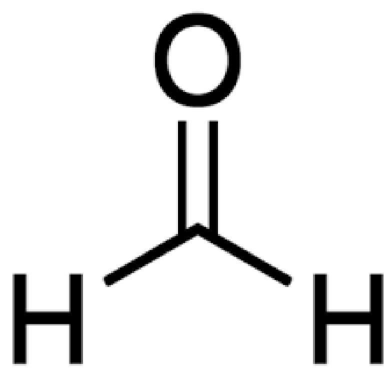
United States
Environmental Protection Agency

December 2024
Office of Chemical Safety and
Pollution Prevention

Indoor Air Exposure Assessment for Formaldehyde

CASRN 50-00-0



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The indoor air environment includes commercial settings, new homes, mobile homes, and automobiles—all of which are a major source of formaldehyde exposure to humans. Exposure to formaldehyde in these settings is the result of ubiquitous use of formaldehyde in the manufacturing of consumer products and articles (*e.g.,* rubber mats, plastic chairs, hardwood floors). Formaldehyde might also be present in the indoor environment due to the use of fireplaces, gas stoves, additional combustion sources, human breath, and other sources. The number of potential sources of formaldehyde to consider makes an indoor air exposure assessment of formaldehyde highly complex.

According to the U.S. Department of Housing and Urban Development (HUD) (QuanTech, 2021) indoor air concentrations of formaldehyde range from 0.27 to 124 µg/m^3 (3.5-hour time-weighted average [TWA]). Monitoring data are expected to represent concentrations of formaldehyde from all sources of formaldehyde within the sampled space. In addition, the majority of the available monitoring data are expected to represent typical formaldehyde concentrations in indoor air; however, some datasets may capture peak exposures.

Indoor air monitoring data were used in this assessment to characterize known formaldehyde indoor air exposures. However, these monitoring data do not differentiate between Toxic Substances Control Act (TSCA) and other sources of formaldehyde, such as gas stoves. Therefore, EPA utilized modeling tools to assess TSCA conditions of use (COU) exposures for formaldehyde in indoor air. EPA used the Consumer Exposure Model (CEM) as a tier 1 modeling tool, which CEM was not used to estimate peak exposures for the draft risk evaluation. Based on the available data, the Agency assumed formaldehyde indoor air exposures would be primarily from long-term emissions. It is unclear how often people purchase or replace articles, remodel their homes or article-specific lag-times between the manufacture and installation of an article into an indoor environment. For a comprehensive consideration of all potentially relevant durations of exposure to formaldehyde and to address uncertainties associated with CEM's potential overestimation of long-term exposures, EPA revised its assessment using the Indoor Environmental Concentrations in Buildings with Conditioned and Unconditioned Zones (IECCU) as a tier 2 modeling tool to characterize 15-minute peak, 3-month average and 1-year average formaldehyde residential indoor air concentrations. The IECCU modeling considered article-specific lag-times between the manufacture and installation of an article into an indoor environment by foregoing the use of initial weight fractions reported in article safety data sheets (SDSs) and relying on the emission factors reported from chamber studies of finished articles.

EPA identified four COUs under TSCA as significant formaldehyde contributors to commercial, automotive, and residential indoor air environments. Formaldehyde exposures from individual articles for these TSCA COUs were estimated using two different standard exposure models and product-specific emissions data. Using CEM, estimated modeled average daily concentration over 1 year ranged from 4.01 µg/m^3 to 423.47 µg/m^3. Using IECCU, the estimated formaldehyde 15-minute peak concentrations ranged from 0.007 to 142 µg/m^3 and 1-year annual averages ranged from 0.0003 to 6.1 µg/m^3 in the applicable room(s) from IIECCU modeling. The highest exposures are expected to result from laminate flooring and pressed wood furniture, using either modeling tool.

EPA also assessed aggregate exposure scenarios (new construction, new décor, and laminate with background) and evaluated available formaldehyde indoor air monitoring data from within residential homes, automotives, offices, and other buildings. These aggregate exposures are expected to vary according to conditions of use, product specifications, activity patterns, purchase habits, etc.

Estimated formaldehyde 15-minute peak concentrations ranged from 3 to 160 $\mu g/m^3$ and 1-year annual averages ranged from 0.1 to 6.9 $\mu g/m^3$ for aggregate exposures in the applicable room(s) of use based on IECCU modeling.

EPA also considered other sources of formaldehyde including fireplaces, air cleaning devices, cooking, candles, ethanol fireplaces and incense. Examination of indoor air monitoring data suggest that in some spaces, combustion may substantially contribute to indoor air formaldehyde concentrations, but typically, combustion does not substantially result in higher formaldehyde concentrations in indoor air. Concentrations of formaldehyde in homes with combustion sources, reported by residents at the time of indoor monitoring surveys, are not different than homes without combustion sources or government buildings where combustion is not expected.

There is uncertainty in the precise estimates from both CEM and IECCU due to model limitations—especially for long-term concentrations. However, when used together, EPA has high confidence in the potential range of formaldehyde concentrations from TSCA COUs. This conclusion is supported by available monitoring data. While the exposure durations and scenarios do not perfectly align, consideration of all of the available data suggests model estimated and measured formaldehyde are in reasonable agreement. Specifically, model estimated formaldehyde concentrations were within the same order of magnitude as measured concentration data (*e.g.*, HUD's American Healthy Homes Survey II). In addition, the estimated aggregate exposures fall within the range of available monitoring data. This suggests that TSCA COUs are contributors to real-world concentrations of formaldehyde in indoor air. Formaldehyde concentrations are expected to be highest for newly constructed residences with formaldehyde-based materials (including laminate flooring) and when new formaldehyde-based articles are added to a residence (including furniture covers).

EPA has high confidence in the conclusions of this indoor air assessment, including that exposures to formaldehyde occur as the result of TSCA COUs on a short- and long-term basis in indoor air environments. However, the precise concentrations on a long-term basis are uncertain and are expected to be highly variable.

EXECUTIVE SUMMARY

Formaldehyde is a chemical ingredient in many articles such as furniture, flooring, cabinets, to name just a few, which can be significant contributors to its peak and long-term indoor air concentrations.

EPA used a combination of modeling and monitoring data to characterize formaldehyde indoor air exposures while considering the relative contributions of TSCA COUs to the indoor air environment. The Agency assessed indoor air exposures for four COUs expected to be significant sources of formaldehyde in indoor air. Monitoring data were further used to characterize indoor air exposures and provide context for estimated concentrations.

In the *Draft Indoor Air Exposure Assessment for Formaldehyde*, EPA used the CEM as a tier 1 modeling tool. However, CEM was not used to estimate peak exposures for the draft assessment and due to uncertainties with CEM's potential overestimation of long-term exposures, along with an inability to consider first-order exponential decay for articles in the long-term based on the E5 emission condition. This revised assessment also utilizes IECCU as a tier 2 modeling tool to characterize 15-minute peak, 3-month average, and 1-year average formaldehyde residential indoor air concentrations. Specific consumer article categories were modeled by incorporating relevant low, median, and high emission factors and corresponding surface areas expected in a room according to reasonably available information. In addition, some COUs were aggregated to estimate indoor air concentrations from a home renovation and a décor update.

According to CEM, the highest modeled average daily concentration over 1 year is for building wood articles (423.47 $\mu g/m^3$). The lowest concentrations were due to furniture seat covers (4.01 $\mu g/m^3$) and clothing (5.19 $\mu g/m^3$). In contrast, IECCU-estimated 1-year concentrations ranging from 0.00003 to 6.9 $\mu g/m^3$ across all COUs and scenarios. The COU contributing to the highest residential indoor air formaldehyde concentrations was laminate flooring. Modeled 15-minute peak concentrations ranged from 0.00009 to 142 $\mu g/m^3$. In addition to individual COUs, IECCU was used to aggregate COUs and estimate potential indoor air concentration. High-end aggregate scenarios for indoor air (*i.e.*, new construction and new décor scenarios) produced the highest peak modeled indoor air concentrations (160 $\mu g/m^3$).

It should be noted that the CEM modeling for the formaldehyde does not consider the lag time between when articles may be manufactured and installed indoors since it relies on the initial formaldehyde concentration from a finished article, as reported by relevant SDSs, as the initial indoor air concentration to which an individual is exposed. This results in a conservative emission rate and exposure estimate via modeling because it is unlikely that a newly manufactured product will be instantly installed in a home and individuals will immediately be exposed to those higher concentrations early in their exposure period. It is more likely that the actual emissions from any given product will be the rate following some period of storage time where initial off-gassing at those high-rates would have occurred prior to being installed in a residence. The IECCU modeling considered this lead time by foregoing the use of initial weight fractions reported in article SDSs and relying on the emission factors reported from chamber studies of finished articles.

The 1-year results for IECCU are significantly lower than those from CEM and are likely an underestimate. Available data suggest a biphasic emission profile (rapid emission of formaldehyde when the product is new followed by a much slower emission of formaldehyde) for laminated wood products that is not captured in the modeling results. This biphasic emission profile may also occur for other urea-formaldehyde based products; however, data are not available to confirm. As such, CEM was used in conjunction with IECCU to characterize 1-year average indoor air concentrations.

Monitoring data were incorporated into this assessment to characterize the indoor air concentrations most people are exposed to in their homes. EPA used data acquired through systematic review and publicly available to characterize indoor air concentrations of formaldehyde. These monitoring data do not differentiate between TSCA COU and other sources of formaldehyde like cigarette smoke or gas stoves. Monitoring data also may not capture peak concentrations or fluctuations in indoor air concentrations of formaldehyde. Indoor air monitoring data can, however, provide insight to long-term and aggregate exposures to formaldehyde. In addition to data captured from homes, EPA considered monitoring data from various environments including schools, government buildings and mobile homes.

Monitoring data from the American Healthy Homes Survey II, a comprehensive survey of American homes, ranged from 0.27 to 124.2 $\mu g/m^3$. Additional monitoring data identified through systematic review demonstrates the potential for much higher concentrations (up to 4,500 $\mu g/m^3$) in the indoor environment when construction materials with high emission factors are used. Some of these higher concentrations are anticipated to be addressed by enactment and implementation of the composite wood standards for formaldehyde emissions, but comprehensive monitoring data allowing for evaluation of the impact of these standards are not yet available.

Indoor air monitoring data were an integral aspect of the formaldehyde indoor air assessment as it was used to provide the best available data on real world formaldehyde indoor air concentrations. Although it should also be noted that the formaldehyde indoor air monitoring data, even if recent, may not represent future potential exposures from laminate wood articles in homes due to implementation of the composite wood standards. This may be an artifact of how monitoring data cannot fully reflect how and when formaldehyde-emitting materials—including imported articles from places with varying wood standards—are installed. Similarly, monitoring data cannot explain how frequently these materials are replaced. Lastly, the monitoring data may not reflect changes in energy efficiency home improvements that reduce ventilation (*e.g.*, leaks). Considering limitations in the monitoring data, it is reasonable to rely on modeled concentrations according to TSCA COUs.

Based on consideration of the weight of scientific evidence, EPA has high confidence in the overall findings for this indoor air exposure assessment.

1 INTRODUCTION

Formaldehyde is a naturally occurring chemical produced during combustion and the decomposition of organic matter, and as a normal part of metabolism in humans as well as many other organisms. Formaldehyde is also commercially used and manufactured extensively in construction, furniture manufacturing, consumer products and articles. As such, formaldehyde is ubiquitous in indoor and outdoor environments. Formaldehyde is a gas that is distributed in aqueous solution as formalin or in a solid as paraformaldehyde.

Formaldehyde is a high priority chemical undergoing the Toxic Substances Control Act (TSCA) risk evaluation process for existing chemicals following passage of the Frank R. Lautenberg Chemical Safety for the 21st Century Act in 2016. It is concurrently undergoing a risk assessment under the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA). This document presents a formaldehyde indoor air exposure assessment of TSCA COUs, as defined by TSCA sections 3(2) (defining “chemical substance”) and 3(4) (defining “conditions of use”). This TSCA-specific assessment serves to support risk management needs by EPA’s Office of Pollution Prevention and Toxics (OPPT) and is one of many documents included within the *Risk Evaluation for Formaldehyde.*

1.1 Risk Evaluation Scope

The TSCA risk evaluation of formaldehyde comprises several human health and environmental assessment modules and two risk assessment documents—the environmental risk assessment and the human health risk assessment. A basic diagram showing the layout of these modular assessments and their relationships is provided in Figure 1-1. This indoor air exposure assessment is shaded blue. In some cases, individual assessments were completed jointly under TSCA and FIFRA. These modules are shown in dark gray.

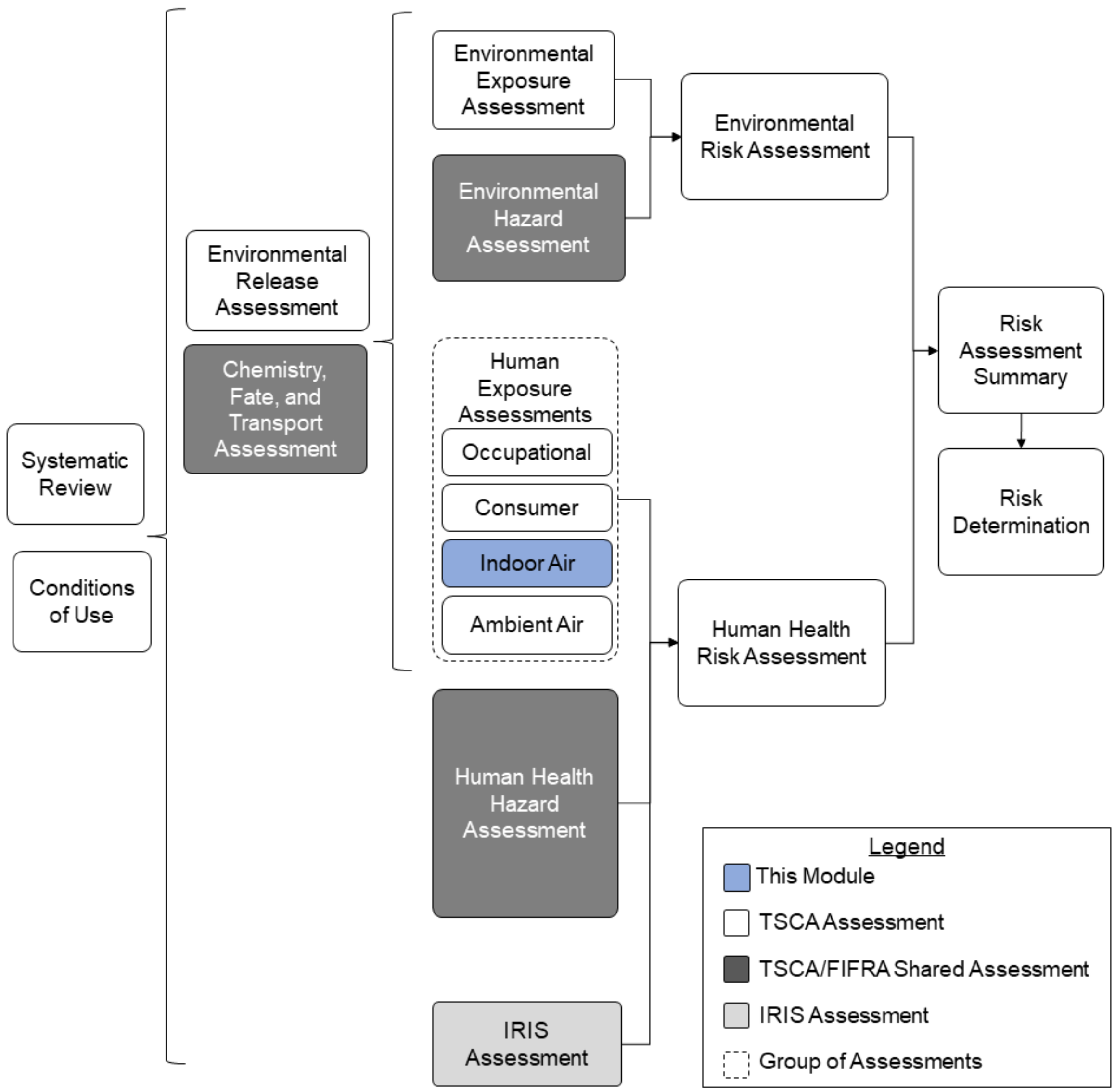

Figure 1-1. Risk Evaluation Document Summary Map

1.1.1 Indoor Air Exposure Assessment Scope

Prior publications by regulatory and regulatory support bodies indicate that the indoor air environment is a significant source of formaldehyde exposure (IPCS, 2002; ATSDR, 1999). EPA considered all reasonably available data regarding TSCA conditions of use (COUs), including consumer products[1] and articles[2] with high emissions and surface areas in the indoor environment. While the emission data compiled for all articles initially modeled with CEM were published in 2009 or prior, for the revised indoor air exposure assessment, EPA identified emission factors for composite wood materials that were

[1] In the context of this TSCA risk evaluation, products are generally consumable liquids, aerosols, or semi-solids that are used a given number of times before they are exhausted (EPA, 2019a). This is consistent with the regulatory definition of "product" at 40 CFR 751.5.

[2] In the context of this TSCA risk evaluation, articles are generally solids, polymers, metals, or woods, which are always present within indoor environments for the duration of their useful life, which may be several years (EPA, 2019a). Articles made of wood are often described as "wood products" commercially, but they are considered "articles" in this assessment. This is consistent with the regulatory definition of "article" at 40 CFR 751.5). Similarly, a "composite wood product" as defined at 40 CFR 770.3 is considered an "article" for purposes of this assessment.

published in 2019 (FIND, 2019) and included this information in the higher tier IECCU modeling. EPA recognizes that while California established formaldehyde emission standards in 2010 by the California Air Resources Board (CARB) which were intended to reduce formaldehyde emissions from pressed wood articles in California, these standards did not apply nationally (EPA, 2016). Consequently, Congress established formaldehyde emission standards for composite wood products (based on the CARB formaldehyde emission standards for pressed wood) which began to go into effect on June 1, 2018, pursuant to the Formaldehyde Standards for Composite Wood Products regulations (40 CFR Part 770), which implement TSCA Title VI. No studies were identified that measured emission rates from products that are known to be compliant with TSCA Title VI. Therefore, it is unknown if the currently available emissions data reflect TSCA Title VI emission standard compliance. As such, emission factors incorporated into the indoor models for composite wood materials (FIND, 2019) were estimated based on assumed compliance with emission standards.

In 1982, the U.S. Consumer Product Safety Commission (CPSC) banned the sale of urea formaldehyde foam insulation (UFFI) for use in residences and schools because of associated health concerns (47 FR 1662, January 13, 1982). However, this ban was reversed in 1983 (see *Gulf S. Insulation v. United States Consumer Prod. Safety Com.*, 701 F.2d 1137 (5th Cir. 1983)). During the public comment period for the high priority designation of formaldehyde, the North American Insulation Manufacturers Association submitted a comment that stated, "For those insulation products in which formaldehyde is a component of the binder, the products are cured at high temperatures during the manufacturing process after the binder has been applied, virtually eliminating the free formaldehyde content. Any free formaldehyde released from the binder during heat cure is destroyed either during the cure process or by emissions control equipment required by the MACT [maximum achievable control technology] standard…. Therefore, formaldehyde off-gassing from the majority of finished products is highly unlikely" (Docket ID EPA-HQ-OPPT-2019-0131-0029). However, formaldehyde off-gassing has been reported from such materials in the literature (Maddalena et al., 2009). Thus, EPA considered the quantification of such exposures from upholstery that are added to indoor air environments.

The Agency only quantified exposures from articles that are currently available on the consumer market. Among other applications, formaldehyde is used for personal care products, embalming and taxidermy. However, estimated exposures from these uses were not included in this indoor air exposure assessment because these uses are excluded from the chemical substance definition under TSCA section 3(2)(B)(vi) (pertaining to cosmetics as defined under the Federal Food, Drug, and Cosmetic Act) and (ii) (pertaining to pesticides as defined under FIFRA), respectively.

Although formaldehyde is a combustion byproduct (ATSDR, 1999), this indoor air exposure assessment does not focus on byproduct or secondary formations of formaldehyde, but rather acknowledges exposure to formaldehyde from these sources is possible. Specifically, generation of formaldehyde as a combustion byproduct (*e.g.*, cigarette smoking, fireplaces, wood stoves) may occur in indoor environments and contribute to total indoor air concentrations of formaldehyde. When data are available, combustion sources of formaldehyde are discussed in the monitoring data analysis.

Among the TSCA sources of formaldehyde contributing to indoor air exposure, wood articles are expected to be the primary contributors (EPA, 2016) in addition to textiles and wallpaper due to the relatively high emissions of formaldehyde and abundance in indoor environments (IPCS, 2002; ATSDR, 1999). Through a consideration of the aforementioned information, EPA modeled indoor air formaldehyde concentrations for the following four conditions of use (TSCA COUs):

1. Construction and building materials covering large surface areas, including wood articles; Construction and building materials covering large surface areas, including paper articles; metal articles; stone, plaster, cement, glass and ceramic articles;
2. Fabric, textile, and leather products not covered elsewhere;
3. Floor coverings; Foam seating and bedding products; Cleaning and furniture care products; Furniture & furnishings including stone, plaster, cement, glass and ceramic articles; metal articles; or rubber articles; and,
4. Paper products; Plastic and rubber products; Toys, playground, and sporting equipment

EPA acknowledges that short-term (*i.e.*, 15-minute peak), intermediate (*i.e.*, 3-month), and long-term (*i.e.*, 1-year) formaldehyde indoor air inhalation exposures can occur via article uses (*e.g.*, wood, wallpaper, seat covers). Therefore, all three exposure durations are considered in this assessment.

1.2 Revisions between Draft and the Revised Assessment

Substantial updates have been incorporated into this assessment. The most substantial change is the use of a second EPA model to better characterize indoor air concentrations of formaldehyde. The *Draft Indoor Air Exposure Assessment for Formaldehyde* relied on the CEM to estimate 365-day average formaldehyde concentrations from articles that may be contributing to long-term indoor air concentrations. This model is commonly used by EPA to estimate exposure to chemicals in consumer products and articles for TSCA conditions of use. Since articles are the subject of the formaldehyde indoor air exposure assessment, EPA considered using CEM's E6 model that is used to estimate emissions from articles placed in an indoor environment. To improve the specificity of the CEM model, EPA also considered replacing default emission rates with article-specific emission rates from the literature. However, this is a key limitation of the model. Therefore, EPA used an alternate emissions model (E5) that would allow for the incorporation of article-specific emission rates. Although, the E5 model is typically used to estimate emissions from products (not articles) placed in an indoor environment (EPA, 2019a). The subtle differences between *products* and *articles* may lead to a mismatch in the exposure profile. Products are generally liquids, aerosols, or semi-solids that release formaldehyde only when they are used whereas articles are solids, polymers, metals, or woods that may continuously release formaldehyde for an extended period (EPA, 2019a). COUs modeled with CEM were based on products with two key assumptions:

1. how often an individual may be in a room, and
2. a constant rate of emission.

Articles are more likely to have a first order decay rate of emissions and the E5 model does not account for this. Thus, concentrations of formaldehyde in the indoor environment may be overestimated using CEM.

In this revised assessment, EPA used the Simulation Program for Estimating Chemical Emissions from Sources and Related Changes to IECCU to estimate short-term (*i.e.*, 15-minute peak), intermediate (*i.e.*, 3-month), and long-term (*i.e.*, 1-year) concentrations. This model is better parameterized for volatile organic carbons like formaldehyde. It provides exposure decay curves allowing for better characterization of exposure concentrations over time (*i.e.*, after an article is introduced to the home). However, available data suggest IECCU may underestimate long-term exposure concentrations. As such, modeled concentrations for both CEM and IECCU are presented in the results of this assessment to characterize the potential range of formaldehyde concentrations in indoor air.

