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SURFACE EMISSION MONITORING OF PRESSED-WOOD PRODUCTS CONTAINING UREA-FORMALDEHYDE RESINS

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A survey of formaldehyde (CH_2O) emission rates from U.S.-manufactured particleboard, hardwood plywood paneling, and medium density fiberboard products has been performed using a Formaldehyde Surface Emission Monitor (FSEM). The results indicate approximately two orders of magnitude variation in CH_2O emission rates between weakly emitting paneling and strongly emitting fiberboard products. The measured CH_2O emission rates for particleboard, paneling, and fiberboard products averaged 0.30, 0.17 and 1.5 mg/m^2 h, respectively. Sources of variation in CH_2O emission rate data among the survey boards are investigated. The relative intraboard, interboard, and intermanufacturer variation observed in the test data varies strongly between particleboard, paneling, and fiberboard product categories. The FSEM has also been used to determine the CH_2O emission rate of carpet-covered particleboard underlayment in two unfurnished research homes. Measurements were conducted at 16 different temperature and relative humidity (RH) conditions ranging from 17–29 °C and 41%–88% RH to field-test the response of the FSEM to varying CH_2O emission strength resulting from the variable environmental conditions. Substituting the FSEM CH_2O emission rate data into a simple steady-state, CH_2O concentration model (that does not account for variation in temperature and RH conditions) gave good agreement between FSEM-modeled and measured CH_2O concentrations.

Introduction

Formaldehyde (CH_2O) is an important indoor air pollutant (Gough *et al.*, 1983) that is emitted by a variety of formaldehyde resin-containing products in indoor environments (Calvert, 1981). Pressed-wood products containing urea-formaldehyde (UF) resins are among the strongest and most commonly used CH_2O emitters in indoor environments (Pickrell *et al.*, 1983; Matthews *et al.*, 1985a). Formaldehyde emissions from UF resin-bonded particleboard and hardwood plywood paneling products have been measured using a variety of chemical extraction, small-scale static chamber, and small- to large-scale dynamic chamber methods (Meyer, 1979). In North America, a 2-h desiccator test and large-scale environmental chamber test, called FTM-1 and FTM-2, respectively, are most commonly used by the pressed-wood industry (NPA, 1983). The chamber test is used to predict the potential impact of pressed-wood products under specified product loading, air exchange, temperature, and relative humidity (RH) conditions on indoor CH_2O concentrations. The desiccator test is a sample-destructive quality control test. Neither method is suitable for field measurements.

A passive formaldehyde surface emission monitor (FSEM) has been developed for nondestructive measurement of formaldehyde (CH_2O) emission rates from the surface of CH_2O resin-containing products (Matthews *et al.*, 1984). The FSEM is a short tubular monitor constructed from a 20-cm mechanical sieve that seals with a compressible flange to a flat test surface. Emissions specific from the measurement site are sorbed inside the FSEM on a planar distribution of 13× molecular sieve. The sorbent is analyzed for CH_2O using a water-rinse desorption and colorimetric analysis procedure. Unlike passive vapor monitors such as the Palmes tube (Palmes *et al.*, 1976), the CH_2O sampling rate of the FSEM depends primarily on board-limited CH_2O transport to the surrounding vapor phase rather than air movement across the opening of the monitor (Matthews *et al.*, 1984). As a re-

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sult, the sampling rate is insensitive to variation in the pathlength between the sorbent and test surface.

The FSEM has been used to measure the CH_2O emission rates from a variety of CH_2O resin-containing products including urea-formaldehyde foam insulation, urea- and phenol-formaldehyde bonded pressed-wood products (Matthews *et al.*, 1984), fibrous glass insulation, and ceiling tiles (Matthews *et al.*, 1986a). Strong, approximate 1-to-1, intermethod correlations between CH_2O emission rates measured with the FSEM and small-scale chamber tests have been observed, particularly for pressed-wood products and urea-formaldehyde foam insulation encased in simulated wall panels (Matthews *et al.*, 1984, 1986b). A preliminary portion of National Particleboard Association studies comparing the response of the FSEM to the 2-h desiccator test and large-scale chamber test (operated at 24 °C, 50% RH, and several different air exchange to loading ratios) has been reported (Zinn, 1984). A somewhat modified FSEM methodology was used, including a 1-week product-conditioning period, two measurement sites per test board (i.e., of area > 1.4 m^2) and a centrifuge to remove particulates from molecular sieve rinse solutions. Although moderately good intermethod correlations between the FSEM and industrial tests were generally found, inconsistent rankings of board emissions between the FSEM and chamber tests were observed under some chamber loading and air exchange conditions. An intermethod, linear regression analysis between the results of 56 boards tested with the FSEM (i.e., dependent variable with units of mg CH_2O/m^2h) and 2-h desiccator test (i.e., independent variable with units of $\mu gCH_2O/mL$ H_2O) yielded a slope, intercept, and r^2 correlation coefficient of 0.37 {(mg · mL)/(m^2 · h · μg)}, 0.15 mg/m^2h, and 0.88, respectively.

