MODELING MOISTURE IN RESIDENTIAL BUILDINGS WITH A MULTIZONE IAQ PROGRAM

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ABSTRACT
Although water vapor is not typically thought of as an indoor contaminant, multizone indoor air quality (IAQ) modeling can be used to predict water vapor concentrations in each zone by applying mass balance equations that incorporate water vapor sources and sinks. However, very few attempts have been made to model water vapor with a multizone IAQ program and such modeling presents unique issues including the appropriateness of model assumptions, the adequacy of moisture storage and generation models, availability of input data, and metrics for analysis.

This paper describes measurements of humidity and other IAQ parameters in a single zone test house. Experiments included generation of water vapor with a humidifier during a variety of ambient conditions. Moisture storage and generation elements were then added to a previously validated airflow model of the building to evaluate the capability of the CONTAMW multizone IAQ model to predict indoor humidity levels.

INDEX TERMS
Humidity, Modeling, Residential.

INTRODUCTION
The U.S. Department of Housing and Urban Development (HUD) is undertaking a major effort to “develop and implement a program of research and demonstration projects that would address multiple housing-related problems affecting the health of children” (HUD 1999). As an outcome of a meeting of leading experts, HUD focused its Healthy Homes Initiative (HHI) around 4 major issues – excess moisture control, dust control, improving air quality, and education. The primary path for the HHI effort is a series of field demonstration projects to implement and evaluate various interventions to address these four issues in deficient urban housing. Due to the costs of field-work, the HHI demonstration projects are only able to implement a limited number of interventions in a small number of houses. However, use of a valid model can allow the evaluation of many potential interventions in a wide variety of houses to provide the knowledge base for recommending future use of the most cost-effective strategies. In support of the HHI effort, NIST is developing a validated multizone airflow and IAQ model of a townhouse using the CONTAM IAQ simulation program and will use the model to analyze the impact of various housing interventions. The model can also be used to evaluate the interventions for possible unintended negative impacts.

Multizone airflow and contaminant transport modeling is a valuable tool for researchers and others studying indoor air quality (IAQ) problems in buildings, including moisture-related

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issues. Multizone IAQ modeling takes a macroscopic view of indoor air quality by evaluating average pollutant concentrations in different zones of a building as contaminants are transported through the building and its HVAC system. Although water vapor is not typically thought of as an indoor contaminant, multizone IAQ models can be used to predict water vapor concentrations in each zone by applying mass balance equations that incorporate water vapor sources and sinks. However, very few attempts have been made to model water vapor with a multizone IAQ program as most efforts modeling moisture in buildings have used models that focus on transport of moisture through a building envelope such as the MOIST model developed at NIST (Burch and Chi 1997) and other models described in the ASTM Moisture Control Handbook (Trechsel 1987). Modeling water vapor with a multizone IAQ model presents issues such as the appropriateness of current model assumptions, the adequacy of moisture storage and generation models, availability of input data, lack of diffusion model, and metrics for analysis.

For example, a recent report described a modeling study of the effectiveness of various ventilation options in a two-story house located in Spokane, WA (Persily 1999). This study included water vapor as one of the indoor contaminants simulated with the CONTAM (Walton 1997) program. Simulating humidity in the house required assumptions for moisture sources (occupants, bathing, dishwashing, gas cooking, and outdoor humidity), storage, and removal due to air conditioning. Figure 1 presents a sample of the humidity simulation results showing the average monthly indoor humidity under various ventilation system assumptions. While this study shows the insight that may be gained from such a modelling effort, the simulation results cannot be relied upon until the humidity modelling assumptions have been validated. This paper describes an experimental effort to validate some of these assumptions primarily the moisture storage model.