In addition to this updated modeling, this technical support document for the risk evaluation further characterizes formaldehyde concentrations in trailer homes, athletic fields with tire crumb surfaces, and government buildings. Furthermore, feedback and resources from data submissions to the docket (Docket ID: EPA-HQ-OPPT-2023-0613) were incorporated throughout this assessment.

1.3 Conceptual Exposure Model

Formaldehyde is a colorless, flammable gas at room temperature and has a strong odor. As described in the *Chemistry, Fate, and Transport Assessment for Formaldehyde* (EPA, 2024a), formaldehyde is subject to several transformation processes (*e.g.*, photolysis) in outdoor air but is not expected to be subject to transformation and degradation processes in the indoor environment (Salthammer et al., 2010). Thus, formaldehyde is expected to persist in indoor environments.

Formaldehyde concentrations in the indoor environment are driven by emission rates from articles and subsequent dissipation. The most common mechanism for dissipation is by mechanical removal (*i.e.*, ventilation). In addition, sorption of formaldehyde to surfaces can occur but is not expected to be significant. Updates to insulation in American homes built after 1990 has generally improved temperature control and energy efficiency, but these updates have also led to reduced dissipation of formaldehyde due to decreased indoor-outdoor air exchange.

Depending on the article, formaldehyde emissions may last multiple years but are expected to decrease over time and follow a first-order exponential process (EPA, 2016). For example, according to chamber studies of formaldehyde emissions from pressed wood articles over time, emissions half-life for such articles ranged from 1.5 to 2 years. Furthermore, with an emissions half-life of 1.5 years, the emission rate of formaldehyde from pressed wood articles after 10 years was estimated to be approximately 1 percent of the initial emission rate (EPA, 2016). Such emissions and the half-lives may vary according to formulations, chemical or article-specific properties, article thickness, article surface area, usage patterns, and environmental conditions (*e.g.,* humidity, sun exposure).

EPA considered reasonably available information, including (1) physical and chemical properties of formaldehyde based on its specific forms in relevant products and articles, (2) public comments received on the draft scope document, and (3) public comments and peer review on the draft risk evaluation for formaldehyde in finalizing the relevant exposure pathways, exposure routes, and hazards. Figure 1-2 is a graphical depiction of the actual or predicted relationships of a subset of TSCA COUs, exposure pathways, exposure routes, hazards, and exposed groups throughout the consumer life cycle of formaldehyde in indoor air.

It is important to note that the COUs assessed as part of this indoor air exposure assessment, including an assessment of these COUs based on their expected persistence and relatively high emissions of formaldehyde per room of use, were also assessed in the *Consumer Exposure Assessment for Formaldehyde* under different exposure scenarios (*e.g.,* hobbyist installs laminate flooring in living room for 4 hours). Unlike the Consumer Exposure Assessment, the Indoor Air Exposure Assessment especially focuses on longer (or less intermittent) durations of exposure expected in indoor air environments. Furthermore, while the Consumer Exposure Assessment focuses on the installation (*i.e.,* by hobbyists) and intermittent use of certain articles, the Indoor Air Exposure Assessment focuses on the relative contributions of all relevant articles added to an indoor air environment using screening and higher tier modeling approaches and facilitates the consideration of aggregate exposures for the general population in indoor environments.

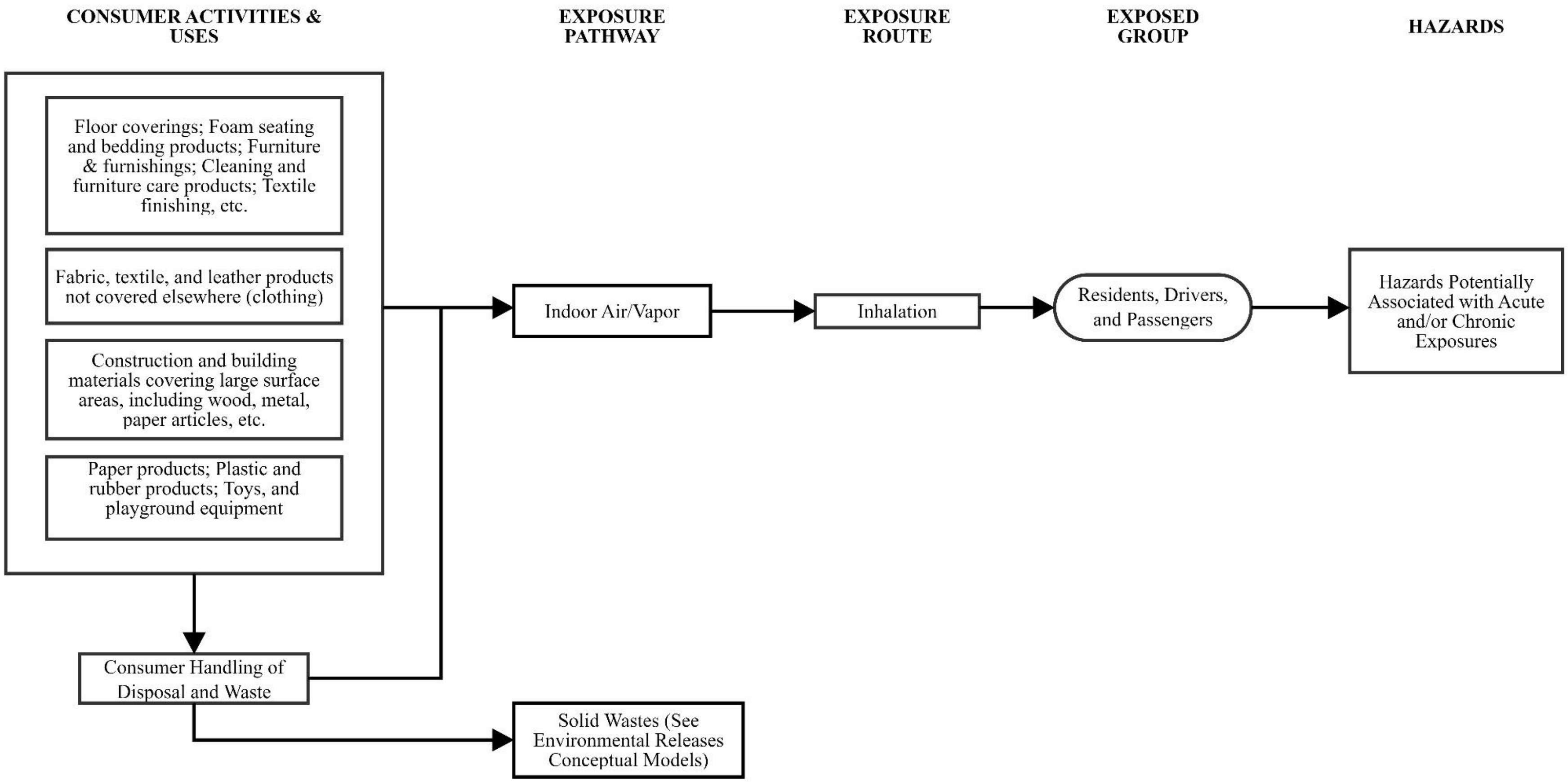

Figure 1-2. Formaldehyde Conceptual Model for Consumer Activities and Uses in Indoor Air: Consumer Exposures and Hazards

A person who installs new laminate flooring or has it installed in their home may be exposed to peak concentrations of formaldehyde when it is first installed, followed by progressively and significantly lower concentrations of formaldehyde from off gassing to air over the span of the first year following installation, especially within the first two to four months. Similarly, uses of consumer articles such as wood, furniture seat covers, and wallpaper contribute to indoor air concentrations that lead to exposures to formaldehyde. As such, this indoor air exposure assessment provides 15-minute peak, 3-month, and 1-year formaldehyde exposure concentrations resulting from TSCA COUs.

It should be noted that the CEM modeling does not consider the lag time between when articles may be manufactured and installed indoors since it relies on the initial formaldehyde concentration from a finished article, as reported by relevant safety data sheets (SDSs), as the initial indoor air concentration to which an individual is exposed. This results in a conservative emission rate and exposure estimate via modeling since it is unlikely a newly manufactured product will be instantly installed in a home and individuals will immediately be exposed to those higher concentrations early in their exposure period. It is more likely that the actual emissions from any given product will be the rate following some period of storage time where initial off-gassing at those high-rates would have occurred prior to being installed in a residence. The IECCU modeling considered this lead time by foregoing the use of initial weight fractions reported in article SDSs and relying on the emission factors reported from chamber studies of finished articles.

In addition, this assessment considers available indoor monitoring data to fully characterize total formaldehyde concentrations across a range of indoor environments.

2 APPROACH AND METHODOLOGY

EPA used the CEM to estimate indoor air concentrations from articles in the *Draft Indoor Air Exposure Assessment*. The Agency considered using CEM's E6 model which is normally used to estimate emissions from articles placed in an indoor environment, since it articles were the subject of the indoor air exposure assessment. EPA also wanted to parametrize CEM's E6 by incorporating article-specific emission rates into the model. However, this is one key limitation of CEM's E6 model. The Agency used CEM's E5 model, as an alternate, which is normally used to estimate emissions from products placed in an indoor air environment. This facilitated the incorporation of article-specific emission rates in the CEM modeled indoor air estimates.

The subtle difference between products and articles may lead to a mismatch in the exposure profile. Products are generally liquids, aerosols, or semi-solids that release formaldehyde only when they are used whereas articles are solids, polymers, metals, or woods that may continuously release formaldehyde for an extended period. COUs modeled with CEM were based on articles with two key assumptions:

1. how often an individual may be in a room, and
2. a constant rate of emission.

Previous studies have demonstrated that formaldehyde emissions from newly purchased or installed articles generally exhibit an initial period of high emissions, followed by a rapid, non-linear decline in the emission rate (Beckett et al., 2022; Jung and Mahmoud, 2022; He et al., 2019; Liu et al., 2015). The decline in emissions is often modeled using a decay rate described by an exponential or power function. Modeling emissions at a constant rate over long durations (as was done via CEM) tends to over-estimate indoor air concentrations as a result.

To address uncertainties with the CEM long-term modeling and to generate peak estimates, EPA modeled indoor air concentrations using the higher tier IECCU model. IECCU is peer reviewed (EPA, 2019b) and used in TSCA risk evaluation including the Final Risk Evaluation for 1-Bromopropane (EPA, 2020) to model chemical exposures. Modeling formaldehyde exposures with high emissions and large surface areas in IECCU is expected to have several benefits. First, IECCU allows for the use of an emissions model that includes applicable exponential decay rates from the literature (Beckett et al., 2022; Jung and Mahmoud, 2022; He et al., 2019; Liu et al., 2015) to better predict the long term formaldehyde indoor air contributions from TSCA articles. The model may also estimate exposures over longer periods of time as compared to the CEM E5 condition and is expected to provide relatively improved estimates of long-term exposure. The IECCU modeling also improves estimation of formaldehyde indoor air concentrations by considering lead time (*i.e.*, the time it takes to procure materials used to manufacture the articles of interest and the delivery of the finished article to a home). This was done by considering emission rates from finished articles. In addition, IECCU models can be configured to include multiple items with individual emission rates in the same space. This allows for the generation of aggregate models, as suggested by the Science Advisory Committee on Chemicals (SACC) during the peer review of the *Draft Indoor Air Exposure Assessment*, for scenarios in which consumers may bring several articles belonging to the same TSCA COU into the home simultaneously (*e.g.*, newly built homes, décor change scenarios). A brief overview of the IECCU model is provided in Section 2.3.

Using IECCU, EPA estimated 15-minute peak, 3-month, and 1-year average daily indoor air concentrations of formaldehyde from individual TSCA COUs and aggregate scenarios. EPA also considered measured formaldehyde residential, commercial, and automobile indoor air concentration data from indoor air monitoring studies. Given the complexities of the exposure assessment of formaldehyde in indoor air, multiple lines of evidence were considered to understand the indoor air concentrations of formaldehyde resulting from formaldehyde TSCA COUs. These different data sources are described in the following sections. Monitoring results are presented in Section 3.1, while modeling results are presented in Section 3.2 for CEM and Section 3.3 for IECCU.

EPA considered the "best available science" under TSCA 26(h) and "reasonably available information" under TSCA 26(k) to assess formaldehyde indoor air concentrations. This was accomplished by applying EPA's systematic review process per the *Draft Systematic Review Protocol Supporting TSCA Risk Evaluations for Chemical Substances, Version 1.0: A Generic TSCA Systematic Review Protocol with Chemical-Specific Methodologies* (also called "draft systematic review protocol") (EPA, 2021b) to identify literature and data of most relevance to the indoor air pathway and modeling formaldehyde exposures from articles of most concern in residential air. Such articles (*e.g.*, wood articles) have a relatively large indoor surface area and significant formaldehyde emissions relative to other articles. EPA used the CEM as a screening tool and IECCU to refine its final assessment of formaldehyde in residential indoor air. Although, together these two models may provide a potential range of formaldehyde concentrations in indoor air given the uncertainties of both when calculating long-term estimates. CEM is expected to provide the highest concentrations while IECCU is expected to provide the lowest concentrations for TSCA COUs. Though, it should be noted that IECCU modeling cannot be performed for automobile cabins - this is a limitation of that model. Thus, CEM modeling results are the only estimates provided for the TSCA COUs relevant to automobile cabins and is considered best available.

2.1 Indoor Air Monitoring Data

Monitoring data were deemed as an integral aspect of the formaldehyde indoor air assessment. Below, EPA presents its approach to acquiring such data using a fit-for-purpose systematic review process.

2.1.1 Systematic Review Prioritization for Formaldehyde Data

Summary of the Fit-for-Purpose Systematic Review (SR) Approach for Exposure Discipline

OPPT refined the *Draft Risk Evaluation for Formaldehyde* by prioritizing high-quality, fit-for-purpose data that is critical for the formaldehyde exposure analyses while meeting timeline requirements. A targeted approach was implemented to the systematic review of exposure studies for formaldehyde to address key data needs for the formaldehyde exposure assessment.

As of March 17, 2023, there were a total of 1,137 exposure studies; of which 1,029 studies had completed initial reviews (*i.e.*, primary evaluations performed by the contractor) and 388 studies had quality control (QC) assessments completed by EPA staff. A total of 135 had data evaluation issues pending resolution. Generally, after exposure studies undergo initial review and QC, data relevant to the TSCA risk evaluation are extracted. Of all exposure studies, only about 30 percent were available for data extraction with a due date of June 30, 2023. To meet deadlines and improve the quality and relevance of formaldehyde data incorporated into the relevant exposure assessments, the formaldehyde systematic review approach had to be improved to be more efficient and fit-for-purpose.

Prioritization Methodology

The data needs highlighted in Appendix A.1, according to exposure study type, emphasize the inhalation pathway. Studies were prioritized if they contained indoor air concentrations and emission rate data that were product-, article-, and COU-specific. Data were extracted from studies with an overall high rating based on the draft systematic review protocol (EPA, 2021b)—assuming that such studies would be distinctly supportive to the formaldehyde exposure assessment.

To identify the most relevant studies to the formaldehyde exposure assessment, the Formaldehyde Assessment Team performed a title and abstract screening (TiAB) using over 130 key words (see Appendix A.2) determined to be associated with formaldehyde COUs and indoor air parameters of interest, using a list of all existing formaldehyde exposure studies that provide integral or supplemental information that is relevant to the population, exposure, comparator, and outcome of interest (PECO) and have primary data. A Boolean search criterion was applied, generally separating keywords by COU/product or article synonym using an *or* followed by an *and* with the air/emission criteria. For example: ((“paint” OR “vinyl wallpaper” OR “fiber glass” OR “fiberglass” OR “latex paint” OR “glue” OR “adhesive”) AND (“air” OR “indoor air” OR “ambient air” OR “air pollution” OR “air release” OR “emission*” OR “emission rate*” OR “emission flux” OR “flux” OR “inhalation” OR “atmosphere” OR “fume*” OR “fugitive” OR “gas*” OR “release*” OR “air release*”). Effectively, this creates a scenario where the Agency identified a paper with a product term such as “adhesive” in its title or abstract, but only when they appeared with an air/emission term.

Of 1,137 studies, approximately 290 were relevant to the exposure assessment of formaldehyde based on the mentioned criteria. Of the 290 relevant studies, 185 had outstanding QCs that have been completed. In addition, 41 articles out of the 290 prioritized studies were rated high according to the Exposure discipline data evaluation metrics and proceeded through data extraction for incorporation into the exposure assessment as needed. A visual representation of the formaldehyde exposure SR prioritization scheme is included in Figure 2-1.

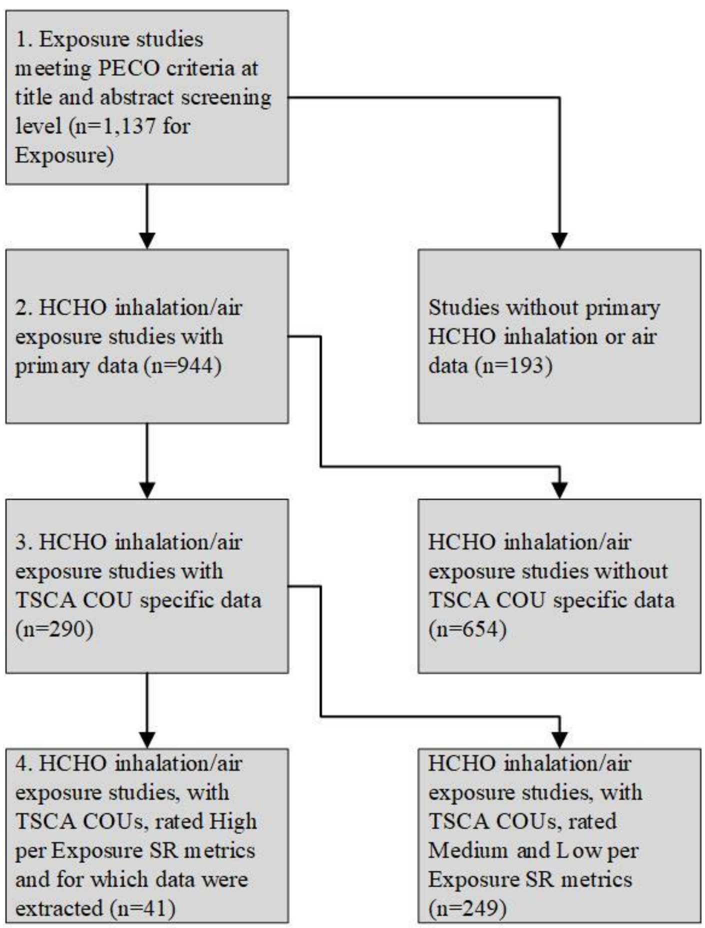

Figure 2-1. Schematic of the Approach Used to Identify and Extract TSCA COU-Specific Data Pertinent to the Formaldehyde Exposure Assessment

EPA considered and incorporated several indoor air monitoring studies into this assessment (see Section 3.1). Among the presented monitoring studies, the Agency focused its review and analysis efforts on a nationally representative formaldehyde indoor air monitoring data from the American Healthy Homes Survey II (AHHS II) as it is the most current and first nationally representative residential indoor air study of formaldehyde (QuanTech, 2021). See Appendix B for a detailed description of the AHHSII data collection methodology. In addition, the SR-identified monitoring sources were supplemented by a review of previous exposure and risk assessments, along with literature and data acquired through backward searches, and those submitted by stakeholders including article chamber studies from industry.

In addition, the term "background" indoor air concentration has often been used in reference to indoor air chemical assessments. This term may be generally used to define the typical measured concentrations of a chemical in media (*i.e.*, indoor air). It can also be used to describe the naturally occuring concentration of a chemical. For the formaldehyde indoor air exposure assessment, this term is being used to address the prior definition, "typical" formaldehyde indoor air concentrations, and to describe aggregate indoor concentration of formaldehyde assumed to be composed of combinations of TSCA sources and others that vary across indoor environments.

Interpreting available indoor air monitoring data is difficult because the ancillary data needed to understand the data are not always available or is overwhelming in some cases for formaldehyde. This results in assessment uncertainties associated with what the measured data represent. Ancillary information needed to fully interpret available monitoring data include

- Variability in sample locations (multiple or unknown formaldehyde sources, volume of samples, varying ventilation rates, etc.);
- Temporal variability (sample duration, lead time, collection time compared to article introduction or installation, new homes/products, seasons, etc.);
- Activity pattern variability across demographic categories (*e.g.,* stay at home/work from home individual vs. an office worker);
- Variability in article-specific properties; and
- Variability in consumer purchasing, use or installation of products and articles as appropriate.

These data are typically not available for the data considered in this assessment. In addition, the source of formaldehyde resulting in the measured concentration values cannot be linked to TSCA COUs.

Generally, indoor air monitoring data available for consideration in this assessment represent typical formaldehyde concentrations from all sources that people may be exposed to. It should be noted that "concentrations" and "exposures" are used interchangeably in this assessment because the concentrations of formaldehyde in indoor air are assumed to be equivalent to the exposure concentration inhaled by people in an indoor environment. EPA used modeling tools to estimate the contribution to formaldehyde indoor air concentrations from certain relevant TSCA COUs. The following sections describe each modeling tool and how it was applied for this exposure assessment.

2.2 CEM Model Development and Parameterization

Formaldehyde indoor air concentrations from TSCA COUs were first estimated using CEM. Because CEM is computationally efficient and estimates air concentrations from individual articles, it was chosen to develop screening level estimates for this indoor air exposure assessment. CEM is a longstanding model used by OPPT in several previous TSCA new and existing chemical risk evaluations to model consumer and bystander exposures from products and articles. The model has been updated based on feedback on both the performance and ease of use of the tool through beta testing and peer review (EPA, 2019a).

The scenarios, chemicals, and defaults currently included in CEM are based on available data and professional judgment and allow the use of all parts of the model based on built-in default inputs. At any time, defaults, chemicals, or use scenarios can be deleted, added, or refined based on newly available information. In addition, generic (blank) scenarios are available that can be populated with user-defined inputs (*e.g.,* article-specific emission rates) (EPA, 2019a).

CEM retains 6 existing models from EPA's Exposure and Fate Assessment Screening Tool (E-FAST) model and adds 15 additional models, including 6 emission models and 3 inhalation models. All CEM models are used to estimate chemical concentrations in exposure media, including indoor air, airborne particles, settled dust, etc. (EPA, 2019a).

A supplemental quantitative assessment, presented in Appendix D.1, compares formaldehyde indoor air concentrations in homes with and without reported combustion sources from AHHS II monitoring estimates vs. CEM TSCA COU modeling estimates. In addition, a supplemental quantitative assessment of wood articles is presented in Appendix D.2 to consider the potential impact of the Title VI emission standards for composite wood materials. This supplemental analysis allowed EPA to get an initial projection of formaldehyde concentration reductions for hardwood floors, assuming compliance with the Title VI rule 40 CFR part 770 (EPA, 2016) and using CEM as a screening tool. As described in Appendix D.2, it relied on key assumptions and formulas used to determine indoor air formaldehyde concentrations and emission rates derived from the Title VI emission standards for composite wood materials (EPA, 2016). This approach was applied to EPA's assessment of wood articles in indoor air using IECCU as a more refined modeling tool (see Section 2.3).

2.2.1 Model Output Time Period

While intermittent or peak article uses contribute to indoor concentrations of formaldehyde (including peak concentrations), indoor air monitoring studies suggest long-term exposure to formaldehyde. Therefore, to assess potential 1-year exposures from TCSA COUs in indoor air, through the CEM screening assessment, EPA estimated 1-year average concentrations in automobiles and homes based on TSCA COUs.

2.2.2 Scenario Selection

Certain materials are known to be significant emitters (*e.g.,* wood articles) of formaldehyde compared to others (EPA, 2016; Matthews et al., 1984; Pickrell et al., 1983). In addition, certain materials from which formaldehyde may be emitted cover larger surfaces (*e.g.,* wallpaper) compared to others (EPA, 2019a). After considering surface areas and rates of emissions from all formaldehyde TSCA COUs based on the literature and professional judgement, EPA identified four COUs along with eight scenarios deemed to be significant contributors to formaldehyde indoor air exposures. The application of this criteria led to a focus on all relevant consumer articles and the omission of all consumer products as defined in Section 1.1.1. Generally, consumer articles tend to be associated with more persistent exposures over time and over relatively larger spaces, compared to consumer products, even when not actively being used (EPA, 2019a).

