

## **Key findings from USAID/OFDA wind tunnel testing of transitional shelters at Florida International University's International Hurricane Research Center**

*As part of its Disaster Risk Reduction Programs, the United States Agency for International Development through the Office of U.S. Foreign Disaster Assistance (USAID/OFDA) initiated a series of tests in 2012 to evaluate the wind resistance of full-scale transitional shelters (often referred to as t-shelters). This project was carried out at the Florida International University's International Hurricane Research Center's (IHRC) and Wall of Wind (WoW) facility in Miami.*

**The overall objective of the WoW collaboration was to identify materials and construction practices that would allow t-shelters to withstand Saffir-Simpson Category 1 winds (74-95 mph (119-153 km/h)).**

The study evaluated the performance of full-scale t-shelter models against wind-induced forces. While the models were built to full-scale, they were designed to fit on the facility's turntable and therefore were not the same size in square meters as a t-shelter and did not include a foundation. In addition to testing full-scale models, tests were also conducted on individual components used in the construction of t-shelters. To carry out component and t-shelter tests, IHRC staff built three t-shelters based on designs commonly utilized in donor-supported programs. Although none of the t-shelters were exact copies of those built in the field, all were closely modeled on structures built in Haiti as part of the response to the earthquake of 2010.

Test results are now available. The key findings summarized in this quick start guide are intended to provide a starting point for information in building wind-resistant t-shelters. To learn more about the specific details and for photo illustrations, you are encouraged to read the entire report.

For more information on Shelter and Settlements and to read the entire report on USAID/OFDA wind tunnel testing of transitional shelters, go to:

<http://www.usaid.gov/what-we-do/working-crises-and-conflict/responding-times-crisis/how-we-do-it/humanitarian-sectors/shelter-and-settlements>

OFDA's goal in sharing this information is to aid our partners to design and build more wind-resistant t-shelters. In addition to improved wind resistance, OFDA is placing a greater emphasis on the construction of t-shelters that can be upgraded to permanent homes. Thus, t-shelter designs should meet the key wind resistance recommendations below and use construction practices that contribute to a durable and sturdy shelter that can be upgraded to permanence.

### **FINDINGS/RECOMMENDATIONS**

A t-shelter should be designed and constructed as a fully integrated structure that is tied together from foundation to roof in order to prevent structural failure under wind induced stresses. Building wind resistant shelters requires good design, good construction practices and selection of appropriate materials.

T-shelters in hurricane-prone areas must be built with materials that have adequate strength to withstand wind-induced forces. The overall wind resistance of a t-shelter will be determined by its

weakest component. Therefore, the choice of component materials is crucial to creating a t-shelter that will withstand Category 1 hurricane force winds. All t-shelters, of whatever material, must have tightly attached wall cladding to produce a wind-resistant shell. In addition, the shelter must have fitted windows and doors that can be firmly closed and latched during high winds. **Any shelters lacking these components is not complete and does not meet OFDA requirements.**

#### **GUIDANCE FOR T-SHELTER COMPONENTS:**

**FOUNDATIONS:** T-shelter foundations should be properly designed to be strongly tied in to the shelter superstructure. Foundations are a key component of structural rigidity; foundations and walls that are strongly attached increase wind resistance and reduce destructive vibrations. In addition, solid attachment of the t-shelter frame to the foundation allows wind load to be transmitted from the roof and walls to the foundation.

**WALLS:** (a) All structural components (i.e. wall studs, roof joists, roof trusses) must be assembled from dimensional lumber. Undersized lumber reduces wind resistance; it creates weak connections between structural elements and, during high winds, the flexing of undersized lumber greatly increases the vulnerability of the entire shelter. Ripping lumber to smaller dimensions (2x2") is a false economy and does not meet OFDA requirements for wind resistant construction.

(b) The use of ring-shank nails is highly recommended in the construction of wooden-frame structures. Ring shank nails are less susceptible to pulling out during episodes of extreme wind loading.

**ROOF:** (a) Resistance to wind is increased by the proper number and spacing of roof trusses to distribute wind loads and reduce the forces on each truss connection. Widely spaced roof trusses cause roof flexing and create increased stressing of structural connections. The spacing and dimension of purlins (roof stringers) is critical in building a wind-resistant roof. Under no circumstances should purlins smaller than a nominal 2x4" be used.

(b) The roof structure (trusses and purlins) should provide enough attachment points for the sheeting to ensure adequate spacing of the fasteners, especially around the edges of the roof. The addition of an increased number roofing nails along the gable end of roofing material at the exposed edges of the roof greatly improves wind resistance (see report for photos).