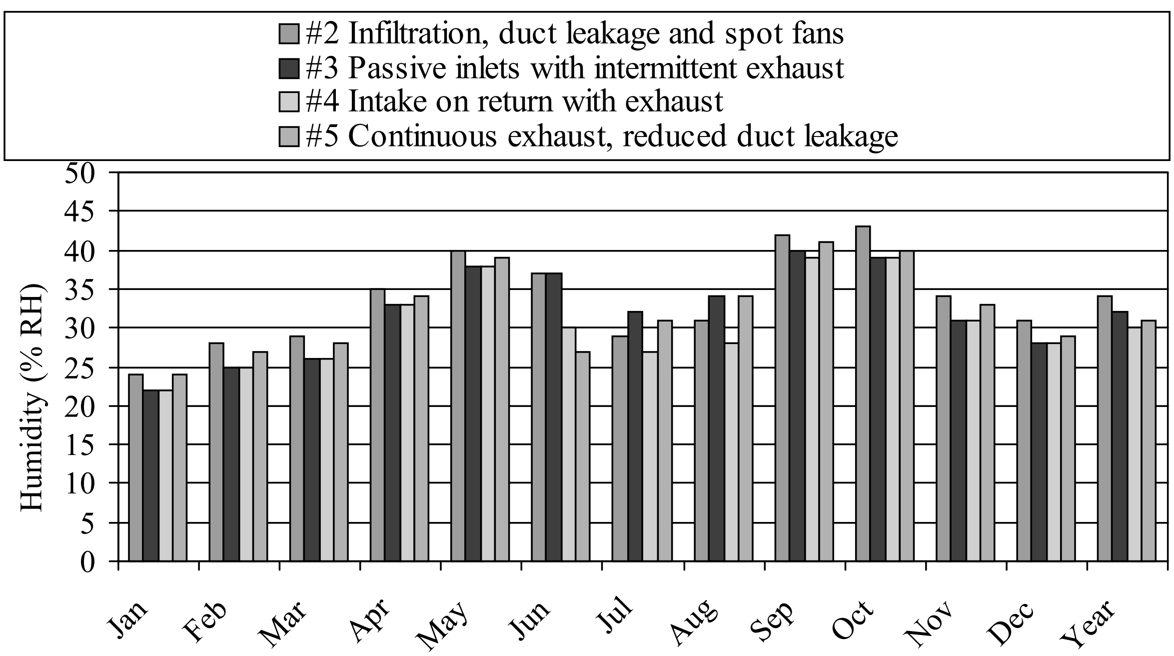

Figure 1. Average indoor humidity with various ventilation options

METHODS

Experimental

Experiments were conducted in a single-room test house located on the NIST campus (see Figure 2). The house has a floor area of 37 m^2 (400 ft^2) and a ceiling height of 2.3 m (7.5 ft). Its construction details include uninsulated wood-frame walls, paneled wood exterior, painted gypsum board interior, slab-on-grade foundation, unpainted concrete floors, vented attic, asphalt-shingled roof, two double-hung windows on the north and south walls, and a metal exterior door on the east wall. A fan pressurization test, performed according to ASTM Standard E779-99 (ASTM 1999), found the building air change rate at 50 Pa to be 7.3 h^{-1} and the effective leakage area at 4 Pa to be 140 cm^2 (21.1 in^2). The test house has a simple heating and cooling system with a nominal recirculation flow of 0.17 m^3/s (360 cfm). As is typical for residences, the system has no outdoor air intake.

Instrumentation used in the test house included an automated tracer gas decay system for air change rates, thermistors for indoor and outdoor tempatures, bulk polymer resistance sensors for indoor and outdoor relative humidity, a sonic anemometer for local wind speed, and a hot wire anemometer for HVAC system air flow. Per the manufacturer, the RH sensors have an accuracy of 3 %RH or better in field conditions. A typical residential room humidifier was used as a water vapor source. This test house has been instrumented for IAQ measurements for several years, and Emmerich and Nabinger (2001) describes the instrumentation in more detail.

Figure 2. Single zone test house

Simulation

The test house described in the measurement section was modeled using CONTAMW (Dols et al. 2000) - a program for analyzing the air movement and IAQ in multizone buildings. CONTAMW has a graphic interface, or Sketchpad, used to create and edit a description of a building's features relating to airflow and the generation and removal of contaminants. This data along with ambient weather and pollutant contaminant data are used to calculate the airflows and concentrations of indoor contaminants. An airflow model of this house created and validated in an earlier project (Emmerich and Nabinger 2001) was used as the basis for the simulations.