In this paper, the FSEM results of a laboratory survey of CH_2O emission rates from U.S.-manufactured particleboard, paneling, and fiberboard products and field measurements of CH_2O emission rates from carpet-covered underlayment in unoccupied research homes are presented. The purpose of the pressed-wood product survey was to estimate the potential distribution of CH_2O emission rates from contemporary products commonly incorporated in conventional U.S. housing. FSEM measurements were performed on all acquired samples to provide intrasample, interboard, intermanufacturer, and interproduct comparisons. Environmental chamber tests were also performed on a subset of the boards for intermethod comparison with the FSEM using strict product conditioning and testing protocols (Matthews *et al.*, 1986b). FSEM measurements of CH_2O emission rate were conducted inside two unoccupied research homes under a variety of temperature and RH conditions as part of a study to investigate the impact of indoor temperature and RH on indoor CH_2O concentrations (Matthews *et al.*, 1985b). The FSEM tests were performed on the predominant CH_2O emission source, carpet-covered particleboard underlayment, to monitor temperature- and RH-dependent changes in CH_2O emission rate. The results are evaluated by substituting the CH_2O emission rate data into a steady-state CH_2O concentration model (that does not account for variation in temperature and RH) to compare against measured CH_2O levels. This analysis provides a field test of the FSEM for CH_2O emissions from a predominant pressed-wood emission source under a variety of controlled temperature, RH, and air exchange conditions.

Experimental Designs and Methods

Pressed-Wood Product Survey

The pressed-wood product survey included particleboard underlayment, industrial particleboard, print-, paper-, and domestic veneer-overlayed hardwood plywood paneling, and medium density fiberboard materials acquired from a total of seven different U.S. manufacturers. Six 1.2 × 1.2 m samples were collected from each of the three largest U.S. manufacturers of each product category, comprising a total of 108 samples. Some manufacturers contributed samples to more than one product category. All boards were selected by members of the U.S. Consumer Product Safety Commission and the industry during unannounced visits to manufacturing plants to obtain a random selection of available materials in each product category (Medford, 1983). All samples were collected between January and June 1983. Each group of six boards represented a minimum of two populations of boards based on different manufacturing dates for particleboard and fiberboard products, and on different overseas suppliers of hardwood plywood substrates for paneling products (Matthews *et al.*, 1985c).

Prior to FSEM testing, all boards were conditioned for ≥2 weeks at approximately 22 ±3 °C, 50 ±15% RH, and ≤0.2 mg/m^3 CH_2O to achieve approximate steady-state emission levels. Tighter environmental control was maintained during FSEM measurements at typically 23.5 ±1.5 °C and 50 ±10% RH. All boards for a given manufacturer and product classification were tested simultaneously to avoid interboard variation due to changes in environmental conditions. All boards were tested on a single side; hardwood plywood paneling samples were tested on the decorative side. FSEM testing typically occurred 3 to 10 weeks after sample collection at the manufacturing plant.

