Reducing Structure Ignitions from Small Storage Sheds

NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY U.S. DEPARTMENT OF COMMERCE

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Sheds Research Overview

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1. Fire Hazard of Storage Sheds

2. NISSE and NOSSE Series
   - Effects of Construction Material
   - Effects of Fuel Loading
   - Effects of SSD
   - Effects of Wind

3. Technical Findings

4. Limitations

5. Implementation

The Fire Hazard of Sheds

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The Fire Hazard of Sheds

Fuel Agglomeration

Structure Separation Experiments

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Goal: Provide guidance for the placement of auxiliary structures with floor area < 120 ft²

NISSE (NIST Indoor Structure Separation Experiments)

and

NOSSE (NIST Outdoor Structure Separation Experiments)

Structure Separation Experiments

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Goal: Provide guidance for the placement of auxiliary structures with floor area < 120 ft²

Primary objective: to characterize burning behavior of small storage sheds

- ✓ sizes,
- ✓ construction types,
- ✓ fuel loading, and
- ✓ separation distance

- ✓ **Heat Release Rate**
- ✓ **Mass loss**
- ✓ **Heat Flux**

Commercially Available Storage Sheds

Combustible

Closets

Very Small Sheds

Noncombustible

< 75 ft^3

< 150 ft^3

Fuel (1-A Wood Cribs) Loading for Closets

High Fuel Loading

Combustible

Low Fuel Loading

Noncombustible

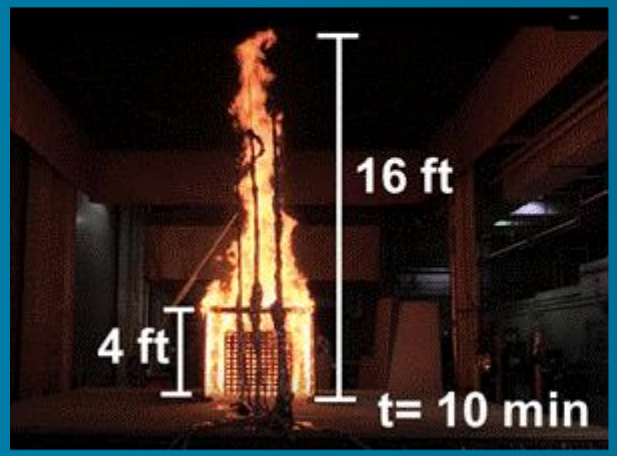
Experimental Matrix

Test #	Test ID	Material	Shed Type	Fuel Load*	Mass, kg			Fuel Density, MJ/ft^2
					Shed	Cribs	Total combustible	
1	1B-WCh0	Wood	Closet	High (4)	49	78	127	152
2	1B-WCh0-R1	Wood	Closet	High (4)	48	78	126	152
3	1B-WCh0-R2	Wood	Closet	High (4)	48	78	126	152
4	1B-PVSh0	Plastic	Very Small	High (6)	61	115	176	161
5	1B-WVSh0	Wood	Very Small	High (6)	75	117	192	142
6	1B-SVSh0	Steel	Very Small	High (6)	42	116	116	111
7	1B-WCl0	Wood	Closet	Low (2)	49	38	87	79
8	1B-PCl0	Plastic	Closet	Low (2)	38	39	67	104
9	1B-SCl0	Steel	Closet	Low (2)	24	38	38	49

*(number of 1-A cribs)

NIST TN 2235, Section 4, Table 7.