Although the CEM exposure assessment focused on individual COUs, generally, an individual may be exposed to a chemical such as formaldehyde through multiple use scenarios—including using formaldehyde-emitting seat covers on automobile car seats vs. using formaldehyde-emitting seat covers on a living room sofa. In these examples, the surface area of the article, size of room of use, and interzonal ventilation rate are important inputs that have a major impact on the CEM-modeled indoor air concentration and assumed exposure for the user of the formaldehyde-emitting article. A description of the room of use and predefined exposure scenarios in CEM along with default parameters that can be adjusted by the user (*e.g.*, article-specific emission rates) can be found in the CEM user guide (EPA, 2019a). In certain cases, the modeler uses a generic product or article scenario if the scenario of interest does not fit CEM's pre-built options. For this screening assessment, EPA utilized pre-built CEM scenarios to model article-specific formaldehyde indoor air concentrations. The Agency assumed that the formaldehyde indoor air exposure would occur according to the activity patterns of the individual. The individual was assumed to be someone who goes to work or school for most of the day and spends 1 hour in a vehicle, 2 hours in a living room, and 10 hours in a bedroom every day (EPA, 2019a).

The four indoor air TSCA COUs and the relevant scenarios are described in Table 2-1.

Table 2-1. Formaldehyde Indoor Air Conditions of Use and Relevant Exposure Scenarios

Condition(s) of Use	CEM Exposure Scenarios
Construction and building materials covering large surface areas, including wood articles; Construction and building materials covering large surface areas, including paper articles; metal articles; stone, plaster, cement, glass and ceramic articles	Building/Construction Materials – Wood Articles: Hardwood Floors (residential)
Fabric, textile, and leather products not covered elsewhere	Seat Covers (automobile)
	Furniture Seat Covers (residential)
	Fabrics: Clothing (residential)
Floor coverings; Foam seating and bedding products; Cleaning and furniture care products; Furniture & furnishings including stone, plaster, cement, glass and ceramic articles; metal articles; or rubber articles	Furniture & Furnishings – Wood Articles: Furniture (residential)
Paper products; Plastic and rubber products; Toys, playground, and sporting equipment	Paper-Based Wallpaper (residential)

As shown in Table 3-1, some COUs may contain multiple exposure scenarios. In such cases, EPA provided EPA selected a "representative" scenario (*i.e.*, article) per COU according to the highest estimated concentration. However, uncertainties with this approach include that the single identified representative exposure scenario per COU, although based on the highest estimated concentration, may not necessarily be the most common; and that an individual may be exposed to formaldehyde through multiple articles that belong to the same COU all at once. In other words, this approach assumes that an individual is only exposed to one of the potentially many articles that belong to the same COU at any given time.

2.2.3 Chemical-Specific Input Parameters for CEM

EPA modeled indoor air concentrations by identifying

1. The chemical of interest with a name (*i.e.*, formaldehyde) and physical chemical properties (*e.g.*, vapor pressure).
2. The emission models of interest.
    a. In this assessment, article-specific information used the E5 model (for products placed in room) instead of E6 (for articles placed in room), even though the COUs identified are articles. Under the E6 emission model, CEM estimates an initial rate of emissions based on the initial concentration of the chemical in the solid article followed by a decline in

emission rate according to a first order exponential decay coefficient. However, EPA was not able to obtain data for free formaldehyde content in the relevant article materials, and it was determined that the use of an emission estimate based on gross formaldehyde content would produce a significant overestimation of formaldehyde concentration in air that could not be readily verified given the available data. Given the high level of uncertainty in this approach, the E5 emission model was chosen instead. The E5 model assumes that emissions occur at a constant rate until the chemical content is depleted; and the emission rate is input directly by the user rather than estimated, allowing for the use of real-world observations. While it was understood that the use of a constant rate emission model would not yield ideal modeling conditions, and would potentially overestimate exposures, the uncertainties arising from these conditions were well understood and expected to be less impactful than issues arising from the use of the E6 model.

3. The room of use (*e.g.*, automobile, whole home, living room) and relevant environmental inputs for the area in which the article is assumed to be placed (*e.g.*, building volume, use environment volume, air exchange rates)
4. The weight fraction of the chemical in the product or article.
    a. While CEM provides a default value, weight fraction is typically identified via a search of SDSs from articles currently on the consumer market, as was done for this exposure assessment.
5. Product or article properties (*e.g.*, surface area of article, frequency of use, duration of use, emission rates)
    a. While defaults are typically based on the Westat (1987) survey and EPA's *Exposure Factors Handbook* (EPA, 2021a), among other sources, the modeler has the ability to edit these parameters as they see fit. For modeling of formaldehyde concentrations, formaldehyde emission rates from articles identified in the literature were incorporated. Only emission rates for relevant TSCA COUs were utilized. Emission rates for COUs other than the ones identified were irrelevant to this assessment. CEM cannot be used to model smoking and other sources of formaldehyde resulting from combustion.
        i. Emission rates presented in Table 2-2 were extracted from literature identified through a Google search for relevant references (Maddalena et al., 2009; Kelly et al., 1999; Yu and Crump, 1998; Matthews et al., 1984; Pickrell et al., 1984; Pickrell et al., 1983). Emission rates were not initially part of systematic review search terms at the time of the draft assessment because EPA expected weight fractions to be sufficient indicators of formaldehyde content in articles modeled. However, article-specific emission rates were determined to be influential input parameters for article-specific formaldehyde indoor air modeling and have since been added to the systematic review search terms that yielded new or updated emission rates as presented in Table 2-3. Emission rates identified for CEM screening assessment were commonly reported in ranges. Therefore, the midpoint of such ranges was calculated for each product identified in the literature to estimate the typical emissions of formaldehyde in a residential or automobile indoor air environment.
        ii. To estimate the most common emission rates per COU category for comparison with nationally representative indoor air monitoring data from the American Healthy Home Survey II, a central tendency of emission rates was estimated using

an average of the median emission rates for all articles identified per COU category. However, indoor air exposures for potentially exposed or susceptible subpopulations (PESS) are expected to be sufficiently addressed via an aggregate assessment of indoor air exposure from multiple TSCA COUs.

iii. During systematic review, the relevant population, exposure, comparator, and outcomes (PECO) were identified to target only relevant sources of data for the exposure and risk evaluation of formaldehyde. From the identified PECO-relevant sources, emission rates were reported as ranges except for a few studies where a single value was reported per product (Table 2-2). Although the list of identified sources does not represent all relevant sources of data, these sources were deemed to be sufficiently representative of article-specific emission rate data per the systematic review process (EPA, 2021b). In instances where the emission rate was reported in a source as less than a given value (*e.g.*, <0.1), the emission rate was assumed by EPA as the given value (*i.e.*, 0.1). Non-detects (ND) were assumed to be 0. The median of ranges was used to approximate the 50th percentile or central tendency. The average of medians were calculated to generate a central tendency across articles based on COU.

6. The activity pattern that identifies the start time of exposure during a product or article use day and the general expected movement from room to room in a residence over time (EPA, 2019a).

Table 2-2. Formaldehyde Emission Rates by TSCA Condition of Use (COU)

Condition(s) of Use	Exposure Scenario	Identified Product Types in Literature	Source (HERO ID)	Reported Emission Rates, per Surface Area (µg/m²-hr)[a]	Median Emission Rates per Identified Product, within a COU, per Surface Area (µg/m²-hr)	Average Emission Flux per Exposure Scenario (µg/m²-hr)	Expected Room of Use	Expected Surface Area of Article in Room of Use (m²)	Average Emission Rates, per COU, and Room of Use (mg-hr)
Construction and building materials covering large surface areas, including wood articles; Construction and building materials covering large surface areas, including paper articles; metal articles; stone, plaster, cement, glass and ceramic articles	Wood Articles: Hardwood Floors	Pressed wood articles (concentration : 0.05 ppm)	(Matthews et al., 1984)	10[b]	10	454.5	Residence – Living Room	27.87	12.67
		Pressed wood articles (concentration : 0.10 ppm)	(Matthews et al., 1984)	40[b]	40				
		Pressed wood articles (concentration : 0.20 ppm)	(Matthews et al., 1984)	70[b]	70				
		Pressed wood articles (concentration : 0.40 ppm)	(Matthews et al., 1984)	120[b]	120				
		Pressed wood articles	(Pickrell et al., 1983)	ND (assuming "0")−1,500	750				
		Bare urea-formaldehyde wood articles (¼– ¾")	(Kelly et al., 1999)	8.6−1,580[c]	794.3				
		Coated urea-formaldehyde wood articles	(Kelly et al., 1999)	<2.7−460[c]	231.35				
		Bare phenol-formaldehyde wood articles	(Kelly et al., 1999)	4.1−9.2[c]	6.65				
		Particle board	(Pickrell et al., 1984)	1,500−2,167[d]	1833.5				

Condition(s) of Use	Exposure Scenario	Identified Product Types in Literature	Source (HERO ID)	Reported Emission Rates, per Surface Area (µg/m²-hr)[a]	Median Emission Rates per Identified Product, within a COU, per Surface Area (µg/m²-hr)	Average Emission Flux per Exposure Scenario (µg/m²-hr)	Expected Room of Use	Expected Surface Area of Article in Room of Use (m²)	Average Emission Rates, per COU, and Room of Use (mg-hr)
		Plywood	(Pickrell et al., 1984)	1,292−1,375[d]	1333.5				
		Cabinet (including end cabinet)	(Maddalena et al., 2009)	5.21–419	212.105				
		Door (including cabinet door)	(Maddalena et al., 2009)	14.3–91.8	53.05				
Fabric, textile, and leather products not covered elsewhere	Furniture Covers, Car Seat Covers, Tablecloths	Curtain	(Maddalena et al., 2009)	14.4–323	168.7	118.8	Automobile (Furniture Seat Covers)	1	0.12
		Permanent press fabric	(Kelly et al., 1999)	42−215[c]	128.5				
		Cushion	(Maddalena et al., 2009)	69.2–410	239.6		Residence – Living Room (Furniture Seat Covers)	1	0.12
		Carpet	(Maddalena et al., 2009)	42.4–-57.6	50				
		Fabrics	(Pickrell et al., 1983)	ND (assuming “0”)−14.58	7.29				
	Fabrics: Clothing	New clothing	(Pickrell et al., 1983)	0.63−31.25	15.94	15.9	Residence – Bedroom (Clothing)	1.18	0.02
Floor coverings; Foam seating and bedding products; Cleaning and furniture care products; Furniture & furnishings including stone, plaster, cement, glass and ceramic articles; metal articles; or rubber articles	Wood Articles: Furniture	Bed Deck	(Maddalena et al., 2009)	4.1–-136	70.05	116.6	Residence – Living Room	27.87	3.25
		Bench/Seat Bottom	(Maddalena et al., 2009)	33.3–293	163.15				

Condition(s) of Use	Exposure Scenario	Identified Product Types in Literature	Source (HERO ID)	Reported Emission Rates, per Surface Area (μg/m²-hr)[a]	Median Emission Rates per Identified Product, within a COU, per Surface Area (μg/m²-hr)	Average Emission Flux per Exposure Scenario (μg/m²-hr)	Expected Room of Use	Expected Surface Area of Article in Room of Use (m²)	Average Emission Rates, per COU, and Room of Use (mg-hr)
Paper products; Plastic and rubber products; Toys, playground, and sporting equipment	Paper products	Paper-based wallpaper	(Kelly et al., 1999)	27	27	27.0	Residence-Living Room (Drywall area used as surrogate for wallpaper area)	20	0.54

[a] Emission rates were reported as ranges with the exception of a few cases where a single value could be found per product. In instances where the emission rate was reported in a source as less than a given value (*e.g.*, <0.1), the emission rate was assumed by EPA as the given value (*i.e.*, 0.1). Non-detects (ND) were assumed to be 0. The median of ranges were taken to approximate a 50% percentile value, median or central tendency. The average of medians were calculated to generate a 50% percentile or central tendency values across products per COU.
[b] At 23 °C, 50% relative humidity, CH20 ER data interpolated to fixed CH20 concentrations from 0.05–0.40 ppm. This portrays the range of ERs according to range of concentrations.
[c] Emission rates represent typical conditions, defined as 70 °F, 50% relative humidity, and 1 air change per hour.
[d] Range indicates different test conditions in temperature and relative humidity.

Table 2-3. Formaldehyde Emissions for Materials with the potential for large applications

Material Reported	Source (Hero ID)	Reported Emissions Factors (µg/m²-hr)		
		min	mid	max
Pressed Wood Articles	(FIND, 2019)	72.0	130.0	257.0
Carpet	(Kelly et al., 1999)	0.33	0.64	2.7
Carpet	(Maddalena et al., 2009)	42.4	50	57.6
Carpet	(Yu and Crump, 1998)		28.2	
Vinyl Flooring	(Maddalena et al., 2009)	1.69	7.795	13.9
Laminate Flooring (with exposed seams)	(Sheehan et al., 2017)	17.7	49.8	81.9
Laminate flooring (no exposed seams)	(Sheehan et al., 2017)	7.9	61.8	115.7
Laminate Flooring (with exposed seams)	(Chen et al., 2018)	14.0	135.5	160
Laminate flooring (no exposed seams)	(Chen et al., 2018)	5.0	7.5	10.0
Drapery and Upholstery	(Kelly et al., 1999)	0.25	3.6	14.6
Miscellaneous Textiles	(Kelly et al., 1999)	0.83	2.01	4.17
Fabric Curtains	(Maddalena et al., 2009)	4.97	168.7	323.0
Foam and Fiberfill Seat Cushions	(Maddalena et al., 2009)	30.4	165.15	410.0
Wallpaper	(Kelly et al., 1999)		27.0	

2.3 IECCU Model Development and Parameterization

In addition to the improvements imparted using IECCU, EPA further improved exposure models for consumer articles by developing low, medium, and high exposure scenarios to better account for inherent variability in key parameters. Where possible, EPA used the minimum, arithmetic mean, and maximum reported values for emission factors (µg/m^2-hr) in specific article materials to populate low, medium, and high exposure scenarios. In instances where only one value was reported for a material, it was used to populate all scenarios. Where appropriate, high, medium, and low surface areas were also modeled for each type of article to capture variability in items consumers may place in a home. In instances where reported emission factors might be relevant to a variety of consumer goods with large surface areas (*e.g.*, pressed wood articles and textiles), a single representative item for each relevant TSCA COU was chosen for modeling. These values are shown in Table 2-3. A detailed description of all data sources and modeling inputs is provided in Sections 2.3.4, and 2.3.5.

2.3.1 IECCU Model Description

IECCU Version 1.1 (EPA, 2019b) was selected to model consumer inhalation exposures to formaldehyde in solid articles. Formaldehyde emissions from solid articles were modeled with a single exponential decay model. In this model, the emissions are modeled at an initial rate specified by the user followed by a decay in rate as the chemical concentration in the article declines.

The calculated emission rates are then used in a deterministic, mass balance calculation of indoor air concentrations. IECCU can be configured with one, two, or three zones within a building. To match the conditions used in CEM, articles modeled in a whole home used a single zone configuration while articles modeled in a single room used a two-zone configuration. There is no distinction made between user and bystander, and no near-field option as in CEM product models. IECCU does have preconfigured models for environmental inputs including building volumes, ventilation rates, and interzonal air flows, but these were not used in this assessment. Instead, these conditions were matched to conditions used in CEM for specific room or whole house scenarios to ensure that calculations were consistent across models.

2.3.2 Model Output Time Period

As with the CEM screening approach, IECCU was also used to generate 1-year average concentrations of formaldehyde in indoor air due to article uses. To evaluate long term air concentrations relevant to chronic exposure, the simulation duration selected was 10,000 hours (~1 year), and the number of data points selected was 5,000. At the end of this duration, air concentrations in all models were not zero, but small enough to be negligible when compared to typical indoor air concentrations of formaldehyde, according to monitoring studies summarized in Section 3.1. Concentrations began approaching zero after approximately three months and peaked within the first day of article uses. Therefore, simulations were additionally generated for 3-month average and approximately 15-minute peak exposures. To evaluate 3-month average concentrations relevant to intermediate exposures, the simulation duration selected was 2,190 hours (~90 days) and the number of data points was 1,098. To evaluate peak air concentrations relevant to short-term exposure, the simulation duration selected was 1,200 hours (50 days), and the number of data points selected was 5,000. The highest value reported in the output thus represents the peak air concentration for a 14.4 min period.

2.3.3 Article Characterization and COU Mapping

Based on the results from the CEM screening analysis, EPA updated the list of reported emission factors to focus on emissions from materials likely to be used as building materials or manufactured into consumer articles with large surface areas for emissions. To ensure that emission factors were representative of items which might enter a home, EPA only used emission rates reported for goods purchased from a retailer or sampled from a finished home environment. Key updates included addition of emission factors for carpet, laminate flooring, vinyl flooring and foam/fiber filled seat cushion materials and the removal of emission factors related to clothing. See Table 2-3 for all emission factors. Emission standards are based on the concentration of formaldehyde in the air around the product in a controlled test environment, typically expressed in parts per million (ppm). This measurement is conducted using standardized chamber testing methods, which allows for the estimation of emission factors. Emission standards for pressed wood articles commonly used in building material and furniture manufacturing contexts include 0.05 ppm from hardwood plywood, 0.09 ppm from particleboard, and 0.11 ppm from medium-density fiberboard as defined at 40 CFR 770.3. Under standard test conditions (25°C, 1 atm pressure, 67-L chamber operating at one air change per hour) these values can be converted to area specific emission rates of 72 μg/m^2-hr for hardwood plywood, 130 μg/m^2-hr for particleboard, and 257 μg/m^2-hr for medium-density fiberboard. These values were used to define a range of values for emission factors in pressed wood articles likely to be relevant to household indoor air as shown in Table 2-3.

The emission factors were grouped by material (pressed wood articles, carpet, vinyl flooring, laminate flooring, textiles, and seat cushion materials) and a range of emissions from each material type was defined as shown in Table 2-3. The high and low values are the highest and lowest values reported across all data sources for a given material type. The average value is calculated by averaging the mean or midrange values for a given material type across all data sources.

For each material type, exposure scenarios were developed based on representative articles with large surface areas. For flooring materials, including carpet, vinyl flooring, and laminate flooring, the representative scenario is newly installed flooring in a whole home or only part of the home. For wallpaper, the representative article was assumed to be newly installed wallpaper in part of the home. For both textiles and seat cushion materials, the representative article chosen was a new furniture set consisting of a couch and loveseat. However, in the case of textiles it was also considered that the material may also be used for furniture covers rather than as upholstery. While surface area and emission rates would be the same for these items, they belong to separate TSCA COUs, and the material must therefore be considered in both capacities. Similarly, for pressed wood articles, the materials were considered both as building materials and furniture. As such, both kitchen cabinets and an entertainment center were selected as representative articles for pressed wood materials.

In total, EPA mapped the reported emissions factors for materials likely to be used as building materials or manufactured into consumer articles with large surface areas to eight consumer articles representing four TSCA COUs. Surface areas were then estimated for each representative article as described below.

Flooring

To estimate surface areas for flooring materials (vinyl tile, laminate flooring, and carpet), it was assumed that the material may be used in the whole home or only part of it. As such, surface area of flooring materials was equal to 100, 50, and 25 percent of the total floor space in high, medium, and low exposure scenarios, respectively. The value for whole house floor space (~205 m^2) was back calculated from the CEM house volume (492 m^3) and an assumed ceiling height of 8 ft (2.4 m).

Furniture Set (Upholstered or with a Textile Cover)

A furniture set consisting of a couch and loveseat was used as the representative article for both textile and furniture cushion articles. To estimate the total surface area for a furniture set, an informal survey was conducted to identify common dimensions sold by various internet retailers. Based on this information, it was determined that there was considerable variability in sizes available so small, medium, and large estimates were developed. The low, medium, and high surfaces areas, respectively, are based on open bottom (the bottom surface is not typically upholstered or covered) prisms measuring 60” × 30” × 25”, 80” × 36” × 30”, and 100” × 42” × 35” for a couch; 48” × 30” × 25”, 60” × 36” × 30”, and 72” × 42” × 35” for a loveseat. EPA added the lowest values for couch and loveseat to estimate exposures to smaller furniture in the low-end scenario, and similarly for the medium and high estimates.

Pressed Wood Furniture

To estimate the total surface area for an entertainment center, an informal survey was conducted to identify common dimensions sold by various internet retailers. Based on this information, it was determined that there was considerable variability in sizes available so small, medium, and large estimates were developed. The low estimate is for a small unit with dimensions of 1.22 m × 1.22 m × 0.46 m and two internal shelves. The medium estimate is for a unit with dimensions of 1.83 m × 1.52 m × 0.61 m and three internal shelves. The high estimate is for a large unit with dimensions of 2.44 m × 1.83 m × 0.76 m and four internal shelves.

Pressed Wood Cabinets

The default value for the kitchen cabinet surface area (59 m^2) from the Formaldehyde Indoor Air Model (FIAM) was used in low, medium, and high exposure scenarios (EPA, 2012). Because this value is a central tendency value calculated from multiple floorplan schematics and has been previously peer reviewed; it was considered reasonable for use without further consideration of variability.

Wallpaper

The surface area used in low, medium, and high exposure scenarios (100 m^2) is the recommended value for wallpaper surface area in a home provided in the *Exposure Factors Handbook* Table 9-13 (EPA, 2011). This source is considered the default for exposure related inputs for EPA risk assessments and was thus considered a reliable estimate without further consideration of variability.

2.3.4 Model Inputs for Single Article Models

Key inputs for modeling air concentrations in IECCU using a first order exponential decay emission model include initial emission rate (µg/hr), first order exponential decay constant (hr^{-1}), ventilation rate (m^3/hr), interzone exchange rate (m^3/hr), and zone 1 volume (m^3). Values for zone 1 volume, interzonal air exchange rate, and the ventilation rate were taken from CEM 3.2 default values (EPA, 2019a). Values were chosen based on the expected area of article use or installation, which may be a single room or whole home. For whole house models, a single zone model was used so interzone air exchange rates were not needed. The initial emission rate was calculated as the product of the emission factor and article surface area. Development of values for emission factors and surface area are described in detail for each representative article in Section 2.3.3 and all parameters which vary between articles are summarized in Table 2-4.

Table 2-4. IECCU Modeling Inputs for Single Articles with Large Surface Area Representing TSCA COUs

COU(s)	Article	Level	Emission Factor (µg/m^2-hr) [a]	Article Surface Area (m^2) [b]	Initial Emission Rate (µg/hr) [b]	Zone 1 Volume (m^3) [b]	Ventilation Rate (m^3/hr) [b]	Interzone Air Exchange Rate (m^3/hr) [b]
Construction and building materials covering large surface areas, including wood articles; Construction and building materials covering large surface areas, including paper articles; metal articles; stone, plaster, cement, glass and ceramic articles	Laminate Flooring	High	160.0	202	32,320	492	221.4	N/A
		Med	50.1	101	5,060			
		Low	5.0	50.5	252			
	Carpet	High	57.6	202	11,635	492	221.4	N/A
		Med	26.3	101	2,654			
		Low	0.3	50.5	17			
	Vinyl Flooring	High	13.9	202	2,808	492	221.4	N/A
		Med	7.8	101	787			
		Low	1.7	50	84.5			
	Pressed Wood Cabinets	High	257.0	59	15,163	24	221.4	108.98
		Med	130.0	59	7,670			
		Low	72.0	59	4,248			
Fabric, textile, and leather products not covered elsewhere	Textile Furniture Covers	High	323.0	17	5,491	50	221.4	108.98
		Med	58.1	12	697			
		Low	0.3	7.9	2			
Floor coverings; Foam seating and bedding products; Cleaning and furniture care products; Furniture & furnishings including stone,	Textile Furniture Components	High	323.0	17	5491	50	221.4	108.98
		Med	58.1	12	697			
		Low	0.3	7.9	2			

COU(s)	Article	Level	Emission Factor (µg/m²-hr) [a]	Article Surface Area (m²) [b]	Initial Emission Rate (µg/hr) [b]	Zone 1 Volume (m³) [b]	Ventilation Rate (m³/hr) [b]	Interzone Air Exchange Rate (m³/hr) [b]
plaster, cement, glass and ceramic articles; metal articles; or rubber articles	Foam Furniture Components	High	410.0	17	6,970	50	221.4	108.98
		Med	165.2	12	1,982			
		Low	30.4	7.9	240.2			
	Pressed Wood Furniture	High	257.0	30.2	7761	50	221.4	108.98
		Med	130.0	16.4	2,129			
		Low	72.0	7.46	537			
Paper products; Plastic and rubber products; Toys, playground, and sporting equipment	Wallpaper	High	27.0	100	2,700	492	221.4	N/A
		Med	27.0	100	2,700			
		Low	27.0	100	2,700			

[a] See Table 2-3 for a list of sources used for article-specific emission factors.
[b] The article surface areas and building configurations were sourced from the EPA *Exposure Factors Handbook* (EPA, 2011), Formaldehyde Indoor Air Model (EPA, 2012), CEM User Guide (EPA, 2019a) and IECCU User Guide (EPA, 2019b).