An experimental protocol for FSEM testing of CH_2O emissions from pressed-wood products has been previously published (Matthews *et al.*, 1983). The preparation, CH_2O exposure, water-rinse desorption, and analysis of 13× molecular sieve sorbent,

pararosaniline colorimetric analysis procedure for CH_2O, and pressed-wood product conditioning and measurement techniques are discussed. Refinements to the water-rinse desorption and CH_2O colorimetric analysis of the molecular sieve sorbent have also recently been reported (Matthews *et al.*, 1986b). The primary change is the use of a centrifuge in place of filter paper to remove microparticulate matter from the sieve rinse solution during the CH_2O desorption of the molecular sieve (Zinn, 1984). The recommended number of FSEM measurement sites on a test board has also been clarified to better compensate for intra-sample variability in CH_2O emissions from pressed-wood products. Previously, a minimum of two measurement sites was recommended for samples as small as 0.5 m^2, but no specific recommendation was offered for larger samples. The current protocol recommends a minimum of three sites for 1.2 × 1.2 m or smaller samples, and a minimum of five sites for larger samples. In the survey, three sites with roughly equal intersite and site-edge spacing were chosen. The 3σ lower limit of detection for the FSEM in these tests was approximately 0.025 mg/m^2h (Matthews *et al.*, 1984).

Measurements in Research Houses

The experimental design of the FSEM studies inside the unoccupied research homes involved 3- to 5-day conditioning and measurement periods at 16 different environmental conditions spanning 17–29 °C and 41%–88% RH. Temperature and RH levels were controlled for 2–4 days prior to simultaneous CH_2O concentration, air exchange, and FSEM CH_2O emission rate measurements to obtain quasi-steady-state conditions inside the homes. Continuous operation of internal circulation fans tended to stabilize the temperature, RH, and air exchange rates of the homes and provided internal mixing for air exchange rate measurements using tracer gas decay techniques.

An illustration of the design of the research houses and the measurement sites for the FSEM, CH_2O vapor concentration, and air exchange rate are shown in Fig. 1. FSEM measurements of carpet-covered underlayment were performed at a total of five sites in the living room and three bedrooms. Formaldehyde vapor concentration measurements were performed at three sites in the houses with 30-min, 30-L pumped vapor samples using 13× molecular sieve sorbent (Matthews *et al.*, 1982). Similar refinements in the water-rinse desorption and colorimetric analysis protocol to those described for the FSEM were used (Matthews *et al.*, 1986b). Tracer gas decay measurements of the air exchange rates of the houses were performed by monitoring the decline in Freon concentration with a single-beam infrared spectrometer (Hawthorne *et al.*, 1984).

