EVALUATING THE CONTRIBUTION OF UF-BONDED BUILDING MATERIALS TO INDOOR FORMALDEHYDE LEVELS IN A NEWLY CONSTRUCTED HOUSE

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ABSTRACT

A Pilot Study to evaluate methods for measuring the contribution of UF-bonded building materials to indoor formaldehyde concentrations in newly constructed conventional and manufactured houses was recently conducted by the U. S. Environmental Protection Agency (EPA). The Pilot Study was funded by the National Particleboard Association (NPA); and was conducted under a Cooperative Research and Development Agreement (CRDA) between the two organizations. The Pilot Study followed scientifically designed protocols and evaluated indoor formaldehyde concentrations in a newly constructed, conventionally built, single-family house that contained two different combinations of UF- bonded building materials with known emission characteristics. Higher than expected expenditures in the conventional house resulted in the cancellation of the manufactured housing portion of the Pilot Study. The UF-bonded building materials used in the Pilot Study were fully characterized; environmental conditions in the house were carefully controlled and recorded; and indoor concentrations were measured on a regular basis.

Results of the Pilot Study show that initial indoor formaldehyde concentrations in the house, even at a “High” loading of UF-bonded building materials, were below 0.076 parts per million and were as much as 50 percent below the levels that had been predicted by commonly used indoor air models. After 30 days, average indoor formaldehyde concentrations in the house were less than 0.045 parts per million.

The Pilot Study pointed out significant technical and logistical problems inherent in studies of this type. House availability, control of test conditions, budgeting, scheduling, measurement techniques, and other issues posed challenges to all involved. Researchers eventually were able to resolve most of these problems in a satisfactory manner. However, these challenges may proliferate in a wider study of this type, or in one involving a greater number of houses in multiple locations.

INTRODUCTION

On September 29, 1994, the National Particleboard Association (NPA) signed a Cooperative Research and Development Agreement (CRDA) with the U.S. Environmental Protection Agency (EPA) to fund a Pilot Study in newly constructed conventional and manufactured houses. The purpose of the Pilot Study was to evaluate methods used to measure the contribution of UF-bonded building materials to indoor formaldehyde concentrations in newly constructed conventional and manufactured houses.

The Pilot Study is noteworthy in several respects. First, this carefully controlled and scientifically designed protocol provided for a more comprehensive investigation and better documentation of results than most prior studies of formaldehyde levels in houses. The specific products used in the Pilot Study were fully characterized; conditions in the house were charted; and the resulting ambient levels were measured consistently. The levels reported for all product loading scenarios were below 0.1 ppm and were up to 50 percent below the levels that had been predicted by commonly used indoor air models.

Second, the Pilot Study helped to identify the significant technical and logistical problems inherent in studies of this type. House availability, control of test conditions, budgetary projections, scheduling, difficulties with measurement techniques, and other issues posed challenges to all involved. Eventually, most of these were satisfactorily resolved in the context of a single-family conventional house, but the challenges may proliferate in a wider study of this type, or in one involving a large number of houses in multiple locations. Although the project plan called for testing to be conducted in both conventionally built and manufactured houses, higher than expected expenditures encountered in the conventional house affected the budget and forced a decision in July 1995 to scale back testing in the conventional house and to cancel testing in the manufactured houses.

The Pilot Study was also noteworthy as an example of scientific cooperation among the EPA, its contractors and the industries involved. Although there were, and continue to be, some disagreements regarding the subject of formaldehyde, the work is a tribute to the professionalism and insight of the experts at Versar, Inc., GEOMET Technologies, Inc., and Battelle who participated in the design of the Pilot Study and conducted the testing, the professional staff of EPA's Office of Pollution Prevention and Toxics, and the Industry Advisory Panel.

HISTORY OF EPA PILOT STUDY

In December 1992, the EPA placed a notice in the Federal Register announcing the need to conduct a Formaldehyde Exposure Assessment Study in new houses to determine whether formaldehyde emissions from UF-bonded pressed wood products were sufficiently high to cause health concerns. At a public meeting in January 1993, EPA representatives outlined a proposed study plan that had been developed by EPA with support from Battelle of Columbus, Ohio. The proposed study would be conducted in two phases - a main study and a pilot study. The proposed main study would have involved exposure testing using passive monitors in 108 newly constructed conventional and manufactured houses located throughout the United States. A smaller pilot study would have been conducted first to evaluate the feasibility and logistical considerations of the experimental design for the larger main study.

Throughout early 1993, NPA and EPA discussed the need for such testing and the appropriate scope and design of a Pilot Study. The Agency initially proposed a broader, survey type study. NPA proposed that smaller, more focused, and more controlled studies were more appropriate. In September 1993, a compromise was reached. NPA agreed to fund a Pilot Study in a single conventionally built newly constructed house and in four (4) newly constructed manufactured houses. NPA's commitment was for the Pilot Study only.

A letter of intent to conduct the Pilot Study was signed by both parties in December 1993 and a formal Cooperative Research and Development Agreement (CRDA) was finalized in September 1994. Under the terms of the Cooperative Agreement:

EPA would:

- be responsible for the overall management of the study,

- provide funding to develop the Quality Assurance Project Plan (QAPP), and
- provide limited quality control checks by performing independent formaldehyde emissions tests on trim materials, on carpet/padding, and on other non-wood materials used in the houses.

