Indoor Air 2012
wileyonlinelibrary.com/journal/ina
Printed in Singapore. All rights reserved

Published 2012.

INDOOR AIR
doi:10.1111/j.1600-0668.2012.00800.x

Formaldehyde levels in FEMA-supplied travel trailers, park models, and mobile homes in Louisiana and Mississippi

Abstract In 2006, area physicians reported increases in upper respiratory symptoms in patients living in U.S. Federal Emergency Management Agency (FEMA)-supplied trailers following Hurricanes Katrina and Rita. One potential etiology to explain their symptoms included formaldehyde; however, formaldehyde levels in these occupied trailers were unknown. The objectives of our study were to identify formaldehyde levels in occupied trailers and to determine factors or characteristics of occupied trailers that could affect formaldehyde levels. A disproportionate random sample of 519 FEMA-supplied trailers was identified in Louisiana and Mississippi in November 2007. We collected and tested an air sample from each trailer for formaldehyde levels and administered a survey. Formaldehyde levels among all trailers in this study ranged from 3 parts per billion (ppb) to 590 ppb, with a geometric mean (GM) of 77 ppb [95% confidence interval (CI): 70–85; range: 3–590 ppb]. There were statistically significant differences in formaldehyde levels between trailer types ($P < 0.01$). The GM formaldehyde level was 81 ppb (95% CI: 72–92) among travel trailers ($N = 360$), 57 ppb (95% CI: 49–65) among mobile homes ($N = 57$), and 44 ppb (95% CI: 38–53) among park models ($N = 44$). Among travel trailers, formaldehyde levels varied significantly by brand. While formaldehyde levels varied by trailer type, all types tested had some levels ≥ 100 ppb.

M. W. Murphy[1,2], J. F. Lando[1], S. M. Kieszak[1], M. E. Sutter[1,3], G. P. Noonan[1], J. M. Brunkard[2,4], M. A. McGeehin[1,5]

[1]National Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, GA, USA, [2]Epidemic Intelligence Service, Centers for Disease Control and Prevention, Atlanta, GA, USA, [3]Davis – Department of Emergency Medicine, University of California, Sacramento, CA, USA, [4]Louisiana Office of Public Health, Baton Rouge, LA, USA and [5]Research Triangle Institute International, Atlanta, GA, USA

Key words: Formaldehyde; Trailer; U.S. Federal Emergency Management Agency; Gulf Coast; Indoor air; Temporary housing.

Matthew W. Murphy
CDC/NCEH/DEHHE/HSB
4770 Buford Hwy NE, MS F-57
Atlanta, GA 30341, USA
Tel.: +770-488-3417
Fax: +770-488-3450
e-mail: MMurphy@cdc.gov

Received for review 26 March 2012. Accepted for publication 5 July 2012.

Practical Implications

Temporary housing units such as trailers are commonly used to provide shelter for displaced populations following disasters. The results of this study can inform public health, disaster response, and manufacturing decision-makers about potential formaldehyde exposure risks in temporary housing. This study data will contribute to gaps in the scientific literature and provide guidance for future studies, exploring trailer design and manufacturing techniques that could decrease formaldehyde levels in trailers.

Introduction

In late August 2005, Hurricane Katrina—a Category 4 storm—made landfall on the U.S. Gulf Coast between New Orleans, Louisiana (LA) and Mobile, Alabama. On September 24, 2005, Hurricane Rita—a Category 3 storm—made landfall along the Texas-Louisiana border. Many families that evacuated from the U.S. Gulf Coast region returned later to find their homes severely damaged or destroyed.

After Hurricanes Katrina and Rita, the U.S. Federal Emergency Management Agency (FEMA) purchased over 145 000 trailers to serve as temporary housing units for over 120 000 displaced families (U.S. Senate, 2009). Descriptions of the types of temporary units provided are in Table 1. Starting in the spring of 2006, some residents of these FEMA-supplied trailers developed health concerns typically manifested as respiratory symptoms such as cough and shortness of breath. One potential etiology to explain their symptoms included formaldehyde; however, formaldehyde levels in these occupied trailers were unknown.

Table 1 Definition of U.S. Federal Emergency Management Agency (FEMA)-supplied trailer types definitions for trailers used by FEMA for Gulf coast residents displaced by Hurricanes Katrina and Rita

Mobile homes are manufactured homes wider than 8 feet or longer than 40 feet (for an area $\geq$ 320 ft^2). They are built on permanent chassis; contain plumbing, heating, air-conditioning, and electrical systems; and are designed for use as permanent dwellings. Mobile homes are defined and regulated by the U.S. Department of Housing and Urban Development (HUD).
Park models are manufactured homes of 320–400 ft^2 administratively exempted from HUD formaldehyde standards. Park models may be regulated by transportation authorities and by manufacturer acceptance of a voluntary American National Standards Institute standard applying to their construction.
Travel trailers are wheel-mounted trailers designed to provide temporary living quarters during periods of recreation, camping, or travel. Travel trailers generally have size limits, such as 8 feet wide and 40 feet long, for an area <320 ft^2. Travel trailers generally are considered vehicles rather than structures and are regulated by state transportation authorities rather than by housing authorities. Travel trailers have been used principally for short-term housing needs. They are placed on private sites, while a homeowner's permanent residence is repaired or in group configurations primarily to support displaced renters.
Manufactured homes include mobile homes and park models and are used to meet both short- and long-term disaster housing needs. Manufactured homes typically are placed on commercial pads or in group sites developed expressly for this purpose.
'Trailers' in this report refer collectively to travel trailers, park models, and mobile homes.

