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April 12, 2006

Dr. Robert Sawyer
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Re: HPVA comments regarding the March 9, 2007 "PROPOSED AIR TOXIC CONTROL MEASURE TO REDUCE FORMALDEHYDE EMISSIONS FROM COMPOSITE WOOD PRODUCTS"

Dear Jim,

We sincerely appreciate the opportunity to comment now and in the past as your department has worked to develop an ATCM on formaldehyde emissions regarding composite wood panel products including hardwood plywood. Our hardwood plywood panels play an important role in a wide variety of products and that is why we feel it is important to make specific comments regarding the most recent version of the rule as presented at the public workshop March 20 in El Monte, California.

We propose that the appropriate Phase 2 emissions levels should be 0.06 ppm rather than 0.05 ppm proposed in the current version of the rule.

Although we have raised this issue before and we appreciate the recent move from a proposed phase 2 level of 0.03ppm, we continue to believe that testing variability, when added to the inherent manufacturing variability of hardwood plywood compared to other composite panel products, and CARB's March 2007 Fact Sheet that concludes the actual average formaldehyde emissions will be 0.03 to 0.04 ppm lower than the proposed caps, supports the establishment of the phase 2 level at 0.06ppm.

Some may consider the 0.01ppm difference a minor point. However, when emissions are being measured at such extremely low levels, these differences are likely to be the tipping point that determines whether some companies can survive by meeting such a restrictive ceiling.

The current ATCM for formaldehyde is extremely restrictive. Other world standards allow some excursions precisely to recognize the variability in both test methods and the manufacturing process. We understand that the ATCM must be a ceiling value. That's why we believe that the ceiling should be set to allow for these variability factors. That clearly justifies setting the ceiling in phase 2 at 0.06 ppm.

We propose that the sell through period for domestic manufacturers should be at least 90 days rather than 30 days as allowed in the current version of the rule. But more important- we believe that whatever sell through period is set, it must be the same for importers as it is for domestic manufacturers.

Considering the variety of species, core types, thickness, and other hardwood panel characteristics produced by our manufacturers in order to supply the numerous small business operations that use hardwood plywood to make cabinetry and furniture, it is extremely onerous to require a complete flushing of the supply chain in 30 days.

If the ATCM allows a longer period of sell through for importers than what is allowed for domestic producers, it will further erode market share for our North American manufacturers and give a tremendous advantage to imported products. Your team has specifically mentioned that your testing shows a tendency for imports to test at higher emission levels. It would appear logical in such circumstances that you would not seek to disadvantage domestic producers by allowing longer sell through periods for importers. That's why we believe that the sell through dates must be same for importers and domestic manufacturers.

The current version of the rule has significantly underestimated the cost to the hardwood plywood industry, especially in the area of third-party certification and in-plant quality control testing.

Virtually all particleboard and MDF manufacturers are already paying for the cost of third-party certification and the conduct of in-plant quality control testing for formaldehyde emissions. Laboratories and personnel to conduct the testing are already in place. This regulation will not add to their financial burden in these areas. Third-party certification and in-plant quality control testing will be a new expense for a large majority of hardwood plywood manufacturers. Since the capital investment in most hardwood plywood facilities is dwarfed by the capital investment in particleboard and MDF facilities, the relative financial burden of third-party certification and in-plant quality control testing could be devastating to some hardwood plywood manufacturers. We expect third-party certification to cost at least $15,000 per year in addition to the in-plant quality control testing costs.

Although we have no direct economic data on the cost of in-plant quality control testing for formaldehyde emissions, we are informed by particleboard and MDF manufacturers that their experience shows these costs to be at least $30,000 to $50,000 per plant per year. We believe initial first year costs for hardwood plywood facilities will be more than $100,000 for personnel (salary plus benefits), training, purchase of testing equipment, and construction of a laboratory and conditioning room for test samples. Subsequent annual costs per plant are likely to be approximately $50,000. The current economic analysis section of the ATCM fails to take into consideration these new costs for hardwood plywood manufacturers. Changes in adhesive technology may also require modifications of equipment, reduced throughput, and greater energy consumption based on a number of unknowns, adding additional costs to hardwood plywood manufacturers.

Considering the significant difference in capitalization of particleboard and MDF mills compared to hardwood plywood facilities, the cost of this ATCM may put many small to mid-size hardwood plywood companies in a position where they will not be able to sell their products in California either directly or indirectly.

The Architectural Plywood Exemption is the wrong approach to exempt small business.

The real question is what are architectural plywood producers, a.k.a. small businesses, exempt from? Are they exempt from meeting the Section 93120.2(a) emission limit for hardwood plywood? Or are they only exempt from third-party certification? As defined in the ATCM, a huge loophole exists as there is nothing in the definition of architectural plywood for "special order" or what it means to be "used as produced". Here are some of the questions raised that need to be answered by CARB based on the current language in the ATCM.