The decay rate of formaldehyde emissions can be estimated by measuring the emission rates from consumer goods over time in a controlled environment and fitting these measurements to a single exponential decay model. Estimated decay rates for formaldehyde emissions from consumer goods were obtained from two studies. The selected studies focus on consumer goods purchased from a retailer (rather than immediately after manufacture) to ensure that decay rates are relevant to emissions for items which could be purchased and installed in a home. In the first study, four types of furniture products with solid wood, stained wood veneer, and pressed wood components were tested for 4000 hrs in a controlled study chamber and emissions data were fitted to a first order exponential decay model (Liu et al., 2015). In the second study, three kinds of flooring and three kinds of wallpaper were tested for 400 hours in a controlled study chamber and decay rates were estimated by fitting emissions data to a first order decay model (Jung and Mahmoud, 2022). In total, eleven values for single exponential decay rate of emissions were reported from separate chamber experiments in these two studies. The reported values ranged from 8.7×10^{-4} to 4.18×10^{-3} hr^{-1}, with an average reported value of 2.41×10^{-3} hr^{-1}. The relatively low level of variability in this parameter is notable given that these studies examined different materials, used different test conditions, and calculated decay rates using different methods. As such, the mean value for decay rate (2.41×10^{-3} hr^{-1}) was chosen for use in all exposure scenarios.

For articles modeled in the same area of the home, environmental factors affecting air concentration (*e.g.*, volume, interzonal air flow, and ventilation rate) will be the same. In these cases, the only factor which would produce a difference in air concentration between these items is the initial emission rate (µg/hr); higher initial emission rates will result in higher air concentrations. As such, when more than one representative article belonging to the same TSCA COU would be modeled in the same area of the home, it was not necessary to generate models for each article to identify the item which would result in the highest air concentrations. In these cases, only the representative article with the highest initial emission rate was modeled. As such, models for carpet, vinyl flooring, textile furniture components, and foam furniture components were not run and will not be reported in individual model results. However, some of these items were included in the aggregate scenarios described in Section 2.3.5.

2.3.5 Model Inputs for Aggregate Models

In addition to the model scenarios generated for individual articles representing TSCA COUs, EPA generated two composite scenarios in which multiple new articles belonging to the same COU are assumed to be installed in the home at the same time. The first scenario is the "décor change" scenario in which it is assumed that a new couch, loveseat, and entertainment center are purchased and brought into the home at the same time. For the upholstered furniture, both textile and foam furniture components are assumed to emit formaldehyde.

The second scenario is the "new build" scenario in which the home has newly installed flooring and new kitchen cabinets. Note that building materials which may emit formaldehyde are used widely in home construction, but many of these items such as underlayment, insulation, and plywood subflooring are generally covered by other materials which would serve as a barrier to emissions. In addition, these materials are added earlier in the construction process and will have an air out period before construction is complete. Flooring and cabinetry are generally added at the end of construction and surfaces can emit freely to air; thus, EPA considers it reasonable that these materials may contribute to air concentrations at the time of occupancy by the purchaser. In this scenario, the home is assumed to have mixed flooring installed. This includes four carpeted bedrooms with the remainder of the home flooring made of laminate material (except in the garage, which is assumed to be unfinished concrete). The surface area of carpet was calculated using the default CEM room volume of 36 m^3 per bedroom and an assumed ceiling height of 8 ft (2.4 m). Garage floor area (~37.5 m^2) was calculated using the default CEM room volume 90 m^3 for the garage and an assumed ceiling height of 8 ft (2.4 m). The area of laminate flooring surface area was calculated as the difference between the previously described value for whole home floor area and the combined values for carpeted areas and unfinished garage floor. Surface areas for pressed wood cabinets were the same as described in single item scenarios. All materials used the same value for single order decay rate previously described. Model inputs for aggregate scenarios are summarized in Table 2-5.

Table 2-5. IECCU Modeling Inputs for Aggregate Scenarios with Multiple Articles Representing a Single TSCA COU

COU	Scenario	Article	Level	Emission Factor (µg/m²-hr)	Article Surface Area (m²)	Initial Emission Rate (µg/hr)	Zone 1 Volume (m³)	Ventilation Rate (m³/hr)	Interzone Air Exchange Rate (m³/hr)
Floor coverings; Foam seating and bedding products; Cleaning and furniture care products; Furniture & furnishings including stone, plaster, cement, glass and ceramic articles; metal articles; or rubber articles	Décor Change	Pressed Wood Furniture	High	257.0	30.2	7,761	50	221.4	108.98
			Med	130.0	16.4	2,129			
			Low	72.0	7.46	537			
		Indoor Furniture (Foam Components)	High	410.0	17	6,970			
			Med	165.2	12	1,982			
			Low	30.4	7.9	240.2			
		Indoor Furniture (Textile Components)	High	323.0	17	5,491			
			Med	58.1	12	697			
			Low	0.3	7.9	2			
Construction and building materials covering large surface areas, including wood articles; Construction and building materials covering large surface areas, including paper articles; metal articles; stone, plaster, cement, glass and ceramic articles	New Build	Laminate Flooring	High	160	104.5	16,720	492	221.4	N/A
			Med	50.1	104.5	5,236			
			Low	5	104.5	523			
		Pressed Wood Cabinets	High	257.0	59	15,163			
			Med	130.0	59	7,670			
			Low	72.0	59	4,248			
		Carpet	High	57.6	60	3,456			
			Med	26.3	60	1,577			
			Low	0.33	60	20			

3 RESULTS

3.1 Monitoring Data

A summary of formaldehyde concentrations identified from residential (
Table 3-1) and non-residential (Table 3-2) indoor air monitoring studies was evaluated to understand how people are exposed to formaldehyde in these settings. These monitoring data do not differentiate among the various sources of formaldehyde whether they be from TSCA articles or other sources. Additionally, these monitoring data are not expected to represent peak exposure concentrations since the air monitoring often occurs some period of time after articles are installed in a home. These data are more representative of long-term exposures to formaldehyde. In a few cases, however, monitoring studies do capture peak concentrations such as those that sample new homes or trailers (*e.g.,* unoccupied Federal Emergency Management Agency [FEMA] trailers). These tend to be outliers in the monitoring data and show substantially higher concentrations when compared to other monitoring data. It is important to note that the available monitoring studies were conducted prior to the implementation of the Title VI pressed wood product emission standards. Formaldehyde concentrations in all indoor air settings may be reduced as these standards are implemented over time.

Table 3-1. Indoor Air Monitoring Concentrations for Formaldehyde

Reference	Monitoring Study Description	Formaldehyde Concentrations (µg/m^3)	
		Central Value	Range/Percentiles
(ATSDR, 2007)	96 unoccupied FEMA trailers assessed during the summer of 2006	Mean: 1,280	Range: 12.28–4,500
American Healthy Home Survey II (QuanTech, 2021)	Nationally representative sample of 689 U.S. homes of various ages, types, conditions, and climates	Mean: 23.2	Range (lower/upper 95% tiles of mean): 21.4–24.9
(Board, 2004)	Portable and traditional classrooms in 67 California schools (Phase II study)	Arithmetic Mean: 18.42 (portable) 14.74 (traditional)	95th Percentile: 31.93 (portable) 27.02 (traditional)
(Gilbert et al., 2005)	59 homes in Prince Edward Island, Canada	Geometric Mean: 33.16	Range: 5.53–87.33
(Gilbert et al., 2006)	96 homes in Quebec City, Canada	Geometric Mean: 29.48	Range: 9.58–89.91
(Hodgson et al., 2004)	4 new relocatable classrooms	Unspecified Mean: 9.83 (indoor-outdoor)	Range: 4.91–14.74 (indoor-outdoor)
(Hodgson et al., 2000)	New homes in eastern/SE U.S.: 4 new manufactured homes 7 new site-built homes	Geometric Mean: 41.76 44.22	Range: 25.79–57.73 17.2–71.24
(Liu et al., 2006)	234 homes in Los Angeles County, CA; Elizabeth, NJ; and Houston, TX	Median: 20.02	Range: 12.53–32.43 (5th–95th percentiles)
(LBNL, 2008)	4 FEMA camper trailers	Unspecified Mean: 568.67	Range: 330.39–924.85

Reference	Monitoring Study Description	Formaldehyde Concentrations (µg/m³)	
		Central Value	Range/Percentiles
(Murphy et al., 2013)	Sample: All structures (519) Travel trailers (360) Park models (90) Mobile homes (69)	Geometric Mean: 94.57 99.49 54.04 70.01	Range: 3.68–724.65 3.68–724.65 3.68–196.52 13.51–393.03
(Offermann et al., 2008)	108 new SF homes in CA	Median: 38.2	Range: 4.67–143.33
(Sax et al., 2004)	Inner-city homes: NY City (46) – winter (W), summer (S) Los Angeles (41) – winter (W), fall (F)	Median: 12.28 (W), 18.42 (S) 18.42 (W), 14.74 (F)	Range: 4.91–22.11 (W), 6.14–50.36 (S) 7.37–55.27 (W), 7.37–31.93 (F)

Table 3-2. Formaldehyde Monitored in Commercial Buildings in the United States

References	Monitoring Study Description	Formaldehyde Concentrations (µg/m³)	Descriptor
(Ceballos and Burr, 2012)	Office space indoor air monitoring for formaldehyde in a commercial building	24.56	Average
(EPA, 2023c)	Indoor air monitoring across 100 randomly selected U.S. commercial buildings	3.68	5th Percentile
		14.74	50th Percentile
		30.71	95th Percentile
(Page and Couch, 2014)	Indoor air U.S. government offices	<61.41	Maximum
(Lukcso et al., 2014)		12.28	Geometric mean
		56.50	Maximum
(Dodson et al., 2007)	Classrooms in U.S. school buildings	17.69	Median

An important consideration in these data is how formaldehyde may dissipate in homes. The most prominent cause is home ventilation either through mechanical systems or through open windows. Due to improved insulation in American homes built after 1990, formaldehyde may persist longer in newer homes compared to older homes as a result of reduced indoor-outdoor air exchange (see Appendix C). Sorption is not expected to be a key source of dissipation for homes. Also, the available monitoring data may not reflect expected future indoor concentrations as energy efficiency and building materials change over time. These factors are not readily presented in the monitoring data but do play an important role in understanding why some homes may have higher formaldehyde concentrations than others.

3.1.1 Summary of Monitoring Data Results

As previously mentioned, indoor air environments may have a variety of attributes that influence indoor formaldehyde concentrations including, but not limited to, the age of the building, ventilation rates, types, quantity, and age of articles. Indoor air concentrations of formaldehyde in the AHHS II study ranged from 0.27 to 124 µg/m^3 (QuanTech, 2021).Table 3-1. Indoor Air Monitoring Concentrations for Formaldehyde Outside of the United States, the average measured formaldehyde concentrations are between 20 and 40 µg/m^3 in European homes (ECHA, 2019) and 30 to 40 µg/m^3 in Canadian homes (Canada, 2005).

Unlike residential settings, most commercial settings are not expected to have sources of formaldehyde attributable to combustion. A comparison of formaldehyde indoor air concentrations from both residential and commercial settings and residential settings suggests similar concentration ranges of formaldehyde. The similar ranges of concentrations across residential and commercial settings also suggests that, while combustion sources may be notable contributors in some residential settings, combustion is not a substantial contributor to typical indoor air concentrations that Americans may be exposed across all indoor air environments.

3.1.2 American Healthy Homes Survey II (AHHS II)

The AHHS II formaldehyde residential indoor air monitoring survey is the most recent and relevant high-quality American residential indoor dataset for formaldehyde. It is a well-designed study. See Appendix B for a detailed summary of the AHHS II data collection methods. The AHHS II was the first national study of formaldehyde concentrations in homes across the contiguous United States. The AHHS II survey was sponsored by the U.S. Department of Housing and Urban Development (HUD) along with EPA, and was conducted by QuanTech, Inc. (QuanTech, 2021) from March 2018 through June 2019. The AHHS II measured household levels of lead, lead-based paint hazards, pesticides, formaldehyde, and mold in American homes. Ninety-eight percent of the homes surveyed (689 out of 703 housing units) were randomly selected in 78 cities and counties across 37 states. A sample was not collected in 14 housing units due to air sampling pump failure. The sampled homes represent both owned housing units and rented units (QuanTech, 2021).

Summary statistics for the AHHS II measured formaldehyde concentrations in indoor air are presented in Table 3-3 and a histogram of the data is provided as Figure 3-1. Indoor air concentrations of formaldehyde in the AHHS II study ranged from 0.27 to 124 µg/m^3 (3.5-hour TWA). These samples represent the indoor air concentration of formaldehyde in the most used room in the home. Statistical weights reported in the AHHS II data are applied here to reduce sampling bias and provide a more nationally representative distribution of monitored values (QuanTech, 2021).

Table 3-3. Range and Weighted Quantiles of AHHS II Residential Indoor Air Formaldehyde Concentrations (µg/m^3)

Minimum	10th Percentile	Median	90th Percentile	Maximum
0.27	7.54	19.8	41.8	124.2

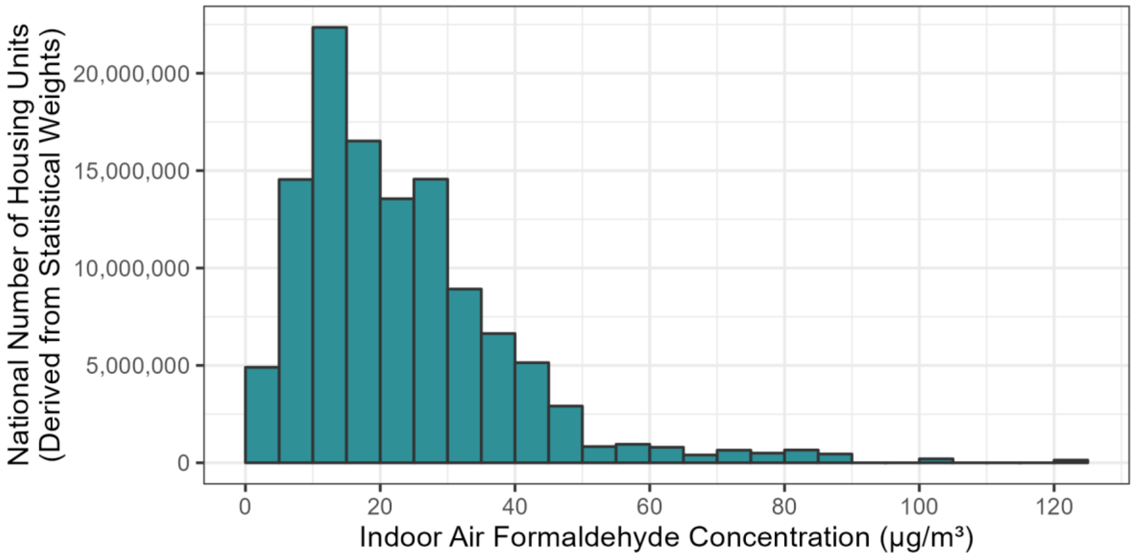

Figure 3-1. Histogram of Formaldehyde Indoor Air Sampling Results from AHHS II with Statistical Weights Applied

Surprisingly, AHHS II researchers found that homes without tobacco smoke had significantly higher average formaldehyde concentrations compared to homes with reported smokers (23.79 µg/m^3 vs 19.21 µg/m^3). In addition, homeowners were twice as likely to report smoking at least once per day compared to renters; 26.2 vs. 12.5%, respectively (QuanTech, 2021). The AHHS II does not provide a reason for these differences. However, these differences suggest that tobacco smoke is not a significant source of formaldehyde in the surveyed homes.

Despite the utility of this robust dataset, the measured concentrations cannot be linked to a specific TSCA COU or group of COUs. The concentrations represent aggregate formaldehyde concentrations in homes across the United States and provide context on how much formaldehyde people are regularly exposed to in their homes.

3.1.3 New Homes

New homes tend to have significantly higher concentrations of formaldehyde due to improved insulation and the incorporation of new articles that may still be off-gassing formaldehyde. Two studies were identified that highlight these issues.

Hodgson et al. (2000) measured indoor air formaldehyde concentrations in newly manufactured homes and new site-built homes. Formaldehyde concentrations ranged from 25.79 to 57.73 µg/m^3 among four *newly manufactured* homes in the Eastern and Southeastern United States after 2 to 9.5 months. In contrast, indoor air concentrations ranged from 17.20 to 71.24 µg/m^3 among seven *new site-built* homes after only 1 to 2 months (Hodgson et al., 2000). The difference in the range of these concentrations are attributed to the construction type and the sampling period. Furthermore, several of the *site-built* homes had relatively poor ventilation rates per the American Society of Heating, Refrigerating and Air-Conditioning Engineers. All homes were in hot and humid climates that generally increase emissions of formaldehyde. According to the authors, plywood flooring, latex paint, and sheet vinyl flooring were major sources of formaldehyde (Hodgson et al., 2000). All are TSCA COUs.

Offerman et al. (Offermann et al., 2008) also measured formaldehyde concentrations in newly constructed homes. In this study, 108 newly constructed homes were sampled in California (Offermann et al., 2008). The measured indoor air concentrations of formaldehyde ranged from 4.67 to 143.33 µg/m^3. Given that a primary focus of this study was on the effect of ventilation on indoor air formaldehyde concentrations, the authors determined that because new single-family homes in California are built relatively air-tight, and because the windows and doors were kept shut during the duration of the study—the indoor-outdoor air exchange rates were generally low (*i.e.,* 0.2 air exchanges per hour). This resulted in significantly elevated indoor air concentrations of formaldehyde (Offermann et al., 2008).

3.1.4 Trailer Studies

Trailers may also have substantially higher concentrations of formaldehyde when constructed with materials that significantly emit formaldehyde. Three monitoring studies were identified that provide insight to how formaldehyde concentrations may vary among these housing units.

In the summer of 2006, as part of a health consultation, the Agency for Toxic Substances and Disease Registry (ATSDR (2007)) was requested by the FEMA to assess formaldehyde indoor air concentrations in 96 unoccupied residential trailers (ATSDR, 2007). Such trailers are often provided to victims as a form of temporary housing following displacement from their home due to natural disasters. The air samples were collected by the EPA. Formaldehyde concentrations were initially measured when the trailers were unventilated, and again during a two-week intervention in which either air conditioning was turned on or windows were open. Results showed that each intervention was able to lower formaldehyde concentrations significantly. Without any intervention, the measured formaldehyde concentrations ranged from 12.28 to 4,500 µg/m^3, with an average of 1,280 µg/m^3. The interventions reduced formaldehyde concentrations, with open windows causing greater reductions (to an average of 110 µg/m^3) compared to air conditioning (to an average of 480 µg/m^3). The authors noted that while concentrations were reduced during the air conditioning intervention, formaldehyde concentrations in the unoccupied FEMA trailers remained at a range that may be associated with acute health symptoms in certain individuals. They also stated that during both interventions, formaldehyde concentrations remained above certain federal health-based guidelines. Furthermore, when windows were closed, higher temperatures were associated with higher formaldehyde concentrations. In addition, formaldehyde levels tended to differ across commercial brands of trailers. However, it is important to note that this health consultation did not assess formaldehyde under normal use or living conditions. Hence, the authors caution that these results should not be generalized to all FEMA trailers, and that the findings do not predict health outcomes due to living in such trailers. Lastly, since the health consultation did not assess human exposures, the authors noted that this analysis could not be used to define levels of concern (ATSDR, 2007).

Lawrence Berkeley National Laboratory (LBNL) measured formaldehyde indoor air concentrations within four FEMA camper trailers with concentrations ranging from 330.39 to 924.85 µg/m^3 (LBNL, 2008). According to LBNL, relatively high concentrations of formaldehyde measured in FEMA temporary housing units are likely due to the very high composite wood surface area relative to room volume in addition to low ventilation rates—specifically for low area-specific fresh air flow rates in relation to the internal surface area in the assessed temporary housing units. Notably, the authors indicated that results from this study were not representative of all FEMA temporary housing unit conditions given only four such units were assessed. It is, however, representative of other temporary housing unit indoor air conditions with similar materials and low air flow conditions (LBNL, 2008).

According to a study by Murphy et al, with a sample of 519 FEMA-supplied trailers, including travel trailers, park models, and mobile homes, peak formaldehyde indoor air concentrations ranged from 196.52 to 724.65 µg/m^3 according to trailer type (Murphy et al., 2013). The geometric mean concentration of formaldehyde in such homes were higher than levels found in traditional homes, as also presented in the (Murphy et al., 2013) study. (Murphy et al., 2013) noted that low air flow (caused by closed windows more than by lack of adequate air conditioning) was a key reason for the relatively high concentrations of formaldehyde found in trailers. Increased indoor air temperate and relative humidity also correlated with increased formaldehyde concentrations in trailer indoor air. Although the authors did not investigate the impact of material type and trailer material composition on measured formaldehyde indoor air concentrations, all trailer brands had some trailers with formaldehyde concentrations exceeding 123 $\mu g/m^3$ (Murphy et al., 2013).

It is important to note that these studies which show elevated indoor air formaldehyde concentrations, especially compared to other settings, were conducted prior to the implementation of the Title VI pressed wood product emission standards. Therefore, it is conceivable that formaldehyde concentrations in these settings (and all indoor air settings) may be reduced as these standards are implemented over time.

3.1.5 Commercial and Other Buildings

Formaldehyde emissions in commercial and other buildings can expose office workers, students, and the general population. These settings may have high formaldehyde concentrations due to off gassing from building materials and other articles. Likewise, these emissions may be from multiple COUs (*e.g.*, composite wood articles; coatings, paints, adhesives, sealants; formaldehyde-based furnishings; and building materials). Twelve monitoring studies were identified that provide some context for formaldehyde exposures in these settings.

Ceballos and Burr (2012) evaluated formaldehyde indoor air exposures in an office located in a two-story commercial building. The office contained cubicles separated by fabric-covered dividers and most of the office was carpeted. Over the 2-day sampling period inside the office, area concentrations remained at 25 $\mu g/m^3$. Dodson et al. (2007) conducted personal breathing zone (PBZ) sampling of teachers in primary and secondary schools, as well as office workers. The median of these personal samples was 18 $\mu g/m^3$.

Additionally, EPA identified studies measuring formaldehyde exposure in office environments outside of the United States. Hanazato et al. (2018) measured area concentrations in a newly constructed commercial bank in Japan, and the formaldehyde concentrations in the samples ranged from 1.5 to 3.2 $\mu g/m^3$. Samples were collected in the lobby, office space, seminar room, and outdoor space. Another study in Japan measured area formaldehyde concentrations across 17 office buildings with concentrations ranging from 3.4 to 21 $\mu g/m^3$ in the winter and 12 to 45.2 $\mu g/m^3$ in the summer (Azuma et al., 2017).