Formaldehyde is a colorless gas at room temperature with a pungent, distinct odor, which may cause a burning sensation to the nose, eyes, and lungs at high concentrations [Agency for Toxic Substances and Disease Registry (ATSDR, 1999)]. Exposure to low levels of formaldehyde is commonplace in buildings, including single-family homes, because it is frequently used in plywood, resins, glues, carpets, and other construction components in addition to medium density fiberboard used in residential furnishings such as cabinets, drawers, and furniture tops (USCPSC, 1997; USEPA, 2007). In the past, formaldehyde was also used in home insulation (USCPSC, 1982; Salthammer et al., 2010). Differences in formaldehyde levels measured in a particular home can be affected by several factors, such as temperature, relative humidity (RH), ventilation, and age of the house. Formaldehyde levels in traditional homes of non-smokers were also found to be higher with the presence of furniture bought new or recently restored (Lovreglio et al., 2009). In longitudinal studies, formaldehyde emission rates were found to be nearly constant over the first 8 months after construction and then began to decline, indicating that formaldehyde off-gassing continues for extended periods but decreases with the age of the home (Park and Ikeda, 2006). Studies have also shown that older homes have lower formaldehyde levels than newer homes (Gordon et al., 1999; Guo et al., 2009; Hodgson et al., 2000).

Formaldehyde is an eye, skin, and respiratory tract irritant, and children may be more susceptible than adults to the respiratory effects of formaldehyde. Acute and chronic health effects of exposure to formaldehyde may vary by individual (ATSDR, 1999). No U.S. federal regulation or standard exists for formaldehyde levels in residential settings. Even in occupational settings, regulations and standards established for formaldehyde by government agencies and other organizations to an 8-h exposure time period—such as the U.S. Department of Labor Occupational Safety and Health Administration [Time-Weighted Average (TWA): 750 ppb], CDC's National Institute for Occupational Safety and Health (NIOSH) [TWA: 16 ppb; Ceiling: 100 ppb (15-min)], and the American Conference of Governmental Industrial Hygienists (Ceiling: 300 ppb)—differ markedly for both long-term and short-term exposures (OSHA, 2008; NIOSH, 2010; ACGIH, 2001). The State of California Office of Environmental Health Hazard Assessment (OEHHA, 2008) chronic and 8-h guidelines for formaldehyde are less than typical ambient levels. OEHHA (2008) recommended an 8-h reference exposure level, the concentration at or below which adverse noncancer health effects would not be anticipated for repeated 8-h exposures, at 7 ppb (OSHA, 2008). In the USA, the ATSDR had established minimal risk level (MRL) as 8 ppb for respiratory health outcomes associated with chronic inhalation exposure to formaldehyde (ATSDR, 1999).

Internationally, the World Health Organization (2001) has published the formaldehyde exposure guidelines recommending 0.1 mg/m^3 over a 30-min average as the level where there is a minimal risk of upper respiratory tract cancer. Canada has a proposed formaldehyde indoor air quality guidelines for short-term exposures established at 100 ppb and recommended guidelines of 40 ppb for long-term (8-h averaged) exposures (Health Canada, 2007). According to The International Agency for Research on Cancer (IARC), formaldehyde is currently classified as 'carcinogenic to humans', with sufficient evidence that formaldehyde can cause nasopharyngeal cancer in humans (IARC, 2010).

Given that the respiratory symptoms reported by people living in the temporary housing units were unexplained by other medical diagnoses and that they occurred after people moved into the trailers, environmental causes were suspected. The symptoms reported were consistent with potential symptoms of formaldehyde exposure. The objectives of our study were to identify formaldehyde levels in occupied trailers and to determine factors or characteristics of occupied trailers that could affect formaldehyde levels.

Methods

Study participants

Investigators obtained from FEMA a list of 46 970 trailers in LA and MS that were identified as occupied as of November 2007. The list included information on trailer type, manufacturer, location, and occupant contact information. From this information, 519 trailers were selected for participation by use of stratified random sampling. SAS 9.1 (version 9.1; © SAS Institute, Inc., 2002–2003, Cary, NC, USA) software was used to randomly generate a list of trailers to be sampled.

The three trailer types most commonly used—travel trailer, park model, and mobile home—were stratified by manufacturer, a total of 11 strata. Travel trailers comprised seven strata: the top six manufacturers were each an individual stratum (Gulfstream, Forest River, Fleetwood, Fleetwood CA, Pilgrim, and Keystone), which together represented 61% of occupied travel trailers, and ‘all other’ travel trailer brands constituted the seventh strata. Because Gulfstream was the most frequently used travel trailer, that brand was oversampled. Park models comprised two strata: the most common model manufactured by Silver Creek (21% of park models) and ‘all other’ park model manufacturers. Mobile homes also comprised two strata: the most common model manufactured by Cavalier (17% of mobile homes used) and ‘all other’ manufacturers. Each brand in the ‘all other’ groups made up <3% of all trailers.