Burning Behavior of Combustible Wood Closet



Wood Closet

Four 1-A wood cribs

Peak HRR = 4.2 MW

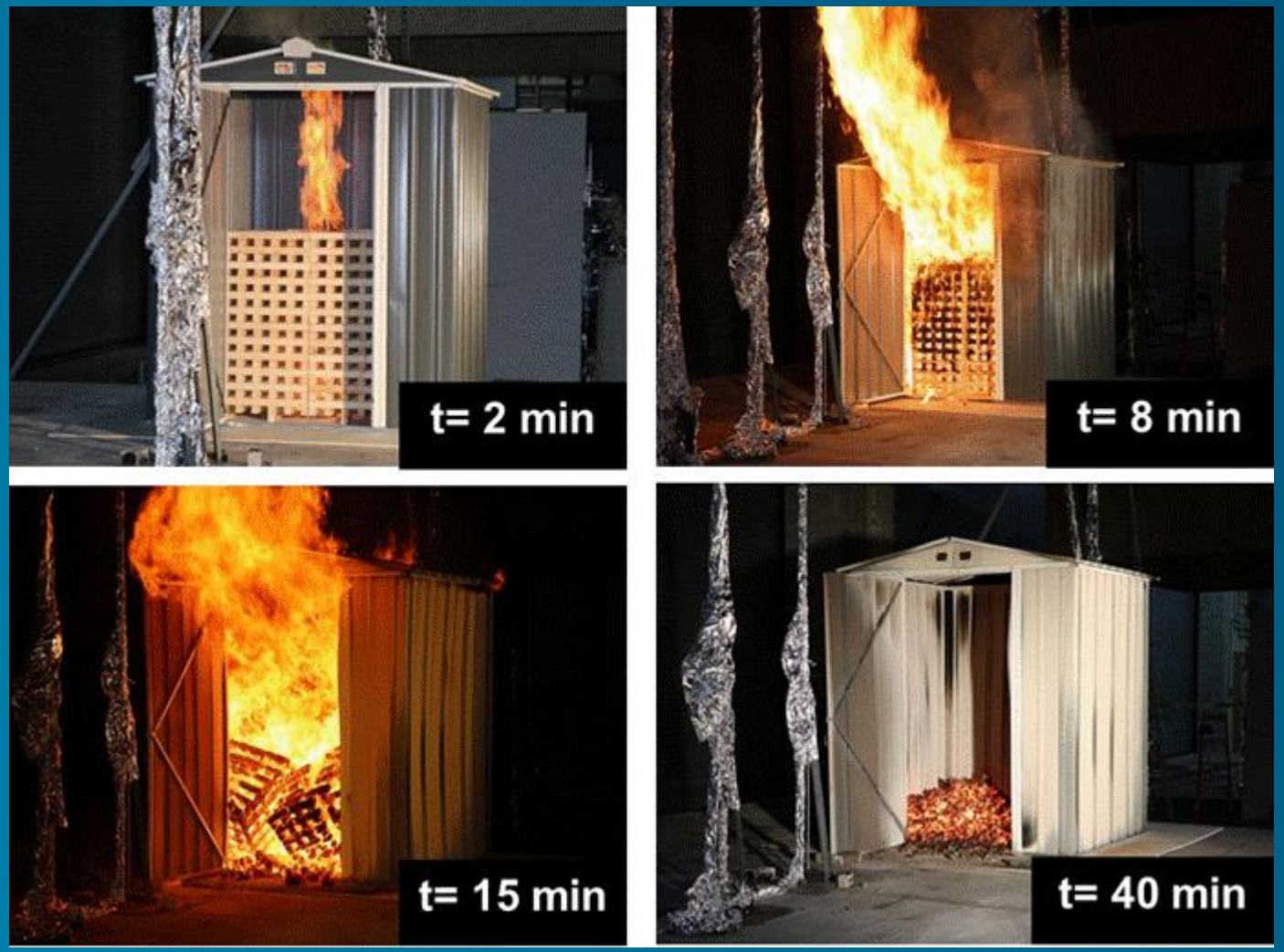
NIST TN 2235, Section 4, Figure 26.

Burning Behavior of Combustible Plastic Shed

Plastic Very Small Shed
Six 1-A wood cribs
Peak HRR = 6 MW
No structural protection
Pool fire
✓ Higher burning intensity

NIST TN 2235, Section 4, Figure 31.

Burning Behavior of Noncombustible Steel Shed



- ✓ Steel Very Small Shed
- ✓ Six 1-A wood cribs
- ✓ Peak HRR = 2.2 MW
- ✓ Good structural integrity
- ✓ Longer duration burn
- ✓ Flame jetting

NIST TN 2235, Section 4, Figure 41.

Technical Findings

- Good Repeatability
  - Comparisons of the HRR curves for repeated tests had similar shapes, magnitudes, and burning periods
  - Data show reproducibility of the measured quantities with PHRR variation of 5 % and THR variation of 2 %
- Construction material for wood and plastic sheds contributed approximately 60 % increase in fuel load compared to the steel shed
- Lower fuel loading density allows for
  - ➢ higher oxygen availability
  - ➢ faster flame spread

Technical Findings Contd.

- Total heat release from source structure corresponded with their respective total combustible mass
- Measured peak heat flux show an inverse square relationship with radial distance.
- Generally, lower heat flux gauges recorded higher heat fluxes compared to the upper heat flux gauges due to their relative proximity to the source fire compared to the upper flux gauges.
- Flame “jetting” resulted in very high local exposures.
- Flame jetting depends on size of door opening.

Shed + Target Structure Experiments

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Objective:

To assess target structure performance for different exposures from sheds (construction, size, fuel loading) placed at different SSDs with no added wind field.