Each order for plywood is different. Could one call them all "special orders? What does used as produced mean? Must the production from an architectural plywood producer be used internally or can it be sold commercially? If it is sold commercially can it be processed further by cutting a panel into smaller components to be used in furniture or kitchen cabinets?

Architectural plywood manufacturers are listed as fabricators in Section 93120.1(11). Fabricators are required to use "reasonable prudent precautions" to ensure composite wood products used in fabricating shops are in compliance with Section 93120.2(a) of the standard. This should mean architectural plywood producers must meet the emission limit for hardwood plywood. Are producers of architectural plywood required to meet the other requirements for fabricators such as labeling, recordkeeping, chain-of-custody documentation, and facility inspections? The bottom line is fabricators must use product that complies with Section 93120.2(a). Is this true for architectural plywood producers, or are they exempt from the entire ATCM?

HPVA does not believe the manufacture of any hardwood plywood should be exempt from the emission limits established in 93120.2(a). It may be acceptable to exempt small businesses from the third-party certification requirement as users of no added formaldehyde resins are allowed in 93120.3(e)(1), but not the emission limits established in 93120.2(a). Small businesses should also be required to meet the other requirements established for manufacturers that exclusively use NAF resins in 93120.3(e).

Our preference would be for a small business exemption based on production. Accordingly, HPVA would recommend a small business exemption set at $\leq$500,000 ft^2 per month.

We recommend that industrial panels and wall panels be tested at the industrial panel loading rate of 0.13 ft^2/ft^3.

The emission limits established in 93120.2(a) of the ATCM are based on testing done on hardwood plywood industrial panels at a 0.13 ft^2/ft^3 loading rate. This is an appropriate benchmark for both industrial panels and wall panels. As shown in our white paper on hardwood plywood wall paneling loading rates submitted on March 8, 2007 (and attached again), the 0.29 ft^2/ft^3 loading rate established by the Department of Housing and Urban Development in 1985 for wall paneling used in manufactured housing is completely outdated. The HUD 0.29 ft^2/ft^3 loading rate was established on the basis of every wall in a manufactured home required to have a Class C flame spread rating being covered with hardwood plywood wall paneling. That was just about every wall in the home. The use of hardwood plywood wall panels has declined dramatically since HUD established the 0.29 ft^2/ft^3 loading rate for wall panels in the 1985 manufactured housing standard. As our white paper conclusively shows the actual average loading rate for wall paneling in residential homes is closer to 0.03 ft^2/ft^3.

We recommend that wall panels and industrial panels be tested at the same loading rate. The information contained in our attached white paper on wall panel loading rates shows current loading in residential construction to be significantly below 0.13 ft^2/ft^3, which is the industrial panel loading rate.

NOTE: Attached to this letter are two documents.
The first is a word document explaining the wall paneling loading rate in conventional homes.
The second is an Excel spreadsheet of wall panel loading rate data.

We again thank you for the opportunity to comment on the March 9, 2007 "PROPOSED AIR TOXIC CONTROL MEASURE TO REDUCE FORMALDEHYDE EMISSIONS FROM COMPOSITE WOOD PRODUCTS". We look forward to your response.

Sincerely,

Gail Overgard,
Chairman, HPVA technical Committee

Bill Altman
HPVA President

CC: Jim Aguila
Stationary Source Division
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HARDWOOD PLYWOOD PANELING LOADING RATES AND THE RELATIONSHIP OF FORMALDEHYDE EMISSIONS FROM PANELING AND PARTICLEBOARD IN CONTROLLED CHAMBER TESTS

February 22, 2007

William J. Groah

I HARDWOOD PLYWOOD LOADING RATES

A. The origin of standard large chamber test loading rates for hardwood plywood paneling

Concerns about formaldehyde levels in residential manufactured (mobile) homes in the late 1970s prompted an investigation by the Department of Housing and Urban Development (HUD). At that time the most important formaldehyde sources in manufactured homes were believed to be two urea-formaldehyde (UF) bonded wood based building products. Hardwood plywood paneling was the primary interior wall finish used in these homes and particleboard was extensively applied as the structural floor. HUD sponsored a research project to measure formaldehyde levels in four new experimental manufactured homes, two with then typical formaldehyde emissions from paneling and particleboard floor decking, and two with lower formaldehyde emission paneling and decking. Materials were tested in large chambers prior to the installation of the products in the study homes. This enabled the ability to determine any relationship between home formaldehyde concentrations and emission characteristics of the two wood based panel products. HUD selected Clayton Environmental Consultants to conduct the research. The Hardwood Plywood Manufacturers Association and the National Particleboard Association[1] participated in the study.

