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Keeping the Recovery Safe

April 29, 2009, Joseph Hagerman and Brian Doherty

In late April of 2009, media outlets reported that families displaced by the Sichuan Earthquake housed in Temporary Housing Units (THUs) were experiencing health related problems due to the buildings. There is speculation that formaldehyde is the culprit.[1] While FAS has no direct evidence to support or discredit this claim, the work we did on air quality in emergency housing built after Hurricane Katrina makes it possible to make some informed guesses about what is happening in China.

Examples of buildings under construction at the time of the earthquake (Dujiangyan, Sichuan Province, China).

The Sichuan Earthquake: A Background

In November of 2008, FAS's Building Technology Project Manager, Joe Hagerman, and Building Technology Research Associate, Brian Doherty, traveled to China to research disaster relief housing and rebuilding after the Sichuan earthquake in May of 2008. The earthquake was the 19th deadliest of all time. Early surveys indicate that over 170,000 square miles were affected at a level of "slightly damaging", and over 1200 square miles on the level of "devastating". As of May 7th,, 2009, there are 68,712 dead and more than 17,923 missing. With such excessive damage, rebuilding has been required on a massive scale.

At the time of FAS's trip, roughly 5 million people were homeless and 15 million displaced, and nearly 2 million households across the Sichuan region needed to be rebuilt or

[1] "Chinese Media Ordered Not to Report Miscarriages Linked to Sichuan's Toxic Homes" (http://www.theepochtimes.com/n2/content/view/15717/), "Reporting Ban In China 'Puts Women's Health At Risk'" (http://www.unityunaa.info/media_matters.html), and "Reporting Ban in China Puts Women's Health at Risk" (http://asiapacific.ifj.org/en/articles/reporting-ban-in-china-puts-women-s-health-at-risk).

repaired. [2] In the town of Mianzhu, approximately 100,000 homes needed to be rebuilt. As of May of 2009, more than 241,000 houses in the rural areas of the quake zone and 105,000 apartments in cities and townships are under construction, with another one million in rural areas and 33,000 in cities already finished.[3]

FAS was invited to China to make a connection between FAS's building materials research history (particularly in Structural Insulated Panel (SIP) construction), and China's need for rebuilding safe, energy-efficient housing after the recent Sichuan Earthquake. Both topics address the central mission of FAS's building technology program – to support building technology innovations that are scalable to the problems of energy use, climate change, and energy efficiency.

SIPs offer many qualities that are becoming increasingly desirable, and there is tremendous opportunity for SIPs in current and new construction markets. This is largely driven by the rapidly increasing energy and construction costs, and the ever-growing interest in "green" building. Due to their inherent energy-efficient performance (with high insulation values) and ease of construction (with reduced number of parts and joints), SIPs are an attractive candidate for addressing these variables. When paired with other energy-efficient and green technologies, SIPS provide the ability to impact building owner return on investment, asset turnover, opportunity cost, and leveraging the green building trend. However, SIP application must be designed and evaluated on a perspective of a whole building analysis, where insulation, mechanical ventilation, and other interior building loads are all analyzed studied and reacted to.

Staff from the University of Sichuan took the FAS team on a tour of earthquake damaged areas and temporary relief housing in Dujiangyan, a town roughly 20 kilometers from the earthquake's epicenter and a center of extensive destruction. We visited several buildings that were in different stages of construction before the earthquake and had an opportunity to see how typical Chinese construction reacted and failed under seismic loading. We were then taken to a temporary housing village. Small blue roofs stretched as far as the eye could see. The village had several thousand small white buildings constructed from metal skinned polyurethane SIPs. Each home was roughly 4m x 5m = $20m^2$ or $215ft^2$, and was relatively bare (only a small amount of furniture was provided by the government). Families of less than five were given one unit. Families larger were given 2 units. We were able to speak with an older couple who had been relocated to the temporary village until their home could be rebuilt. The couple was generous and friendly, and spoke openly while giving a tour of their new home.

[2] USAID Provides Earthquake Relief to China. http://www.usaid.gov/locations/asia/countries/china/earthquake/
[3] "Official tally: 5,335 students killed in quake", China Daily News. http://www.chinadaily.com.cn/china/2009-05/07/content_7753288.htm

Recent press reports have linked these units to concerns about occupant health caused by formaldehyde. We did not have equipment to measure air quality in any of these units but were able to obtain information about construction details, furnishing, and the size and dimensions of the units. Unhealthy levels of indoor air pollutants depend on both the rate at which gases like formaldehyde are generated by furnishings and the components of the building itself (e.g. plywood), and the rate at which indoor air is replaced by fresh outside air.

The Chinese units we saw were made from prefabricated, steel skinned structural insulated panels (SIPs) with a polyurethane core which were used as floors, walls, and roofs. The panels were fabricated in a factory and shipped to a construction site, where they were assembled quickly into an energy efficient building envelope.