Target Structure Performance

- ✓ Window
- ✓ Vent
- ✓ Eaves
- ✓ Exterior layer of wall

Measurements

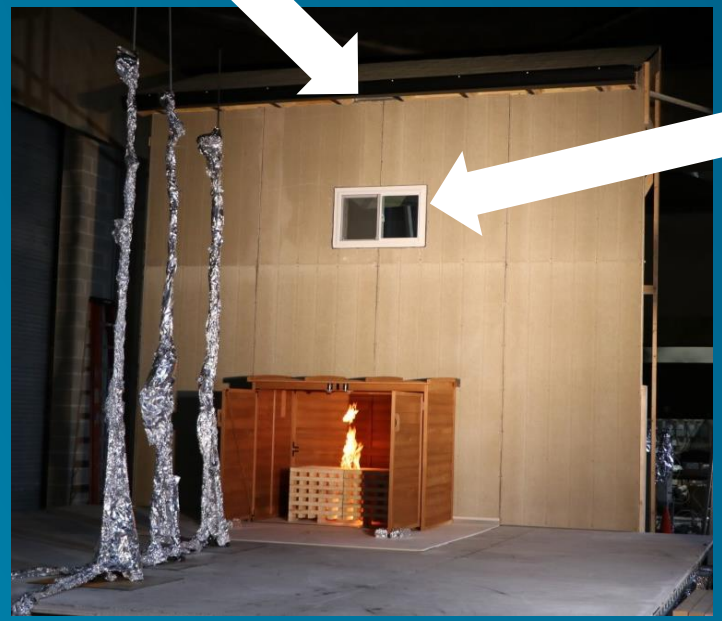
- ✓ HRR
- ✓ Heat Flux
- ✓ Temperature

Realistic no-wind scenario

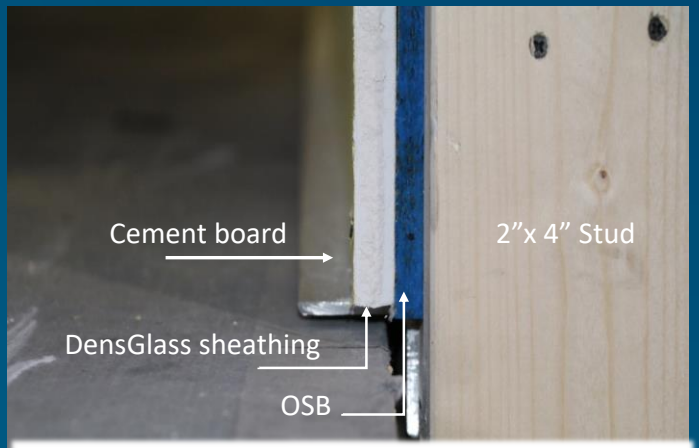
Target Structure Assembly

Eave Vent Front

Eave Vent Back

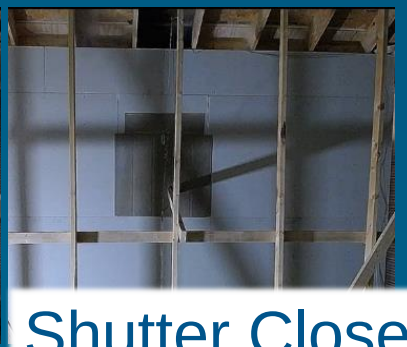


Annealed Glass Window



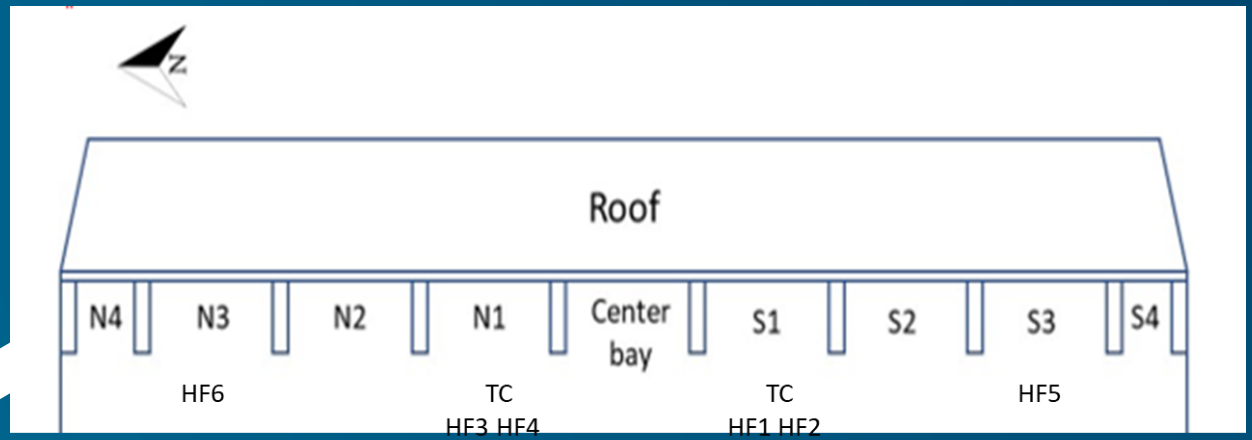
X Section of Wall

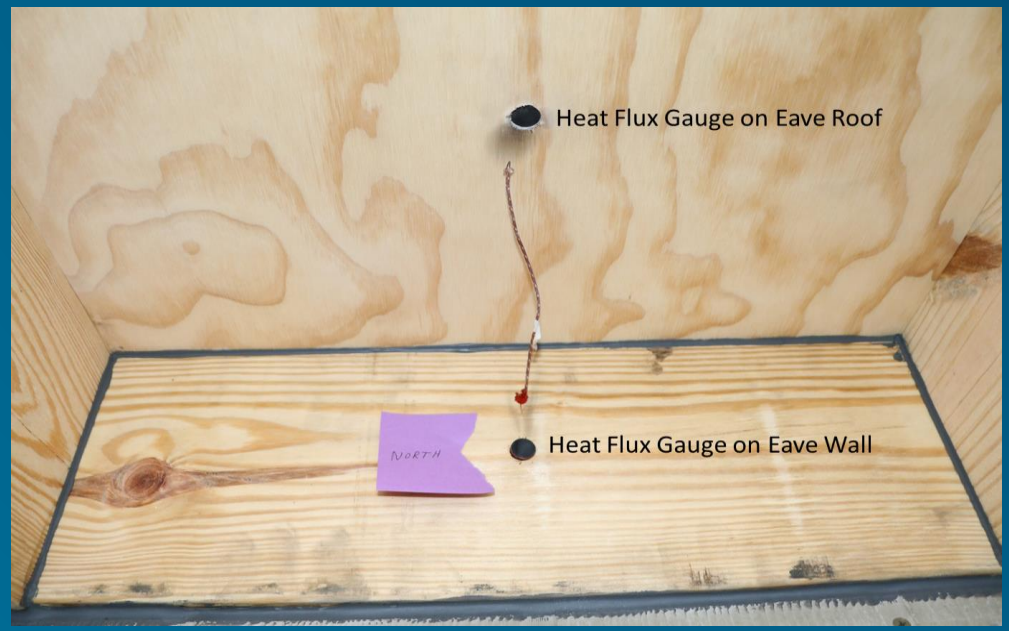
Shutter Open



Shutter Closed

Target Structure Instrumentation





Shed + Target Structure Experiment (1 of 4)

