the crawl space to outside. The results of these tests are included in the description of the house model in the next section. The leakage from the air distribution system was measured using ASTM E1554 (ASTM 1994), yielding a leakage area to the belly volume of 320 cm^2. Comparing these measurements to other recently-constructed U.S. manufactured homes reveals that the building envelope leakage is fairly typical but that the duct leakage is on the high end (Persily and Martin 2000).

HOUSE MODEL

In order to be able to explore alternate system configurations and the impacts of airtightness and system retrofits, a model of the house was developed in the multizone airflow and indoor air quality model CONTAM (Dols and Walton 2002). The model contained four levels: crawl space, belly volume, living area and attic. The duct modeling capabilities of CONTAM were employed to model the forced-air system. The leakage values of the airflow paths in the model are listed in Table 1. The leaks in the living space envelope include the exterior wall, the interfaces between the ceiling and wall, the floor and wall, and the walls at the corners. In addition, there are two types of windows, the exterior doors and the living space floor, which contains openings into the belly. There are also a number of interior airflow paths, including leaks in the walls, doorframes and open doors. Note that for all the tests described in this report, all interior doors were open. The attic has leakage in its “floor,” i.e., the ceiling of the living space, as well as the two types of attic vents to the outdoors. The crawl space has leaks to the outdoors in the walls, vents located in the front and rear of the house, and an access door. The model also includes a leak from the crawl space into the belly. Finally, the duct leak into the belly, based on the measurement described above, is included in the model.

	Exterior airflow paths	**ELA at 4 Pa**
Living space envelope	Exterior wall	0.14 cm^2/m^2
	Ceiling wall interface	0.81 cm^2/m
	Floor wall interface	1.24cm^2/m
	Window #1	5.00 cm^2
	Window #2	1.94 cm^2
	Corner interface	0.808 cm^2/m
	Exterior doors	18.7 cm^2
	Living space floor to “belly” volume	3.65 cm^2/m^2
Interior airflow paths	Interior walls	2 cm^2/m^2
	Bedroom doorframe	410 cm^2
	Open interior doors	2 m x 0.9 m
	Bathroom doorframe	330 cm^2
	Interior doorframe	250 cm^2
	Closet doorframe	4.6 cm^2
Attic	Attic floor	2 cm^2/m^2
	Roof vents	0.135 m^2
	Eave vents	106 cm^2/m
Crawl space and belly	Exterior walls of crawl space	25 cm^2/m^2
	Rear crawl space vents	323 cm^2
	Front crawl space vents	465 cm^2
	Crawl space access door	206 cm^2
	Crawl space to “belly”	258 cm^2
	Duct leak into belly	320 cm^2

Table 1: CONTAM model leakage values

AIR CHANGE RATE MEASUREMENTS AND PREDICTIONS

Figure 3 shows the measured and predicted air change rates with the forced-air system off as a function of indoor-outdoor air temperature difference under low wind speed conditions. The values predicted with the CONTAM model of the house are in good agreement with the measurements, particularly at low values of ΔT, but tend to underpredict by around 20 % at higher values. Note that in all the reported measurements and predictions, the outdoor air intake on the forced-air system and the window inlet vents are closed.

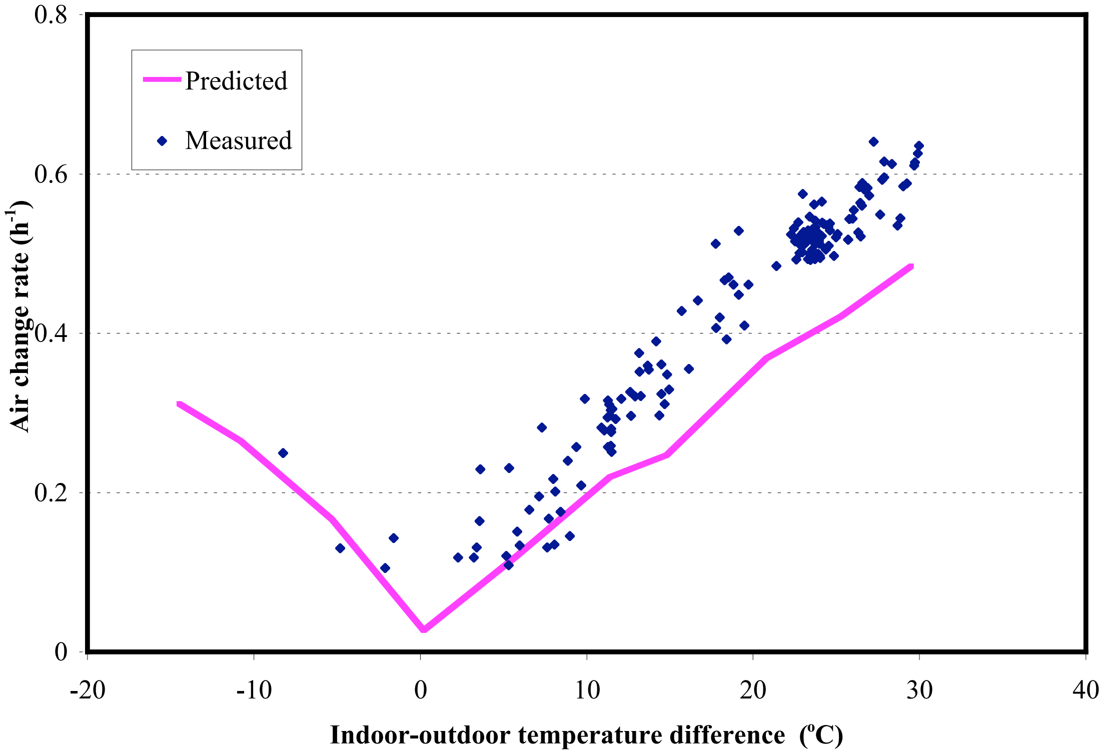

Figure 3: Measured and predicted air change rates, system off (wind speed < 2 m/s)