The objectives and results of this project were reported by Singh et al. (1982). Details of the loading rates for the paneling and certain other formaldehyde sources were further detailed by Groah et al. (1985). The loading rate for paneling in these homes was 0.98 m^2/m^3 (0.30 $ft.^2/ft.^3$), of which 0.79 m^2/m^3 (0.24 $ft.^2/ft.^3$) was simulated grain printed lauan paneling and 0.20 m^2/m^3 (0.06 $ft.^2/ft.^3$) vinyl overlay lauan paneling. Vinyl overlay paneling was used in areas of the kitchen and the two baths because it provides more surface resistance to water and is easy to clean. Vinyl film overlays have been shown to be effective in suppressing formaldehyde emissions from the paneling to which it is applied (Groah et al. 1984). Based on the paneling loading rates in these experimental homes and verification with other typical single-wide manufactured homes of the time,

[1] The Hardwood Plywood Manufacturers Association is now know as the Hardwood Plywood and Veneer Association (HPVA), and the National Particleboard Association is now known as the Composite Panel Association (CPA). Henceforth in this paper these organizations will be referred to as HPVA and CPA.

HUD established the large chamber test loading rate of 0.95 m^2/m^3 (0.29 $ft.^2/ft.^3$)for hardwood plywood in the Manufactured Home and Construction Standards (1984).[2]

ASTM E 1333 - 96 (Reapproved 2002), Standard Test Method Determining Formaldehyde Concentrations in Air and Emission Rates from Wood Products Using a Large Chamber was first published in 1990 and retained the loading rates for hardwood plywood wall paneling and for industrial panels as established by HUD in 1984 as clarified by HUD in 1985 (Nistler 1985).

B. Hardwood plywood wall paneling rates in homes

A number of studies of formaldehyde levels among U. S. homes were undertaken in the 1980s. Formaldehyde studies in manufactured homes were no doubt motivated by " a class of prefabrication construction techniques which rely greatly upon the use of particle board and hardwood plywood paneling for structural components" (Hanrahan 1985). These projects primarily focused on surveys of formaldehyde concentrations and sometimes examined the relationship of formaldehyde levels to home age or other variables. Loading rates for UF-bonded wood building materials were generally not determined in these investigations. Loading rates for hardwood plywood paneling and other formaldehyde sources were reported only in rare occasions in home studies, usually when the project involved a single or very small number of homes.

The Sexton et al. (1986) mail-out passive monitor sampling study in over 500 California manufactured homes examined home age, cooking fuel (natural gas is a source of formaldehyde), and cigarette smoking. Hanrahan et al. (1985) took on-site air samples and examined formaldehyde concentration and home age in 137 Wisconsin manufactured homes. The study of 397 mobile homes and 489 conventional homes in Minnesota reported by Ritchie and Lehnen (1985) also involved on-site air sampling. The analysis included home age, home manufacturer, and manufactured and conventional home comparisons. Manufactured home formaldehyde concentrations, on average, were about 3 times that of conventional homes. Syrotynski (1985), in a report of a five-year testing campaign by the New York State Department of Health involving 2,272 homes, compared results from four home categories, permanent residential complaint homes with UFFI (urea formaldehyde foam insulation), permanent residential complaint homes without UFFI, permanent residential non-complaint homes without UFFI, and complaint mobile homes without UFFI. UFFI is not normally used in manufactured or mobile homes.

A notable exception to these survey studies in a relatively large number of homes was the University of Iowa 31 conventional home project sponsored by the Formaldehyde Institute (Schutte et al. 1981). The average loading rate of the hardwood plywood paneling was 0.031 m^2/m^3 (0.0095 $ft.^2/ft.^3$) among the 31 homes. The average loading rate was 0.082 m^2/m^3 (0.025 $ft.^2/ft.^3$) among the 11 homes that contained paneling, with a

[2] HUD modified the loading rate for hardwood plywood industrial panels (used for cabinets, and other furnishings) to 0.13 ft^2/ft^3 in a letter of clarification (Nistler 1985).

range of loading rates from 0.00066 m^2/m^3 to 0.30 m^2/m^3 (0.0002 $ft.^2/ft.^3$ to 0.0915 $ft.^2/ft.^3$)

During the 1980s the Consumer Product Safety Commission (CPSC) sponsored a number of projects in their investigation of formaldehyde emissions from wood based materials. CPSC estimated loading rates of hardwood plywood wall paneling and particleboard underlayment in new single family detached homes (CPSC 1986). These estimates relied on National Association of Home Builders survey data among 4 home types: 1-story, 2-story, splitlevel, and bilevel. When paneling was present in these homes, the average loading rate in all four home types was 0.066 m^2/m^3 (0.02 $ft.^2/ft.^3$).

The equivalent of twelve 4' x 8" plywood wall panels, sufficient to panel all four walls in a room greater than 12' x12', were used in the EPA/CPA pilot home study (Koontz et al. 1996) for the two "high load" configuration in a Cape Cod style conventional home. The paneling loading rate in the top two floors of the home was 0.118 m^2/m^3 (0.036 $ft.^2/ft.^3$). The loading rate was 0.076 m^2/m^3 (0.023 $ft.^2/ft.^3$) if the full volûme of the home, 471.4 m^3 (16,647 ft^3), including the basement is considered. The basement was closed off from the top two floors and used as an office by the testing team during the course of the experiment.