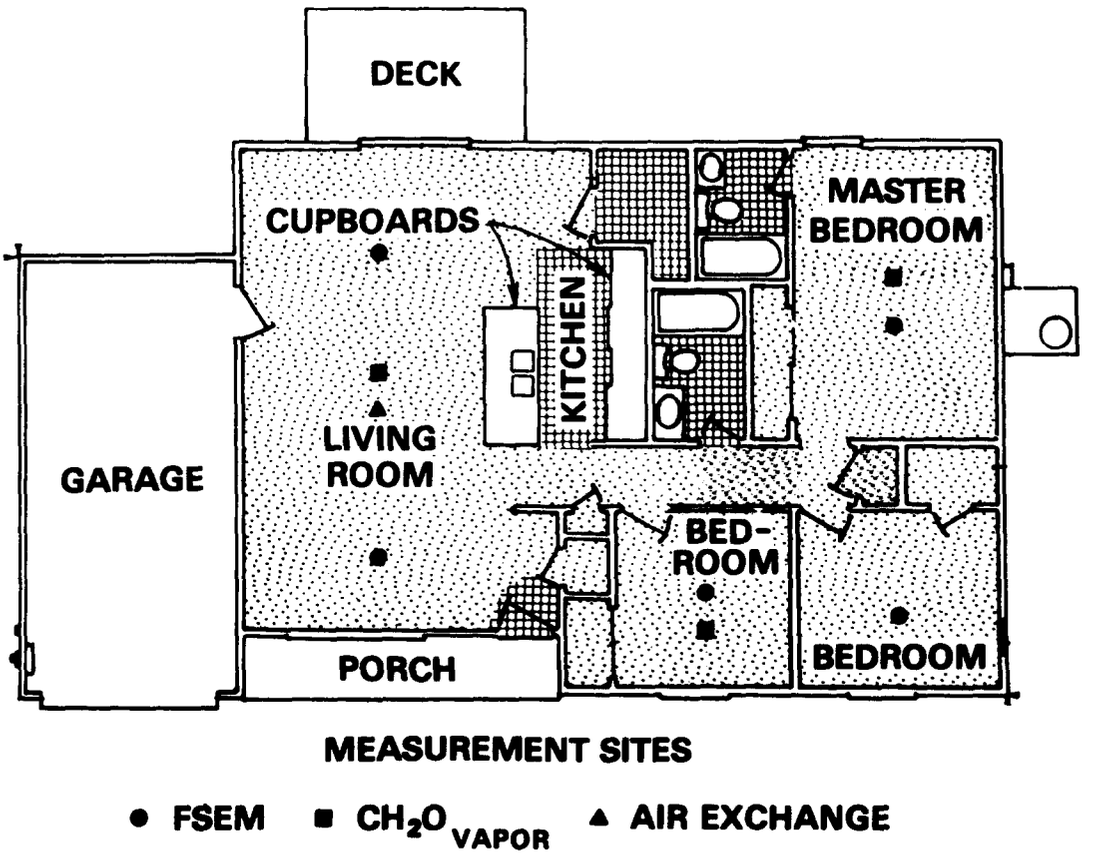

Fig. 1. Measurement sites in ORNL unoccupied research houses.

Table 1. Average CH_2O emission rate data[a] for particleboard underlayment (PBU), industrial particleboard (PBI), print- (PR), paper- (P), and domestic veneer- (D) overlayed hardwood plywood paneling, and medium density fiberboard products.

Manufacturer	Particleboard		Hardwood Plywood Paneling			Medium Density Fiberboard
	PBU	PBI	PR	P	D	
1	0.13 ± 0.02	0.18 ± 0.02	0.13 ± 0.12	0.08 ± 0.03	0.13 ± 0.05	1.77 ± 0.22
2	0.18 ± 0.02	0.28 ± 0.03	0.47 ± 0.13	0.19 ± 0.06	0.11 ± 0.02	0.91 ± 0.18
3	0.58 ± 0.13	0.47 ± 0.11	0.25 ± 0.15	0.08 ± 0.03	0.13 ± 0.05	1.78 ± 0.45
Product Average	0.30 ± 0.22	0.31 ± 0.14	0.28 ± 0.20	0.11 ± 0.07	0.12 ± 0.04	1.49 ± 0.50
Corrected[b] Product Average	0.32 ± 0.27	0.33 ± 0.17	0.30 ± 0.25	0.09 ± 0.08	0.10 ± 0.05	1.81 ± 0.64

[a]All manufacturer-average emission data are determined from the average emission rates of six individual boards.
[b]$E_{corrected} = (E_{raw} - 0.04)/0.80$, based on an empirical relationship between FSEM and environmental chamber data.

Results and Discussion

Pressed-Wood Product Survey

A summary of the FSEM results for the particleboard, hardwood plywood paneling, and medium density fiberboard products are given in Table 1 (see Matthews *et al.*, 1985c for a detailed listing of the raw experimental data). For each of six product categories, the average CH_2O emission rate of six tests boards are listed for each of three different manufacturers. The manufacturer-average CH_2O emission rates span approximately twentyfold from 0.08 to 1.8 mg/m²h for paneling with paper overlay and medium density fiberboard products, respectively. For individual boards, the CH_2O emission rates span nearly two orders of magnitude from 0.03 to 2.3 mg/m²h with log normal distributions among the particleboard and paneling emission data (Matthews *et al.*, 1985b). The generic ranking of products in order of increasing CH_2O emission strength is paneling and particleboard materials (with strongly overlapping distributions of emission rates), followed by fiberboard samples, which have by far the strongest emission factors. The average CH_2O emission rates for all tested hardwood plywood paneling, particleboard, and medium density fiberboard products are 0.17 ±0.14, 0.30 ±0.18, and 1.5 ±0.5 mg/m²h, respectively.