- **Wood Closet**
- **Low fuel loading: two 1-A wood cribs**
- **SSD = 0**
- **No wind**

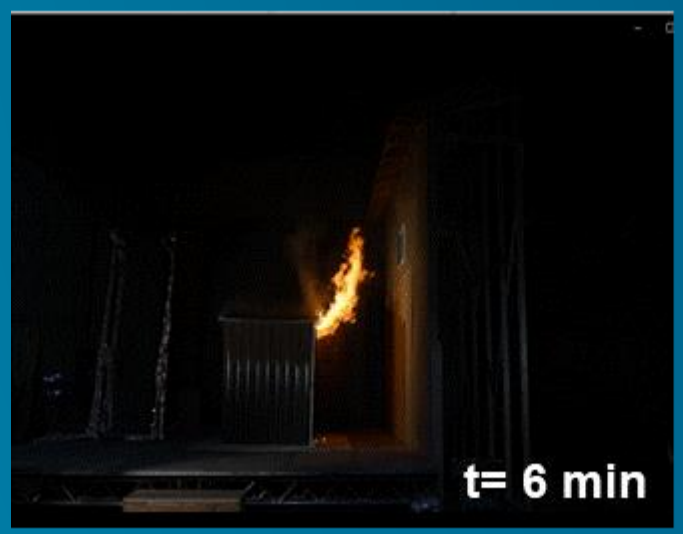
NIST TN 2235, Section 5, Figure 78.

Shed + Target Structure Experiment (2 of 4)

- Steel Closet
- High fuel loading: Four 1-A wood cribs
- SSD = 0
- No wind

NIST TN 2235, Section 5, Figure 88.

Shed + Target Structure Experiment (3 of 4)