NPA and industry would provide:

- $460,000 in direct funding,
- materials for the study, such as

    particleboard underlayment and industrial board for countertops,

    hardwood plywood wall paneling,

    kitchen cabinets and bathroom vanities,

    cabinet and vanity countertops,

    interior doors, and

- wood product emission testing (large and small chamber),
- access to manufactured houses, and
- 1.5 person years of technical and administrative assistance.

EPA had contracted with Versar, Inc. of Springfield, Virginia, to manage the Pilot Study. Field and laboratory testing would be conducted by a subsidiary of Versar Inc., GEOMET Technologies, Inc. of Germantown, Maryland.

An Industry Advisory Panel comprised of technical representatives from the particleboard, hardwood plywood, kitchen cabinet, and manufactured housing industries met with EPA personnel to discuss the logistical and technical aspects of conducting the EPA designed Pilot Study. Technical issues addressed included:

- types of houses to be included in the study,
- products to be included in the study,
- emission characteristics of those products,
- combinations of products to be installed in the house,
- environmental conditions (temperature, relative humidity, ventilation rate) in the houses, and
- the method of determining indoor concentration levels in the houses.

The joint EPA-Industry Technical Advisory Team identified the experimental variables that would be included in the Pilot Study and defined low, medium, and high categories for each variable.

QUALITY ASSURANCE PROJECT PLAN (QAPP)

In October 1994, the Quality Assurance Project Plan (QAPP) for the Pilot Study was finalized by GEOMET. The QAPP is over 100 pages long and gives a detailed description of the experimental design, experimental variables, and quality assurance/control procedures that would be employed.

The objectives of the Pilot Study were to:

- Test the logistical considerations relevant to carrying out the experimental procedures of the testing program in a single conventionally-built single-family house and in multiple manufactured houses.
- Demonstrate that the experimental variables or conditions likely to affect formaldehyde concentrations in new houses (namely, UF-bonded wood product emission characteristics, UF-bonded wood product loading rates, temperatures and indoor air exchange rates) can be controlled, individually and jointly varied, and held sufficiently constant, and that the response can be measured to a specified precision.
- Demonstrate that test results can be obtained across a range of different experimental conditions similar to that which can be present in new houses and that the response can be measured with specified precision.
- Estimate the extent of variability of the experimental results and the variation with changes in experimental conditions.
- Determine how to account for, or to eliminate or minimize, residual formaldehyde carryover between test runs in the conventional house due to the effects of inherent sinks.
- Evaluate the ability to control and vary the air exchange rate of houses using an adjustable mechanical air handling system.

According to the QAPP, the Pilot Study would include one (1) unoccupied, conventionally built single-family house and four (4) unoccupied manufactured houses. Four manufactured houses were specified in the Pilot Study because it is not practical to install and remove products in a manufactured house. The conventional house was to be a two-story house on a slab or crawlspace.

The QAPP also specified that the following variables would be evaluated in the Pilot Study:

- Product emission characteristics: Only "medium" emitting products would be used in the Pilot Study. Emissions from particleboard and plywood wall paneling (as measured by ASTM E 1333) would be between 0.12 and 0.14 ppm. Since there were no established protocols for measuring formaldehyde emissions from kitchen and bathroom cabinets, commercially available cabinets constructed with "medium" emitting materials (melamine wrapped particleboard) would be used.
- Product loading rate: Two combinations of products, Medium and High (defined below) would be installed in the house:

Material	High	Medium
PB Underlayment	Full (0.10)[1]	Half
Cabinets	Full	Full
Counter Tops	Full	Full
Interior Doors	Full	Full
Plywood Wall Paneling	Full (0.02-0.036)[1]	None

[1] Approximate loading rate in ft^2/ft^3

- Environmental conditions in the house:

Temperature	75 ^oF
Ventilation rate	0.5 ACH

Relative humidity level in the house, while not a controlled variable, would be targeted at 50 percent.

Conventional House Preparation and Testing

Since the manufactured houses were eventually dropped from the Pilot Study, the following discussion of the QAPP provisions will pertain solely to the conventional house.

Air leakage - Air leakage in the house would be determined through blower-door tests conducted in accordance with ASTM E 779. Every effort would be made to make the house as tight as possible.

Ventilation rate - Ventilation rates would be controlled by a mechanical heat recovery ventilator (HRV) attached to the heating and air conditioning system (HAC). Air exchange rates would be measured by using two tracer gas methods - Perfluorocarbon tracers (PFT's) and sulfur hexafluoride (SF_6).

Product loading - Four product loadings would occur - two Medium and two High. Prior to loading the products in the house, a baseline value for the house without any experimental UF-bonded wood products in it would be determined. The products would then be installed in the house and indoor formaldehyde concentration measurements would be taken over approximately a 30-day period. At the completion of 30-day period, the products would be removed from the house. The house would be allowed to "air out" for several days until a new equilibrium level (baseline) was reached, then the next set of products would be installed. The order of the loading configurations in the house would be randomized, with the single constraint that loadings 1 and 2 would be different (i.e. one High, one Medium).

All of the products in the house would be installed according to manufacturers' recommended installation instructions.

Indoor formaldehyde measurements - Indoor formaldehyde concentration levels would be tested 7, 12, 28, and 33 days after the products were installed in the house. If necessary, additional testing could take place to confirm any trends or unexpected results. Day 12 and 33 readings would be considered statistical replicates of Day 7 and 28 readings, respectively.