The relationship between the response of the FSEM and small-scale environmental chamber tests of CH_2O emission rates from pressed-wood products has been previously investigated (Matthews *et al.*, 1984, 1986b). An approximate 1-to-1 linear relationship between the CH_2O emission rates determined with the FSEM (E_F) and environmental chamber tests (E_c) interpolated to 0.1 ppm CH_2O has been empirically determined for a wide variety of pressed-wood products. The root mean square error for the regression of the FSEM and interpolated chamber data is 0.05 mg/m²h:

$$E_F = 0.80 \cdot E_c - 0.04. \quad (1)$$

Correcting the FSEM-emission rate data to those predicted for chamber experiments on the basis of Eq. (1) results in a 20% increase for strong emitters (i.e., >0.5 mg/m²h), <10% change for moderate emitters (i.e., 0.15–0.35 mg/m²h) and proportionally larger decreases for weak emitters (i.e., <0.1 mg/m²h). The results of this correction, which has been applied to the average CH_2O emission rate for each survey board, are shown in Table 1. Only small changes in manufacturer-average CH_2O emission rates (i.e., <0.02 mg/m²h) are observed for most particleboard and paneling product categories.

An important goal of the pressed-wood product survey was to characterize the sources of variation in the measured CH_2O emission rates among the test boards and to separate the variability of the test method from these results. A comparison of the intraboard, interboard, and intermanufacturer variation in CH_2O emission rates among the six particleboard, paneling, and fiberboard product categories is considered. To quantitate the interboard and intraboard variability of the CH_2O emission data, a one-way analysis of variance (Snedecor and Cochran, 1973) has been performed on the particleboard, paneling, and fiberboard data sets. The statistical model assumed for the total of 18 CH_2O emission rates measured from six boards in each manufacturer-product combination is

$$E_{ij} = \mu + \beta_i + \epsilon_{ij}, \quad (2)$$

where E_{ij} is the jth measurement of the ith board; μ is the population mean for the manufacturer-product combination; β_i is the between-board variation in CH_2O emission rate, which is assumed to be random with variance σ^2_{inter}; and ϵ_{ij} is the combined within-board variation and measurement error with variance σ^2_{intra}. An estimate of the inter-board variance (i.e., σ^2_{inter}) is calculated as

$$\sigma^2_{inter} = (\text{Model Mean Square} - \text{Error Mean Square})/3, \quad (3)$$

where

$$\text{Model Mean Squares} = \left[\sum_{i=1}^{6}\left(\sum_{j=1}^{3} E_{ij}\right)^2/3 - \left(\sum_{i=1}^{6}\sum_{j=1}^{3} E_{ij}\right)^2/18\right]/5$$

and

$$\text{Error Mean Squares} = \left[\sum_{i=1}^{6}\sum_{j=1}^{3} E_{ij}^2 - \sum_{i=1}^{6}\left(\sum_{j=1}^{3} E_{ij}\right)^2/3\right]/12.$$

Note that σ^2_{inter} is the minimum variance that can be achieved assuming an ideal analytical method that measure the CH_2O emission rate of the entire test sample, account for all intrasample variation in emission strength (i.e., $\sigma^2_{inter} = 0$). This is the best estimate of strict interboard variance within each manufacturer-product combination. The intraboard variance is estimated as

$$\sigma^2_{intra} = \text{Error Mean Square.} \quad (4)$$

This is a combination of the measurement error of the analytical method for a temporally and spatially invariant source (i.e., 5%–10%, Matthews *et al.*, 1984) and the intraboard variance of the measured board based upon the sampling characteristics (i.e., 0.032-m^2 sampling area) of the FSEM. The model for combined interboard and intraboard variance is

$$\sigma^2_{combined} = \sigma^2_{intra} + \sigma^2_{inter} \cdot (a \cdot n - n)/(a \cdot n - 1) \quad (5)$$

where a is the number of boards (i.e., 6) that are tested and n is the number of measurements per board (i.e., 3). Equation (5) has been previously derived (Matthews *et al.*, 1985c). However, calculated $\sigma^2_{combined}$ values represent expected values based on the measured CH_2O emission rates for each manufacturer-product combination rather than a true population parameter.

The results of the one-way analysis of variance for all of the survey products are listed in Table 2. The results for each estimated component of variance are reported as coefficients of variation (CV), expressed as a percentage of the mean CH_2O emission rate $\bar{E}$).

$$CV(\%) = 100 \cdot \sigma/\bar{E}. \quad (6)$$

The relative magnitude of intraboard and interboard variation in the measured CH_2O emission rates is different between the various test product categories. For particleboard the average CV for intraboard variation (i.e., 20%) was about twice that for interboard variation (i.e., 11%). This may indicate a consistent board-to-board manufacturing process (with regard to resultant CH_2O emissions) at each of the particleboard production plants sampled in the survey. For hardwood-plywood paneling and medium density fiberboard, the opposite trend was observed in the survey products data. The average CV for interboard variation in the paneling products (i.e., 43%) was about twice that for intraboard variation (i.e., 18%). This may be caused in part by variation in the CH_2O emission strength of imported hardwood plywood substrates. For medium density fiberboard samples, the average CV for interboard variation (i.e., 18%) was about 1.5-fold larger than that for intraboard variation (i.e., 12%), which was the lowest intraboard variation among all test product categories.