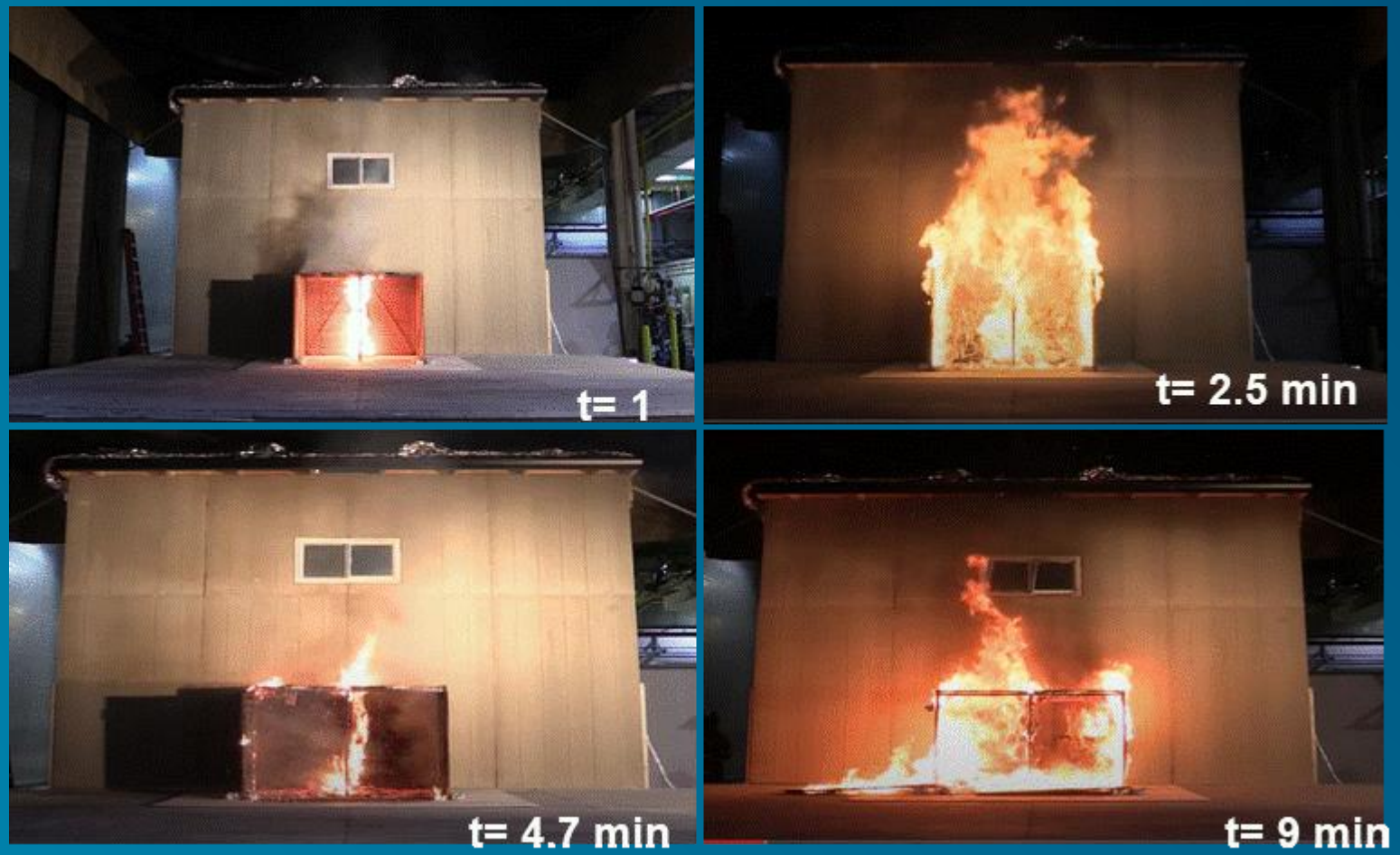


- Steel Very Small Shed
- High fuel loading: Six 1-A wood cribs
- SSD = 5 ft
- No wind

Shed Orientation
Door Opening

NIST TN 2235, Section 5, Figure 93.

Shed + Target Structure Experiment (4 of 4)



- Wood Closet
- No fuel loading
- SSD = 0
- No wind

NIST TN 2235 Section 4, Fig. 108

Exterior Wall Performance

With extra protective layer

Significant spalling of cement board

Cracking of cement board

No thermal damage to sheathing

Without extra protective layer

Code Compliant

Significant thermal damage to OSB

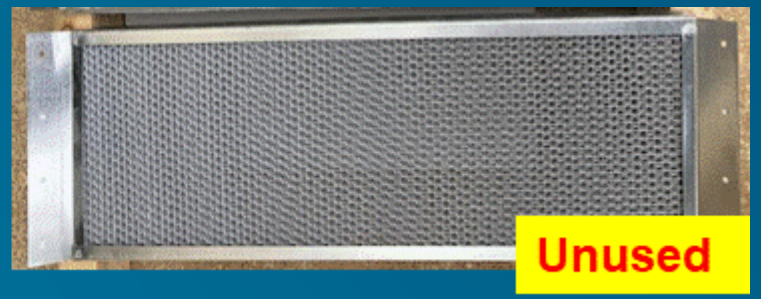
Window Performance

Flame Contact

No Flame Contact

Vent Performance

✓ Flame contact
✓ Intumescent coating activated



X No flame contact
X Intumescent coating not activated

Vent Performance

- **ASTM E 2886 exposure:** 300 kW ± 10 kW for 10 min
- **Failure Criterion:** T_{vent} > 360 ºC on the unexposed side of the vent

Peak exposures tested > 10-20x ASTM exposure

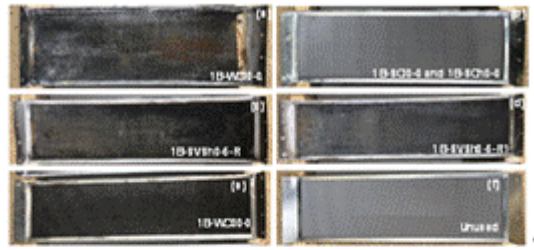


Figure 118. Photographs of vents showing effects of exposure compared to the unused vent in (f).¶

¶

The radiant and convective heat exposure were significantly lower with noncombustible Closets (test 1B-5C10-0 and test 1B-5Ch0-0), with the door opening facing away from the target wall, keeping the temperatures in the vent area well below the activation temperature of the intumescent coating. However, for the Very Small steel shed with door opening facing towards the target wall and with an SSD = 5 ft (test 1B-5V5h0-5 and test 1B- 5V5h0-5-R1), the vents were exposed to significant radiant and convective heat. While the intumescence mechanism activated during such high heat exposures, the protective barrier thus formed was not effective for a longer duration of exposures. The performance of these vents cannot be interpreted as failures with respect to the standard test method (ASTM E 2886) as the thermal exposures to the vents were significantly different than those specified in the standard. The standard test method (ASTM E 2886) specifies exposure of vents to flaming fire with HRR of 300 kW ± 10 kW for 10 min.¶

Table 15. Maximum measured temperatures at the vent during thermal exposures from burning sheds.¶

Test ID	Material	PHRR, MW	Maximum measured temperature at the vent, °C					
			~~TCventtop~~		~~TCventback~~		~~TCventback~~	
			Peak-1	Peak-2	Peak-1	Peak-2	Peak-1	Peak-2
1B-WC10-0	Wood	3.38	952	—	994	425	285	310
1B-SC10-0	Steel	0.89	58	—	55	—	46	—
1B-SCh0-0	Steel	1.40	116	—	101	—	92	—
1B-5V5h0-5	Steel	2.71	400	434	153	413	276	278
1B-5V5h0-5-R1	Steel	3.11	403	855	376	704	371	709
1B-WC00-0	Wood	2.77	386	—	144		372	—