Within each stratum, each trailer was assigned a random number. Each list then was sorted in numeric order according to the random number assignment. To participate in our study, an individual was required to be an adult ≥ 18 years of age who resided in a FEMA-issued trailer in MS or LA at the time of phone recruitment and who spent at least 6 h each day in the FEMA-issued trailer. Informed consent was obtained when we visited the trailer. This study was approved by CDC’s Institutional Review Board.

Environmental sampling and participant activities

The investigation was conducted from December 11, 2007–February 8, 2008. To evaluate formaldehyde levels in occupied trailers and to determine potential factors and characteristics that can affect them, study investigators collected a 1-h indoor sample measurement of formaldehyde and a concurrent sample measurement of indoor temperature and RH from each participating trailer. In addition, we administered a short questionnaire to consenting adults to obtain demographic information about trailer residents and typical daily activities; investigators also conducted a short walk-through survey to record visual observations of the indoor environment and the home exterior.

Investigators collected indoor temperature, RH, and a 1-h sample of air in each participating trailer by using Analytical Method 2016 (NIOSH, 2008). Residents were asked to configure doors and windows as they would have them while they slept, and no cooking or smoking was allowed in the travel trailers or mobile homes during the 1-h sample collection period because these activities could affect formaldehyde levels.

Samples were collected by use of standard industrial hygiene pumps and Supelco S10 LpDNPH cartridges (Supelco, St. Louis, MO, USA). Samples were drawn at a flow rate of 500 ± 50 ml/min for 1 h at a height of 4 feet, which is comparable to a person’s breathing zone while sitting. An investigator observed sample collection at all times and followed all quality assurance and quality control standards. Samples were analyzed for formaldehyde levels at the Bureau Veritas laboratory, an American Industrial Hygiene Association accredited laboratory in Novi, Michigan.

Statistical analysis

All statistical analyses were conducted by use of SAS 9.1 (SAS Institute, Inc.). A natural log transformation was applied to the formaldehyde levels to normalize the distribution. Tests for normality were conducted on the transformed levels, and the levels were plotted for the purpose of examining the form of the distribution. Univariate linear regression models were constructed for the purpose of evaluating the significance of selected questionnaire items in predicting the natural log of formaldehyde levels. Variables with cell counts of five or fewer in the smallest category were not included in the regression models. The sampling weights were the reciprocals of the probabilities of selection. They were used in SAS PROC SURVEYMEANS, PROC SURVEYFREQ, and PROC SURVEYREG to produce unbiased estimators. Categorical and squared temperature and humidity variables were also initially considered.

To develop a model, a backward elimination procedure was manually conducted. All independent variables with cell counts >5 initially were entered into the linear regression model. At each step, the variable contributing the least to the model, as assessed by the F statistic, was removed. The final model included variables that were significant at a P of ≤ 0.05.

Results

Participation rates

During recruitment, investigators contacted residents at 1137 (76%) trailers of the 1489 trailers where contact was attempted (Figure 1). Of the 717 eligible trailers, occupants in 519 (72%) participated. Reasons for ineligibility of the remaining 420 trailers included the following: the trailer was not occupied [367 (87%)]; the target sample size for that stratum had been previously achieved [27 (6%)]; the trailer occupant was unable to schedule an appointment time because of work, travel, hospitalization, or other reasons [15 (4%)]; hostility by occupants [3 (1%)]; and unknown reasons [8 (2%)].