The intermanufacturer variation in the measured CH_2O emission rates is estimated as the CV between the three manufacturer-average emission rates in each of the six product categories. The results shown in Table 2 demonstrate that for the survey boards the CV for intermanufacturer variation differs strongly between different categories of pressed-wood products. For industrial particleboard and particleboard underlayment, the intermanufacturer CV values of 47% and 83%, respectively, are approximately two- to fourfold larger than the CV for combined intraboard and interboard effects. For print- and paper-overlayed paneling, and medium density fiberboard, the CV values for intermanufacturer variation are comparable in magnitude to those for combined intraboard and interboard effects. For paneling with domestic veneer overlays, the CV for intermanufacturer variation (i.e., 11%) is small in comparison to the mean CV for intraboard (i.e., 15%) and interboard (i.e., 31%) variation. This indicates that the dominant sources of variation in measured CH_2O emission rates from the survey products are intermanufacturer variation among particleboard products, interboard and sometimes intermanufacturer variation among paneling products, and a combination of interboard and intermanufacturer variation among the fiberboard products.

The intraboard variation in CH_2O emission strength is an intrinsic property of pressed-wood products. However, the measured intraboard variation with the FSEM could be reduced with appropriate modifications to the test protocol. For example, the exposed sorbent from several surface monitors on a given board could be collectively analyzed as a single experiment. The effective sampling area of the FSEM would then be increased to the total area underneath all of the monitors. However, a goal of this survey was, in part, to measure the intraboard variation in CH_2O emission strength of contemporary pressed-wood products.

The relative interboard and intraboard variation that is measured for a given product line may be an important factor in the design of a quality control monitoring

Table 2. Analysis of variation in pressed-wood product CH_2O emission data.

Product, Manufacturer	Coefficient of Variation (%)			
	Intra-Board[a]	Inter-Board[a]	Combined[a]	Inter-Manufacturer
Particleboard				
PBU-1	16	16	22	–
PBU-2	18	8	19	–
PBU-3	16	20	25	–
Mean PBU	17	14	22	83
PBI-1	23	≅0	22	–
PBI-2	39	≅0	34	–
PBI-3	11	22	23	–
Mean PBI	24	7	26	47
Mean Particleboard	20	11	24	65
Paneling				
PR-1	15	94	90	–
PR-2	16	29	31	–
PR-3	16	64	62	–
Mean PR	16	62	61	62
P-1	32	37	47	–
P-2	19	31	35	–
P-3	16	44	44	–
Mean P	22	37	42	56
D-1	12	39	39	–
D-2	15	17	22	–
D-3	18	36	38	–
Mean D	15	31	33	11
Mean Paneling	18	43	45	43
Medium Density Fiberboard				
MDF-1	5	12	12	–
MDF-2	17	17	23	–
MDF-3	14	24	26	–
Mean MDF	12	18	21	33

[a]See Equations 2-5.

strategy for CH_2O emissions. For product lines with large interboard variation it may be more important to measure a large number of boards than to precisely characterize the average CH_2O emission strength of individual boards. A nondestructive sampling and analytical method may, therefore, be advantageous. For products with low interboard variability, the contribution of the analytical method to the measured variation in CH_2O emission strength must be carefully analyzed and reduced. For either situation, $\sigma^2_{combined}$ can be minimized using Eq. (5) within pertinent technical and economic boundary conditions.