SIP built houses are typically very tight and do not allow many air changes per hour. Air changes are the result of two things: mechanical ventilation (when provided), and air leaking through joints and penetrations in the house construction. While we took no measurements in the Chinese units, observation suggests that they are very tight and none of the units we visited had mechanical ventilation. We expect that the air changes per hour were very low.

Two US building codes establish commonly accepted standard for safety in buildings at 0.30 Air Changes per Hour (meaning that 30% of the indoor air is changed every hour).[4] A National Institute of Standards and Technology (NIST) study of manufactured homes, however, found that ACH must be at least 0.50

[4] The two codes referenced are the International Residential Code, which is the primary building code for residential construction under 3 stories, and ANSI/ASHRAE Standard 62.2, *Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*, which is the only nationally recognized indoor air quality standard developed solely for residences.

ACH (50% of the indoor air changed per hour) to achieve a 50ppb concentration of formaldehyde.[5] The NIST study is important because manufactured homes are typically smaller than site built homes and include a higher ratio of wood products to interior volume. Post-Katrina, LBNL studied the emission rates and indoor air concentration of formaldehyde in FEMA supplied THU.[6] LBNL found that FEMA supplied THUs constructed from lightweight sandwich panels made of wood and various foam cores achieved an air exchange rate of 0.15 (15% of the indoor air exchanged per hour). As both Chinese THUs and FEMA THUs achieved the tight construction which is a hallmark of all SIPs and SIP-like panels, it is assumed that air change rates are between the numbers produced by these studies, and they will be used as a comparison point to the housing in China because of their similar size and construction type.

The Chinese SIPs were made from polyurethane cores and metal skins. These metal skinned SIPs contain no formaldehyde. Any formaldehyde problem in the THUs could not come from the building products but could come from furniture or other possessions placed in the homes that were either salvaged by homeowners from their previous residence or provided by the government.

Estimating Risk

Based on the evidence available, it's possible to make some informed guesses about the source of indoor air quality problems using methods described in a recent LBNL report. [7] This report provides a method for calculating the emissions of formaldehyde in a residence and, conversely, the fresh air mechanical ventilation requirements to insure an inhabitant is safe. We used these methods to estimate air quality in the Chinese THUs based on a range of assumptions about air exchange rates and emission rates of products consistent with what we saw in the units. An accurate estimate, of course, would require onsite measurements.

The Chinese THU volume is roughly **50 m^3 (roughly 1,765 ft^3)**

4m x 5m = 20m^2 (roughly 215ft^2) x 2.5m tall = **50 m^3 (roughly 1,765 ft^3)** [8]

The following air change rates (in air changes per hour) are used in the US:

0.15 (cited as FEMA's THU in LBNL, pg 19),
0.30 (per ASHRAE 62), and
0.50 (per NIST).

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[5] "Volatile Organic Compound Concentrations and Emission Rates Measured over One Year in a New Manufactured House", Alfred T. Hodgson, Steven J. Nabinger, and Andrew K. Persily, September 2005

[6] "Aldehyde And Other Volatile Organic Chemical Emissions In Four FEMA Temporary Housing Units – Final Report," Randy Maddalena, Marion Russell, Douglas P. Sullivan, and Michael G. Apte, November 2008 (LBNL-254E)

[7] Randy Maddalena, Marion Russell, Douglas P. Sullivan, and Michael G. Aptein, " Aldehyde And Other Volatile Organic Chemical Emissions In Four FEMA Temporary Housing Units – Final Report" LBL December 2008

[8] As seen in the photographs from our site visit, units are 5 panels long by 4 panels wide. Published estimates (such as http://www.bloomberg.com/apps/news?pid=20601087&sid=aj.BXz_QEUTg&refer=home) indicate that units are roughly 20 square meters, so the assumption is that each panel is 1 meter wide.

We'd estimate, given that the units are SIPs and that no other mechanical penetrations or ventilation is shown on the exterior of the units, that the ACH of the units is quite low, between 0.15ACH and 0.5 ACH.

Formaldehyde Emission Rates:

The following formaldehyde emission rates reported in the California Air Resource Board (CARB) Battelle study (1996).[9]

Material	Min (ug/m2-hr)	Mean (ug/m2-hr)	Max (ug/m2-hr)
Hardwood Plywood	6.8	87	170
Medium Density Fiberboard	210	293	385
Particleboard	104	189	508

Material	Min (ug/ft2-hr)	Mean (ug/ft2-hr)	Max (ug/ft2-hr)
Hardwood Plywood	0.6	8.1	15.8
Medium Density Fiberboard	19.5	27.2	35.8
Particleboard	9.7	17.6	47.2

3) Potential Concentrations Scenarios:

The Agency for Toxic Substances and Disease Registry (ATSDR, a part of the CDC) estimates that daily human exposure of more than 40ppb (parts per billion) of formaldehyde creates an appreciable risk of adverse noncancerous health effects over a specified duration of exposure.[10] Using the LBL methods, it's possible to estimate the allowable emission rates for material in the THUs. Given the known emission rates of the material used in furnishings (hardwood plywood, fiberboard, particleboard), it's then possible to estimate the area of such materials that would be allowable in the structure to ensure that the 40ppb threshold is not exceeded.