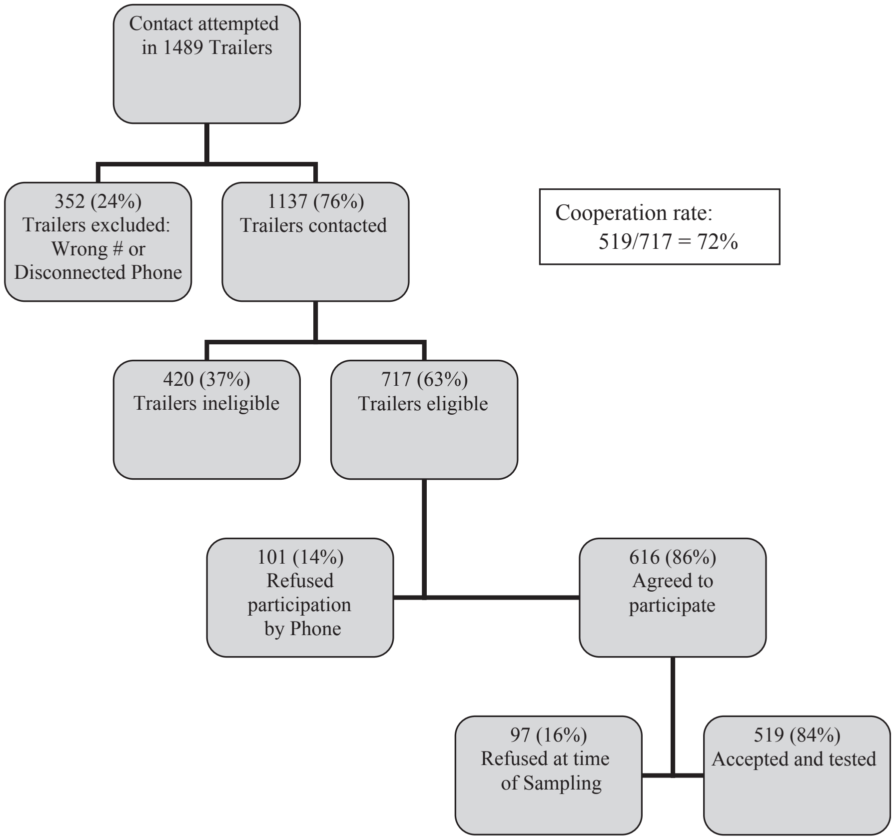

Fig. 1 Recruitment of participants in a study of occupied U.S. Federal Emergency Management Agency-supplied trailers in Louisiana and Mississippi, December 2007–January 2008

Overall range and variability of formaldehyde levels

The geometric mean (GM) formaldehyde level for all trailers sampled was 77 ppb [95% confidence interval (CI): 70–85; range: 3–590 ppb]. The GM formaldehyde level in the 1-h air samples was 81 ppb for travel trailers (95% CI: 72–92), 44 ppb for park models (95% CI: 38–53), and 57 ppb for mobile homes (95% CI: 49–65) (Figure 2). GM formaldehyde levels varied significantly among travel trailers, park models, and mobile homes ($P < 0.001$) and ranged widely among all types of trailers. In all three trailer types, some trailers had formaldehyde levels ≥ 100 ppb. The mobile home and travel trailer groups each had individual trailers with formaldehyde levels ≥ 300 ppb (Table 2). GM formaldehyde levels differed significantly among strata; each stratum included some trailers with levels ≥ 100 ppb (Table 2).

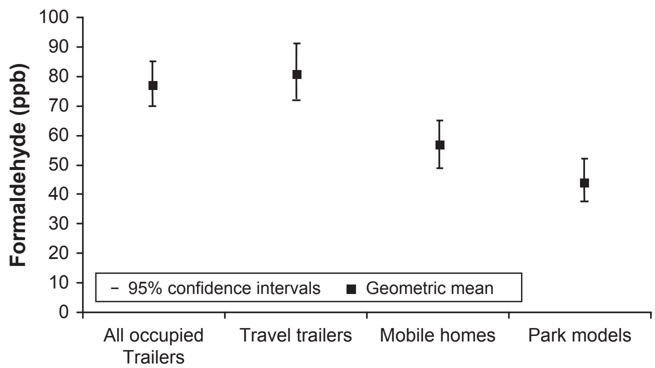

Fig. 2 Geometric mean formaldehyde levels in occupied U.S. Federal Emergency Management Agency-supplied trailers, Louisiana and Mississippi, December 2007–January 2008 ($N = 519$). GM, geometric mean; ppb, parts per billion (divided by 1000 to get parts per million); CL, confidence limit

Occupant activities

Selected occupant activities that were performed directly preceding the sampling period were analyzed to determine whether they significantly affected sampling results. During the 3 h before testing, 44% of homes had windows, doors, and scuttles open, and smoking had occurred in 19%. Other activities performed during the week before testing included use of air fresheners (61%), candles (24%), and glue, paint, or furniture finish (3%) (Table S1).

Multivariate analysis

Backward elimination modeling yielded a final regression model containing the following statistically significant variables: stratum ($P < 0.0001$); average

Table 2 Formaldehyde levels by manufacturer in 519 occupied U.S. Federal Emergency Management Agency-supplied trailers in Louisiana and Mississippi, December 2007–January 2008

Home Type	Brand	No. in stratum	No. in sample	Formaldehyde GM (ppb)	95% CI for GM (ppb)	Range (ppb)	Weighted Percentage of the Sample with Levels	
							≥ 100 ppb	≥ 300 ppb
Travel trailer	Gulfstream	14 624	123	104	88–123	3–590	56%	9%
	Forest River	3220	36	82	61–109	17–510	42%	6%
	Fleetwood	2371	47	39	32–48	3–140	6%	0%
	Fleetwood CA	1699	39	43	34–55	7–300	13%	3%
	Pilgrim	1584	39	108	85–136	25–520	51%	3%
	Keystone	1395	38	102	79–131	23–480	53%	11%
	Other	15 637	38	74	57–96	11–330	37%	3%
	Total	40 530	360	81	72–92	3–590	42%	5%
Park model	Silver Creek	224	53	33	29–39	3–170	6%	0%
	Other	809	37	48	39–60	11–160	16%	0%
	Total	1033	44	44	38–53	3–170	14%	0%
Mobile home	Cavalier	921	42	78	65–95	14–320	36%	2%
	Other	4486	27	53	45–63	11–120	4%	0%
	Total	5407	57	57	49–65	11–320	9%	<1%
Total All		46 970	519	77	70–85	3–590	38%	5%