In Sweden, the PBZ of 79 participants across 8 office buildings was measured (Glas et al., 2004). The PBZ samples ranged from 2 to 18 $\mu g/m^3$, with an average of 9 $\mu g/m^3$. Another study measured the PBZ of office workers in Sweden and Finland, with geometric means of 7.6 $\mu g/m^3$ and 8.1 $\mu g/m^3$, respectively (Glas et al., 2014). Dingle et al. (2000) measured the area concentrations of formaldehyde across 18 conventional offices and 20 portable office buildings located on a university campus in Australia. The concentrations in the conventional office buildings ranged from 12 to 90 $\mu g/m^3$, and the concentrations in the portable office buildings ranged from 516 to 2,592 $\mu g/m^3$. The elevated formaldehyde concentrations in the portable office buildings were believed to be from the particleboard and plywood present in those buildings (Dingle et al., 2000).

In general, higher formaldehyde indoor air concentrations had been reported in the past. EPA identified two studies from office environments in the United States in the 1990s with area concentrations ranging from less than 12 to 2,456 μg/m^3 (Hedge et al., 1995; Kaiser and Sylvain, 1994). Additionally, EPA identified three studies spanning multiple office buildings in Canada with individuals exposed to formaldehyde (Haghighat and Donnini, 1999; Allaire et al., 1997; Menzies et al., 1996). Menzies et al. (1996) measured formaldehyde concentrations in the air ranging from 15 to 59 μg/m^3 in two office buildings. Between the other two studies, concentrations ranged from less than 2 to 2,590 μg/m^3, and most of the office buildings were carpeted (Haghighat and Donnini, 1999; Allaire et al., 1997). A study conducted in 29 office buildings in northern Sweden measured air concentrations of formaldehyde ranging from 11 to 59 μg/m^3 (Sundell et al., 1993).

3.1.6 Japan National Study

In 1996, Japan's National Institute of Health Sciences administered the first national survey of formaldehyde in approximately 230 homes with an arithmetic mean concentration of approximately 74.92 μg/m^3. After repeating this monitoring study with 1,181 homes in 2005, the arithmetic mean of formaldehyde across Japanese homes decreased to approximately 29.98 μg/m^3 (Osawa and Hayashi, 2007; Azuma et al., 2005). As reported by the World Health Organization, this reduction in average formaldehyde concentration in Japanese homes from 1996 to 2005 was likely due to an amendment of the national building codes and, more specifically, a restriction of materials that emit formaldehyde in interior finishing (WHO, 2010).

3.1.7 Relative Contributions of Formaldehyde Sources in Residential Indoor Air

Monitoring data from AHHS II suggests that concentrations of formaldehyde may range from 0.27 to 124.2 μg/m^3 for all homes, with 95 percent of homes having concentrations below 47 μg/m^3 (QuanTech, 2021). Those data include formaldehyde produced from both TSCA sources and other sources of formaldehyde such as tobacco smoke or the use of fireplaces, gas-burning appliances, candles, incense and air purifiers (QuanTech, 2021; Salthammer, 2019). Of these other sources, the most common and significant contributors to indoor air are likely from fireplaces, gas burning appliances and air purifiers. It should be emphasized that some of these sources (*i.e.,* tobacco smoke) may not contain formaldehyde but rather lead to the formation of formaldehyde during use.

For other sources of formaldehyde in indoor air, simulated 50th percentile room concentrations ranged from 12.3 to 44.2 μg/m^3 individually for wood combustion, air cleaning devices, cooking, candles, and incense, and up to 152.2 μg/m^3 for ethanol fireplaces (ECHA, 2019). Air cleaning devices such as photocatalytic air purifiers can produce formaldehyde from irradiation of air contaminants, leading to increased indoor air concentrations of formaldehyde (Salthammer, 2019). Formaldehyde production associated with cooking depends on many factors, including cooking temperature and type of oil and variety of food being cooked. Select gas-oven cooking tests involving a variety of cooking parameters resulted in formaldehyde concentrations ranging from 36.5 to 417.3 μg/m^3 (Salthammer, 2019). Tobacco smoke is also known to be a contributor to formaldehyde concentrations within all indoor air environments (EPA, 2016; Girman et al., 1982), although according to the World Health Organization tobacco smoke primarily increases formaldehyde concentrations in indoor air environments where the rates of smoking are high with minimal ventilation (IPCS, 2002).

In addition, tire crumb-based surfaces may also be a source of formaldehyde exposure for some populations including children or adults who play sports on fields made of such materials. Due to increased concerns from parents, athletes, schools and communities regarding potential chemical exposures from recycled tire crumb surfaces, in 2016 the Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry (CDC/ATSDR) and the EPA, in collaboration with the CPSC, launched a multi-agency effort via the Federal Research Action Plan on Recycled Tire Crumb Used on Playing Fields and Playgrounds (FRAP) to investigate potential human exposures to the substances associated with recycled tire crumb rubber used on synthetic turf fields (EPA, 2019c). Researchers collected tire crumb rubber samples from nine tire recycling facilities, and tire crumb rubber infill material from 40 synthetic indoor and outdoor turf fields located throughout the United States. These samples were quantitatively analyzed for formaldehyde through chamber emission testing at 25 °C and at 60 °C using high-performance liquid chromatography/ultraviolet spectroscopy. At 25 °C, all formaldehyde measurements were below limits of quantification for synthetic field tire crumb rubber infill. At 60 °C, the average formaldehyde emissions from the chamber studies were 16 ng/g/h for such materials. The average emissions of formaldehyde were 23 ng/g/h for indoor field based materials and 12 ng/g/h for outdoor field based materials. The authors reported no statistical difference among the measured emissions based on the period of installation (2004–2008, 2009–2012, and 2013–2016) and that no specific chemical hazards from recycled tires in playground surfacing were identified (EPA, 2019c).

Many of these other sources of formaldehyde represent temporary emission sources, which may affect the overall impact on indoor air quality. Further, qualities such as the frequency and duration of use of these temporary formaldehyde sources (*e.g.*, using a fireplace), age of the indoor spaces and formaldehyde-containing finishes and furnishings, and ventilation rate will impact the total concentration of formaldehyde in indoor air and the relative contribution of TSCA and other sources to indoor air.

Although there are some uncertainties in estimating indoor air concentrations of formaldehyde, EPA generally expects that a larger number of formaldehyde sources will lead to higher concentrations of formaldehyde in the indoor air (EPA, 2016; IPCS, 2002; ATSDR, 1999; Girman et al., 1982). As previously noted, there is insufficient data to quantify the relative contributions of the modeled TSCA COUs to the AHHS II monitored concentrations of formaldehyde in American residential indoor air with certainty. However, article-specific and aggregate scenario based indoor air concentrations of formaldehyde were within the same order of magnitude as reported in the AHHS II study. Therefore, it is reasonable to conclude these results support the hypothesis that the identified TSCA COUs are key contributors to real-world concentrations of formaldehyde in residential indoor air.

3.1.8 Comparing Indoor to Outdoor Air

As has been presented, indoor air concentrations of formaldehyde can vary due to the materials used in construction, the timing of when new articles are introduced, and the amount of ventilation present. Indoor air concentrations tend to be much higher than those found outside. To understand the quantitative difference in these numbers, EPA developed Figure 3-2 to show the distribution of monitoring data in both settings.

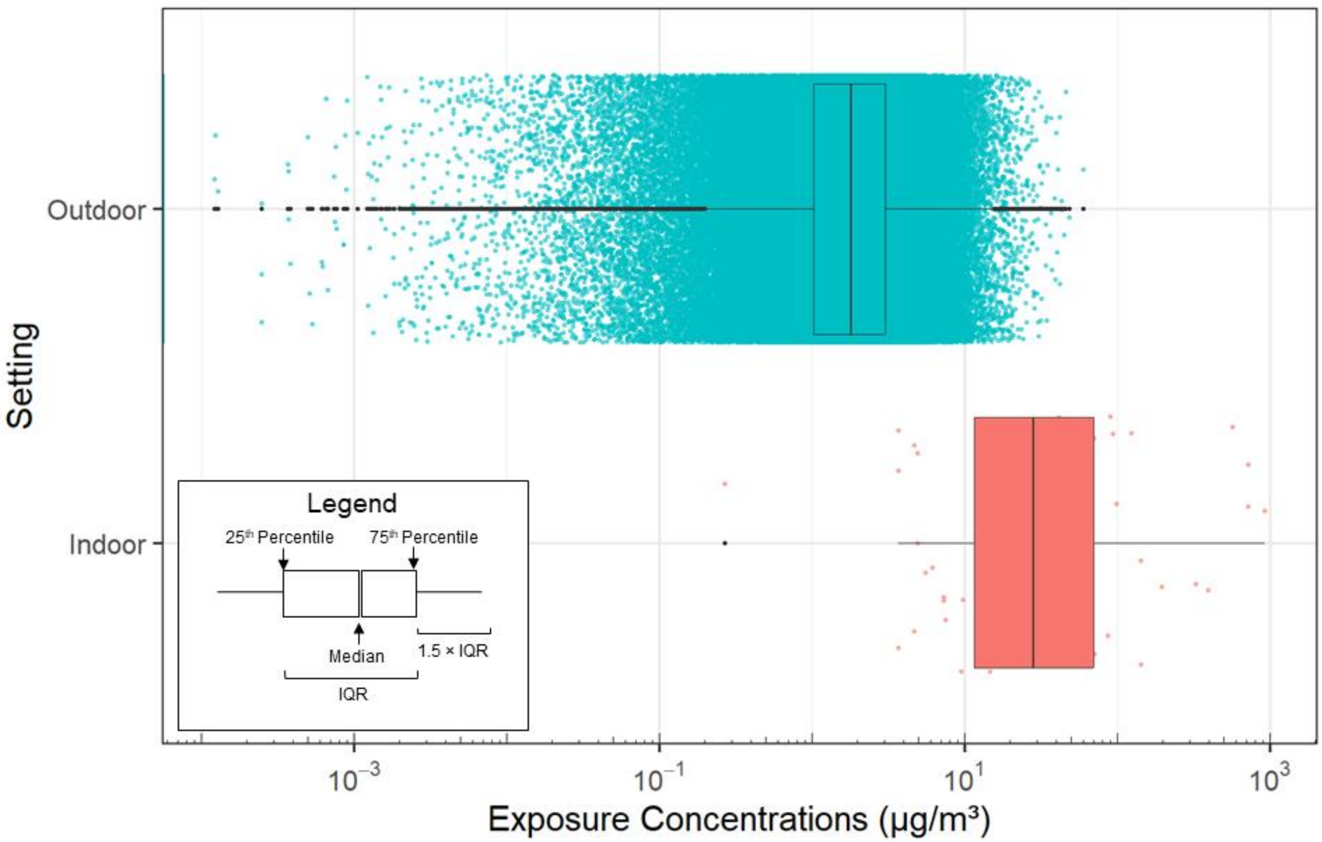

Figure 3-2. Monitoring Formaldehyde Concentrations in Indoor Compared to Outdoor Settings
Note: The black dots in the figure are outliers.

As shown, indoor air monitoring data were generally higher than concentrations measured in the outdoor air (approximately one order of magnitude higher). These findings are consistent with previous investigations conducted by EPA which generally found indoor air concentrations of pollutants are at least two times greater than outdoor air (EPA, 2016). This is also consistent with other findings presented in published literature (ATSDR, 1999). A study of concurrent 24-hour indoor and outdoor air monitoring for Canadian residences reported average formaldehyde concentrations an order of magnitude higher in indoor air compared to outdoor air—a finding that has also been reported in other countries (IPCS, 2002). It is expected that most indoor air environments contain more sources of formaldehyde per volume of air compared to outdoor air environments, and with improvements to building efficiency, especially in homes built after 1990 (Persily et al., 2010), less indoor-outdoor air ventilation is expected, which can lead to higher and persistent concentrations of formaldehyde in American homes (IPCS, 2002; ATSDR, 1999).

Considering the formaldehyde concentrations in indoor as compared to outdoor environments, along with findings in published literature indicating individuals spend on average of 87 percent of their day inside homes or buildings (Klepeis et al., 2001), EPA expects exposure to formaldehyde in indoor air will be higher than exposure to formaldehyde in outdoor air. This is likely due to both the presence of multiple sources of formaldehyde indoors (from TSCA and other sources), which can contribute to continuous formaldehyde concentrations within a home or residence over an extended period of time, and periodic short-term contributions to indoor concentrations of formaldehyde from off-gassing or short-term but repetitive use of articles or appliances such as gas-fired stoves, and other products. Even products designed to clean/purify indoor air of certain pollutants can be a source of formaldehyde exposure (or other chemical exposures) in homes or residences (Salthammer, 2019).

3.2 Tier 1: CEM Modeling

This section summarizes the CEM indoor air exposure modeling results for formaldehyde. A full description of the general screening methodology can be found in Section 2.2. Supplemental CEM results not presented in this section can be found in Appendix D. EPA did not model indoor air concentrations of commercial buildings as residential homes were considered a more protective indoor air scenario.

3.2.1 CEM Modeling Results

Modeling results for inhalation exposures estimated with CEM are summarized and presented, respectively, in Table 3-4 and Figure 3-3Figure 3-3. , according to COU. Table 3-4 and Figure 3-3Figure 3-3. present the various TSCA sources contributing to formaldehyde concentrations in residential and automobile indoor air environments. The largest contributor to the 1-year average daily concentration of formaldehyde in a typical home is the building wood articles (423.47 μg/m^3) scenario. The lowest contributors to formaldehyde indoor air concentrations were furniture seat covers (4.01 μg/m^3) and clothing (5.19 μg/m^3).

Table 3-4. Estimated Chronic Average Daily Formaldehyde Indoor Air Concentrations (According to CEM)

COU Subcategory	Scenario	Environment	CEM Calculated 1-Year Average Daily Concentration (μg/m^3)
Construction and building materials covering large surface areas, including wood articles; Construction and building materials covering large surface areas, including paper articles; metal articles; stone, plaster, cement, glass and ceramic articles	**Building / Construction Materials – Wood Articles: Hardwood Floors (Residential)** [a]	Living Room	**423.47**
Fabric, textile, and leather products not covered elsewhere	Seat Covers (Automobile)	Automobile	7.10
Fabric, textile, and leather products not covered elsewhere	Furniture Seat Covers (Residential)	Living Room	4.01
Fabric, textile, and leather products not covered elsewhere	**Fabrics: Clothing (Residential)**	Bedroom	**5.19**
Floor coverings; Foam seating and bedding products; Cleaning and furniture care products; Furniture & furnishings including stone, plaster, cement, glass and ceramic articles; metal articles; or rubber articles	**Furniture & Furnishings –Wood Articles: Furniture (Residential)**	Living Room	**108.62**
Paper products; Plastic and rubber products; Toys, playground, and sporting equipment	**Paper-Based Wallpaper**	Living Room	**18.05**

[a] The bolded text are representative scenarios (as described in Section 2.2.2).

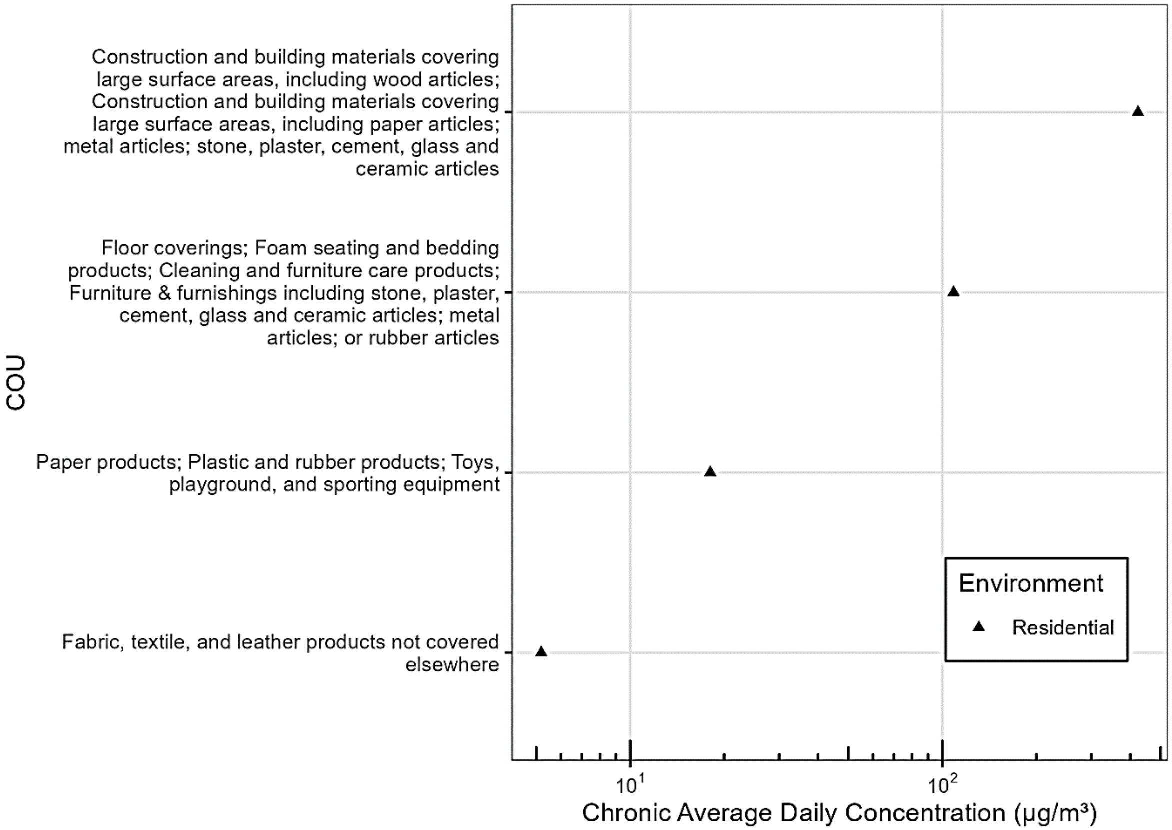

Figure 3-3. CEM Estimated 1-Year Average Daily Formaldehyde Indoor Air Concentrations

3.2.1.1 Aggregate Exposure

As previously noted, per the indoor monitoring data, there is robust evidence that people are exposed to multiple sources of formaldehyde simultaneously. As suggested by the SACC during the peer review of the *Draft Formaldehyde Indoor Air Exposure Assessment*, EPA considered realistic scenarios where an individual may be exposed to multiple TSCA COUs to better characterize indoor air exposures to formaldehyde. For example, if aggregating all the representative scenarios (bolded text in Table 3-4) including Building/Construction Materials - Wood Articles: Hardwood Floors (Residential), Fabrics: Clothing (Residential), Furniture & Furnishings –Wood Articles: Furniture (Residential), and Paper-Based Wallpaper, the total CEM-modeled indoor formaldehyde concentration may be approximately 555 µg/m^3.

3.2.2 CEM Modeling Discussion

Estimated air concentrations were driven by the emission rate per surface area in the expected room of use, which is dependent on the emission rates taken from literature and the anticipated surface area of the product in the assumed room of use. CEM accounts for some dissipation over time via air exchanges between the room of use and the rest of the home, and between the home and outdoor air. Since the CEM E5 emission model does not consider a decline in emission rates over time or chemical half-life (EPA, 2019a), COU-specific estimates likely represent formaldehyde air concentrations if new articles were repeatedly introduced to a home or automobile. It should also be noted that while all age groups were considered, there were no differences observed in formaldehyde 1-year average concentrations per room of use across age groups.

3.2.2.1 Data Integration

From the COUs identified as significant contributors to the indoor air environment, the CEM modeling results highlight potential COU-specific contributions of formaldehyde to indoor air were driven primarily by the reported emission rates in literature along with the expected surface area of the article(s) in the home. Higher emission rates and surface areas corresponded with higher air concentrations. Central tendency product-specific emission rates (within a COU category) were used for the CEM modeling to represent emission rates in the typical American home or automobile. Therefore, it is conceivable that the estimated formaldehyde air concentrations would be lower if the lowest emission rates were used or higher if the highest reported emission rates were used.

CEM does not allow the user to adjust the model according to a chemical-specific half-life. This was a key source of uncertainty in the indoor air analysis of formaldehyde. In general, it is unclear whether the CEM modeling results are reflective of most indoor air home environments in American residences as there is uncertainty in the results from these models, especially given the CEM E5 emission condition only allows for a constant rate of emissions instead of an exponential or power law decay rate (as is done in IECCU modeling).

Considering the breadth of potential sources of exposure to formaldehyde in indoor settings, evaluating exposures and associated risks resulting specifically from TSCA COUs in this setting is complex. As such, the uncertainties in EPA's analysis of formaldehyde exposure in indoor air from TSCA COUs via CEM should be recognized. Furthermore, assumptions made in CEM modeling created a conservative exposure scenario, likely resulting in higher modeled concentrations than may typically be found in indoor air. EPA characterized this uncertainty by comparing modeled concentrations to monitored concentrations and found modeled concentrations for an individual TSCA COU typically fall within the range of monitored values, and therefore are not unreasonable. However, most homes have more than one source contributing to formaldehyde concentrations, and monitored concentrations may represent all sources of formaldehyde. When multiple individual TSCA COU contributions are added together, the total exposure to modeled concentrations is generally greater than monitored values. This supports EPA's recognition that most CEM-modeled concentrations are conservative in nature and may not be representative of actual exposures over extended periods of time. This recognition is particularly important when considering off-gassing from various articles (*e.g.*, wooden cabinets, flooring, carpet) as typical dissipation curves associated with off-gassing show high concentrations immediately following installation, which typically peak within the first week but fall off significantly to much lower concentrations to which individuals are exposed over an extended period of time.

Through the CEM modeling, EPA assumes and uses the initial formaldehyde concentration from a finished article, as reported by relevant SDSs and literature, as the initial concentration to which an individual is exposed when in their residence. This results in a conservative emission rate and exposure estimate via modeling since it is unlikely a newly manufactured product will be instantly installed in a home and individuals will immediately be exposed to those higher concentrations early in their exposure period. It is more likely that the actual emissions from any given product will be the rate following some period of storage time where initial off-gassing at those high-rates would have occurred prior to being installed in a residence. The IECCU modeling considered this lead time by foregoing the use of initial weight fractions reported in article SDSs and relying on the emission factors reported from chamber studies of finished articles.

The actual emission rate to which an individual is exposed over an extended period indoors would likely be significantly lower than the initial measured emission rate following manufacturing of the product. Nonetheless, the current assessment using CEM can be considered as a screening approach to ensure potential exposures to formaldehyde via the indoor air pathway are not missed and to provide a conservative exposure estimate that can be considered for characterizing exposures and associated risks while recognizing the uncertainty around such estimates.

Although EPA modeled a scenario using measured emission rates from manufactured articles for this indoor air exposure assessment within CEM, the Agency investigated other modeling approaches (*i.e.*, IECCU) and emission rate values available to evaluate prior to finalizing its indoor air formaldehyde exposure assessment. Ideally, these models and emission rates will consider multiple factors like the rapid dissipation of off-gassing pollutants, and a more representative actual emission rate (per article-specific surface areas) from off-gassing to model exposures.

A general residential dissipation curve of formaldehyde over time (in years) is presented in Figure_Apx C-1.

3.2.2.2 Automobile Exposures

At the time of the CEM exposure assessment, EPA considered all potential TSCA related sources of formaldehyde in typical automobile environments. The estimated formaldehyde concentration in an automobile interior due to automobile seat covers was 7.1 µg/m^3. By comparison, a study of automobile formaldehyde concentration in the New York City Metropolitan Area reported that the measured average concentration of formaldehyde inside automobiles during commutes was approximately 300 µg/m^3 (Lawryk and Weisel, 1996; Lawryk et al., 1995). The two automobiles used in this study were a 1988 Chevrolet Celebrity and a 1987 Plymouth Horizon (Lawryk and Weisel, 1996). While this is a well-executed study, it is relatively dated. It is unclear how this monitoring data represent current vehicular formaldehyde indoor air concentrations during a typical commute. Regarding the difference between the modeled seat cover estimates and monitoring values, it is also unclear which sources other than seat covers may be contributing to typical automobile indoor air exposures.