The baseline model of the house was modified to account for moisture sources (the humidifier and outdoor humidity), storage, and removal due to air conditioning. In an earlier indoor humidity modelling effort, Persily (1999) used a moisture storage model developed at the Centre Scientifique et Technique du Batiment (CSTB) (Jones 1995) based on its mathematic similarity to an existing CONTAM sink model. In contrast to the CSTB model that relies on two empirical constants, the boundary layer diffusion controlled (BLDC) sink with a linear adsorption isotherm is based on fundamental mass transport principles (Axley 1990). The BLDC model has the form of equation 1:

$$S(t) = h\rho A(W_i - W_s/K) \quad (1)$$

In equation 1, h is the surface-average mass transfer coefficient (estimated to be 0.72 m/h), ρ is the film density of the air (taken as 1.2 kg/m^3), A is the surface area of the sink (estimated to be 65 m^2), W_i is the water vapor concentration in the air, W_s is the moisture concentration in the sink material, and K is the partition coefficient (estimated to be 5). More recent work has indicated that the BET sorption isotherm may be more appropriate for situations like moisture in buildings where concentrations may be within an order of magnitude of their saturated values (Axley 1995). For this study, the BLDC model parameters were estimated from fundamental principles.

Since CONTAM lacks a cooling coil model, removal of moisture by the air conditioning system was modelled as a constant water ‘filter’ that operated only when the air conditioning was on. Based on observations of the operation of the test house air conditioning system, a filtration efficiency of 3 % was used in the model.

RESULTS

Experimental and simulated results are presented for two test periods:

- A single day test on March 6, 2001 during which outdoor humidity was low and the humidifier was used as a constant source of moisture for four hours.
- A three day test from June 29, 2001 through July 1, 2001 during which outdoor humidity was high but variable and no indoor source of moisture was used.

Figure 3 presents a comparison of measured and predicted indoor humidity ratio for the March 6th test. While the very close agreement of the CONTAM predictions with the sink model to the measurements is not expected to be a typical result, clearly the sink model is needed to moderate the humidity increase due to the source operation.

Figure 4 presents a comparison of measured and predicted indoor humidity ratio for the June 29th to July 1st test. While the CONTAM prediction with sink does not so closely match the measurements for this case, it certainly seems to capture the trends and once again performs far better than the prediction without a sink model.