GM, geometric mean; ppb, parts per billion (divided by 1000 to get parts per million); CI, confidence interval.

temperature in degrees F ($P < 0.0001$); RH expressed as a percentage ($P < 0.0001$); a dichotomous variable indicating whether doors, windows, or scuttles were open in the 3 h before testing ($P = 0.02$); and a dichotomous variable indicating whether mold was observed in the trailer (≥ 1 ft^2) ($P = 0.05$). Temperature accounted for the most variation in the natural log of formaldehyde levels explained by the model. Figures 3 and 4 show the unadjusted relationship between the natural log of formaldehyde and temperature and humidity, respectively. Temperatures ranged from 41 to 91°F inside the trailers, and RH was 23–88%.

The observation of ≥ 1 ft^2 of mold was associated with a significant increase in GM formaldehyde levels (adjusted mean 86 ppb vs. 63 ppb) (Table 3). Windows, doors, or scuttles open in the 3 h before testing were associated with a significant decrease in GM formaldehyde levels (adjusted mean 65 ppb vs. 83 ppb) (Table 3).

Although each of three strata (Forest River, other park models, and other mobile homes) contained fewer than 38 trailers, contrasts comparing the GM formaldehyde level in each of them to the overall GM of the others still showed significant differences ($P = 0.01$, 0.01, and 0.04, respectively). Table 4 presents the adjusted GM formaldehyde level by stratum from the multivariate model. GM formaldehyde levels in travel trailers manufactured by Fleetwood and Fleetwood CA were significantly lower than levels in the other travel trailers combined, after adjustment for covariates ($P < 0.001$ for both). They did not differ significantly from each other. GM formaldehyde levels for Pilgrim, Keystone, and Gulfstream were significantly higher than for the other travel trailers combined, after adjustment for covariates ($P < 0.001$ for all three); however, they did not differ significantly from each other. After adjustment for covariates, levels in Silver Creek park models were

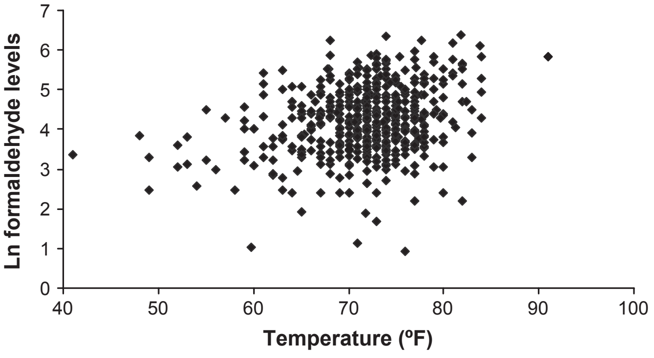

Fig. 3 Association of indoor temperature with natural log formaldehyde levels in occupied U.S. Federal Emergency Management Agency-supplied trailers in Louisiana and Mississippi, December 2007–January 2008

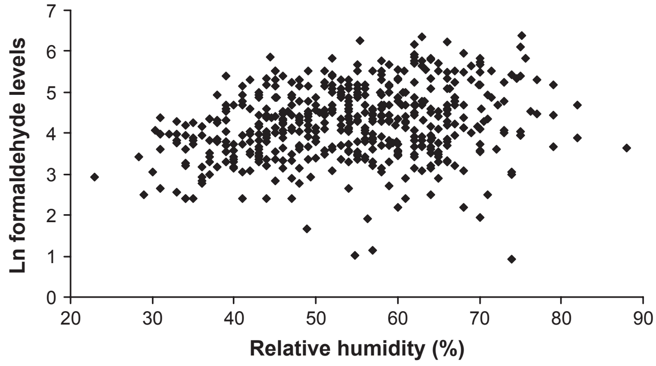

Fig. 4 Association of indoor relative humidity with natural log formaldehyde levels in occupied U.S. Federal Emergency Management Agency-supplied trailers in Louisiana and Mississippi, December 2007–January 2008

Table 3 Adjusted geometric mean formaldehyde level from occupied U.S. Federal Emergency Management Agency-supplied trailers in Louisiana and Mississippi that had mold ($\geq$1 ft^2) or had open windows, doors, or scuttles 3 h before testing, December 2007–January 2008, from multivariate analysis

Mold $\geq$ 1 ft^2	No. Trailers	Adjusted GM Formaldehyde (ppb)[a]
Yes	28	86
No	491	63

Windows/Doors/Scuttles Open	No. Trailers	Adjusted GM Formaldehyde (ppb)[b]
Yes	202	65
No	299	83

[a]Adjusted for stratum, average temperature, relative humidity (RH), and open windows/doors/scuttles 3 h before testing (all significant multivariate variables).
[b]Adjusted for stratum, average temperature, RH, and the presence of mold ($\geq$1 ft2) (all significant multivariate variables).
GM, geometric mean.