3.3 Tier 2: IECCU Modeling

This section summarizes the IECCU indoor air exposure assessment results for formaldehyde. A full description of the modeling methodology can be found in Section 2.3. EPA did not model indoor air concentrations of commercial buildings as residential homes were considered a more protective indoor air scenario. The Agency also did not model indoor air concentrations of automobiles using IECCU since this model is unable to estimate chemical concentrations in such indoor air settings.

3.3.1 IECCU Modeling Results

Modeled 15-minute peak, 3-month, and 1-year average indoor air concentrations for both single item and aggregate scenarios are shown in Table 3-5 and Figure 3-4. For the TSCA COU covering building materials with large surface areas, models were generated for both pressed wood cabinets and laminate flooring. Though, as described in Section 2.2.2, only the highest exposure scenario was selected to represent a COU. 15-minute peak air concentrations for the high exposure scenario (*i.e.*, high “level”), were 51 µg/m^3 for pressed wood cabinets and 142 µg/m^3 for laminate flooring. As such, model results for laminate flooring are reported as the representative article for the building materials COU. Model results for pressed wood cabinets are not reported in Table 3-5 or shown in Figure 3-4 because it did not meet the criteria to represent the building materials COU. However, as previously noted pressed wood cabinets are included in the modeled results for the new construction aggregate scenario. Also, note that for items modeled in a whole home, a single zone model was used, and Zone 2 concentrations are therefore recorded as N/A. In all, IECCU-modeled concentrations ranged from 0.00009 to 142 µg/m^3, across all individual COUs and exposure scenarios (*i.e.*, “levels”).

Table 3-5. 15-Minute Peak, Mean 3-Month (Intermediate) and Mean 1-Year (Chronic) Formaldehyde Concentrations (μg/m^3) in Indoor Air for Single Representative Article and Aggregate Model Scenarios

COU(s)	Representative Scenario [a]	Level	15-Minute Peak Air Concentration Zone 1 (μg/m^3)	3-Month Average Air Concentration Zone 1 (μg/m^3)	1-Year Average Air Concentration Zone 1 (μg/m^3)	15-Minute Peak Air Concentration Zone 2 (μg/m^3)
Construction and building materials covering large surface areas, including wood articles; Construction and building materials covering large surface areas, including paper articles; metal articles; stone, plaster, cement, glass and ceramic articles	Laminate Flooring	High	142	27.5	6.1	N/A
		Med	22	4.3	1	N/A
		Low	1	0.2	0.05	N/A
	New Construction (Aggregate) [b]	High	160	31.1	6.87	N/A
		Med	64	12.3	2.72	N/A
		Low	21	4.1	0.9	N/A
Fabric, textile, and leather products not covered elsewhere	Textile Furniture Covers	High	18	3.5	0.8	0.3
		Med	2	0.4	0.1	0.03
		Low	0.007	0.001	0.0003	0.00009
Floor coverings; Foam seating and bedding products; Cleaning and furniture care products; Furniture & furnishings including stone, plaster, cement, glass and ceramic articles; metal articles; or rubber articles	Pressed Wood Furniture	High	26	5	1.1	0.4
		Med	7	1.4	0.3	0.1
		Low	2	0.3	0.1	0.03
	Living Room Décor Change (Aggregate) [c]	High	68	12.9	2.9	0.9
		Med	16	3.1	0.7	0.2
		Low	3	0.5	0.1	0.04
Paper products; Plastic and rubber products; Toys, playground, and sporting equipment	Wallpaper	–	12	2.3	0.5	N/A

[a] Representative scenarios are defined in Section 2.2.2.
[b] New construction aggregate scenario includes laminate flooring, pressed wood cabinets, and carpet.
[c] Décor change aggregate scenario includes pressed wood furniture, indoor furniture (foam components), and indoor furniture (textile components).

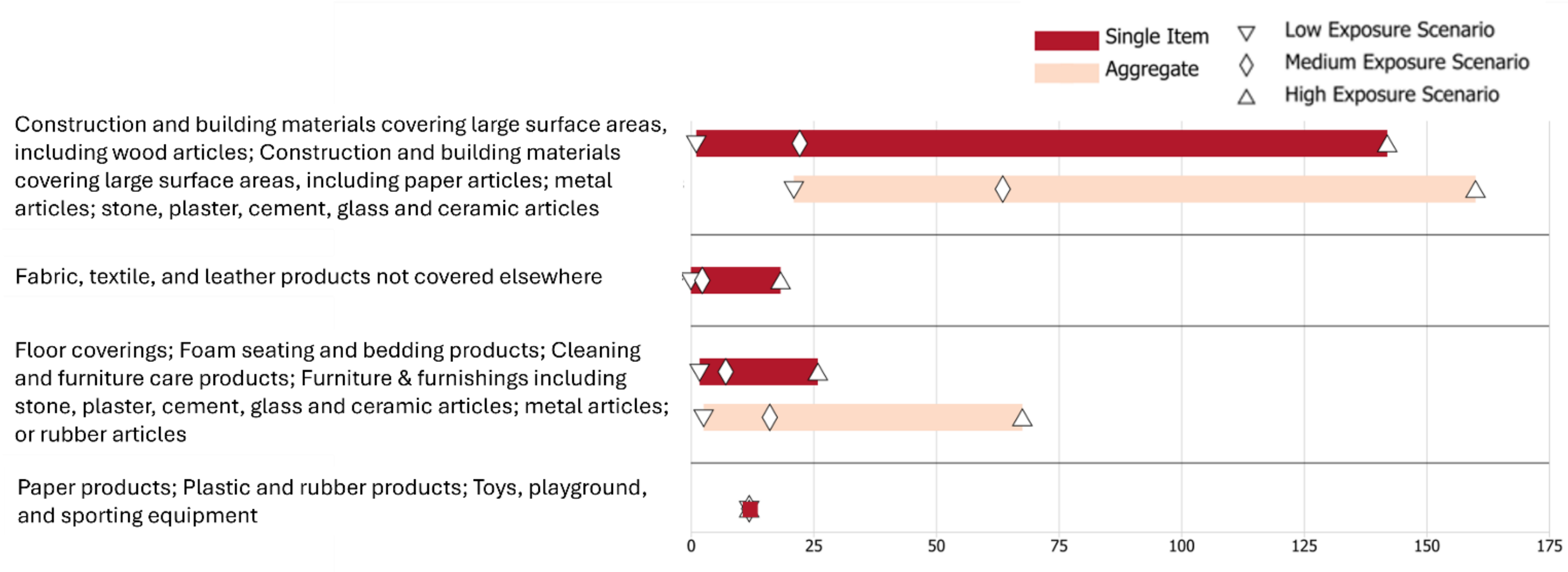

Figure 3-4. 15-Minute Peak Concentrations (μg/m³) of Formaldehyde in Indoor Air for TSCA COU Representative Article and Aggregate Models

Except for wallpaper, modeled air concentrations for each representative scenario, as described in Section 2.2.2, showed a significant range in values. This was driven largely by variability in emissions factors and estimated surface areas from actual articles in the literature (Table 2-4). However, these parameters likely exhibit significant variability due to differences in materials, manufacturing practices, and purchasing preferences. As such, EPA considers it reasonable that the range of estimated concentrations reflects real-world conditions for each COU assessed.

Figure 3-5 shows air concentrations over the full duration of modeling (10,000 hours) for the high-end models (see Table 2-4 for high, med, low-end scenarios) and for each representative scenario as described in Section 2.2.2. The modeled concentrations of formaldehyde in air peaked on the first day the article was installed in the home. Then, the concentrations in indoor air declined rapidly, approaching zero µg/m^3 after a period of approximately 3 months.

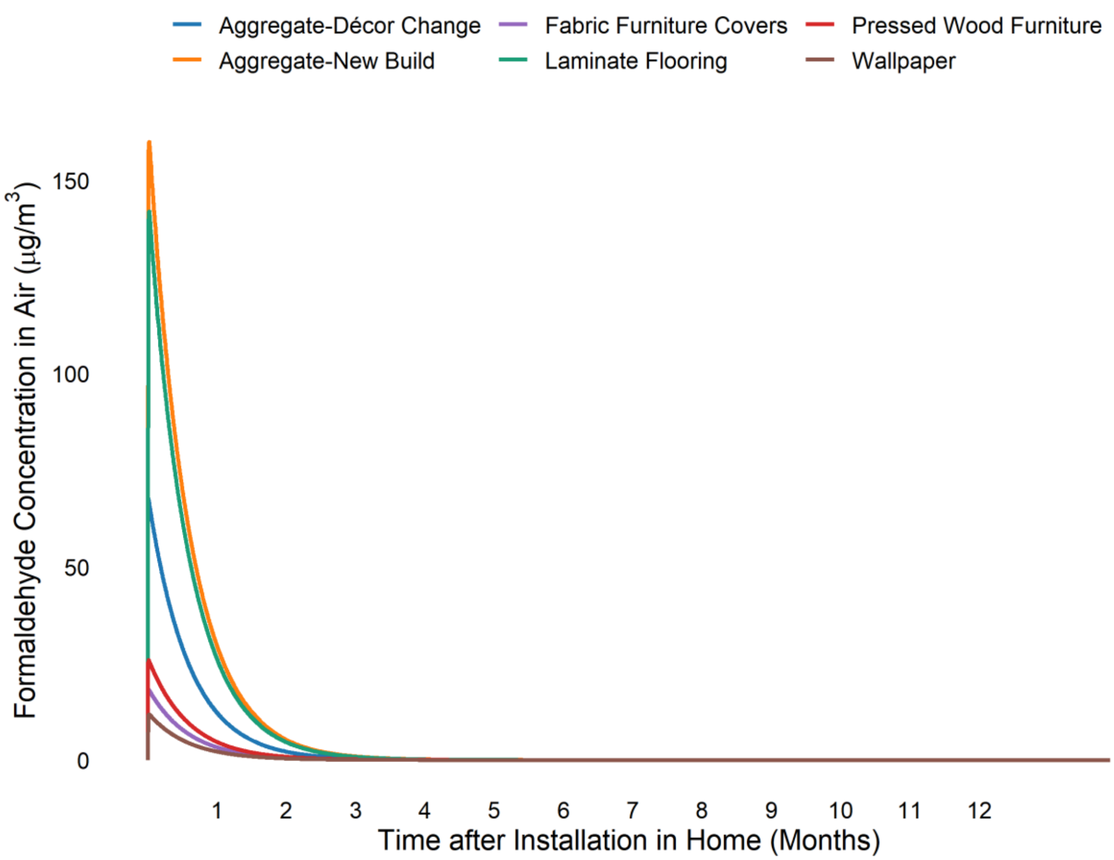

Figure 3-5. Formaldehyde Concentrations in Indoor Air (µg/m^3) for TSCA COU Representative Article and Aggregate Scenarios over the Course of ~1 Year
(10,000-hour simulation duration)

3.3.2 IECCU Modeling Discussion

3.3.2.1 Residential

3.3.2.1.1 Data Integration

As previously noted, EPA considered monitoring data in its risk evaluation to characterize real-world exposures to formaldehyde in indoor air. However, to assess the TSCA COU specific contributions to indoor air, EPA used modeling tools to estimate formaldehyde exposures.

Mobile homes had generally higher concentrations of formaldehyde in indoor air across all monitoring studies (Murphy et al., 2013; LBNL, 2008) identified and also had notably higher concentrations of formaldehyde compared to IECCU modeling results. In addition, according to a 2006 ATSDR study of 96 unoccupied FEMA trailers (ATSDR, 2007), measured formaldehyde concentrations were as high as 4,500 $\mu g/m^3$ for some trailers, with an average of 1,280 $\mu g/m^3$; and were significantly higher than the concentration of 124 $\mu g/m^3$ reported by AHHS II for American homes.

However, drawing conclusions about the relationship between the modeled values and measured values in homes is difficult partly due to the relatively rapid changes in emission rate after placing an article in the home. Unless indoor air monitoring measurements were intentionally conducted after new building materials or articles were placed in a home, it is unlikely that monitoring data will capture the highest period of emissions from these items, and associated peak air concentrations, as displayed in Table 3-5, Figure 3-4, and Figure 3-5.

The reported AHHS II U.S. indoor air measured concentrations of formaldehyde are expected to reflect typical long-term formaldehyde concentrations, and generally does not reflect initial peak concentrations when an article is first introduced into the home. In general, the range of modeled formaldehyde residential indoor air concentrations were within an order of magnitude of the range of monitoring values (0.007 to 142 $\mu g/m^3$, across all individual COUs and scenarios, compared to 0.3 to 124 $\mu g/m^3$, respectively) from the AHHS II residential indoor monitoring study. From a nationally representative sample of 689 homes, the measured concentration of formaldehyde in American homes ranged from 0.3 to 124 $\mu g/m^3$, with 19.77 $\mu g/m^3$ as the 50th percentile. Per Figure 3-1, most homes had a formaldehyde air concentration that was 40 $\mu g/m^3$ or less (Table 3-3). Potential factors that might have impacted the AHHS II and other monitoring results include temperature and humidity (seasonality), and ventilation. For some articles, (*e.g.,* particle boards), an increase in temperature and humidity may increase formaldehyde off-gassing rate (Pickrell et al., 1984); and indoor environments with poor ventilation can lead to higher concentrations of measured formaldehyde in indoor air (EPA, 2016). It should be noted that AHHS II monitoring results cannot be apportioned according to TSCA COUs. Furthermore, the AHHS II air sampling was not performed throughout the entire home, and across multiple seasons.

It should also be reiterated that formaldehyde emission rates decrease over time. Generally, it is expected that after the installation of formaldehyde-bearing materials in a home, there is an initial rise of formaldehyde concentration, followed by a leveling-off period that may be as brief as 30 days or less, depending on the article. This is followed by a significant decline of formaldehyde concentration over time (EPA, 2016; Park and Ikeda, 2006). EPA does not expect, nor assumes (via IECCU modeling), that newly manufactured articles are added immediately to a home. It is possible that air concentrations resulting from solid article emissions may remain elevated longer than the IECCU models indicate. For example, new single-family homes in California are built relatively air-tight, and because the windows and doors were kept shut during the duration of one residential indoor air study, the indoor-outdoor air exchange rates were generally low (*i.e.*, 0.2 air exchanges per hour). This resulted in significantly elevated indoor air concentrations of formaldehyde (Offermann et al., 2008). Furthermore, if home ventilation rates are lower than those used in the IECCU models, peak air concentrations would be somewhat higher than model results and air concentrations would remain elevated above background levels for a longer duration of time.

Although IECCU incorporates formaldehyde's first-order exponential decay from finished articles, according to the literature and as described in Section 2.3.4, it does not incorporate indoor sinks that may capture and re-emit formaldehyde. The model also does not incorporate various forms of barriers (*e.g.*, lamination, coatings, article thickness, etc.) that may accelerate, delay, and/or prolong formaldehyde emissions over time, or other factors including moisture content within the article (for wood), room temperature, and humidity fluctuations, which may differ across housing units, seasons and regions. Also, in some instances formaldehyde emitted from articles with large surface areas may contribute significantly to concentrations measured in homes. Though the extent of this contribution is variable, depending on the article, consumer preferences, room of use, home size and configuration, ventilation rates, and relevant meteorological parameters (*i.e.*, temperature and humidity). The modeled concentrations are also likely dependent on potential replacement rates of articles whose data are currently lacking and could not be integrated into the model nor used to further characterize previously discussed monitoring studies. Thus, while EPA is confident that the range of indoor air concentrations for each modeled scenario provides a reasonable estimate of formaldehyde content that may result from the installation of new solid articles in a home, the modeling results are not intended nor expected to be predictive of measured concentrations of formaldehyde in indoor air.

Due to the highlighted uncertainties and limitations within and across data types, as shown in Figure 3-5, the decay of formaldehyde concentrations in indoor air likely differs depending on the articles added to the home, and modeling tools used. Although IECCU indoor air concentrations were estimated up to a year, modeled results began approaching 0 $\mu g/m^3$ starting around the third month. Yet measured concentrations from AHHS II show typical concentrations of nearly 23 $\mu g/m^3$ for homes of various ages. This highlights a gap between IEECU modeling and AHHS II results. It is possible that the IECCU model slightly underestimates long term indoor air exposures from TSCA COUs.

After formaldehyde volatilizes rapidly from the top layer of a laminated or relatively thick article, there is a significant decrease in the off-gassing of formaldehyde. Some of the remaining formaldehyde may be released slowly over time through a delayed release (or second phase). This delayed release may be triggered by the decomposition of unstable urea-formaldehyde or lignins present in the wood article as a result of hydrolysis over an extended period (Docket ID: EPA-HQ-OPPT-2023-0613-0270-A2). According to He et al. (2019), of the two causes of delayed long-term release, hydrolysis is the primary cause based on chamber studies of finished articles from approximately 3 to 18 months. This hydrolysis typically occurs through crevasses located at the core of wood articles (He et al., 2019). Therefore, the decay curves of formaldehyde concentrations for wood articles are driven mainly by volatility upon installation. Then, as the product ages, hydrolysis becomes the primary cause of further formaldehyde release (Docket ID: EPA-HQ-OPPT-2023-0613-0270-A2).

Figure 3-6, from He et al. (2019), depicts this initial rapid release followed by a gradual decrease of formaldehyde release measured over time. Though only four samples were measured from this chamber study, it is interesting to note the similarity of the high-end peak exposures between the IECCU modeling (Figure 3-5) and the He et al. (2019) experimental study (Figure 3-6). In the long term, though the IECCU modeled decay curves (Figure 3-5) share aspects of the measured formaldehyde concentration decay curves, per the above discussion, potentially due to an inability to account for hydrolysis or a breakdown of urea-formaldehyde, the IECCU models assume a much more rapid approach to 0 $\mu g/m^3$, which may lead to an underestimation of formaldehyde exposures from wood articles in the long-term, following peak off-gassing.

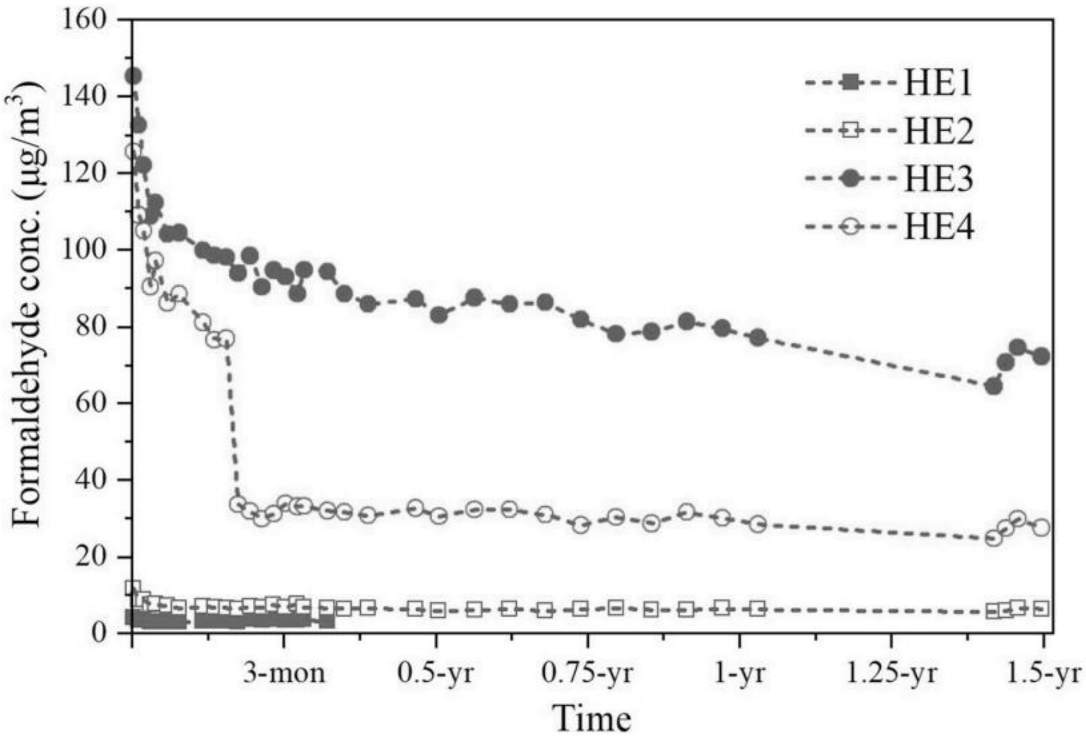

Figure 3-6. Figure from He et al. (2019) Displaying Formaldehyde Concentration Decay Curves from Finished Wood Article Specimens Over Time, Using Test Chamber

HE1 and HE2 represent test specimens without exposed cut edges and seams while HE3 and HE4 represent test specimens with a selected proportion of cut edges and seams exposed (He et al., 2019). According to He et al. (2019), for the HE4 specimen, the exposed perimeter cut edges were sealed at day 57 of the chamber testing. It is possible that the IECCU results for wood articles are best represented by the first portion of the figure from 0 to ~2 months (reading from left to right). IECCU was unable to consider a biphasic distribution. As such, the model would underestimate concentrations resulting from the second and longer emission phase.

Although IECCU-estimated air concentrations from residential articles and AHHS II are individually informative—especially if the modeled home is new or if new articles are introduced to the modeled home—caution should be exercised when comparing the results from these two data types as there are key and impactful aspects to each, presented above. Generally, IECCU results provide a snapshot of the potential relative formaldehyde indoor air contributions from four COUs when they are initially added to a home, individually or all at once (*i.e.*, the aggregate scenario). On the other hand, AHHS II results provide the real-world concentrations of formaldehyde in residential indoor air at the time of sampling, among American households. There are uncertainties and limitations associated with both data types, as illustrated above, but together they provide a fuller depiction of formaldehyde residential indoor air exposures, as opposed to individually.

3.3.2.2 Aggregate Exposure

EPA defines aggregate exposure as "the combined exposures from a chemical substance across multiple routes and across multiple pathways" (40 CFR 702.33). The reported formaldehyde concentrations from the monitoring data may represent aggregate formaldehyde indoor air concentrations, as presented in the AHHS II study across U.S. households (QuanTech, 2021), assuming either at least a 3-hour TWA, or the typical indoor air concentration of formaldehyde in residential environments. An aggregate exposure to formaldehyde via the COUs assessed may occur in the home in which an individual resides.

IECCU modeling estimated aggregate scenario (TSCA COUs only) indoor air concentrations as high as 160 $\mu g/m^3$ for a new construction scenario and 68 $\mu g/m^3$ for a living room décor change scenario, as described in Section 2.3.5. Using the AHHS II measured average concentration of formaldehyde (~23 $\mu g/m^3$) as a baseline residential concentration and considering the addition of new laminate flooring yielding concentrations as high as 142 $\mu g/m^3$, a resident's aggregate exposure may be as high as 165 $\mu g/m^3$. The estimated aggregate exposures suggest potential yet reasonable estimates of total exposures an individual may receive in indoor air. These aggregate exposures may differ according to conditions of use considered, an individual's activity patterns, purchase habits, etc.

4 INDOOR AIR EXPOSURE: WEIGHT OF SCIENTIFIC EVIDENCE

EPA used a combination of modeling and monitoring lines of evidence to characterize formaldehyde indoor air exposures while considering the relative contributions of TSCA COUs to the indoor air environment. EPA assessed indoor air exposures for four COUs expected to be significant sources of formaldehyde in indoor air. Monitoring data were further used to characterize indoor air exposures and provide context for estimated concentrations.