C. Hardwood plywood wall paneling - a product of diminishing popularity

In the 1960s and 1970s hardwood plywood wall paneling was the preferred interior wall covering product in residential manufactured homes because of its low weight and high racking strength allowing the homes to be moved with little or no structural damage from the factory to distribution centers and/or to the home site. Paneling typically selected for use was relatively low cost 5/32 to 1/4 inch thick imported lauan from Southeast Asia, with the application of printed, paper overlay, vinyl overlay surface finishes in North American factories. It should be noted that there is or has been in the past very little prefinished (factory finished) wall paneling imported to the U. S. Imports are in the form of unfinished plywood primarily from Southeast Asia in the lauan trade group category, surface finished and top coated in the U. S. Lauan and similar Asian species have generally represented about 80 to 90% of U. S. wall panel shipments during, at least, the last 25 years.

Several factors led to the general replacement of plywood wall paneling: an Indonesian cartel generally controlled the market in the 1970s and the 1980s and steadily increased prices for unfinished wall paneling blanks. The manufactured home industry began to examine alternative building materials as an outcome of these cost increases. Moreover, and perhaps more important, a 5/16 thick inch gypsum wallboard was developed specifically for the manufactured home industry. Techniques by the manufactured home industry to utilize this product structurally led to greater use of gypsum. An additional factor was that more sectional double wides were produced during this period as the industry moved to present their homes more like smaller size conventional homes. This trend accelerated into the late 1980s and 1990s.

The Manufactured Housing Institute (MHI) reported to the Environmental Protection Agency in 1993 (Walter) that "gypsum wallboard continues to be used in nearly all our homes in place of hardwood panel walls, which was the industry norm 10 or more years ago." The MHI data, representing about 55% of the homes produced or planned for 1993, indicated that only 5.3% of manufactured homes used hardwood panels for interior walls.

U. S. production and shipment figures are provided in Table 1 below to illustrate the declining popularity and use of prefinished hardwood paneling. Each entry is for average shipments during four 3-year periods to avoid annual shipment distortions of unusually high or low figures for any one year that can occur during normal business cycles.

TABLE 1. PREFINISHED HARDWOOD PLYWOOD PANELING SHIPMENTS

THREE YEAR PERIOD	AVERAGE ANNUAL SHIPMENTS DURING THE THREE YEAR PERIOD (square feet surface measure)	RELATIONSHIP OF SHIPMENTS SHOWN AS A REDUCTION FROM THE 1971 -1973 BASE (percent)
1971 - 1973	3,778,000,000	BASE THREE YEAR PERIOD
1983 - 1985	1,472,000,000	61
1993 - 1995	916,000,000	76
2003 - 2005	641,000,000	83

Sources of statistics above:

1971 - 1973 HPVA table dated 8/10/84 providing prefinished hardwood plywood paneling shipments for years 1962 -1982.

1983 - 1985 Prefinished wall paneling annual statistical report for calendar year 1985, George Carter and Affiliates (report includes statistics for 1985 and 3 prior years.)

1993 - 1995 Prefinished wall paneling annual statistical report for calendar year 1996, George Carter and Affiliates (report includes statistics for 1996 and 3 prior years.)

2003 -2005 Prefinished wall paneling annual statistical report for calendar year 2005, George Carter and Affiliates (report includes statistics for 2005 and 3 prior years.)

NOTE:The George Carter and Affiliates reports were sponsored by the HPVA. This company did not prepare reports for HPVA during the 1971 -1973 period.

The years 1971 - 1973 represented the peak of hardwood plywood wall paneling shipments. In the 1983 - 1985 period hardwood plywood was still the preferred wall interior finish for manufactured homes. The reduction figures above from the early 1970s to the mid-1980s was likely due to several factors: a decrease in general popularity of the product, a decline in shipments of manufactured homes which were over produced during a period of the 1970s, and the movement by some manufactured home producers towards using the competitively priced gypsum wall board product. In 1993 - 1995 most of the manufactured home market for wall paneling had been lost as previously indicated by Walter (1993). Since the mid-1990s there was been a further decline in popularity in paneling which has, no doubt, been reflected in decreased use in both new conventional homes and in remodeling. Over the past 20 years the manufactured home industry has continued to emulate conventional homes in their choice of certain building materials and furnishings.

The findings of a fairly recent study (Hodgson et al. 2000) also tend to be consistent with the trend towards the use of similar building products for conventional (site-built) and manufactured homes. In a study of VOC emissions, including formaldehyde, in 7 site-built homes and 4 manufactured homes these authors stated the following:

> "The predominant compounds detected in the new manufactured and site-built houses were generally the same. In addition, the concentrations of many of the target compounds were similar in the two types of homes. The similarities between the manufactured and site-built homes were presumably due to the generally comparable construction practices and materials. It was notable that the concentrations and emission rates of formaldehyde in the manufactured houses were considerable less than historical reported values, and that they were similar to the concentrations and emission rates in site-built homes."

D. Current hardwood plywood wall paneling applications and loading scenarios

Plywood wall panels can be found in a number of building types. Some of the more common applications are in restaurants, travel trailers, and temporary field office and classroom structures. The largest use, by far, is in residential manufactured homes and conventional homes.