Twenty-four (24) hour time-integrated formaldehyde measurements in the house would be determined by the following methods:

- EPA Method IP-6A - Solid Adsorbent Cartridge (DNPH)
- NISOH Method 3500 - Chromotropic Acid (CA)

Indoor formaldehyde concentrations would be measured by both methods at several locations in the house. Measurements would be taken in the kitchen, living room, upstairs bedroom, basement, and outdoors. A duplicate sample would also be collected each time at a location to be systematically varied.

An Interscan Model 1160 electro-chemical continuous formaldehyde analyzer would be used to measure formaldehyde levels in the living room.

Although not a provision of the QAPP, industry would conduct one-hour random "shadow tests" in the house using the NIOSH 3500 chromotropic acid procedure.

Laboratory Testing

Emission characteristics of UF bonded building materials - Product emission testing would be conducted by industry at three different air exchange rates according to the protocol in ASTM E

1333 (Large Chamber Test Method). Since there are no established protocols for large chamber testing of doors and cabinets, the following loading rates would be used:

- Doors - five doors at a total loading rate of 0.125 ft^2/ft^3
- Kitchen cabinets/countertops - one base and one wall cabinet with doors closed at a loading rate of 0.133 ft^2/ft^3. A section of countertop would be placed on the base cabinet during testing.

The above loading rates are similar to those established by the Department of Housing and Urban Development (HUD) for large chamber testing of particleboard and industrial panels.

Sink effect testing of painted gypsum wallboard and carpet/padding - For sink effect testing, products would be placed in a small clean environmental chamber. A known concentration of formaldehyde gas would be injected into the chamber. By accurately measuring concentrations in the small environmental chamber, it could be determined whether the material was absorbing the formaldehyde gas and then re-emitting it after the source was removed.

BUILDER RECRUITMENT

During the summer and fall of 1994, Versar personnel initiated efforts to recruit a builder or homeowner who would be willing to participate in the Pilot Study. Numerous contractors were contacted and ads were placed in local papers. Securing a contractor willing to participate in the Pilot Study proved to be more difficult and costly than anticipated for a variety of reasons. The primary reason given for not participating in the Pilot Study was the fact that the house could not be occupied during the test period. Most contractors or new homeowners wanted to occupy, or at least have access, to the house. After expanding the search geographically, a homeowner in

Centreville, Maryland, agreed to participate in the Pilot Study. Centreville is on the eastern shore of Maryland and is approximately 90 miles from Germantown, Maryland, the location of the offices of the testing contractor, GEOMET Technologies, Inc. The owner was building a rental house and was willing to lease it for as long as necessary. The required paperwork was signed in October 1994, and GEOMET personnel started to prepare the nearly completed house for testing.

CONVENTIONAL HOUSE DESCRIPTION

The Centreville, Maryland, house was a conventionally built, 1326 ft^2, two-story Cape Cod style house with a full basement. Total volume of the finished living space was 10,746 ft^3 (304 m^3). The QAPP had called for a house with a crawl space, but efforts to find such a house in the Washington D.C., area were unsuccessful. The first floor of the house was 712 ft^2 and had 5931 ft^3 (168 m^3) of living space that consisted of a living room, kitchen, bathroom/laundry room, and bedroom. The second floor of the house was 614 ft^2 and had 4815 ft^3 (136 m^3) of living space that consisted of two bedrooms and a bathroom. The door from the first floor finished living space to the unfinished basement was sealed shut during the entire project. The house was unoccupied and contained no furniture or draperies. A floor plan of the house and a picture of the exterior of the house are shown in Figure 1.

PRODUCTS USED IN CONVENTIONAL HOUSE

Under the terms of the CRDA, industry was responsible for procuring the products that would be used in the Pilot Study. Sufficient quantities of 5/8” particleboard underlayment, 3/4” industrial particleboard for countertops, 1/4” hardwood plywood wall paneling (3-ply birch face, tropical hardwood back and core with 7 cut grooves along the length of each panel to simulate random width lumber planking), interior partition doors, and kitchen and bathroom cabinets were obtained from member companies, participating associations, or purchased at local building supply centers. Emission characteristics of the particleboard and plywood wall paneling used in the Pilot Study were determined prior to selecting the materials for testing. Initial emission characteristics of the products used in the Pilot Study (determined by ASTM E 1333 at 0.5 ACH) were determined and are listed below:

Product	Emissions, ppm	Test Loading Rate, ft^2/ft^3
Particleboard Underlayment	0.144	0.130
Plywood Wall Paneling	0.114	0.290
Cabinets	0.053	0.133
Interior Doors	0.052	0.125

All of the products were stored in a GEOMET controlled-access warehouse in Gaithersburg, Maryland until they were installed in the house. During storage, products were wrapped in 6-mil plastic to minimize any formaldehyde off-gassing. It was discovered during the Pilot Study that temperature control in the warehouse was marginal and that temperatures ranged up to 85 ^oF.

Products were installed in the house according to manufacturers’ recommended installation instructions, and conventional practices were followed. The particleboard underlayment was installed with screws for easy removal. The kitchen and bath cabinets were screwed tightly against the wall. The plywood wall paneling was nailed to the wall in order to minimize any damage to the gypsum wallboard.