(c) The thickness of metal sheeting should be sufficient to reduce its vulnerability to fastener punch-through failure. Roofing material that can be "snipped and ripped" is likely to rip loose from the points where it is nailed during high winds.

The thickness of the roof cladding material and the type of fasteners chosen will determine the ability of the roof to withstand wind loads. Thin roof sheeting will be easily ripped loose from its fasteners. Using ring-shank nails reduces the pull-out of roof fasteners.

**HURRICANE STRAPPING:** Roof joists and rafters must be tightly attached to the t-shelter's walls with hurricane strapping. If using commercial hurricane strapping, it must be properly chosen to match the dimension of the lumber used. Non-commercial hurricane strapping can be very effective; galvanized wire and metal bands were both tested by WoW and performed extremely well. The strength of a roof-to-wall connection, reinforced with hurricane strapping, will greatly depend on the correct sizing of the lumber as well as the type of strapping used.

**PLASTIC SHEETING AS WALL CLADDING:** (a) When used as wall cladding, properly attached USAID/OFDA plastic sheeting was shown to be readily able to withstand winds of up to 110 mph. (b) The plastic sheeting's resistance to pulling away from the structure is greatly increased when washers are provided at the points where fasteners pierce the plastic. To meet wind resistance requirements, plastic sheeting must be attached with washers to spread the wind load. When securing plastic sheeting, use washers that have a minimum 1.5" (4.5 cm) diameter and have blunt edges. During the WoW tests, the edges of commercial metal washers (tin caps) tended to cut the plastic as it flexed back and forth. Bottle caps (with the sharp edges facing out) performed well, as did round plastic washers.

**DOORS AND WINDOWS:** Door and window openings are discontinuities in the wooden frame members and experience high stress concentration from external wind loading. In the WoW tests, one of the most vulnerable points of the structure was the door – wind can enter the shelter causing it to “balloon” with wind and blow away. Doors and windows need to fit into a frame that will prevent them from blowing open during high winds.

**BRACING:** Diagonal wall bracing is essential to prevent twisting and weakening of t-shelters and to transmit wind forces laterally throughout the structure. Diagonal bracing must be used in all structures and particularly when plastic sheeting is used as wall cladding on t-shelters. A rigid sheathing (i.e. plywood of suitable thickness for the clear span between studs) reduces -- but does not eliminate -- the need for diagonal bracing.

Diagonal wood braces are preferable due to their capacity to sustain compressive forces; flexible metal straps are effective only in tension and will buckle under compression. Metal straps require X-brace patterns and their effectiveness depends greatly on the strength of the fasteners used; during the WoW testing, metal straps tore loose at the point of fastening.

## **COMPARATIVE ANALYSIS**

During the WoW testing, t-shelter #3, built with the best construction practices in all components was able to withstand wind speeds of 110 mph, while t-shelter #1, built with the worst construction practices and undersized lumber failed catastrophically at wind speeds of 75 mph, well below USAID/OFDA requirements. T-shelter #2, built with correctly-sized lumber, reached 110 mph before failing due to buckling of a window section that had been weakened by placement under a roof truss. The improper window placement eliminated support for the middle roof truss and caused the wall to fail. This was a design flaw - windows should be placed in the wall between roof trusses, not directly under them. **A solid and continuous connection between the roof truss and the wall, and the wall and**

**the foundation, is critical.** T-shelter #3, built with the best construction practices and appropriate, full size components, met and exceeded all USAID/OFDA wind resistance requirements.

As a comparative measure and cautionary tale, USAID/OFDA is providing a snapshot of the costs used to build the full-scale models that were tested at the WoW. Please note that while the models were built to full-scale, they were designed to fit on the facility's turntable and therefore were not the same size in square meters as a t-shelter and did not include a foundation. Therefore the total costs shown in the table are **not** the same as the cost of a t-shelter. However, the ratios of costs are informative. The table below shows the costs of materials for each of the models, based on the wholesale price at hardware and lumber suppliers in Miami in 2012. All prices are given in US dollars. The price of 32 gauge CGI roofing sheets on t-shelter #1 is an estimate, since this material is considered substandard and is not available for sale in the US market. The sheets used in the construction of t-shelter #1 were purchased in Haiti specifically for the WoW tests, and the price stated reflects the local purchase price.