In the 1970s and early 1980s it was relatively easy to determine loading rates in manufactured homes. At that time most of the homes were 12 or 14 foot single wide structures in lengths of 70 to 80 feet. Paneling was generally used throughout the home except behind the kitchen stove and in the compartments enclosing furnaces and hot water heaters. With the general replacement of paneling by gypsum wallboard, loading scenarios are believed to have become similar to conventional homes. When present, in residential manufactured and in conventional homes, paneling is characterized by the following applications: a paneled room usually for recreational use, wainscoting in a room consisting of paneling on the lower part of a wall or walls in a room separated by a chair rail with painted gypsum wall board above, or one or more paneled feature walls in one or more rooms. Because usage rates differ among these applications it is not possible to characterize a common loading rate in either new manufactured or conventional homes. An approach for estimating population based loading rates for hardwood plywood paneling is described below.

E. An estimate of current average loading rates of wall paneling in conventional homes

The use of hardwood plywood wall paneling has decreased dramatically since the peak years in the 1970s. Statistics in Table 1 indicate continuous erosion of use over the past

40 years. Indeed, the product has demonstrated a decline of more than 80% since the 1971 - 1973 period. Average annual shipments in the 2003-2005 period were only about 641,000,000 ft^2 surface measure. The U. S Census Bureau (2006) listed 2,068,300 housing starts in 2005, of which 1,715,800 (83%) were 1 unit structures. If the entire production of hardwood plywood paneling were used in conventional homes, the average surface area of hardwood plywood paneling among all housing starts would be 28.8 m^2 (309.9 $ft.^2$). Using only the 1 unit housing starts, the average surface area of wall paneling would be 34.7 m^2 (373.6 $ft.^2$). These usage rates are conservative in that they allot all wall paneling use to conventional homes and none to residential manufactured homes and other structures where it can be found. In addition, the average annual shipments (2003 - 2005) accounts for a significant quantity of HPWP used in remodeling rather than in new construction.

The U. S. Census Bureau also reports that the average U.S. one-family home has a 2,434 ft^2 living area. Home size is not broken down by states but is shown by regions: Northeast, Midwest, South, and West. The largest homes are in the Northeast and the smallest homes in the Midwest. The average size of homes in the West is at the U. S. average. Moreover, there is no reason to believe that the use of hardwood plywood paneling in California is much different from other states in the West or the U. S. at large. Assuming an average ceiling height of 8 feet, the average U. S. and Western region home volume is 19,472 $ft.^3$. The average hardwood plywood wall paneling loading rate in these homes would be 0.053 m^2/m^3 (0.016 $ft.^2/ft.^3$). For only 1 unit homes the average loading rate would be 0.062 m^2/m^3 (0.019 $ft.^2/ft.^3$). Many newer homes have ceiling heights greater than 8 feet and some have cathedral ceilings, thus these loading rates are conservative.

II RELATIONSHIP OF TWO FORMALDEHYDE CONCENTRATION SOURCES: HARDWOOD PLYWOOD PANELING AND PARTICLEBOARD

The fact that additive chamber values (adding the formaldehyde concentrations of two products tested singly) exceed combination values (the concentration of the same two products tested in the same chamber test) was observed as early as 1981/1982 (Singh et al. 1982). This relationship has also been reported by other investigators (Pickrell et al. 1982, and Sundin 1987).

A number of papers were examined to determine available data for assessing formaldehyde release relationships between two UF-bonded wood based products in dynamic chamber tests: hardwood plywood wall paneling and particleboard. The following criteria was established for the selection of studies to be included in this analysis:

- Testing must be performed on the two products individually and the same two products must be tested together,
- Testing would be in a dynamic chamber at conditions typical of those in buildings,

- Tests in each study should be conducted with relatively small tolerances for temperature, and relative humidity,

- Each study source should consist of five or more test series.

Four data sources are described to illustrate the relationship of formaldehyde concentrations between hardwood plywood paneling and particleboard as tested singly and together (in combination). The results of these tests are collected and summarized in Table 2. Each data source is described below.

Particleboard, hardwood plywood, hardboard, and carpet were tested by Godish and Kanter (1985) in 9-liter (0.009 m^3) desiccators reconfigured as small dynamic chambers. Testing at 21° ± 1° C (70° ± 2° F) and at 50% ± 5% relative humidity was performed on sources evaluated singly, followed by the two sources in combination. Loading rates were fairly high in some of these chamber studies ranging from 0.49 m^2/m^3 (0.15 $ft.^2/ft.^3$) to 2.8 m^2/m^3 (0.85 $ft.^2/ft.^3$). Of the thirteen test series, the seven involving plywood paneling and particleboard were used in this analysis. Two mechanisms were suggested by these authors to account for the interaction observed in concentrations between the two formaldehyde sources: sink mechanisms and emission suppression due to formaldehyde vapor pressure gradients.