For the Medium loading scenario, particleboard underlayment was installed on the first floor of the house. Interior doors and a full set of kitchen and bathroom cabinets and countertops were installed. For the High loading scenario, particleboard underlayment was installed on both the first and second floors of the house. In addition, twelve 4’ X 8’ sheets of plywood wall paneling were installed in the house. In order to establish a somewhat uniform loading and to avoid using partial panels, four full size sheets were installed in an upstairs bedroom, in the downstairs bedroom, and in the living room. Interior doors and a full set of kitchen and bathroom cabinets and countertops (same number as for Medium loading) were also installed. Table 1 lists the square footage of each product type that was installed in the house during the Medium and High loadings. Particleboard underlayment was not installed in the kitchen and bathroom areas of the house. Those areas were covered by vinyl sheet goods which had been permanently installed during final preparation of the house before field testing was initiated.

INSERT TABLE 1 HERE

The location of products in the house for the High loading scenario is shown in Figure 2.

TESTING IN CONVENTIONAL HOUSE

Preparing the house for testing took longer than anticipated. Blower door tests conducted in December 1994 indicated that the house had numerous leaks in the building shell and between the first floor and basement. Air leakage sites were identified (service penetrations between the basement and first floor and along the baseplate) and sealed with caulk and foam. Numerous leaks were also found in the forced-air HAC distribution system. Sealing the leaks helped reduce the leakage in the house to a natural air change rate of 0.2 per hour. In January 1995, the heat recovery ventilator was installed. During this time, laboratory equipment for measuring formaldehyde concentrations in the house and a computer data acquisition system (DAS) were installed. The DAS would provide a continuous record of temperature, humidity, and solar radiation as well as control the SF_6 tracer gas ventilation measurements and Interscan real-time formaldehyde analyzer.

Baseline testing took place in March 1995. Load 1 (Medium) products were installed in April, and indoor concentration levels were measured following the protocols outlined in the QAPP. In late May, it became evident that the contractor was having problems controlling relative humidity levels in the house. While targeted at 50 percent, humidity levels in the house reached over 70 percent in late June. Additional dehumidification equipment was installed in the house, and humidity levels dropped down to the desired range. Since high humidity causes higher formaldehyde emissions, the house was declared to be in an "upset condition" during this time. The EPA decided that Load 1 products should be left in the house until conditions stabilized. The final reading for Load 1 (Day 78) was taken in late July. Results from Load 1 testing are shown in Table 2 and Figure 3.

INSERT TABLE 2 HERE

REVISED PROJECT PLAN

In late May, while Load 1 products were still in the house, the EPA advised NPA that they were encountering financial problems with the Pilot Study and estimated that it would cost more than originally estimated to complete the Pilot Study as outlined in the CRDA. In July, the joint EPA-Industry Technical Advisory Team met to review the status of the project. Given the new financial constraints, the Study Plan was modified with the following changes:

- Conducting only three (3) loadings in the house. If sufficient financial resources became available, a fourth loading (Medium - repeat of Load 1) would be conducted,
- Using only DNPH testing,
- Deferring some of the laboratory sink effect and barrier testing,
- Fixing the air-out period between loads at seven (7) days instead of waiting for formaldehyde levels in the house to come to equilibrium, and
- Deleting the manufactured house portion of the Study.

LOAD 2 AND 3 TESTING IN THE CONVENTIONAL HOUSE

Load 1 products were removed from the house in late July 1995. The house was allowed to air out for 7 days, and Load 2 (High) products were installed. Formaldehyde concentrations were measured on Days 7, 12, 28, and 33. Load 2 test results are shown in Table 3 and Figure 4.

INSERT TABLE 3 HERE

Load 2 products were removed from the house in late September 1995. Load 3 (High - duplicate of Load 2) products were installed in early October 1995 after the house had been allowed to air out for 7 days. Formaldehyde concentrations were measured on Days 7, 12, 28, and 33. Load 3 products were removed from the house in early November 1995, and the house was returned to the homeowner. Load 3 test results are shown in Table 4 and Figure 5.

INSERT TABLE 4 HERE

ADDITIONAL INDUSTRY FUNDED LABORATORY TESTING

As a result of the budgetary constraints, only a limited amount of sink effect testing was conducted as part of the Pilot Study. After reviewing the laboratory sink effect test results and results from Loads 1, 2, and 3, it appeared that the gypsum wall board was acting as a significant sink. EPA modelers felt that the sink characteristics of the painted gypsum wallboard, since the exposed surface area was greater than all of the UF-bonded products installed in the house, would be very important in their efforts to verify existing indoor air models. The modelers indicated that additional information was needed to characterize fully the sink effect behavior of the painted gypsum wallboard. It was also suggested that it would be important to determine whether the carpet/padding used in the house was acting as a sink or had any barrier effect on formaldehyde emissions from the particleboard underlayment. In an effort to provide insights on possible sink and barrier effects, NPA contracted with GEOMET in December 1995 to conduct:

- Additional sink effect testing on the painted gypsum wallboard and carpet/padding used in the house, and
- Barrier testing on the carpet/padding used in the house.