[9] See Appendix D: Basis for Formaldehyde Emission Factors, Rulemaking to Consider Adoption of the Proposed Airborne Toxic Control Measure (ACTM) to Reduce Formaldehyde Emissions From Composite Wood Products, California Air Resources Board. April 2007. http://www.arb.ca.gov/),

[10] http://www.atsdr.cdc.gov/toxprofiles/tp111-a.pdf

Emissions and area of furnishing materials allowed if the units are not to exceed 40ppb formaldehyde concentrations at three different assumptions about air changes per hour

	allowable emissions			material allowance	
ACH	(ug/ft2)	(ug/m2)		(ft2)	(m2)
0.15	365.8	34.0	Hardwood Plywood	<45.2	<4.21
			Medium Density Fiberboard	<13.4	<1.25
			Particleboard	<20.8	<1.94
0.3	731.7	68.0	Hardwood Plywood	<90.5	<8.41
			Medium Density Fiberboard	<26.9	<2.50
			Particleboard	<41.7	<3.87
0.5	1219.5	113.3	Hardwood Plywood	<150.8	<14.02
			Medium Density Fiberboard	<44.8	<4.16
			Particleboard	<69.4	<6.45

4) Interior Wood Products:

The material allowances are obviously quite low. We can estimate the areas of these materials actually in the buildings by examining photographs we took of interiors.

In the picture, two wooden armoires are shown. It is unclear what type of wood this is specifically, so each of the above wood products will be estimated. Additionally, it was unclear how many of these furniture units were provided by the Chinese government, and if this family was given more than one unit or salvaged this from their home. Erring on the conservative side, the emission of only one piece of furniture will be calculated given the above room size.

Given a size of 3'wide x 8' tall x 1.5' deep, a unit would be comprised of the following pieces:

	size (ft)	quantity	area (ft2)	(m2)
top and bottom	3' x 1.5'	4	18	1.7
front and back	3' x 8'	2	48	4.5
sides	1.5' x 8'	2	24	2.2
		TOTAL	**90**	**8.4**

While a number of assumptions were needed to make these estimations, they are conservative. It can be seen that the air quality threshold is likely to be exceeded by this single piece of furniture even if air change rates are quite high. Additional wood products would likely increase indoor air concentrations above the estimates given above. The only options are to remove the source (source control), increase the air exchange rates (ventilation control), or provide another means to keep the occupant's safe (i.e. housing options).

Recommendations

In light of these findings we propose the following…

1. Duplicate the LBNL study in China and make systematic recommendations to keep recovery residents safe. Also, investigate more closely the size of the THUs and materials used to better duplicate the LBNL study to provide more accurate analysis and more specific recommendations;
2. Purchase mechanical ventilation for each THU based on the in-depth study and recommendations. These mechanical ventilation devices could be adapted window fans with solar power and supplemental batteries to decrease the total power usage of the village;
3. Provide wide-spread, better education on SIPs – SIPs are an important building technology that will help China ramp up and address climate change and this current problem shouldn't disincentive SIP's use and adoption, and
4. Integrate whole-building design into future disaster relief planning. China did a remarkable job of constructing relief housing in a fast and efficient manner, but they need to make whole building design, and more specifically indoor air quality, a consideration in the design of future relief efforts in order to avoid health problems related to buildings.

For China to adopt high performance building products (like SIPs) and whole building analysis, US building experts need to hold small focused workshops with Chinese-American partnerships, especially in seismic regions and during post-disaster reconstruction. This would provide a great opportunity for manufacturers, builders, and government officials to exchange best practices in building technologies and construction techniques, and would help address looming problems such as indoor air quality, energy efficiency, and building's role in climate change.

Using the experience of indoor air quality problems in Chinese SIP buildings as an example, one of the most important parts of SIP construction is the quality control and quality assurance in the manufacturing of panels, and the provision of properly sized ventilation. If the panels are manufactured incorrectly, they may delaminate and cause a structural failure. Also, as this study has shown, when panels are manufactured and installed correctly, ventilation must be properly accounted for to achieve safe indoor air quality.

For a workshop to be truly successful and for future projects in China using SIPs to be successful, working with manufacturers to make sure they produce quality materials to scientifically based, consensus standards (such as those published by American National Standards Institute (ANSI)) is essential. This could involve staging a demonstration on how to correctly manufacture SIPs and build with SIPs, which could also highlight how to correctly evaluate and design structures focused on whole building analysis.

The value and opportunity in a joint workshop like this would provide a very good first step towards building a broader base of knowledge in China for advanced building concepts, and would help avoid issues like those discussed in this paper in future building projects.