Godish and Rouch (1987) examined 7 combinations of UF containing materials, 6 of which were particleboard and hardwood plywood wall paneling. Dynamic 0.28 m^3 (10 $ft.^3$) Plexiglass chambers were maintained at 23.5° ± 1° C (74° ± 2° F) and 50% ± 5% relative humidity and at an air change rate of 0.5 AC/hour. Loading rates were at 0.410 m^2/m^3 (0.125 $ft.^2/ft.^3$) for particleboard and 0.722 m^2/m^3 (0.220 $ft.^2/ft.^3$) for hardwood plywood paneling. Only the 6 series of tests on UF-bonded wood panel products are considered in this analysis. Products were tested singly and in combination. In all test series the mixed load concentrations were lower than the addition of the single particleboard and plywood concentrations. For the six test series the addition of particleboard and plywood concentrations averaged about 60% higher than the concentration when the two products were tested together. An experimental house was also used to study formaldehyde concentration interactions from the same populations of materials; however, the relationship between the small chamber studies and the whole house studies were not consistent: two of the series demonstrated results similar to that observed in small chamber tests while four whole house tests suggested that the concentrations of the two sources could be additive. Godish and Rouch (1987) identified some factors that could have contributed to the inconsistent results between the home and small chamber studies:

> "These differences were in all probability due, in part, to differences in our ability to control environmental factors which can influence formaldehyde levels. For example, experimental series 1 and 6 [in the whole house] were conducted under cold winter ambient weather conditions. Source materials prior to evaluation

were placed in a storage garage where environmental conditions (temperature and relative humidity) to a considerable degree were those of the outdoor environment. Although wall temperatures were not measured in this study, it appears likely that higher wall temperatures caused by solar radiation did occur and . . . would result in higher emissions of formaldehyde from hardwood plywood paneling . . . The walls of the bi-level [house] used for most of our evaluations were not insulated."

Newton et al. (1986) described interaction studies among 13 UF-bonded particleboard and hardwood plywood paneling products. Testing was in a large 28.4 m^3 (1003 $ft.^3$) dynamic chamber. Series 14 through 18 experiments were at a loading rate of 0.525 m^2/m^3 (0.16 $ft.^2/ft.^3$) for particleboard and 1.05 m^2/m^3 (0.32 $ft.^2/ft.^3$) for hardwood plywood and were also referenced in an earlier paper (Newton 1982). Particleboard was tested at 0.427 m^2/m^3 (0.13 $ft.^2/ft.^3$) and hardwood plywood at 0.95 m^2/m^3 (0.29 $ft.^2/ft.^3$) in series 19 through 26. Products were tested singly and in combination at 25° ± 1° C (77° ± 2° F), 50% RH ± 4%, and 0.5 air changes per hour.

The fourth set of data represented 10 series extracted from Hardwood Plywood & Veneer Association tests conducted from 1981 through 1988. Some of these results were reported in Singh et al. (1982) and some in Groah and Gramp (1988). Particleboard and hardwood plywood wall paneling were tested singly and in combination at 0.427 m^2/m^3 (0.13 $ft.^2/ft.^3$) and 0.95 m^2/m^3 (0.29 $ft.^2/ft.^3$), respectively. Tests were performed in 30.6 m^3 (1080 $ft.^3$) large chambers at 25° ± 1° C (77° ± 2° F), 50% RH ± 4%, and 0.5 ± 0.05 air changes per hour. These conditions later became standard conditions for large chamber testing (ASTM 1996). Four of the series (H 7a - H 7d, Table 2) were of the same material tested at four different times: approximately 1 month, 6 months, 12 months and 18 months after manufacture; however, test materials were "dead stacked" two months during the course of the 18 month investigation, severely limiting emissions from the surfaces of the samples during that period.

The data from all 36 series from the four data sources are assembled in Table 2 to illustrate the relationships between additive vs. combination formaldehyde concentration values. Even though the data from the four sources were obtained at somewhat different test conditions and loading rates, conditions appeared to be well controlled by the descriptions of tolerances for each data source. Thus, both the within set and between set data are compared. Loading rates, formaldehyde concentrations, the combination test chamber concentration, the additive values, and the percentage that the additive valued exceeds the combination value (when the products were tested together) are provided in the table.

Data from every test from all four sources in chamber testing indicate that the formaldehyde concentrations of hardwood plywood paneling and particleboard are not additive. Additive values averaged a 54% increase over combination values. There was generally more consistency in the additive/combination concentration relationships when products were tested in large chambers. The reconfigured desiccator as a small chamber had a volume of 0.009 m^3 (0.32 $ft.^3$) in series 1 through 7. The volume of this small chamber was over 3000 times smaller than the large chambers used in test series 14 through 36.

The relationships between additive and combination concentrations were remarkably similar from the two data sources using large chambers. In the Newton et al. (1986) experiments, additive plywood and particleboard values (Series 14 - 26, Table 2) exceeded combination values by an average of 44% with a range of 28 to 63%. In the 10 HPVA comparisons (Series 27 - 36) additive values exceeded combination testing values by an average of 45% with a range of 29 to 64%.