Unoccupied Research Houses Measurements

The results of the temperature, RH, air exchange, CH_2O concentration, and FSEM-CH_2O emission rate measurements inside the research homes are summarized in Table 3. To evaluate the FSEM results, the FSEM-CH_2O emission rate data (E_F) are substituted into the following steady-state Ch_2O-concentration model for the research houses, comprising a single emitter of area 77 m^2 inside a single compartment of volume 263 m^3 and air exchange rate, ACH. The model has been derived (Matthews *et al.*, 1985a) from the time-dependent mass balance equation of Wadden and Scheff (1982):

$$[CH_2O]\ (mg/m^3) = \frac{E_F\ (mg/m^2\ h) \cdot 77\ (m^2)}{ACH\ (h^{-1}) \cdot 263\ (m^3)}. \quad (7)$$

Simplifying assumptions for the model include uniform mixing inside the compartment, the absence of permanent losses due to sinks or filtration systems, and the constancy of all model parameters. Using Eq. (7), the FSEM-modelled CH_2O concentrations are then compared against the CH_2O concentrations measured inside the research houses, which span from 0.09 to 0.33 mg/m^3. Since the CH_2O concentration model does not account for fluctuations in indoor temperature and RH, such a comparison evaluates how well the FSEM data account for temperature- and RH-dependent variations in the CH_2O emission rate of the particleboard underlayment. A comparison of the FSEM-modeled and measured CH_2O concentrations is illustrated in Fig. 2. The results of linear regression