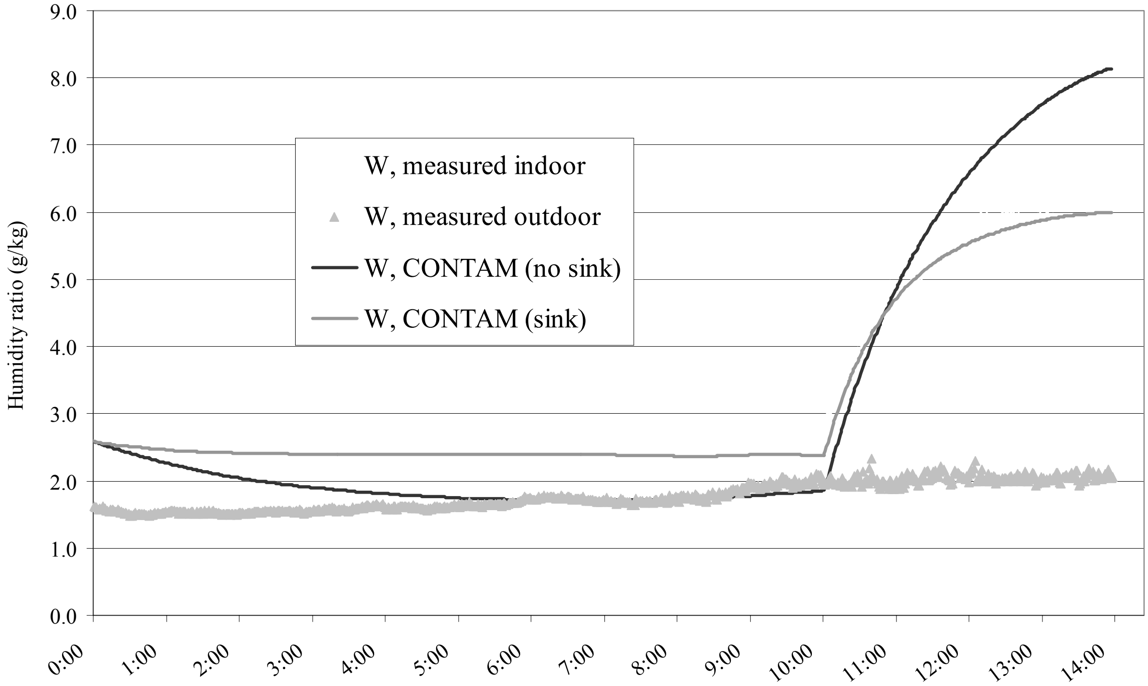

Figure 3. Comparison of measured and predicted humidity ratio for March 6

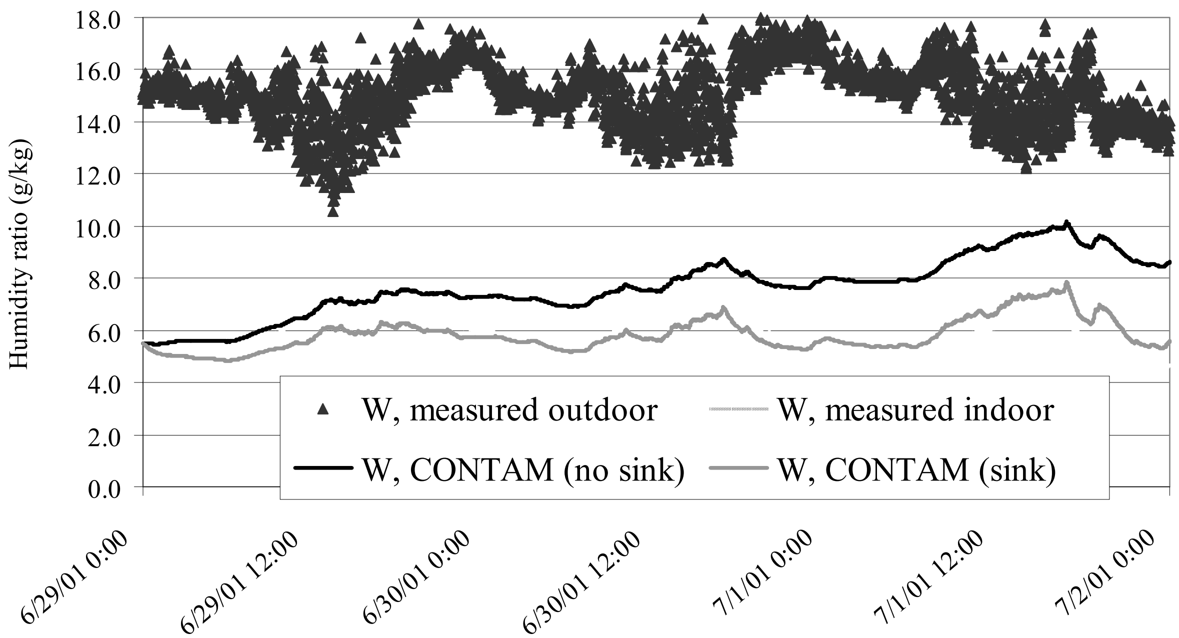

Figure 4. Measured and predicted indoor humidity ratio for June 29 to July 1

DISCUSSION

While the measurement and prediction comparisons presented above are promising, they must be recognized as preliminary. The test conditions are obviously limited in number, concentration range, duration, and in the simplicity of the test house configuration. Work is ongoing at NIST to evaluate model predictions for additional test cases in the single zone test house, in an occupied townhouse, and in a new manufactured test house.

Additionally, the comparisons of model predictions and measurements need to be analysed using valid statistical methods such as those contained in ASTM Standard Guide D5157 *Standard Guide for Statistical Evaluation of Indoor Air Quality Models* (ASTM 1991) and applied in an earlier study of CONTAM predictions of indoor particle concentrations (Emmerich and Nabinger 2001).

CONCLUSION AND IMPLICATIONS

Currently, CONTAMW and similar IAQ models can be used to model water vapor as an indoor contaminant using existing elements but questions exist regarding validity and interpretation of results. A study is underway to experimentally validate model predictions of indoor humidity and to identify needed model improvements. Early comparisons of model predictions to measured data are promising but more work including statistical analysis of such comparisons is needed.

ACKNOWLEDGEMENTS

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