While these additive/combination testing relationships should hold for contemporary UF-bonded wood products and loading rates, a cautionary note is provided. All of the test data from the four sources above involved loading rates of paneling and particleboard flooring considerably higher than in homes built since, at least, the mid to late 1980s. In manufactured homes of the 1970s and into the 1980s effective diffusion barriers such as vinyl sheet goods did not cover most of the particleboard floor area, and most of the wall surfaces were hardwood plywood. Thus, there was considerable opportunity for interaction between these two large surface area products. With the changing use patterns for particleboard flooring and hardwood plywood wall paneling, the potential for interaction between the two products may have diminished. This could be more than offset by the interaction of the most likely substitute for hardwood plywood wall paneling, gypsum wall board, with other formaldehyde sources in the home including particleboard when it is used. Gypsum wallboard has been identified as an important sink for formaldehyde (Chang and Guo 1992). While the sorbed formaldehyde by gypsum is generally reemitted, the reemissions are believed to occur over a fairly long time period. This would act to reduce the initial and higher concentrations when gypsum wallboard and other sinks are present. Gypsum wallboard sinks and the effects on formaldehyde home concentrations and other formaldehyde sources was demonstrated in the EPA/CPA pilot study (Koontz et al. 1996).

Literature cited

ASTM. 1996 (reapproved 2002). Standard test method for determining formaldehyde concentrations in air and emission rates from wood products using a large chamber, E 1333-96.

Chang, J., and Guo, Z. 1992. Sorption and reemission of formaldehyde by gypsum wallboard. ASHRAE IAQ 1992. pp. 301-307.

Consumer Product Safety Commission. 1986. Staff briefing package on pressed wood activities and CFA petition. February 4, 1986.

Godish, T., and B. Kanyer. 1985. Formaldehyde source interaction studies. Forest Prod. J. 35(4):13-17.

________. and J. Rouch. 1987. Formaldehyde source interaction studies under whole-house conditions. Environmental Pollution 48, pp.1-12.

Groah, W., Gramp G., and M. Trant. 1984. Effect of a decorative vinyl overlay on formaldehyde emissions. Forest Prod. J. 34(4):27-29.

________, ________, Garrison S., and R. Walcott. 1985. Factors that influence formaldehyde air levels in mobile homes. Forest Prod. J. 35(2):11-18.

________, ________. 1988. An estimate of home occupant exposures to formaldehyde gas from plywood and reconstituted wood products bonded with formaldehyde based adhesives. CPA/HPVA 1988 exposure and assessment package report.

Hanrahan, L., Anderson, H., Dally, K., Eckmann, A., and M. Kamarek. 1985. Formaldehyde concentrations in Wisconsin mobile homes. JAPCA 35:1164-1167.

Hardwood Plywood and Veneer Association (HPVA). 1981 -1988. Test records of large chamber testing of paneling and particleboard series tested singly and together (in combination).

Hodgson, A., Rudd, A., Beal, D., and S. Chandra. 2000. Volatile organic compound concentrations and emission rates in new manufactured and site-built houses. Indoor Air 2000: 10: 178-192.

Koontz, M., Rector, H., Cade, D., Wilkes, C., and L. Niang. 1996. Residential indoor air formaldehyde testing program: pilot study. GEOMET Technologies Inc. report for the U. S. Environmental Protection Agency. IE-2814.

Newton, L. 1982. Formaldehyde emission from wood products: correlating environmental chamber levels to "secondary" laboratory tests. Sixteenth International Symposium on Particleboard. Washington State University. pp. 45-61.

________. Anderson, W., Lagroon, H., and K. Stephens. 1986. Large-scale chamber methodology for urea-formaldehyde bonded wood products. In: Formaldehyde release from wood products. Meyer, B., Kottes Andrews, B., and R. Reinhardt, eds. ACS Symp. Series 316; 154-187. American Chemical Society.

Nistler, J. 1985. U. S. Department of Housing and Urban Development memorandum to all primary inspection agencies, all home manufacturers, and all state administrative agencies. January 31, 1985

Pickrell, J., Griffis, L., and C. Hobbs. 1982. Release of formaldehyde from various consumer sources. Prepared for the Consumer Product Safety Commission by the Lovelace Biomedical & Environmental Research Institute.

Ritchie, I., and R. Lehnen. 1985. An analysis of formaldehyde concentrations in mobile and conventional homes. Journal of Environmental Health. 47(6): 300-305.

Schutte, W., Scarpellino, C., Sailor, S., Hoffman, J., and C. Frank. !981. Final report to the Formaldehyde Institute [31 Iowa home report]. University of Iowa.

Sexton, K., Liu, K., and M. Petreas. 1986. Formaldehyde concentrations inside private residences; a mail-out approach to indoor air monitoring. JAPCA 36(6): 698-704.