Figure 4 is a plot of the measured and predicted air change rates with the forced-air system on, again for low wind speeds. Under positive temperature differences, the measured air change rates are actually lower than with the system off, which might not be expected with significant duct leakage. Airflow measurements indicate that the system moves about 450 L/s, but about 125 L/s is lost through duct leakage into the belly. Some of this airflow returns to the living space via leaks in the floor, but some flows through the crawl space to the outdoors, which tends to depressurize the house. A significant air change rate is seen at zero ΔT, but this is not unexpected given the duct leakage. At higher values of ΔT, the stack effect "competes" with the duct leakage into the belly, decreasing the air change rate into the house. This effect has actually been proposed as a means of controlling airflow and contaminant entry from crawl spaces (Phaff and De Gids 1994). Overall, with the fan on, the agreement between the predicted and measured air change rates is quite good.

ADDITIONAL WORK

This study has characterized the airtightness and ventilation system of a manufactured house. In addition, a CONTAM model of the house and system has been developed and shown to provide reliable predictions of whole building air change rates. Next phases of the project will include a more detailed validation of the CONTAM model in terms of predicted pressures between zones and impacts of operating local exhaust fans. As a result, the model will be refined and more complete comparisons between predictions and measurements will be performed. In addition, emission rates of volatile organic compounds (VOCs) from building materials and furnishings have been monitored periodically since the summer of 2002. These results will be analyzed to evaluate changes in emissions as a function of time, temperature and ventilation rate. Finally, a retrofit study of the house is planned to evaluate the impacts of reduced duct leakage and increased envelope airtightness.

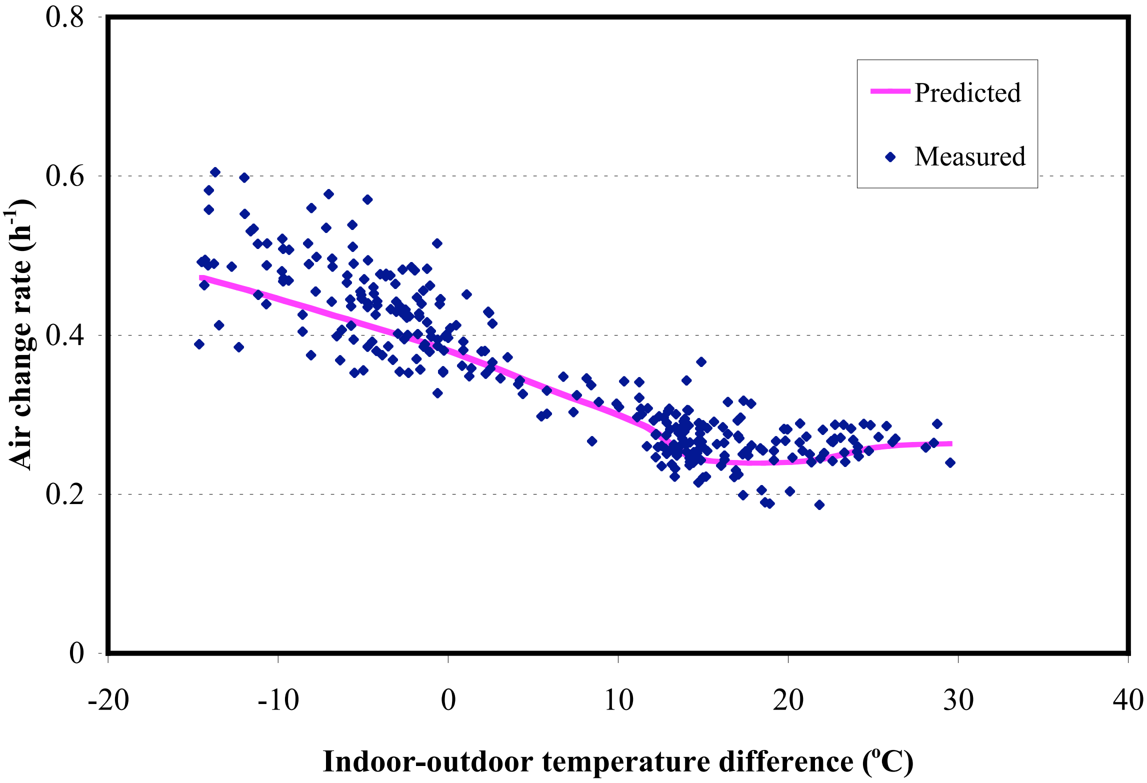

Figure 4: Measured and predicted air change rates, system on (wind speed < 2 m/s)

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