For barrier testing, it was originally proposed that a conventional “break through” testing protocol be followed. GEOMET personnel suggested that an alternative protocol be followed in order to evaluate the floor system with particleboard underlayment and carpet/padding instead of just the carpet/padding. A sample of particleboard underlayment would be placed in a stainless steel pan and inserted in a small environmental chamber. Formaldehyde concentrations in the environmental chamber would be determined using the Interscan analyzer. As a separate test, a second sample of particleboard that had carpet/padding on top of it would be placed in a stainless steel pan and inserted in the small environmental chamber. Again, formaldehyde concentrations in the chamber would be measured. Differences in the concentration profiles for the two tests would reflect the barrier effect of the carpet/padding used in the Pilot Study. To minimize the inherent variability within a piece of particleboard, NPA would prescreen the particleboard samples using a small chamber (Dynamic Microchamber). The two pieces that had the closest emissions would be provided to GEOMET for the test.

RESULTS

Conventional House Formaldehyde Testing

Average formaldehyde concentrations in the house did not exceed 0.070 ppm, even during the two High loadings. The highest individual value obtained in the house was 0.076 ppm and occurred in the kitchen during Load 3 (High). The results clearly show that for all three loadings indoor concentrations peaked before the 33-day measurements. After 30 days, average indoor concentrations in the house were below 0.045 ppm. Average results for the house are shown in Figure 6.

These concentrations are below 0.1 ppm and are lower than concentrations predicted by commonly used indoor air models. As expected, the two High loadings (Loads 2 and 3) resulted in higher initial indoor concentrations than the Medium loading (Load 1), but all of the loadings showed concentrations lower than predicted using indoor air models. Indoor concentrations for the two High loads decreased slowly over time and appeared to reach the same equilibrium concentration obtained with the Medium load (Load 1). Results show that there was fairly good duplication between results for the two High loadings (Loads 2 and 3).

NPA representatives conducted "shadow testing" on several occasions during each loading. Results of this testing were similar to those obtained by GEOMET.

Ventilation rate data indicated differences between the results obtained with the SF_6 and PFT tracer gas methods. Although the collective results were generally in the target range of 0.4 to 0.6 ACH, the PFT values were consistently higher. One possible reason for the discrepancy is the inherent difference between the two measurement technologies. The SF_6 method involves periodic injection and mixing of the tracer through the HAC system, followed by real-time analysis of the concentration decline due to dilution by infiltrating outdoor air. The PFT method relies on near-constant release of tracers from multiple locations near the perimeter of the house, accompanied by time-integrated sampling over a 24-hour period.

DNPH results were consistently lower than corresponding chromotropic acid results in Load 1. EPA contractors attributed this difference to difficulties encountered with processing the samples during analysis; and claim that it is not a reflection of the accuracy of the chromotropic acid method for formaldehyde measurements.

Laboratory Testing

Materials - Emission characteristics of the UF bonded products used in the Pilot Study were determined at three different ventilation rates when the products were removed from the Gaithersburg warehouse for installation in the conventional house. While 0.15, 0.5, and 1.2 ACH were designated in the QAPP, tests were actually conducted at 0.25, 0.5, and 1.0 ACH because of chamber operating parameters. Results indicate that some decay may have occurred during storage, even though the products were wrapped in plastic. The elevated temperatures in the warehouse may have accelerated the decay process somewhat.

Sink Effect - Laboratory testing indicated that the gypsum wallboard definitely acted as a sink. Due to the large exposed surface area of painted gypsum wallboard in a conventional house (walls, ceilings, etc.), the sink effect characteristics of the painted gypsum wallboard are an important factor in indoor air quality modeling. Laboratory tests also indicated that the carpet/padding used in the Pilot Study acted as a minor sink.

Barrier - Barrier testing in the small chamber indicated that the carpet/padding used in the Pilot Study did not substantially inhibit or retard the movement of formaldehyde from the particleboard underlayment.

Other - Despite all of the efforts to isolate the basement from the rest of the house, formaldehyde was detected in the basement during baseline testing and all 3 product loadings. Possible sources of the formaldehyde include:

- Leakage from upstairs area
- Emissions from fiberglass insulation, plywood subfloor (ceiling in basement), or other formaldehyde containing materials in the basement.

CONCLUSIONS

- Several major unanticipated logistical problems were encountered. Although these problems were satisfactorily addressed, they highlight the difficulties inherent in these types of tests, even with one, well-controlled facility.
- The highest average indoor formaldehyde concentration in the occupied areas of the house was below 0.070 ppm.
- The highest indoor formaldehyde concentration in the occupied areas of the house was 0.076 ppm (occurred in kitchen during Load 3 (High).
- The lowest indoor formaldehyde concentration in the occupied areas of the house was 0.020 ppm (occurred in upstairs bedroom during Load 1 (Medium).
- After 30 days, average indoor formaldehyde concentrations in the house had decayed to less than 0.045 ppm for all three loadings.

- There was very good agreement between indoor formaldehyde concentrations in each room of the house for all three loadings, and indicates that there was good mixing of air in the finished areas of the house.
- The Pilot Study demonstrated that the following experimental variables could be controlled within the targeted range:
  - Product emission rates
  - Loading rates in the house
  - Indoor temperature
  - Indoor ventilation rate
- Painted gypsum wallboard appeared to act as a significant sink.
- The continuous formaldehyde analyzer is not suitable for measuring low concentrations over long periods of time, but it may be useful for chamber tests provided it is placed in a temperature-controlled environment.
- The particular carpet and padding used in the house did not appreciably retard the rate of formaldehyde emissions from the particleboard underlayment into the rest of the house.
- There was poor agreement between the PFT and SF_6 tracer gas test methods used to measure ventilation rates in the house.
- Baseline values for Load 2 and 3 were in close agreement and were higher than the Load 1 baseline values. This indicates that the gypsum wall board in the house may have been acting as a reversible sink between Loads 2 and 3. The painted gypsum wallboard apparently reached a near equilibrium value as there was little difference between baseline results for Load 2 and 3.