Singh, J., Walcott, R., St. Pierre, C., Ferrel, T., Garrison, S., Gramp, G., and W. Groah. 1982. Evaluation of the relationship between formaldehyde emissions from particleboard mobile home decking and hardwood plywood wall paneling as determined by product test methods and formaldehyde levels in experimental mobile homes. Report prepared by Clayton Environmental Consultants Inc. for the U. S. Department of Housing and Urban Development.

Sundin, B.. 1987. Formaldehyde source interaction studies. Fesyp Technical Conference Meeting, Munich, March 10-11, 1987.

Syrotynski, S. 1985. Prevalence of formaldehyde concentrations in residential settings. In: Transactions, indoor air quality in cold climates, hazards and abatement measures. D. Walkinshaw, editor. Air Pollution Control Association. pp. 127-136.

U. S. Census Bureau. 2006. Table of new privately owned housing units started.

_______________, 2006. Table of median and average square feet of floor area in new one-family houses completed by location.

U. S. Department of Housing and Urban Development. 1984. Manufactured home construction and safety standards. Federal Register 49(155) 24 CFR Part 3280.

Walter, F. 1993. Manufactured Housing Institute. July 22, 1993 product use survey letter to the Environmental Protection Agency.

Table 2.-- Relationships between particleboard (PB), and hardwood plywood wall paneling (HP) tested singly and in combination in dynamic chamber tests.

Series	Source	PB loading rate (m^2/m^3)	HP loading rate (m^2/m^3)	PB conc. (ppm)	HP conc. (ppm)	Combination PB and HP (ppm)	Additive PB+HP (ppm)	Additive Exceeds Comb. (%)	Additive Exceeds Comb. Ave. (%)
1	G/K 1	1.80	2.00	0.15	0.25	0.28	0.40	43	
2	G/K 2	1.80	2.00	0.16	0.14	0.16	0.30	88	
3	G/K 3	1.80	2.80	0.08	0.06	0.05	0.14	180	
4	G/K 4	0.48	1.20	0.05	0.05	0.05	0.10	100	
5	G/K 5	0.48	1.20	0.06	0.12	0.12	0.18	50	
6	G/K 6	1.80	2.00	0.22	0.04	0.17	0.26	53	
7	G/K 7	1.20	1.20	0.88	0.15	0.79	1.03	30	78
8	G/R 1	0.41	0.72	0.15	0.27	0.19	0.42	121	
9	G/R 2	0.41	0.72	0.14	0.27	0.24	0.41	71	
10	G/R 3	0.41	0.72	0.13	0.11	0.18	0.24	33	
11	G/R 4	0.41	0.72	0.17	0.25	0.33	0.42	27	
12	G/R 5	0.41	0.72	0.17	0.23	0.26	0.40	54	
13	G/R 6	0.41	0.72	0.29	0.38	0.43	0.67	56	60
14	N 1	0.52	1.05	0.19	0.70	0.69	0.89	29	
15	N 2	0.52	1.05	0.32	0.54	0.66	0.86	30	
16	N 3	0.52	1.05	0.23	0.31	0.36	0.54	50	
17	N 4	0.52	1.05	0.19	0.13	0.20	0.32	60	
18	N 5	0.52	1.05	0.08	0.29	0.29	0.37	28	
19	N 6	0.43	0.95	0.19	0.19	0.24	0.38	58	
20	N 7	0.43	0.95	0.23	0.58	0.59	0.81	37	
21	N 8	0.43	0.95	0.75	0.20	0.70	0.95	36	
22	N 9	0.43	0.95	0.28	0.08	0.23	0.36	57	
23	N 10	0.43	0.95	0.40	0.40	0.60	0.80	33	
24	N 11	0.43	0.95	0.40	0.15	0.41	0.55	34	
25	N 12	0.43	0.95	0.31	0.20	0.33	0.51	55	
26	N 13	0.43	0.95	0.53	0.29	0.50	0.82	64	44
27	H 1	0.43	0.95	0.40	0.40	0.62	0.80	29	
28	H 2	0.43	0.95	0.38	0.15	0.41	0.53	29	
29	H 3	0.43	0.95	0.31	0.20	0.33	0.51	55	
30	H 4	0.43	0.95	0.53	0.29	0.50	0.82	64	
31	H 5	0.43	0.95	0.33	0.27	0.43	0.60	40	
32	H 6	0.43	0.95	0.30	0.41	0.41	0.71	73	
33	H 7a	0.43	0.95	0.29	0.19	0.32	0.48	50	
34	H 7b	0.43	0.95	0.19	0.11	0.21	0.30	43	
35	H 7c	0.43	0.95	0.14	0.10	0.17	0.24	41	
36	H 7d	0.43	0.95	0.14	0.08	0.17	0.22	29	45
							AVE.	54	

G/K: Godish and Kanyer, 1985, Formaldehyde spource interaction studies.

G/R: Godish and Rouch, 1987, Formaldehyde source interaction studies under whole house conditions.

N: Newton et al.,1986, Large-scale test chamber methodology for urea-formaldehyde bonded wood products.

H: Test records of the Hardwood Plywood and Veneer Association, 1981 - 1988.