[41] ¶

Caulking Performance

Summary

Target Hardening and Shed Usage

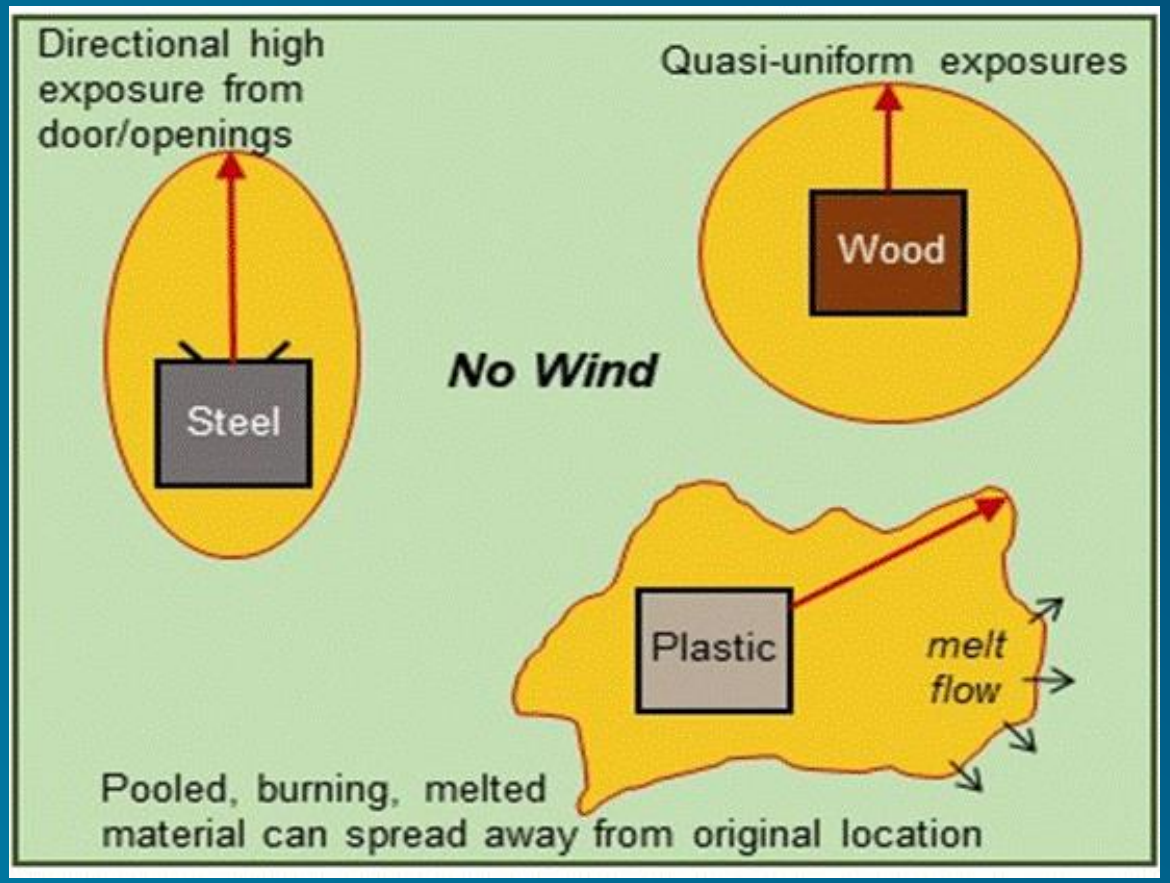
Summary

Target Hardening

- ✓ Replace annealed glass windows with tempered glass where fire exposures are expected on the structure. This should be done in conjunction with window screens and other necessary structure hardening for embers and fire (HMM).
- ✓ Use flame-retardant caulking around windows and eave vents.
- ✓ Additional protective layer sheathing may be used to prevent ignition of combustible layers of the exterior wall assembly.

Summary contd.

Construction materials has unique fire hazard associated that must be considered with its usage.



Summary contd.

Shed Usage

- ✓ Consider Reduce, Relocate, Remove (RRR) as specified in HMM to reduce fire exposures.

Minimum SSD = 10 ft for Closet and Very Small sheds (< 26 ft^2).

Summary contd.

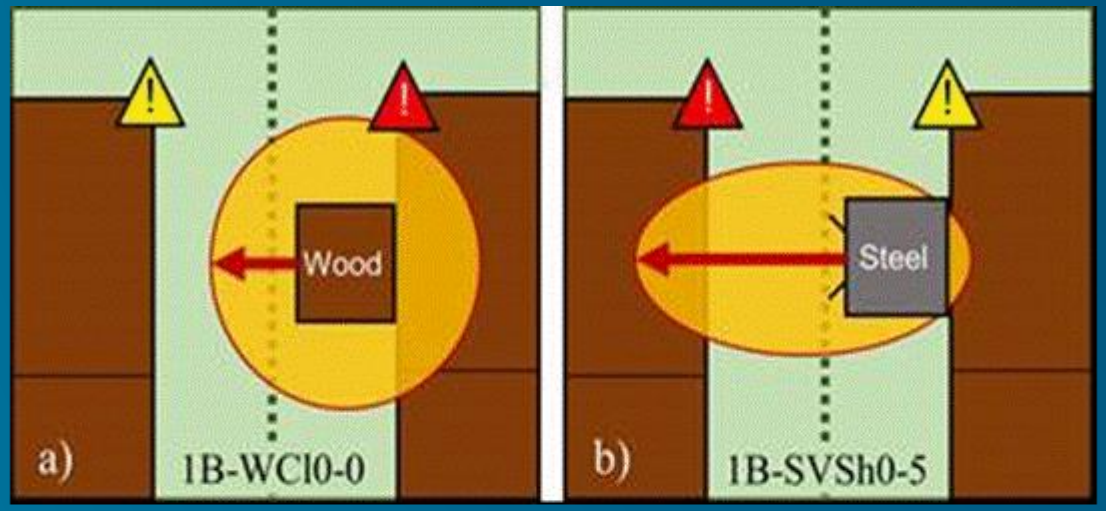
Shed Usage

Choose construction materials to reduce exposures; however, this alone cannot substitute for RRR and SSD

- ✓ Consider relative position of neighboring residence for door orientation of noncombustible steel shed.
- ✓ Keep doors closed.
- ✓ Avoid placing plastic sheds on sloped terrain and/or where pool fires can spread and ignite nearby combustibles.