- Industry chromotropic acid shadow testing exhibited similar trends to EPA's DNPH results.

SUCCESSES

Despite the difficulties, there were a number of positive results demonstrated during the Pilot Study:

- All of the parties involved in the project worked together in a cooperative spirit to obtain as much technically sound data as possible.
- Building materials with appropriate emission characteristics could be readily obtained.
- Targeted temperature and air exchange rates in the house could be controlled with the heat recovery ventilator.
- Results from the two High loading scenarios (Loads 2 and 3) were in close agreement.
- There was adequate mixing of air in the first and second floor living areas of the house.

PROBLEMS

Some problems were encountered in the Pilot Study:

- Budgeting
- Underestimation of time and effort required to prepare and characterize the Centreville, Maryland house
- Location of conventional house - a minimum of a full man-day was required any time a technician visited the house to conduct testing or maintain/service the equipment
- Continuous monitor
    - required weekly maintenance

    - experienced considerable drift

- Difficulties controlling humidity levels in the house

CURRENT STATUS

A final report covering the Pilot Study was delivered to EPA and NPA in late March 1995. The report is over 110 pages long and gives a detailed description of the experimental design, testing in the conventional house and laboratory, and problems encountered. Copies of the report are available from U.S. Environmental Protection Agency or the National Particleboard Association.

REFERENCES

American Society for Testing and Materials. 1987. Standard Practice for Measuring Air Leakage by the Fan Pressurization Method; Standard E 779-87; American Society for Testing and Materials, West Conshohocken, PA.

American Society for Testing and Materials. 1990. Test Method for Determining Formaldehyde Levels from Wood Products Under Defined Conditions Using a Large Chamber; Standard E 1333-90; American Society for Testing and Materials, West Conshohocken, PA.

GEOMET. 1994. Residential Indoor Air Formaldehyde Testing Program: Pilot Study Quality Assurance Project Plan. Report No. IE-2695. GEOMET Technologies, Inc., Germantown, MD.

GEOMET. 1996. Residential Indoor Air Formaldehyde Testing Program: Pilot Study Final Report. Report No. IE-2814. GEOMET Technologies, Inc., Germantown, MD.

National Institute for Occupational Safety and Health. 1994. Chromotropic Acid Method for Determination of Formaldehyde in Air; Method 3500, NIOSH Manual of Analytical Methods (Fourth Edition), National Institute for Occupational Safety and Health, Cincinnati, OH.

U.S. Environmental Protection Agency. 1994. Cooperative Research and Development Agreement (CRDA), Federal Technology Transfer Act (FTTA). Tracking # 103-94. Cooperative

agreement between the National Particleboard Association (NPA) and EPA (OPPT and ORD).

Table 1. *Loading Areas for Underlayment, Paneling, Doors and Countertop at the Conventional House*

COMPONENT	LOADING AREA - FT^2			
	1ST FLOOR		2ND FLOOR	
	MEDIUM LOADING	HIGH LOADING	MEDIUM LOADING	HIGH LOADING
UNDERLAYMENT	496.2	496.2	0	519.3
PANELING	0	256.0	0	128.0
DOORS	203.6		169.6	
COUNTERTOP	37.9		5.65	

Table 2.--*Load 1 (medium) indoor formaldehyde concentrations, ppm*

LOCATION	BASE-LINE	RUN 1 DAY 7*	RUN 2 DAY 12*	RUN 3 DAY 28*	RUN 4 DAY 33*	RUN B DAY 50*	RUN C DAY 78*
LIVING ROOM	0.009	0.028	0.030	0.042	0.037	0.051	0.037
KITCHEN	0.010	0.030	0.031	0.044	0.039	0.047	0.038
BEDROOM	0.010	0.020	0.030	0.036	0.031	0.045	0.032
BASEMENT	0.090	NA	0.027	0.028	NA	0.023	0.030
AMBIENT	0.001	0.001	0.007	0.002	0.002	0.002	0.002
AVG. INDOOR TEMP, °F	72	74	74	75	75	77	74
RH, %	50	42	45	62	50	67	57

* *The number of days after products were installed in the house*

Table 3.--*Load 2 (high) indoor formaldehyde concentrations, ppm*

LOCATION	BASE-LINE	RUN 1 DAY 7*	RUN 2 DAY 12*	RUN 3 DAY 28*	RUN 4 DAY 33*
LIVING ROOM	0.023	0.060	0.056	0.047	0.039
KITCHEN	0.024	0.061	0.058	0.049	0.041
BEDROOM	0.022	0.061	0.055	0.053	0.048
BASEMENT	0.026	0.040	0.040	0.038	0.031
AMBIENT	0.003	0.003	0.002	0.001	<0.001
AVG. INDOOR					
TEMP, °F	74	74	74	75	73
RH, %	53	56	50	47	47