Table 4 Adjusted GM formaldehyde level from occupied U.S. Federal Emergency Management Agency-supplied trailers in Louisiana and Mississippi, by stratum, December 2007–January 2008, from multivariate model

Stratum	Adjusted GM Formaldehyde Level (ppb)[a]
Travel trailer	
Gulfstream	111
Pilgrim	129
Fleetwood CA	44
Fleetwood	42
Forest River	102
Keystone	122
Other	90
Park model	
Silver Creek	37
Other	55
Mobile home	
Cavalier	84
Other	62

[a]Adjusted for average temperature, relative humidity, windows/doors/scuttles open 3 h before testing, and presence of mold ($\geq$1 ft2) (all significant multivariate variables).
GM, geometric mean.

significantly lower than those in other park models (P = 0.004), and levels in Cavalier mobile homes were significantly higher than those in other mobile homes (P = 0.006). The estimated regression coefficients (Table 5) can be used to calculate predicted formaldehyde levels; however, extrapolating beyond observed levels is not recommended. This data are the same as previously presented in the CDC final report (CDC, 2008).

Table 5 Estimated regression coefficients for modeling of statistically significant variables of occupied U.S. Federal Emergency Management Agency-supplied trailers in Louisiana and Mississippi, December 2007–January 2008

Variable	Estimate	P value
Intercept	0.012 (α)	0.983
Gulfstream travel trailer	Reference group	
Pilgrim	0.148 (ß $_1$)	0.232
Fleetwood CA	−0.917 (ß $_2$)	<0.001
Fleetwood	−0.965 (ß $_3$)	<0.001
Forest River	−0.085 (ß $_4$)	0.600
Keystone	0.096 (ß $_5$)	0.477
Other travel trailer	−0.215 (ß $_6$)	0.114
Silver Creek park model	−1.094 (ß $_7$)	<0.001
Other park model	−0.695 (ß $_8$)	<0.001
Cavalier mobile home	−0.275 (ß $_9$)	0.016
Other mobile home	−0.583 (ß $_{10}$)	<0.001
Temperature (°F)	0.052 (ß $_{11}$)	<0.001
Relative humidity (%)	0.017 (ß $_{12}$)	<0.001
Windows/doors/scuttles open (yes)	−0.243 (ß $_{13}$)	0.017
Mold ($\geq$1 ft^2)	0.311 (ß $_{14}$)	0.052

Discussion

Geometric mean formaldehyde levels in the FEMA-supplied trailers tested were higher than those of traditional homes in the United States and the average levels found in previous studies of mobile homes. The average level of formaldehyde in all study trailers was 77 ppb, and many trailers had higher levels (range: 3–590 ppb). In contrast, formaldehyde levels in a study of conventional U.S. homes averaged 40 parts per billion (ppb), with highs of 140 ppb (Stock and Mendez, 1985). A study of new homes found GM formaldehyde levels of 34 ppb in manufactured homes and 36 ppb in site-built homes (Hodgson et al., 2000). A recent study of 105 California single-family homes reported formaldehyde median concentrations of 36 $\mu g/m^3$ and maximum concentrations of 138 $\mu g/m^3$ (Offermann, 2009). The Hodgson study also suggested that formaldehyde levels in conventional homes have decreased greatly since the 1980s, possibly because of the decreased use of plywood paneling and reduced emissions from the composite wood products used. The U.S. Environmental Protection Agency's National Human Exposure Assessment Survey found a median formaldehyde level of 17 ppb, with a high of 332 ppb, in Arizona homes (Gordon et al., 1999). In a recent study of single-family homes in three cities, Weisel et al. (2005) found mean formaldehyde levels of 3 ppb in outdoor ambient air, 17 ppb in home indoor air, and 16–25 ppb in trailers.

Formaldehyde exposure is ubiquitous in our daily lives and includes exposures at home, in automobiles, and at the workplace. At higher levels, people can experience acute symptoms, such as coughing and irritated eyes, nose, throat, and upper respiratory system (ATSDR, 1999). In this study, certain human activities were associated with higher formaldehyde levels. Closed windows, doors, or scuttles increased formaldehyde levels, indicating that ventilation of trailers is an important recommendation to occupants. In addition to the recommendation to keep windows, doors, or scuttles open, using air-conditioning also has been shown to decrease formaldehyde levels in trailers (ATSDR, 2007; Lovreglio et al., 2009). It is important to note that if air conditioners recirculate air, the recirculation would not be as beneficial as opening windows and doors in decreasing indoor air levels of formaldehyde. Most trailers had working air-conditioning, but the majority of people did not use it more than 4 h each day during the time period of the study, likely due to the study being conducted during winter months, although other factors for lack of use could include cost and noise.

Previous studies (Dassonville et al., 2009; Guo et al., 2009; Lovreglio et al., 2009) found that smoking had a small impact on increasing formaldehyde levels in traditional homes; though, results from these studies were not statistically significant. Smoking by occupants in our study was also not significantly associated with increased formaldehyde levels in the multivariate analysis; though, smoking was a common activity and remains an important issue because cigarettes are a source of formaldehyde. Cigarette smoke also contains a wide range of other toxic and irritating compounds associated with increased health risk that can worsen air quality in the trailers.