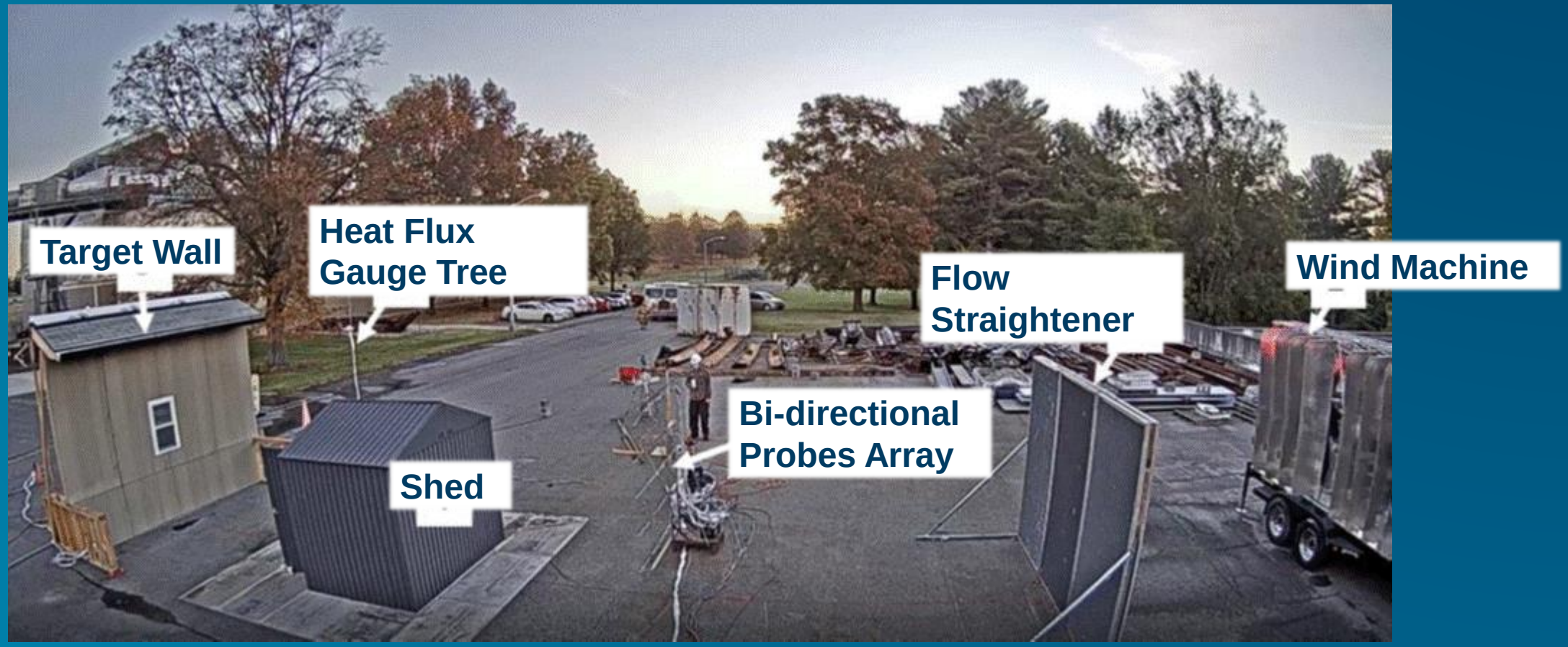
Summary contd.

Consider relative position of neighboring residence for door orientation of noncombustible steel shed.