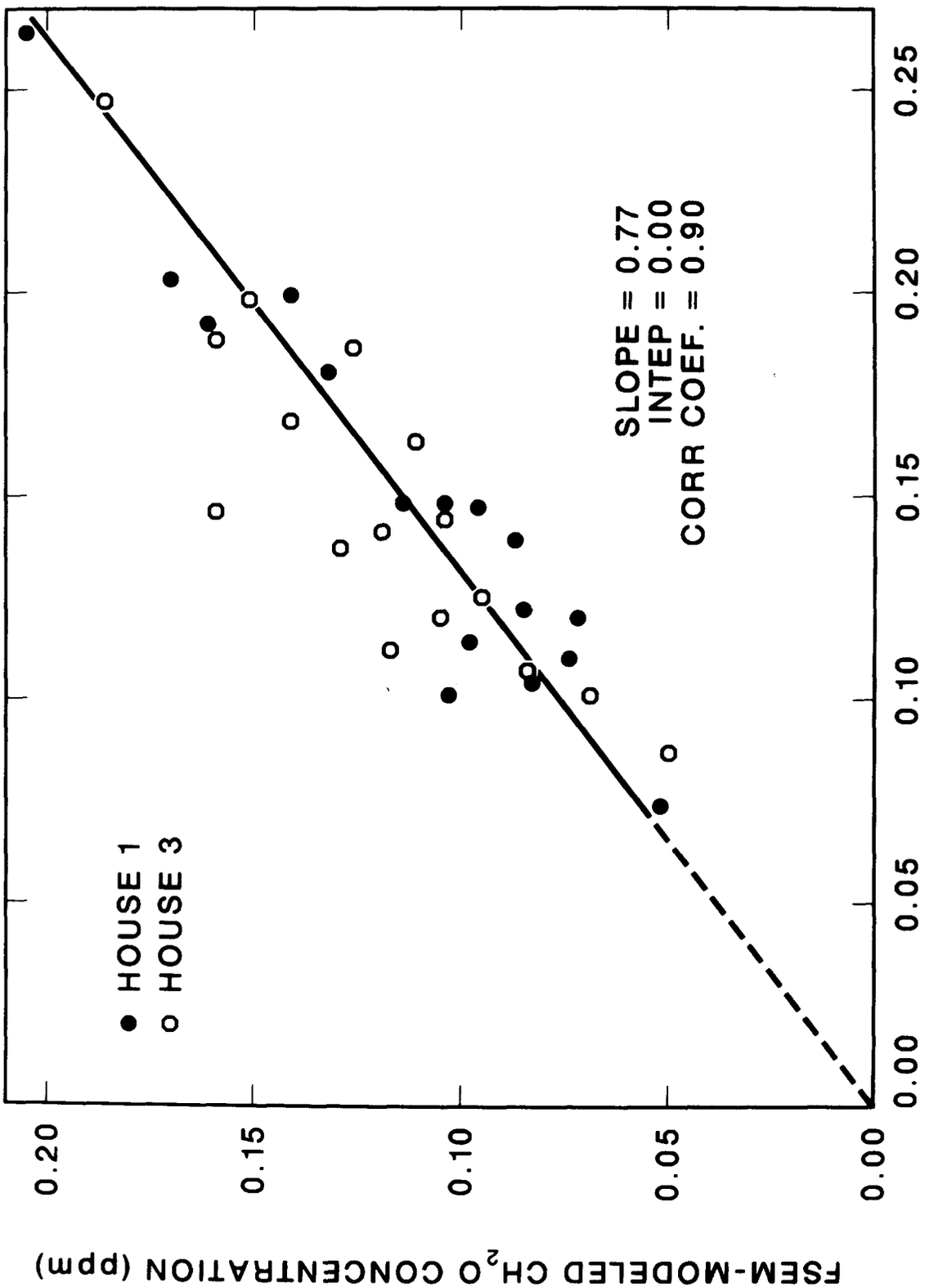

Fig. 2. Comparison of FSEM-modeled and measured CH_2O concentrations inside the ORNL research houses.

Table 3. Summary of measurement means from the research houses.[a]

House	Temp (°C)	RH (%)	Air Exchange (h^{-1})	$[CH_2O]$ (mg/m^3)	E_F (mg/m^2h)
1	17.4	50	0.44	0.09	0.10
1	19.5	88	0.45	0.12	0.20
1	19.9	53	0.44	0.13	0.15
1	24.0	42	0.44	0.14	0.14
1	17.8	80	0.43	0.14	0.18
1	17.5	72	0.50	0.15	0.16
1	17.1	78	0.46	0.15	0.17
1	22.9	64	0.53	0.17	0.20
1	22.7	53	0.47	0.18	0.19
1	21.8	60	0.42	0.18	0.20
1	22.7	51	0.51	0.18	0.21
1	23.0	72	0.47	0.22	0.26
1	26.3	74	0.47	0.24	0.32
1	24.2	75	0.47	0.25	0.28
1	25.4	72	0.51	0.25	0.37
1	29.4	77	0.50	0.33	0.44
3	18.1	52	0.43	0.11	0.09
3	22.3	41	0.46	0.13	0.14
3	17.2	83	0.47	0.13	0.17
3	21.0	54	0.36	0.14	0.18
3	20.7	52	0.40	0.15	0.18
3	17.3	77	0.45	0.15	0.18
3	22.1	52	0.38	0.17	0.21
3	23.0	53	0.40	0.17	0.20
3	20.7	76	0.47	0.18	0.21
3	28.2	43	0.40	0.18	0.27
3	22.1	50	0.38	0.20	0.18
3	26.5	58	0.45	0.21	0.27
3	24.2	68	0.49	0.23	0.26
3	29.0	44	0.44	0.23	0.30
3	22.4	83	0.41	0.25	0.26
3	26.9	67	0.46	0.31	0.36

[a]Continuous operation of HVAC fans controlled the temperature, RH, and air exchange levels to typically ±0.4°C, ±3%RH, and ±0.04h^{-1}, respectively, during measurement periods. The coefficient of variation for CH_2O concentration and emission rate measurements averaged 7% and 10%, respectively.

analyses of the individual and combined house data are given in Table 4. The FSEM-modeled, CH_2O concentration data are on average about 70% to 80% of the measured concentrations in both research houses. These somewhat low results would be consistent with the presence of other low-loading CH_2O emitters such as the kitchen and bathroom cupboards that are not included in the FSEM measurements and single-emitter, CH_2O-concentration modeling. The linear correllation coefficient and root mean square error of about 0.9 and 0.02 mg/m^3, respectively, indicate a good fit between the FSEM-modelled and measured concentrations in the research houses. The results indicate that the FSEM can be used for semiquantitative measurements of CH_2O emission rate from the predominant CH_2O emission source in indoor environments under quasi-steady-state conditions.

Table 4. Linear regression analyses of FSEM-modeled CH_2O concentrations (dependent variable) and measured CH_2O concentrations (independent variable) in the research homes.

House	Slope	Intercept mg/m^3	Lin. Corr. Coef.
1	0.79 ± 0.07	−0.01 ± 0.01	0.95
3	0.73 ± 0.12	0.01 ± 0.02	0.86
1,3	0.77 ± 0.07	0.00 ± 0.01	0.90

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