Increased indoor temperature and RH were associated with increased formaldehyde levels. One previous study has shown a significant association between formaldehyde levels and only increased indoor air temperature (Offermann, 2009), while another chamber study showed that a 10°C increase in temperature and 35% increase in RH did contribute to an increase in formaldehyde emissions (Parthasarathy et al., 2011). These associations indicate that exposure risks could increase during the summer, perhaps dramatically, with warmer and more humid weather. Formaldehyde levels measured during the winter, as in this study, may not represent summer levels, which would likely be higher, especially without adequate ventilation. The observation of mold (≥ 1 ft^2) (6% of trailers) was associated with higher formaldehyde levels. Relative humidity has been shown to be a factor contributing to both increased levels of formaldehyde (Arundel et al., 1986) and mold growth (Environmental Protection Agency (EPA), 2009). Mold and indoor dampness have been associated with a variety of health effects (Mendell et al., 2011).

Some trailer brands showed higher GM formaldehyde levels than others; though, the exact reasons for higher levels in certain brands are unknown. Although formaldehyde levels varied by trailer type, this study showed that all brands had some trailers at ≥ 100 ppb including formaldehyde levels higher than some of the established recommended guidelines. It would be useful to explore the manufacturing and design characteristics of all trailers to determine whether new designs could minimize the need for formaldehyde products in their construction.

Limitations

Formaldehyde levels are expected to be lower in cooler temperatures and lower RH; therefore, levels measured in this study may underestimate peak summer levels when trailers were hotter and more humid. Additionally, many of these trailers were over 2 years old, and previous studies have shown the highest formaldehyde levels in newly constructed trailers and homes (Gordon et al., 1999; Hodgson et al., 2000); therefore, residents could have been exposed to higher levels of formaldehyde when their trailers were newer. In addition, formaldehyde was measured at a central location in the trailer, and different locations in the trailer could have different formaldehyde levels. However, as a gas, formaldehyde is likely to become evenly throughout the trailer.

Study results are not representative of trailers purchased and used in other places and other situations because the sample for this study was selected only from occupied FEMA-supplied trailers in LA and MS. Formaldehyde levels in trailers used elsewhere could differ because of age, characteristics of manufacture, circumstances of use, or characteristics of the environment.

Conclusions

While formaldehyde levels varied by trailer type, all types tested had some levels ≥ 100 ppb. GM formaldehyde levels in FEMA-supplied trailers were higher than levels found in traditional homes in the United States. Future studies should be conducted to explore trailer design and manufacturing techniques that could decrease formaldehyde levels in trailers, and research is needed to further characterize inhalational health risks associated with residential formaldehyde exposure.

Disclaimer—'The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the Centers for Disease Control and Prevention'.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1 Activities reported by occupants in 519 occupied Federal Emergency Management Agency-supplied trailers in Louisiana and Mississippi, December 2007–January 2008.

Please note: Wiley-Blackwell are not responsible for the content or functionality of any supporting materials supplied by the authors. Any queries (other than missing material) should be directed to the corresponding author for the article.

References

Agency for Toxic Substances and Disease Registry (ATSDR) (1999) *Formaldehyde: Toxic Substances Portal*. Available from: http://www.atsdr.cdc.gov/ToxProfiles/tp111.pdf.

Agency for Toxic Substances and Disease Registry (ATSDR) (2007) *An Update and Revision of ATSDR's February 2007 Health Consultation: Formaldehyde Sampling of FEMA Temporary-Housing Trailers, Baton Rouge, Louisiana*, September–October 2006. Available from: http://www.atsdr.cdc.gov/substances/formaldehyde/public_assessment.html.

American Conference of Governmental Industrial Hygienists (ACGIH) (2001). *Documentation of the Threshold Limit Values and Biological Exposure Indices*, 7th edn. Cincinnati, American Conference of Industrial Hygienists.

Arundel, A., Sterling, E., Biggin, J. and Sterling, T. (1986) Indirect health effects of relative humidity in indoor environments. *Environ. Health Perspect.*, **65**, 351–361.

California Office of Environmental Health Hazard Assessment (OEHHA) (2008). *TSD for Noncancer RELs: Formaldehyde Reference Exposure Levels*. Available from: http://www.oehha.ca.gov/air/hot_spots/2008/AppendixD1_final.pdf#page = 128.

Centers for Disease Control and Prevention (CDC) (2008) *Final Report on Formaldehyde Levels in FEMA-Supplied Travel Trailers, Park Models, and Mobile Homes*. Available from: http://www.cdc.gov/nceh/ehhe/trailerstudy/pdfs/FEMA-FinalReport.pdf.

Dassonville, C., Demattei, C., Laurent, A. M., Le Moullec, Y., Seta, N. and Momas, I. (2009) Assessment and predictor determination of indoor aldehyde levels in Paris newborn babies' homes. *Indoor Air*, **19**, 1–10.