EPA first used CEM as a tier 1 modeling tool to model long-term indoor air exposures to TSCA COUs. In the *Draft Indoor Air Exposure Assessment*, peak exposures were not estimated. However, due to uncertainties associated with CEM's potential overestimation of long-term exposures given CEM's E5 emission condition which only allows for a constant rate of emissions, reliance on initial formaldehyde weight fraction in article formulation, along with an inability to consider first-order exponential decay for articles, this assessment also utilized the IECCU as a tier 2 modeling tool to characterize 15-minute peak, 3-month average, and 1-year average formaldehyde residential indoor air concentrations.

The 1-year results for IECCU are significantly lower than CEM and are likely an underestimate of actual indoor air concentrations. Thus, there is uncertainty in the precise estimates of long-term concentrations. A study by He et al. (2019) suggests a biphasic emission profile (rapid emission of formaldehyde when the product is new followed by a much slower emission of formaldehyde) for laminated wood products that is not captured in either modeling results. This biphasic emission profile may also occur for other urea-formaldehyde based products; however, data are not available to confirm. Therefore, CEM was used along with IECCU to characterize 1-year average indoor air concentrations and provide the potential range of longer-term formaldehyde exposures.

In addition, monitoring data were incorporated into this assessment to characterize formaldehyde concentrations most people are exposed to via indoor air. As noted in Section 2.1.1, EPA used publicly available data acquired through systematic review to characterize indoor air concentrations of formaldehyde. Unfortunately, these monitoring data do not differentiate between TSCA COUs and other sources of formaldehyde like cigarette smoke or gas stoves. Monitoring data may also not capture peak concentrations or fluctuations in indoor air concentrations of formaldehyde but provide insight into long-term and aggregate exposures to formaldehyde. Monitoring data also cannot fully reflect how and when (following manufacture) formaldehyde-emitting materials (including imported articles from places with varying wood standards) are installed. Similarly, monitoring data cannot explain how frequently these materials are replaced. Lastly, monitoring data may not reflect changes in energy efficiency home improvements that reduce ventilation (*e.g.*, leaks). Considering limitations in the monitoring data, it is reasonable to rely on modeled concentrations according to TSCA COUs.

Furthermore, currently available indoor air monitoring data may not represent future potential exposures in homes. Congress established formaldehyde emission standards for composite wood products which began to go into effect on June 1, 2018, pursuant to the Formaldehyde Standards for Composite Wood Products regulations (40 CFR Part 770), which implement TSCA Title VI. Some of the relatively high monitoring concentrations seen in the currently available data are anticipated to be addressed by enactment of the composite wood standards for formaldehyde emissions as they are being implemented, but comprehensive monitoring data are not yet available for confirmation.

Although EPA has uncertainty in either modeling tool's long-term estimates, when used together, CEM and IECCU modeled estimates provide confidence in the potential range of indoor formaldehyde concentrations from TSCA COUs. This assumption is supported by the available monitoring data. While the exposure durations and scenarios do not perfectly align, consideration of all of the available data suggests model estimated and measured formaldehyde indoor concentrations are in reasonable agreement. Specifically, model estimated formaldehyde concentrations were within the same order of magnitude as measured concentration data (*e.g.*, HUD's AHHS II). In addition, the estimated aggregate exposures fall within the range of available monitoring data. This suggests that TSCA COUs are contributors to real-world concentrations of formaldehyde in indoor air. Formaldehyde concentrations are expected to be highest for newly constructed residences with formaldehyde-based materials (including laminate flooring); and new formaldehyde-based articles added to a residence (including furniture covers).

Based on consideration of the weight of scientific evidence summarized above, including the strengths and limitations of the available lines of evidence, EPA has high confidence in the indoor air exposure assessment of formaldehyde based on the available monitoring data and the estimated short- and long-term exposures from TSCA COUs. However, the precise concentrations on a long-term basis are uncertain and are expected to be highly variable.

See Appendix E's Table_Apx E-1 for a tabular summary of the weight of scientific evidence for the indoor air exposure assessments.

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APPENDICES

Appendix A SYSTEMATIC REVIEW PRIORITIZATION FOR FORMALDEHYDE DATA

As noted in Section 2.1.1, EPA applied a fit-for-purpose approach to its systematic review of indoor air data for the formaldehyde exposure assessment. This appendix serves as a supplement to the discussion provided in Section 2.1.1.

Impacts of SR Approach

The extracted data provides a high-level of confidence in the supporting data that is available for formaldehyde's exposure analysis, while improving the efficiency of the systematic review of formaldehyde exposure studies and data. This required the reassignment of EPA and contractors to the formaldehyde systematic review project, as necessary. This approach facilitated the ability to meet the necessary deadlines to complete the formaldehyde exposure assessments.

Administrative Actions Involved

EPA and contractors assigned appropriate staff to support the proposed approach to review and extract formaldehyde data of interest. As directed, for the review of formaldehyde data, EPA and the contractor prioritized the evaluation and extraction of COU-specific air concentration and emission rate (and other supporting exposure modeling parameters) data.

A.1 Formaldehyde Data Needs

Within the Exposure study pool are six key study types: monitoring, experimental, modeling, completed assessment, database, and survey.

- *Monitoring:* The Formaldehyde Assessment Team determined that measured indoor and ambient air data associated with formaldehyde COUs from the monitoring study type are most relevant to the formaldehyde exposure assessment. This is because the primary media of exposure for formaldehyde is air. Some monitoring studies contain air concentration data that may be used to compare with formaldehyde exposure modeling results. In addition, modeling parameters such as room ventilation rates, may also be useful for the refinement of models such as the CEM or the execution of higher tier models like the IECCU Model. This monitoring data has been identified as the top priority for formaldehyde. This data has been identified as important to extract.
- *Completed Assessments:* Completed assessments may contain completed risk evaluations of formaldehyde, this study type can be informational and may be referred to for contextual information (*e.g.*, methodologies, conclusions, and other information). Some completed assessment studies contain modeling parameters which may be used for the formaldehyde exposure analysis—namely, product-specific formaldehyde emission rates (and room ventilation rates, if available) useful in CEM modeling refinements or higher tier models like the IECCU model. Under the current systematic review protocol for Exposure, completed assessments are extracted as monitoring or modeling studies. Completed assessments typically make use of secondary data that are not extracted for any study type. However, if completed assessments have been deemed to use primary monitoring data that are COU-specific, extract this data. However, do not extract any other data for this study type as it is not a critical need for the formaldehyde exposure assessment.
- *Databases:* Databases may provide quantitative or supplementary information often useful for exposure analyses. These may include datasets that contain air or water concentration data (*e.g.*,

monitoring data) such as the Water Quality Portal (WQP). Data from such source streams may be referenced or potentially used for comparison to EPA modeled concentrations in its evaluation of formaldehyde exposures. Key datasets of need including the Toxics Release Inventory, Discharge Monitoring Report (which contain data from the WQP), and National Emissions Inventory and other datasets which provide direct inputs to EPA modeling efforts for formaldehyde have already been extracted and provided by ECRAD engineers per the Draft Systematic Review Protocol (EPA, 2021b). Thus, there is currently no need for any other datasets for the formaldehyde exposure assessment. Relevant data evaluation, QC, and extraction for databases which may contain monitoring data relevant to the ambient air, indoor air, and water pathways relevant to formaldehyde COUs has been completed.

- *Experimental:* Modeling parameters typically found in experimental studies such as permeability coefficients, absorption fractions, were identified through systematic review for formaldehyde. However, COU-specific emission rates, room ventilation rates and others, via chamber studies, for instance, are typically found in experimental study types. Such modeling parameters are useful in CEM modeling refinements or higher tier models like the IECCU Model. This experimental data has been identified as the top priority for formaldehyde and such data has been extracted as needed, to support the formaldehyde exposure assessment.
- *Modeling:* Similar to experimental studies, modeling studies are needed for the formaldehyde risk evaluation. Because such COU-specific-modeling parameters (*e.g.*, emission rates) typically found in these study types have been identified as essential to the refinement of CEM modeling of consumer products and articles or the execution of the IECCU Model for the formaldehyde exposure assessment. This modeling data has been identified as a top priority for formaldehyde and such data has been extracted as appropriate, to support the formaldehyde exposure assessment.
- *Survey:* No survey data specific to formaldehyde were identified.

A.2 Boolean Search Terms

The following is a list of search terms derived from the formaldehyde TSCA COUs presented in the *Final Scope of the Risk Evaluation for Formaldehyde; CASRN 50-00-0* (U.S. EPA, 2020):

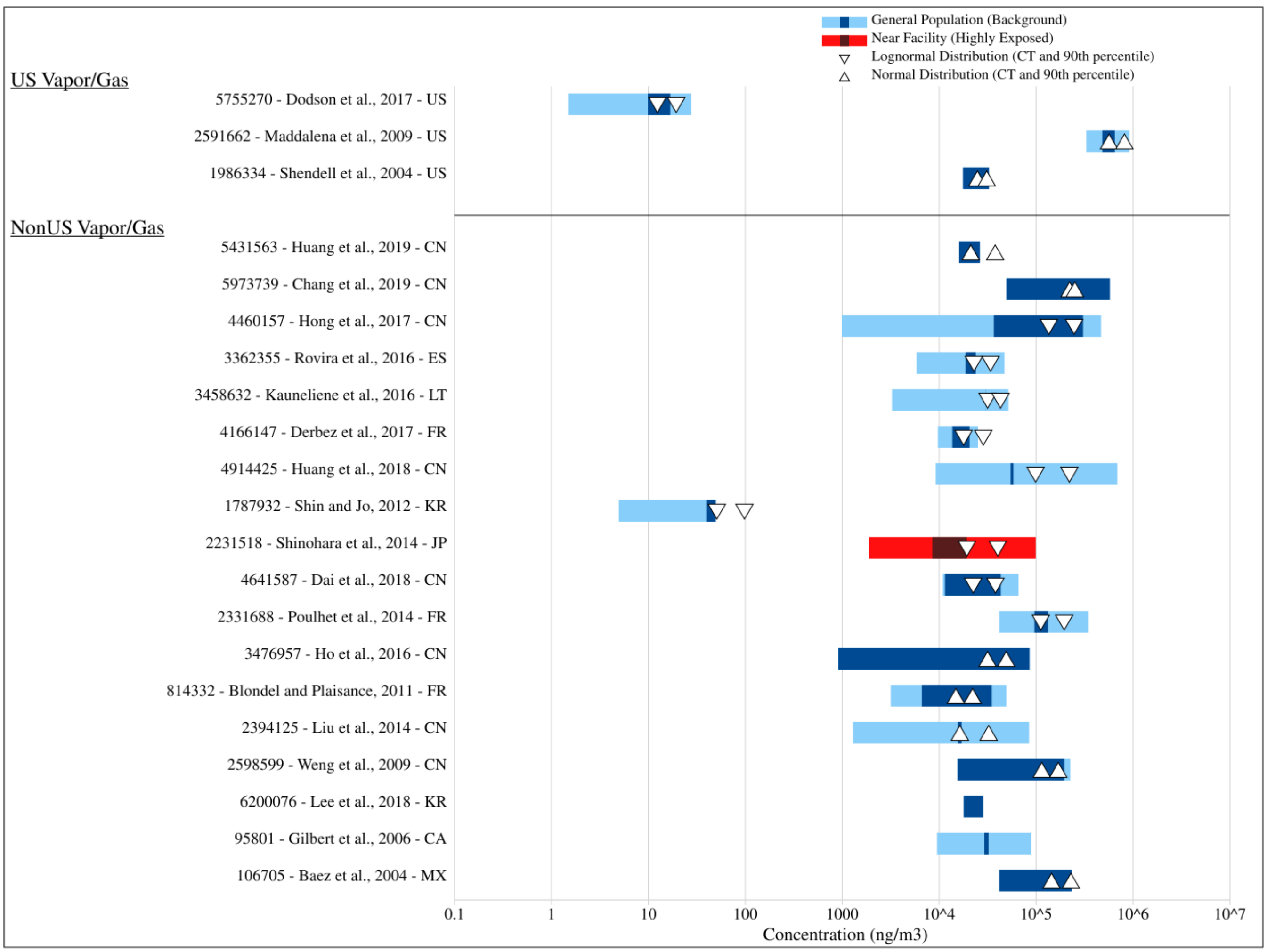
Fertilizer, paint, vinyl wallpaper, fiber glass wallpaper, fiberglass, latex paint, glue, building, wood, hardwood floor, furniture, pressed wood products, particle board, plywood, bare urea-formaldehyde wood product, coated urea-formaldehyde wood product, bare phenol-formaldehyde wood product, adhesive, caulk, sealant, vinyl covering, concrete, cement, plaster, PVC foam wallpaper, PVC wall covering, vapor barriers (bituminous tar), drain cleaner, toilet cleaner, multi-purpose cleaner, cleaner, stain remover, waterproofing agent, leather tanning, electronic, electronic appliance, furniture cover, car seat cover, tablecloth, textile wall, acoustic partitions, office chair, chair, textile, clothing, new clothing, fabric, permanent press fabric, varnish, floor finishes, floor coverings, decorative laminates, commercially applied urea-formaldehyde floor finish, foam insulation, insulation products, insulation, mineral wool insulation batt, glass wool fibrous insulation, insulant, PVC, liquid fuel, motor oil, oil, hardwood floor, furniture, chair, sofa, ink, toner, laundry detergent, dishwashing soap, soap, hand soap, liquid soap, liquid hand soap, lubricant, grease, paper, diaper, wipe, newspaper, magazine, paper towel, paper plates, paper cups, paper grocery bag, glues/adhesives (already noted above), fingernail hardener, photographic supplies, liquid photographic processing solutions, photographic processing solutions, photographic solutions, plastic, rubber, flooring, carpet, rubber mats, vinyl tiles, soft plastic flooring, cork floor tiles, plastic laminated board, black rubber trim, jointing, baby bottle nipple, pacifier, toy, car wax, polish, foam block, foam, tent, fish tank, water treatment product, drinking water treatment product, embalming, taxidermy [and] air, indoor air, ambient air, air pollution, air release, emission, emission rate, emission flux, flux, inhalation, atmosphere, fume, fugitive, gas, release, release rate.

The following section provides a summary of select extracted data for additional context to the formaldehyde indoor air exposure assessment.

A.3 Indoor Air Data Extracted from Systematic Review for Consideration into the Indoor Air Exposure Assessment

A.3.1 Indoor Air (ng/m^3) – Vapor/Gas Fraction

Measured concentrations of FDH in Indoor Air with unit of ng/m^3, extracted from 21 sources, are summarized in Figure_Apx A-1 and supplemental information is provided in Table_Apx A-1. Overall, concentrations ranged from not detected to 928,000 ng/m^3 from 9,007 samples collected between 1998 and 2017 in 9 countries, CA, CN, ES, FR, JP, KR, LT, MX and US. Location types were categorized as General Population (Background) and Near Facility (Highly Exposed). Reported detection frequency ranged from 0.65 to 1.



Figure_Apx A-1. Concentrations of FDH (ng/m^3) in the Vapor/Gas Fraction of Indoor Air from 1998 to 2017

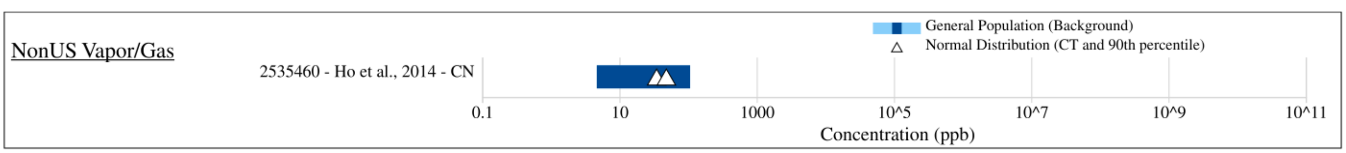
Table_Apx A-1. Summary of Peer-Reviewed Literature that Measured FDH (ng/m^3) Levels in the Vapor/Gas Fraction of Indoor Air

Citation	Country	Location Type	Sampling Years	Sample Size (Frequency of Detection)	Detection Limit (ng/m^3)	Overall Quality Level
Dodson et al. (2017)	US	General Population (Background)	2013–2014	34 (1)	0.056	High
Maddalena et al. (2009)	US	General Population (Background)	2007	8 (1)	600	Medium
Shendell et al. (2004)	US	General Population (Background)	2000–2001	100 (1)	10	High
Huang et al. (2019)	CN	General Population (Background)	2016–2017	88 (N/R)	N/R	High
Chang et al. (2019)	CN	General Population (Background)	2014–2017	176 (0.65)	100000	High
Hong et al. (2017)	CN	General Population (Background)	2014–2015	2284 (1)	N/R	High
Rovira et al. (2016)	ES	General Population (Background)	2014	30 (1)	200	High
Kauneliene et al. (2016)	LT	General Population (Background)	2014	11 (1)	100	High
Derbez et al. (2017)	FR	General Population (Background)	2013–2014	130 (0.89)	N/R	High
Huang et al. (2018)	CN	General Population (Background)	2013	27 (1)	420	High
Shin and Jo (2012)	KR	General Population (Background)	2012	107 (0.96)	10	High
Shinohara et al. (2014)	JP	Near Facility (Highly Exposed)	2012	128 (1)	N/R	High
Dai et al. (2018)	CN	General Population (Background)	2011–2012	15 (1)	N/R	High
Poulhet et al. (2014)	FR	General Population (Background)	2011	8 (1)	30	High

Citation	Country	Location Type	Sampling Years	Sample Size (Frequency of Detection)	Detection Limit (ng/m^3)	Overall Quality Level
Ho et al. (2016)	CN	General Population (Background)	2010–2011	152 (N/R)	N/R	High
Blondel and Plaisance (2011)	FR	General Population (Background)	2009–2010	48 (1)	N/R	High
Liu et al. (2014)	CN	General Population (Background)	2009	510 (N/R)	10	High
Weng et al. (2009)	CN	General Population (Background)	2006–2007	263 (N/R)	150	High
Lee et al. (2018)	KR	General Population (Background)	2007	4702 (1)	1750	High
Gilbert et al. (2006)	CA	General Population (Background)	2005	96 (1)	1000	High
Baez et al. (2004)	MX	General Population (Background)	1998	90 (1)	660	High
Abbreviations: N/R, Not reported						

A.3.2 Indoor Air (ppb) – Vapor/Gas Fraction

Measured concentrations of FDH in Indoor Air with unit of ppb, extracted from 1 source, are summarized in Figure_Apx A-2 and supplemental information is provided in Table_Apx A-2. Overall, concentrations ranged from 4.67 to 107 ppb from 840 samples collected between 2012 and 2013 in 1 country, CN. Location types were categorized as General Population (Background). Reported detection frequency was not reported.



Figure_Apx A-2. Concentrations of FDH (ppb) in the Vapor/Gas Fraction of Indoor Air in General Population (Background) Locations from 2012 to 2013

Table_Apx A-2. Summary of Peer-Reviewed Literature that Measured FDH (ppb) Levels in the Vapor/Gas Fraction of Indoor Air

Citation	Country	Location Type	Sampling Years	Sample Size (Frequency of Detection)	Detection Limit (ppb)	Overall Quality Level
Ho et al. (2014)	CN	General Population (Background)	2012–2013	840 (N/R)	N/R	High
Abbreviations: N/R, Not reported						

Appendix B AHHS II SUMMARY OF DATA COLLECTION METHODOLOGY

To collect the data at each dwelling unit, a two-person team consisting of an interviewer and a technician was used. AHHS II data were captured using three form sets and a tablet survey: a Recruitment Questionnaire Form Set; a Resident Questionnaire Form Set and tablet Resident Questionnaire; and a Technician Form Set [Information Collection Review (ICR) Reference No: 201912-2539-001]. The Recruitment Questionnaire was used by the interviewer to determine whether the dwelling unit could be recruited into the survey. Once recruited, the interviewer used the tablet survey, supplemented by the Resident Questionnaire Form Set, to collect data on the unit. The Technician Form Set was used to collect data such as lead and formaldehyde. All data collected on paper forms were double keyed, reviewed, and entered into the datasets (QuanTech, 2021).

Residential indoor air samples of formaldehyde were collected in absorption tubes within SGS Galson air sampling pumps, in a frequently used location (commonly the living room). Samples ranged from 1 to 15 L of air at 0.03 to 1.5 L/minute. The air pump was run throughout the data collection home visit. Sampling time was not provided, and it likely varied between residences. However, the environmental sampling in AHHS II, while different in some respects from that of AHHS I, was expected to require a similar amount of time based on the AHHS II ICR [ICR Reference No: 201912-2539-001]. Per sampling times reported in AHHS I, the targeted sampling time for AHHS II was approximately 3.5 hours (QuanTech, 2021). As such, it may be reasonable to expect that the air sampling pump was typically on for 3.5 hours. This means that formaldehyde air monitoring air concentrations from the AHHS II were at least 3-hour TWAs. Formaldehyde air samples were then frozen and sent directly to SGS Galson, the provider of the sampling pumps, for analysis. Air samples were analyzed using modified NIOSH 2016 (HPLC – UV detection). The detection limit for formaldehyde air concentrations was 0.15 µg/m^3 for 3-hour sample at 1.5 L/min (which was at or near the maximum capability of the air sampling pump) (Table_Apx B-1). Detailed study methodology and results from the AHHS II are published in a series of reports available from the HUD Office of Healthy Homes and Lead Hazard Control (QuanTech, 2021).

Table_Apx B-1. Summary of Environmental Sampling and Analytical Method

Data Element	Description
ID[a]	T1
Information Captured or Target Analyte	Formaldehyde in air
Data Collection Method or Sampling Media	Absorption tube
Tests or Samples per Dwelling Unit	1 plus 1 blank/primary sampling unit (PSU)
Special Handling Requirements	Frozen after collection
Maximum Media Count	956
Sample Preparation	None
Analytical Method	Modified NIOSH 2016 (HPLC – UV detection)
Detection Limits	0.15 µg/m^3 for 3-hour sample at 1.5 LPM
Notes	Count includes 1 spiked QC/PSU

[a] Identifies the protocol containing detailed instructions for the tests or sample collection (QuanTech, 2021).

Appendix C FORMALDEHYDE RESIDENTIAL INDOOR AIR HALF-LIFE

Residential indoor air formaldehyde concentrations are generally expected to decrease over time following a first-order exponential process as the reservoir of formaldehyde from articles is depleted over time (EPA, 2016). This means that a new home with new formaldehyde-based articles (*e.g.*, hardwood floors, furniture, furniture covers, etc.) is expected to have a high initial contribution of formaldehyde off-gassing to the indoor air environment. This is followed by a gradual decrease in formaldehyde off-gassing as formaldehyde sources are gradually depleted over time; then, a tapering off effect over an extended period, if no new formaldehyde-based articles are added to the home (EPA, 2016).

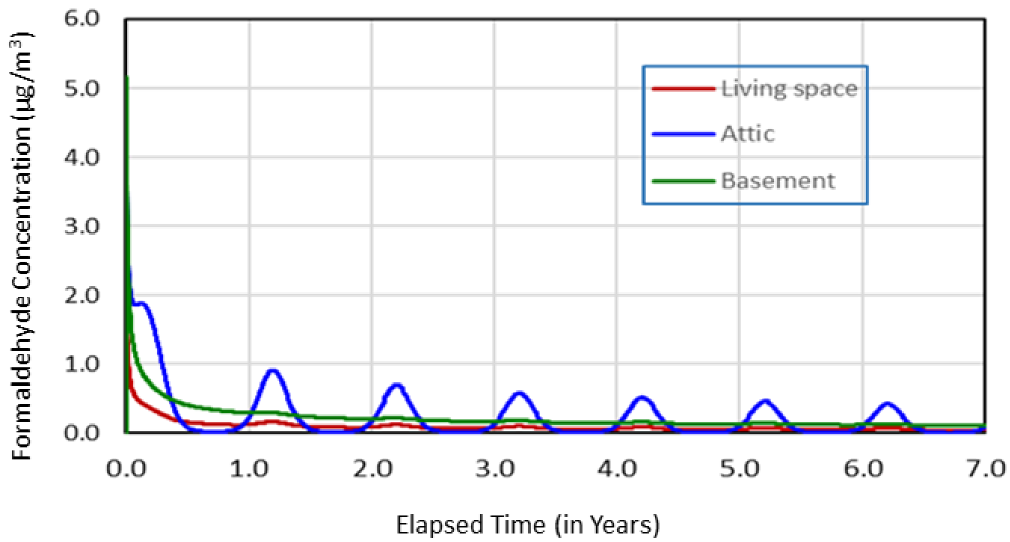
In a study of newer mobile homes (Gammage and Hawthorne, 1985), there were significantly higher measured mean concentrations of formaldehyde compared to older mobile homes—1,032 µg µg/m^3 and 308 µg/m^3 respectively (Gammage and Hawthorne, 1985). These highest reported concentrations are slightly higher than the aggregated high-end modeled concentrations from TSCA COUs representing new articles added to a home. It should also be noted that in addition to new materials added to a home, other activities that may affect indoor concentrations of formaldehyde include ripping out drywall, fixtures, and using various sources of combustion indoors (*e.g.*, wood burning fireplace).