**Again, it is essential to note that t-shelter #1 did NOT meet the requirements for resistance to Hurricane Category 1 winds, failing catastrophically at 75 mph.** Neither the costs nor the construction practices for t-shelter #1 should be used as reference points for planning t-shelter projects.

The increase in price between t-shelters #2 and #3 is due to the use of additional diagonal bracing and reinforced window and doors. The difference in cost between t-shelters #2 and #3 is approximately 12%. Note that the 12% in additional costs made the difference between failure and success in meeting OFDA wind resistance requirements.

T-Shelter 1				T-Shelter 2				T-Shelter 3						
Material	Qty	Unit	Unit Cost	Cost	Material	Qty	Unit	Unit Cost	Cost	Material	Qty	Unit	Unit Cost	Cost
<b>LUMBER</b>					<b>LUMBER</b>					<b>LUMBER</b>				
1x4x8	40	ea	1.9	77.6	2x4x8	70	ea	2.7	190.4	2x4x8	80	ea	2.7	217.6
1x4x10	14	ea	4.2	58.1	2x4x10	11	ea	4.2	46.1	2x4x10	11	ea	4.2	46.1
1x6x8	6	ea	7.5	44.8	2x4x14	14	ea	5.9	82.2	2x4x14	20	ea	5.9	117.4
2x2x8	18	ea	3.0	53.5	19/32 plywood	1	ea	31.0	31.0	19/32 plywood	1	ea	31.0	31.0
				233.9					349.6					412.1
<b>FASTENERS</b>					<b>FASTENERS</b>					<b>FASTENERS</b>				
4D common nail	5	lb	4.2	21.2	12D Hot Galv Common nail	30	lb	1.4	43.0	12D Hot Galv Common nail	30	lb	1.4	43.0
5D electro galv roofing nail	5	lb	2.1	10.5	5D HG Ring Shank Neo	3	lb	4.2	12.7	5D HG Ring Shank Neo	3	lb	4.2	12.7
				31.7	#11 Galvanized roofing nail	5	lb	10.5	10.5	#11 Galvanized roofing nail	5	lb	10.5	10.5
					6D common nail	1	lb	3.5	3.5	6D common nail	1	lb	3.5	3.5
									69.6					69.6
<b>ROOFING</b>					<b>ROOFING</b>					<b>ROOFING</b>				
26x60 32Ga CGI*	10	ea	15.0	150.0	26x60 26Ga CGI	10	ea	20.0	199.8	26x60 26Ga CGI	10	ea	20.0	199.8
26 Ga sheet metal	18	lf	1.4	24.3	26 Ga sheet metal	18	lf	1.4	24.3	10-ft Ridge cap	2	ea	11.3	22.6
*cost not known, estimated				24.3					224.1					222.4
<b>WALL SHEETING</b>					<b>WALL SHEETING</b>					<b>WALL SHEETING</b>				
USAID Plastic	50	ft			USAID Plastic	50	ft			USAID Plastic	50	ft		
<b>ACCESSORIES</b>					<b>ACCESSORIES</b>					<b>ACCESSORIES</b>				
6-in Door hinges	3	ea	5.0	14.9	6-in Door hinges	3	ea	5.0	14.9	6-in Door hinges	5	ea	5.0	24.9
Hurricane ties	48	ea	0.6	28.3	1-in Metal strap	50	ft	0.2	10.0	1-in Metal strap	50	ft	0.2	10.0
Door hardware	0	ea		0.0	Door hardware	1	ea	4.2	4.2	Door hardware	4	ea	4.2	17.0
				43.2					29.1					51.8
<b>TOTAL COST</b>				<b>333.1</b>	<b>TOTAL COST</b>				<b>672.5</b>	<b>TOTAL COST</b>				<b>755.9</b>

The objective of humanitarian Shelter and Settlements (S&S) assistance is to ensure access to safe, habitable, and appropriate living spaces and settlements where affected households are able to resume critical social and livelihoods activities. This assistance facilitates a process of sheltering that focuses on both immediate and short-term economic, social, and physical vulnerability reduction of disaster-affected households and their communities. Simultaneously, the assistance lays the foundation for

longer-term recovery.

Efforts such as wind tunnel testing of t-shelters are intended to enable our partners to contribute toward meeting these goals. We encourage you to read the full FIU report for important details on building wind resistant t-shelters. For any questions or further information, please see these additional documents at the USAID/OFDA Shelter and Settlements site:

<http://www.usaid.gov/what-we-do/working-crises-and-conflict/responding-times-crisis/how-we-do-it/humanitarian-sectors/shelter-and-settlements>