Environmental Protection Agency (EPA) (2009) *IAQ Reference Guide: Appendix H- Mold and Moisture*. Available from: http://www.epa.gov/iaq/schools/tfs/guideh.html.

Gordon, S.M., Callahan, P.J., Nishioka, M. G., Brinkman, M.C., O' Rourke, M.K. and Lebowitz, M.D. (1999) Residential environmental measurements in the national human exposure assessment survey (NHEXAS) pilot study in Arizona: preliminary results for pesticides and VOCs, *J. Exposure Anal. Environ. Epidemiol.*, **9**, 456–470.

Guo, H., Kwok, N.H., Cheng, H.R., Lee, S. C., Hung, W.T. and Li, Y.S. (2009) Formaldehyde and volatile organic compounds in Hong Kong homes: concentrations and impact factors. *Indoor Air*, **19**, 206–217.

Health Canada (2007) *Proposed Residential Indoor Air Quality Guidelines for Formaldehyde*. Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/air/formaldehyde/summary-sommaire-eng.php#a5.

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

International Agency for Research on Cancer (IARC) (2010) *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*. Available from: http://monographs.iarc.fr/ENG/Monographs/vol88/mono88-6.pdf.

Lovreglio, P., Carrus, A., Iavicoli, S., Drago, I., Persechino, B. and Soleo, L. (2009) Indoor formaldehyde and acetaldehyde levels in the province of Bari, South Italy, and estimated health risk, *J. Environ. Monit.*, **11**, 955–961.

Mendell, M., Mirer, A.G., Cheung, K., Tong, M. and Douwes, J. (2011) Respiratory and allergic health effects of dampness, mold, and dampness-related agents: a review of the epidemiologic evidence, *Environ. Health Perspect.*, **119**, 748–756.

National Institute for Occupational Safety and Health (NIOSH) (2008) *NIOSH Manual of Analytical Methods*. Available from: http://www.cdc.gov/niosh/docs/2003-154.

National Institute for Occupational Safety and Health (NIOSH) (2010) *NIOSH Pocket Guide to Chemical Hazards – Formaldehyde*. Available from: http://www.cdc.gov/niosh/npg/npgd0293.html.

Occupational Safety and Health Administration (OSHA) (2008) *Occupational Safety and Health Standards – Toxic and Hazardous Substances*. Available from: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_id = 10075&p_table = STANDARDS.

Offermann, F.J. (2009) *Ventilation and Indoor Air Quality. California Air Resources Board and California Energy Commission, PIER Energy-Related Environmental Research Program*. Available from: http://www.arb.ca.gov/research/apr/past/04-310.pdf.

Park, J.S. and Ikeda, K. (2006) Variations of formaldehyde and VOC levels during 3 years in new and older homes, *Indoor Air*, **16**, 129–135.

Parthasarathy, S., Maddalena, R., Russell, M.L. and Apte, M.G. (2011) Effect of temperature and humidity on formaldehyde emissions in temporary housing units, *J. Air Waste Manag. Assoc.*, **61**, 685–689.

Salthammer, T., Mentese, S. and Marutzky, R. (2010) Formaldehyde in the indoor environment, *Chem. Rev.*, **110**, 2536–2572.

Stock, T.H. and Mendez, S.R. (1985) A survey of typical exposures to formaldehyde in Houston area residences, *Am. Ind. Hyg. Assoc. J.*, **49**, 313–317.

US Consumer Product Safety Commission (USCPSC) (1982) Release # 82-005. Available from: http://classaction.findlaw.com/recall/cpsc/files/1982mar/82005.html.

US Consumer Product Safety Commission (USCPSC) (1997) *An Update on Formaldehyde. 1997 Revision*. Available from: http://www.cpsc.gov/cpscpub/pubs/725.pdf.

US Environmental Protection Agency (USEPA) (2007) *Indoor Air Quality – Formaldehyde*. Available from: http://www.epa.gov/iaq/pubs/insidest.html#Look6.

U.S. Senate, Ad Hoc Committee on Disaster Recovery, 3 Committee on Homeland Security and Governmental Affairs (2009) *Far From Home: Deficiencies in Federal Disaster Housing Assistance After Hurricanes Katrina and Rita and Recommendations for Improvement* (February), U.S. Government Printing Office, Washington DC.

Weisel, C.P., Zhang, J., Turpin, B.J., Morandi, M.T., Colome, S., Stock, T.H., Spektor, D.M., Korn, L., Winer, A.M., Kwon, J., Meng, Q.Y., Zhang, L., Harrington, R., Liu, W., Reff, A., Lee, J.H., Alimokhtari, S., Mohan, K., Shendell, D., Jones, J., Farrar, L., Magerti, S. and Fan, T. (2005) Relationships of indoor, outdoor, and personal air (RIOPA). Part I. Collection methods and descriptive analyses, *Research Report (Health Effects Institute)*, **130**(Pt 1), 1–107; discussion 109–27.

World Health Organization (2001) *Air Quality Guidelines*, 2nd edn. Available from: http://www.euro.who.int/__data/assets/pdf_file/0014/123062/AQG2ndEd_5_8Formaldehyde.pdf.