According to the *2016 Formaldehyde Exposure Assessment Report TSCA Title VI Final Rule* (EPA, 2016), the half-life of formaldehyde in indoor air (*i.e.*, the amount of time for formaldehyde concentrations to decrease by half) is expected to be approximately between 1.5 and 3 years. From a cross-sectional study of homes with varying ages, authors noted that, if new formaldehyde-emitting articles were being added over time within the homes assessed, an estimated half-life would be close to 2.92 years. The latter is assumed to be an upper bound estimate for formaldehyde's half-life in residential indoor air. Instead, according to an analysis of various chamber studies of pressed wood articles as they aged, the authors expect that the residential indoor air half-life of formaldehyde should be approximately 1.5 years in most cases (EPA, 2016).

In newer homes built after 1990, due to improved insulation and relatively less air circulation in certain homes, formaldehyde indoor air concentrations may persist longer (Persily et al., 2010). However, formaldehyde concentrations in remodeled or newly built homes, especially in wooden-framed homes, were found to decrease to mean levels comparable to older homes levels within 2 years (Park and Ikeda, 2006). This is likely because formaldehyde found in newer articles is mostly released within that time frame (Park and Ikeda, 2006).

C.1 General Formaldehyde Dissipation Curve

Figure_Apx C-1 displays the general formaldehyde dissipation in residential indoor air. The figure shows an initial spike in concentration from off-gassing following initial installation of new articles. This is followed by a rapid decrease in concentrations over the first few months. In each building configuration, the living area has less fluctuations in concentrations after the initial concentration spike following installation compared to other areas. Similarly, the basement in the attic/living space/basement building configuration has less fluctuations in concentrations after the initial concentration spike following installation. The higher variability in concentrations seen in the attic of both building configurations and the crawlspace of the attic/living space/crawlspace building configuration reflect the sensitivity of off-gassing to temperature in unconditioned zones within the two building configurations.



Figure_Apx C-1. General Formaldehyde Dissipation in a Residence

Appendix D CEM SUPPLEMENTAL ANALYSES

D.1 CEM Screening Combustion Assessment

Because formaldehyde is a combustion byproduct(ATSDR, 1999), some home with various sources of combustion (*e.g.*, wood fireplace) may contribute to indoor air concentrations of formaldehyde. The purpose of this supplementary indoor air assessment is to contextualize modeled formaldehyde concentrations in the indoor environment and provide confidence in modeled concentrations while accounting for combustion sources of exposure.

D.1.1 Methods

EPA used the AHHS II dataset to identify homes with and without sources of combustion. EPA combined the AHHS2_Hazard and the ResidentQ datafiles from AHHS II, after sorting the data according to dwelling unit id (duid), to collate data on formaldehyde concentration and reported sources of combustion including the presence of smoking (including frequency of smoking events), combustion furnace, gas stove, wood fireplace, gas hot water heater, gas dryer, gas cool stove/oven, portable fuel-fired heater or other combustion sources. Presence or absence of combustion sources in each home was identified based according to yes or no resident response to the relevant question. The data was organized according to homes with at least one reported source of combustion and homes with no reported sources of combustion. Measured formaldehyde indoor air concentrations were analyzed according to this distinction.

CEM was used to model formaldehyde indoor air concentrations for new materials in a home; especially for articles (for the relevant TSCA COUs) that are identified as the biggest emitters of formaldehyde relative to others in the formaldehyde consumer exposure assessment. Such exposures were extrapolated to a year of exposure and further as a lifetime average daily concentration for the identified TSCA COUs

EPA generated box and whisker plots for a summary of all three sets of data including measured formaldehyde indoor air concentrations for homes with and without reported combustion sources, and estimated formaldehyde indoor air concentrations from TSCA COUs.

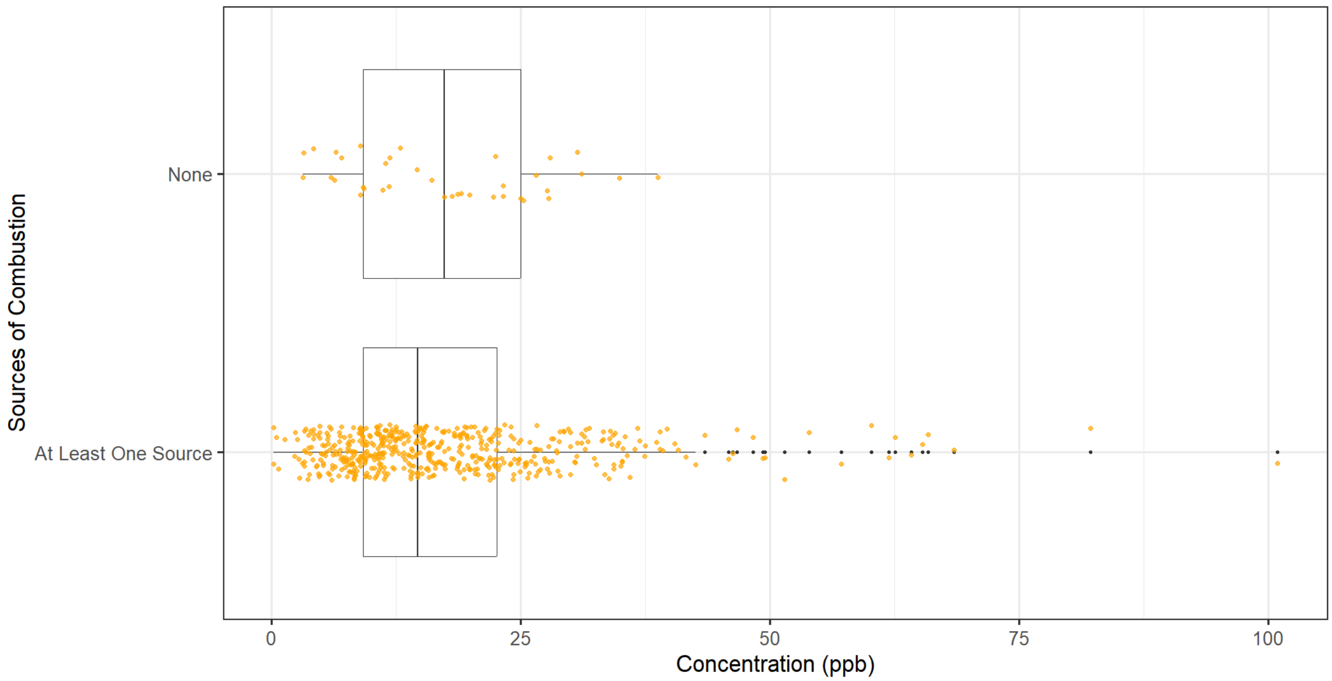
D.1.2 Comparison of Formaldehyde Indoor Air Estimates from CEM Modeling of TSCA COUs Relative to Homes with and without Reported Combustion Sources, According to AHHS II

Regarding the comparison of formaldehyde indoor air concentrations there are fundamental differences between the modeled and the monitoring data. Caution should be applied when comparing modeled to monitoring results, as this is not a 1:1 comparison, due to the following:

1. **Assumed total exposure –** The assessment of exposures in the indoor air environment is an aggregate assessment. This means that the measured indoor air of formaldehyde from AHHS II represent indoor air exposures from all formaldehyde sources across U.S. homes. Despite controlling for combustion sources for exposure, there may be other sources of exposure that could not be accounted for. Through the indoor air exposure assessment of formaldehyde, EPA conducted a targeted assessment of the largest emitters of formaldehyde from TSCA-based sources of exposure. Therefore, the aggregated modeled indoor air concentrations of formaldehyde based on TSCA COUs may not be a directly comparable to AHHS II concentrations of formaldehyde after removing homes without combustion sources.

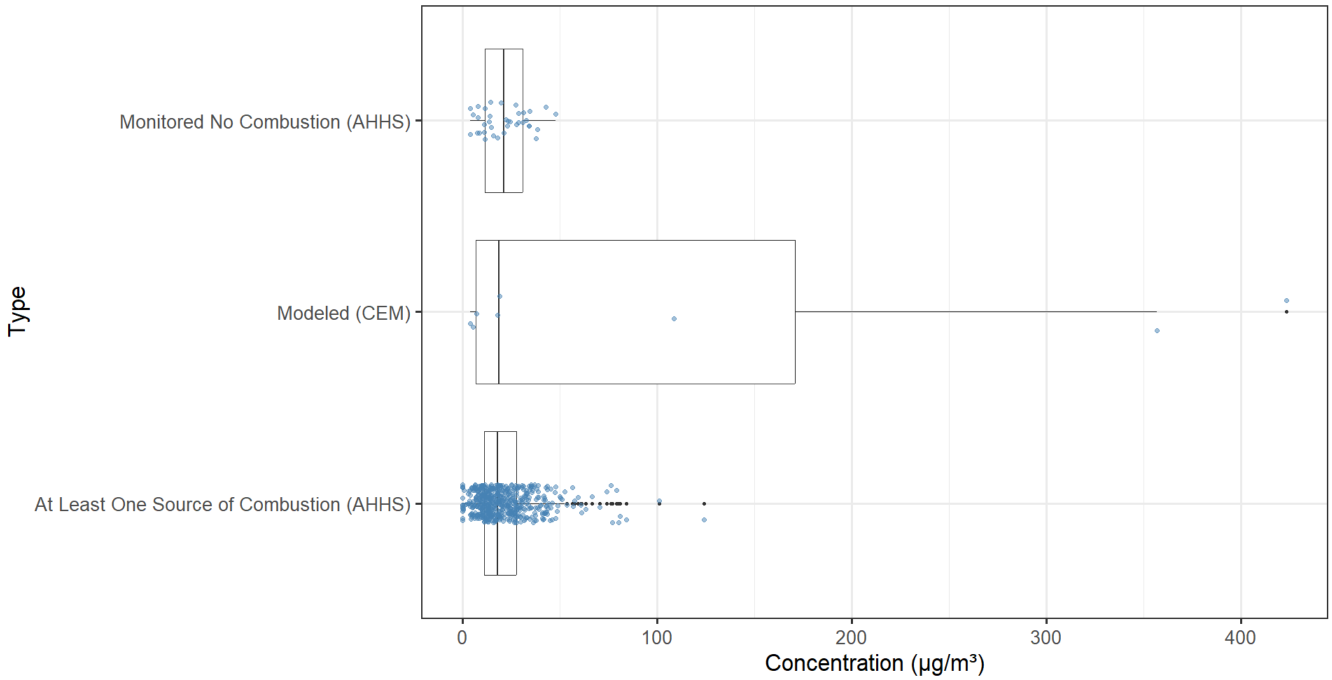
2. **Dissipation over time** – While measured formaldehyde concentrations from AHHS II represent homes that have a combination of new and old materials that have off-gassed over time (and potentially several decades), CEM does not incorporate chemical half-life (EPA, 2019a)
    a. COU-specific estimates represent formaldehyde air concentrations from new articles only
        i. Hence, total modeled estimates may represent formaldehyde air concentrations from a newly built home (or automobile), based on the TSCA COUs assessed.
3. **Room of use** – First, CEM models according to the most likely room of use for a given article per TSCA COU. CEM also assumes a typical home has a building volume of 492 m^3 and specific default room sizes (*e.g.*, 50 m^3 for a living room). AHHS II measured formaldehyde in the most frequently used room in each home, which differed from one to another. For instance, formaldehyde may have been measured a living room for one home and in a kitchen for another. Therefore, the measured monitoring concentration may be from a different room of use or an entire home type than CEM considered. Similarly, CEM also assumes specific interzone ventilation rates and air exchange rates in a residential area per hour, which may differ depending on the home type and size of the home. AHHSII considered homes of varying types (and, therefore, home of varying sizes) including detached single-family homes, mobile homes and apartments in buildings with five or more units. Thus, it may also be assumed that the interzonal ventilation rates and air exchange rates would differ between homes in the AHHS II survey and CEM defaults (EPA, 2019a).
4. **Humidity and temperature** – Increased indoor air temperatures and humidity levels have been demonstrated to correlate with increased formaldehyde indoor air concentrations (Murphy et al., 2013). The degree to which humidity and temperature impacted the measured formaldehyde indoor air concentrations in AHHS II is unknown. CEM cannot yet account for or vary temperature and humidity but is an area of future improvement.
5. **Exposure duration** – CEM assumes durations of exposure specific to TSCA COUs assessed, from which a lifetime average daily concentration is estimated. However, the measurement of formaldehyde indoor air concentrations in the AHHS II survey was according to a 3.5-hour TWA.

Within the AHHS II survey, some homes were reported to have sources of combustion ranging from tobacco smoke to wood fireplaces, which are known to produce formaldehyde as a byproduct. EPA analyzed the formaldehyde concentrations in AHHS II from homes with and without at least one combustion source of formaldehyde (Figure_Apx D-1). Some agreement can be observed in the spread of the two datasets mostly in the lower quartiles of the figure. However, there were more homes in the upper quartile of formaldehyde indoor air concentrations where there was at least one source of combustion compared to when there were none. In addition, some homes with at least one reported combustion source had considerably higher measured formaldehyde indoor air concentrations compared to homes with no reported combustion sources.



Figure_Apx D-1. Comparing the Relative Concentrations of Homes with and Without Sources of Combustion for Formaldehyde in AHHS II

In general, the range of modeled formaldehyde residential indoor air concentrations were within an order of magnitude of the range of monitoring values (4–423 μg/m^3 compared to 0.3–124.2 μg/m^3, respectively) from a nationally representative studies of formaldehyde in residential indoor air, via the AHHS II residential indoor monitoring study (Figure_Apx D-2). Also, a few homes with at least one source of combustion had at least double the concentration of formaldehyde compared to homes with no reported sources of combustion.



Figure_Apx D-2. Comparison of AHHS II Monitoring to Modeling Estimates of Indoor Air Concentrations

D.2 CEM Screening Composite Wood Article Assessment

EPA conducted screening assessment of wood articles focusing on estimating potential exposure levels based upon composite wood article emission limits set under TSCA Title VI.

D.2.1 Methods

This supplementary assessment was conducted using the following general steps:

1. Identify emission standards set for hardwood plywood (HWPW), medium density fiberboard (MDF), and particleboard (PD)
2. Use the identified emission limits to estimate composite wood article-specific emission rates
    a. First, by converting the product-specific emission standards to air concentration(Table_Apx D-1)
    b. Then, using that estimated air concentration to generate emission rates using Equation_Apx D-1 (EPA, 2016) (Table_Apx D-2)

Equation_Apx D-1.

$$[CH_2O]_{SS} = \frac{\frac{b * Area}{PEX * VOL} + [CH_2O]_{out}}{D}$$

Where:

$[CH_2O]_{SS}$	= steady-state formaldehyde concentration inside the compartment (mg/m^3)
$[CH_2O]_{out}$	= steady-state formaldehyde concentration outside the compartment (mg/m^3)
b	= the emission rate at zero CH_2O concentration in the air (mg/m^2-hr)
$Area$	= Exposed surface area of the source (m^2)
PEX	= the compartment's air exchange rate with outdoors (hr^{-1}), assuming a mixing factor equal to unity
VOL	= the volume of the compartment (m^3)
D	$= 1 + \frac{m*Area}{PEX*VOL}$
m	= the mass transfer coefficient (m/hr)

Assuming that $[CH_2O]_{out}$ is zero, substituting for D in Equation_Apx D-1, and denoting $PEX * VOL$ as Q (*i.e.*, the airflow rate in/out of the chamber, in m3/hr), we can solve for b as follows:

Equation_Apx D-2.

$$b = [CH_2O]_{SS} * \left(1 + m * \frac{Area}{Q}\right) * \left(\frac{Q}{Area}\right)$$

3. Model indoor air exposures using other key parameters highlighted in Section 2.2.3
    a. Central tendency weight fractions for building wood articles were used

Table_Apx D-1. Estimated Concentrations in mg/m^3 from Emission Standards in ppm

Pressed Wood Articles	Emissions Standard (ppm)	Molecular Weight	Constant (Volume of 1 mole at 1 atm)	Concentration (mg/m^3)
Hardwood plywood	0.05	30.03	24.45	0.061411043
Medium density fiberboard	0.11	30.03	24.45	0.135104294
Particleboard	0.09	30.03	24.45	0.110539877

Table_Apx D-2. Estimating Emission Rates from Product Specific Concentrations

Pressed Wood Articles	Concentration (mg/m^3)	Assumed Slope or Mass Transfer Coefficient (m/hr)	Assumed Chamber Volume (m^3)	PEX [a]	Q (m^3/hr) [b]	Surface Area (m^2)	Emission Rate (mg/m^2/hr)
Hardwood Plywood	0.061411043	0.27	100	0.5	50	26	0.134679141
Medium Density Fiberboard	0.135104294	1.06	100	0.5	50	26	0.403026503
Particleboard	0.110539877	0.7	100	0.5	50	26	0.289954601

[a] PEX = compartment’s air exchange rate with outdoors (per hour), assuming a mixing factor equal to unity
[b] Q = the airflow rate in/out of the chamber

The exposure scenario modeled was for an individual who spends two hours per day, every day, in a living room with flooring made with engineered wood flooring. Formaldehyde inhalation exposures are assumed to stem from emissions from HWPW, MDF, or PB.

D.2.2 Results

The estimated yearly average daily indoor air concentrations from pressed wood articles ranged from 5.53 to 16.58 μg/m^3 (Table_Apx D-3).

Table_Apx D-3. CEM Estimated Average Daily Concentration Over 1 Year

Condition of Use Subcategory	Scenario	Environment	CEM Calculated Average Daily Concentration (ppm)	CEM Calculated Average Daily Concentration (µg/m^3)
Construction and building materials covering large surface areas, including wood articles; Construction and building materials covering large surface areas, including paper articles; metal articles; stone, plaster, cement, glass and ceramic articles	Building/Construction Materials – Wood Articles: Hardwood Plywood (residential)	Residential (Living Room)	4.50E−03	5.53
Construction and building materials covering large surface areas, including wood articles; Construction and building materials covering large surface areas, including paper articles; metal articles; stone, plaster, cement, glass and ceramic articles	Building / Construction Materials – Wood Articles: Medium Density Fiberboard (residential)	Residential (Living Room)	1.35E−02	16.58
Construction and building materials covering large surface areas, including wood articles; Construction and building materials covering large surface areas, including paper articles; metal articles; stone, plaster, cement, glass and ceramic articles	Building / Construction Materials – Wood Articles: Particleboard (residential)	Residential (Living Room)	9.69E−03	11.9

D.2.3 Conclusion

EPA qualitatively assessed potential exposures from HWPW, MDF, and PB, according to the emission standards established under TSCA Title VI, using the best available information and tools. The degree to which the estimated indoor air concentrations from the modeled composite wood articles are reflective of real-world scenarios is unknown. Due to the following key uncertainties, EPA has a medium confidence in this assessment:

- The identified emission standards were assumed to be equivalent to a product specific indoor air concentration, but it is unknown to what degree this is reflective of composite wood articles currently on the market.
- Whether the assessed wood articles are made entirely of HWPW, MDF, or PB.
    - Wood articles on the market may be composed of a combination of composite wood layers.
- Whether the identified articles are compliant with the relevant emission standards.
- Whether the approach to estimating emission rates from the set emission limits sufficiently represent articles on the consumer market.

Appendix E SUMMARY OF WEIGHT OF SCIENTIFIC EVIDENCE

Table_Apx E-1 summarizes the weight of scientific evidence for the indoor air exposure assessments, as described in Section 4. The weight of scientific evidence for the indoor air exposure assessment of formaldehyde was driven by studies that included article-specific emission factors (Table 2-2, Table 2-3) which were key components of the modeling results. Only studies and datasets useful in generating a quantitative assessment (*e.g.*, via IECCU modeling) progress from data evaluation to data extraction. In the case of the formaldehyde pool of studies, there were several COU-specific studies that did not report any concentrations of formaldehyde but provided emission rates; those are labeled as "supplemental studies" in Table 2-2 and Table 2-3. Because emission rate data for the COUs assessed were generally scarce, from the exposure systematic review pool of studies, emission rates from supplemental studies were used in addition to those with a study rating criteria (low to high-rated studies) (EPA, 2023b).

Nine studies were used to compile COU-specific emission rates used to apply user-defined, COU-specific emission rates to model formaldehyde indoor air concentrations using IECCU—a peer-reviewed, high-tier model that has been used in previous TSCA risk assessments, per the exposure systematic review criteria (EPA, 2021b). Twenty indoor air monitoring studies were used to compare measured formaldehyde concentrations against modeled concentrations from TSCA COUs. This includes a robust nationally representative monitoring study of formaldehyde in indoor air via the AHHS II, jointly sponsored by EPA and HUD.

Table_Apx E-1. Weight of Scientific Evidence Conclusions for the Indoor Air Exposure Assessments

Consumer Route (Assessment)	Confidence in Model Used[a]	Confidence in Model Default Values[b]	Confidence in Key Modeling Inputs[c]			Key Sources of Indoor Air Data[g]	Weight of Scientific Evidence Conclusion[h]
			Emission Factors[d]	Article Surface Areas[e]	Room of Use[f]		
Inhalation (Indoor Air)	High	High	Medium	High	Medium	9 studies incorporated into modeling (using emission factors) 20 indoor air monitoring	High

[a] "Confidence in Model Used" considers whether model has been peer reviewed, as well as whether it is being applied in a manner appropriate to its design and objective. IECCU has been peer reviewed, is publicly available, and has been applied in a manner intended; that is, to exposures associated with uses of household products and articles. IECCU was the best available tool to assess indoor air exposure for formaldehyde.
[b] "Confidence in Model Default Values" considers default value data source(s) such as building and room volumes, interzonal ventilation rates, and air exchange rates in IECCU (similar to CEM) (EPA, 2021a).
[c] "Confidence in User-Selected Varied Inputs" considers the quality of their data sources, as well as relevance of the inputs for the selected consumer condition of use.
[d] "Emission Factors" is primarily sourced from high quality studies used to develop IECCU's COU/article-specific modeling. Without better data, EPA assumed that composite woods currently on the market adhere to the TSCA Title VI formaldehyde emission standards for composite woods. This contributed to the basis for the selection of "Medium" confidence.
[e] "Article Surface Areas" of formaldehyde in articles is sourced from various sources including literature, model defaults (*i.e.*, CEM and FIAM) and the EPA *Exposure Factors Handbook* (EPA, 2011).
[f] "Room of Use" (location of the exposure scenario) is informed by responses in the Westat (1987) survey, which received a high-quality rating during data evaluation, although professional judgment is also applied for some scenarios. The room of use, for example, was selected according to professional judgement. It is conceivable that different rooms of article use may apply across homes. The reasonableness of these judgements contributed to the basis for the selection of "Medium" confidence.
[g] In addition, while emission rates from nine studies were extracted from systematic review and incorporated into IECCU modeling, over a dozen others were used to characterize the indoor air concentrations of formaldehyde.
[h] See the Draft Systematic Review Protocol for a detailed description of weight of scientific evidence ratings (EPA, 2023a).