** The number of days after products were installed in the house.*

Table 4.--*Load 3 (high) indoor formaldehyde concentrations, ppm*

LOCATION	BASE-LINE	RUN 1 DAY 7*	RUN 2 DAY 12*	RUN 3 DAY 28*	RUN 4 DAY 33*
LIVING ROOM	0.026	0.072	0.054	0.043	0.042
KITCHEN	0.026	0.076	0.055	0.046	0.040
BEDROOM	0.028	0.066	0.055	0.040	0.044
BASEMENT	0.025	0.043	0.030	0.020	0.023
AMBIENT	<0.001	<0.001	0.001	0.001	0.001
AVG. INDOOR TEMP, °F RH, %	 73 50	 73 64	 72 48	 75 43	 71 46

** The number of days after products were installed in the house*

FIGURE 3 – AVERAGE INDOOR FORMALDEHYDE CONCENTRATIONS, PPM, LOAD 1 (MEDIUM) – 24 HOUR DNPH RESULTS

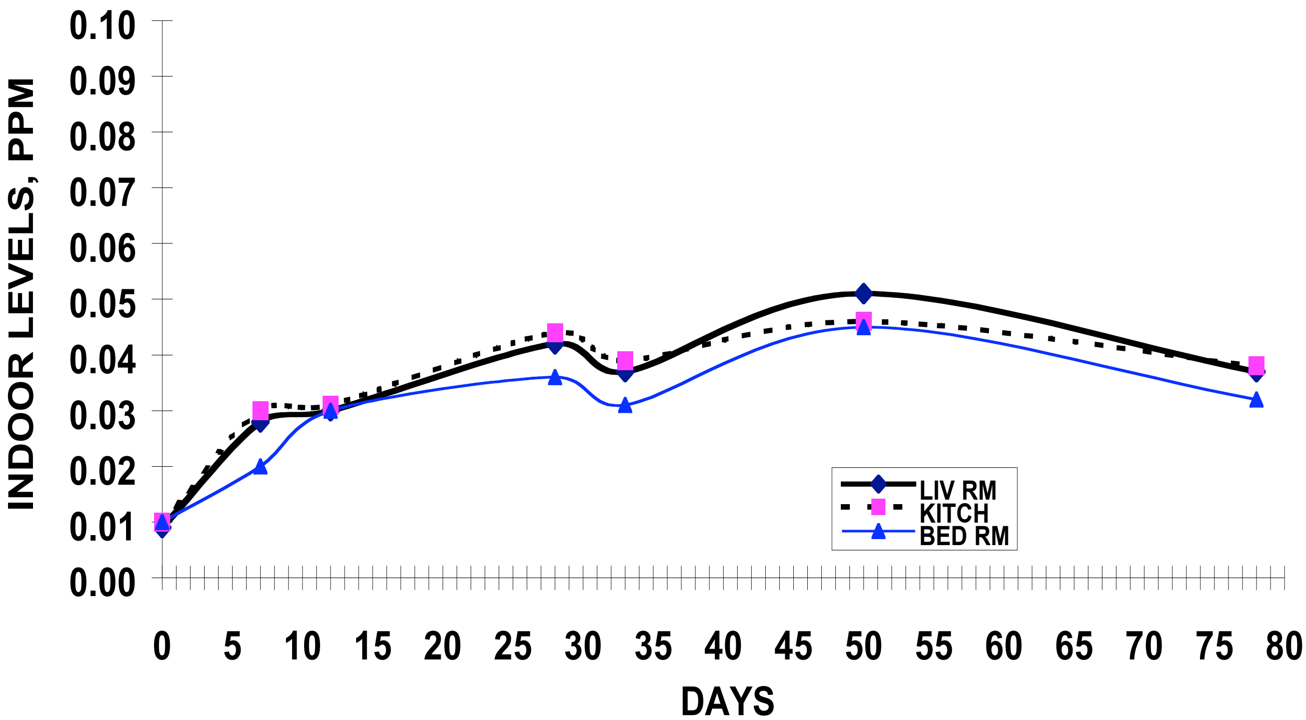

FIGURE 4 – AVERAGE INDOOR FORMALDEHYDE CONCENTRATIONS, PPM, LOAD 2 (HIGH) – 24 HOUR DNPH RESULTS

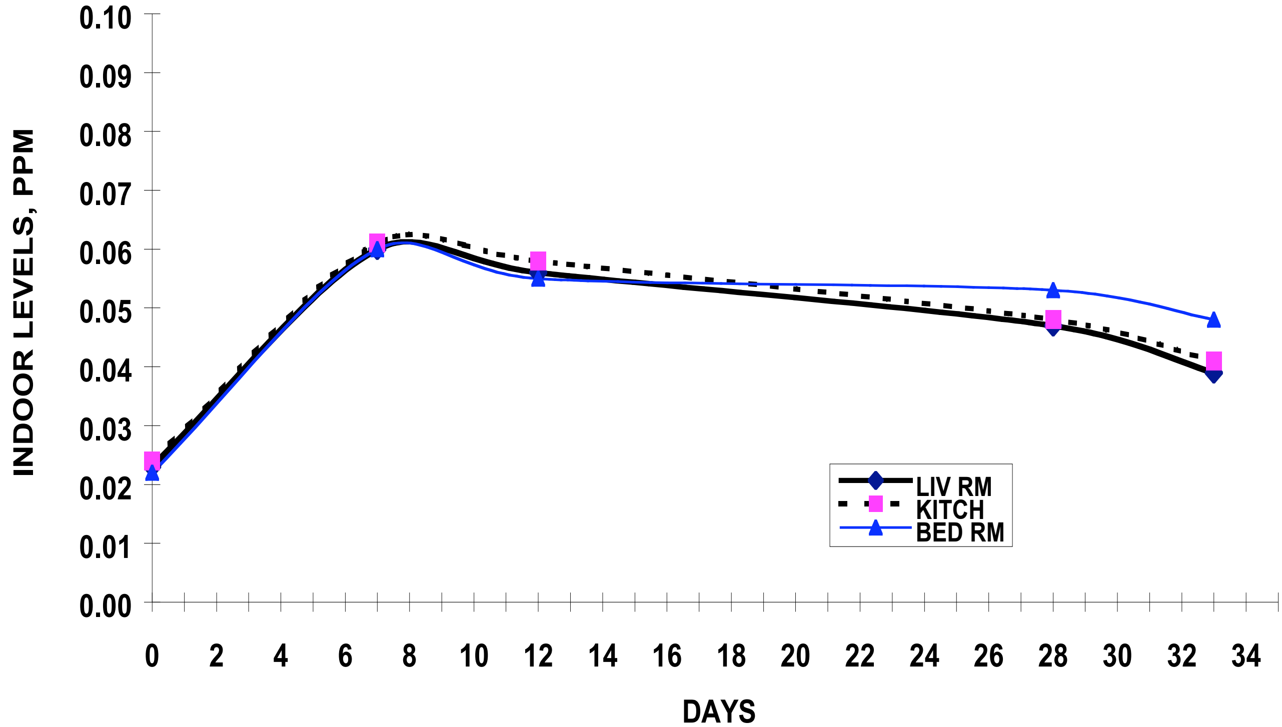

FIGURE 5 – AVERAGE INDOOR FORMALDEHYDE CONCENTRATIONS, PPM, LOAD 3 (HIGH) – 24 HOUR DNPH RESULTS

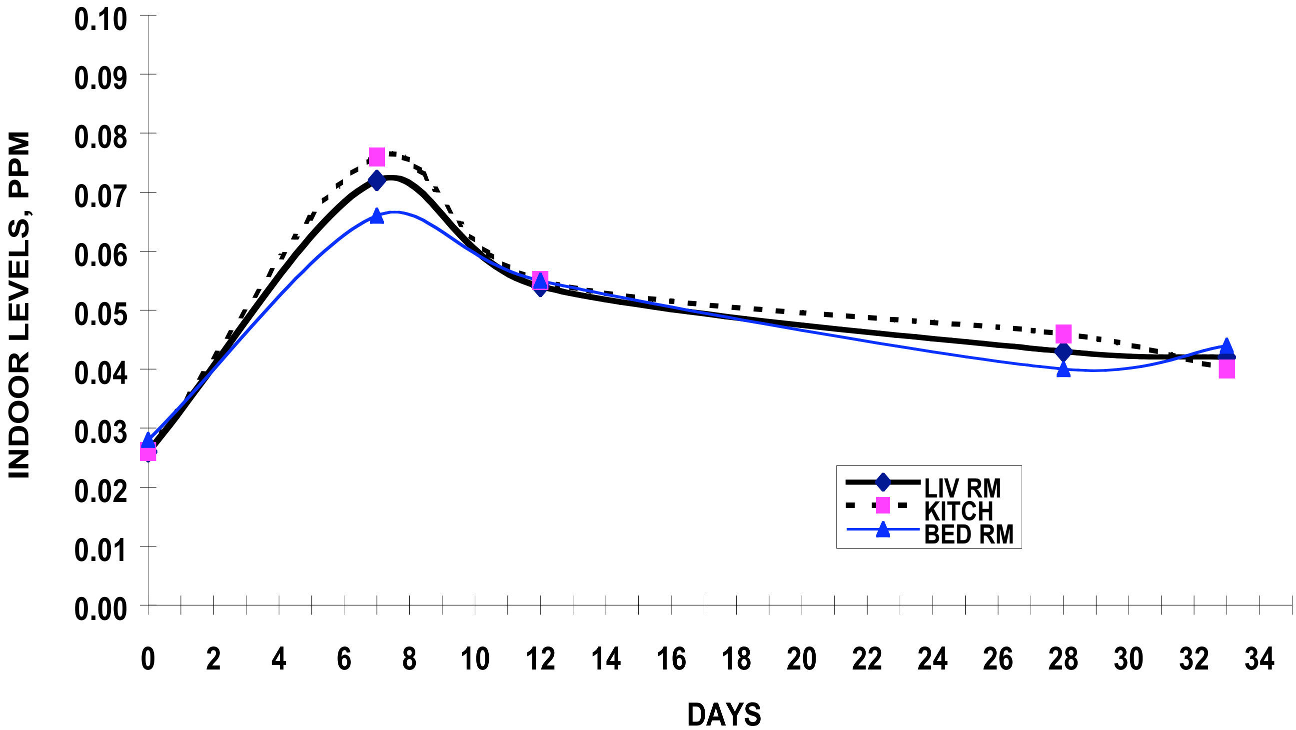

FIGURE 6 – AVERAGE INDOOR FORMALDEHYDE CONCENTRATIONS, PPM, ALL 3 LOADS – 24 HOUR DNPH RESULTS