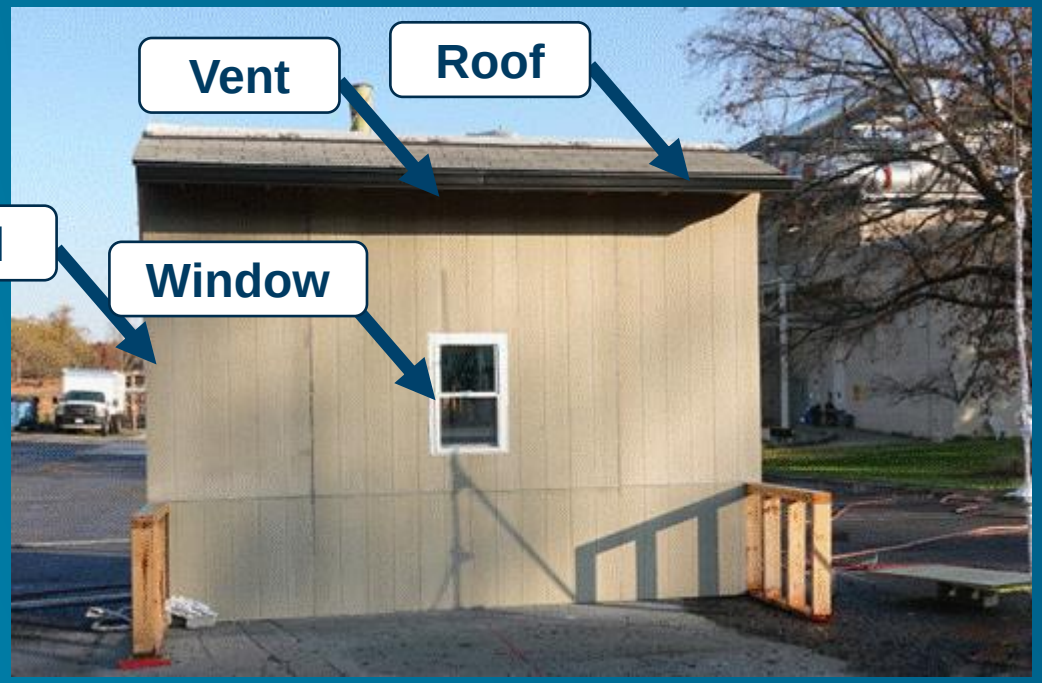


Goal: To study the effects of applied wind on thermal exposures from sheds of various sizes and composition to a target structure.

The results are used to determine the minimum Structure Separation Distance (SSDmin)



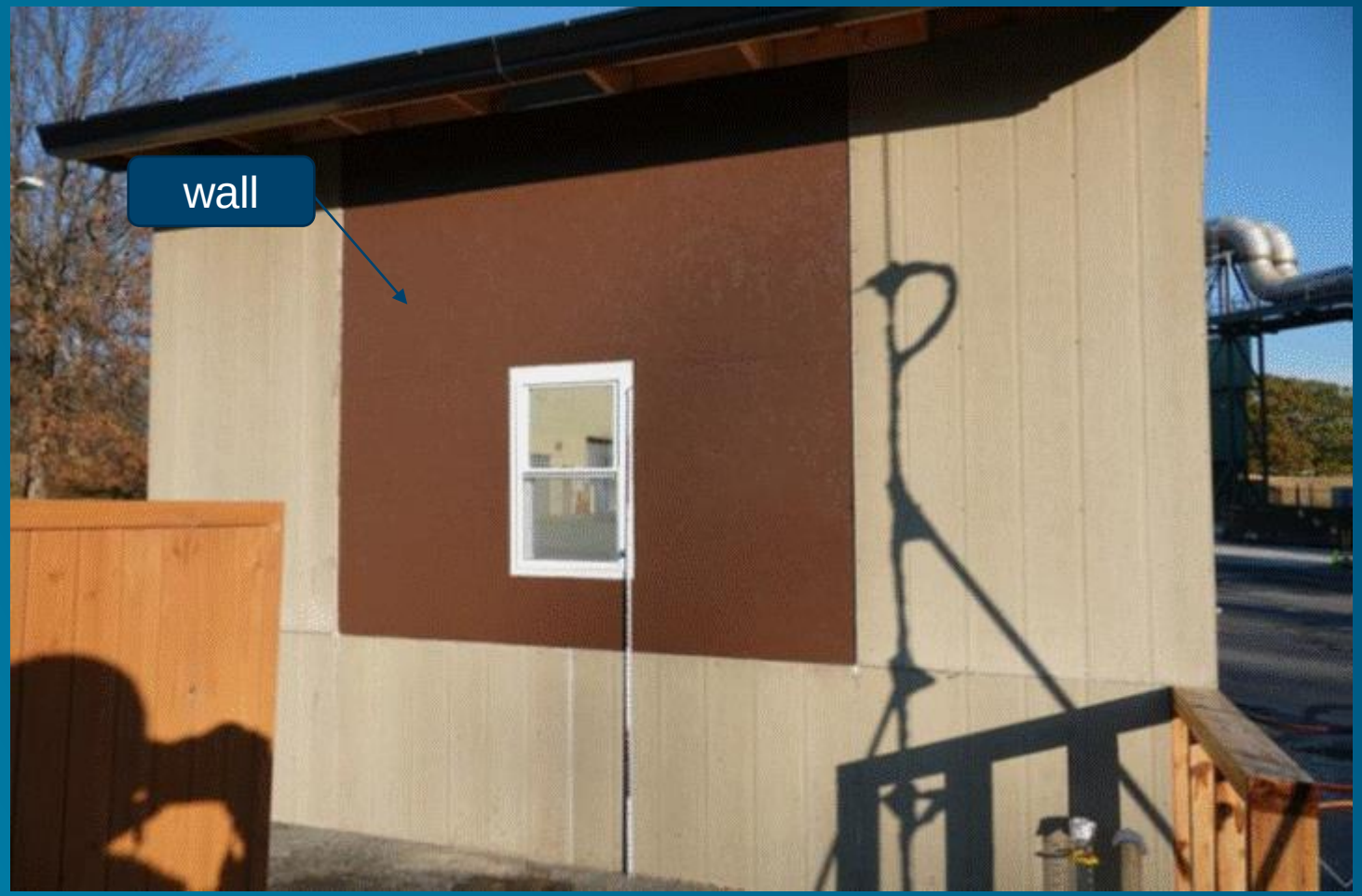
Code Compliant Target Structure



Front

Rear

Non-compliant Exterior Wall

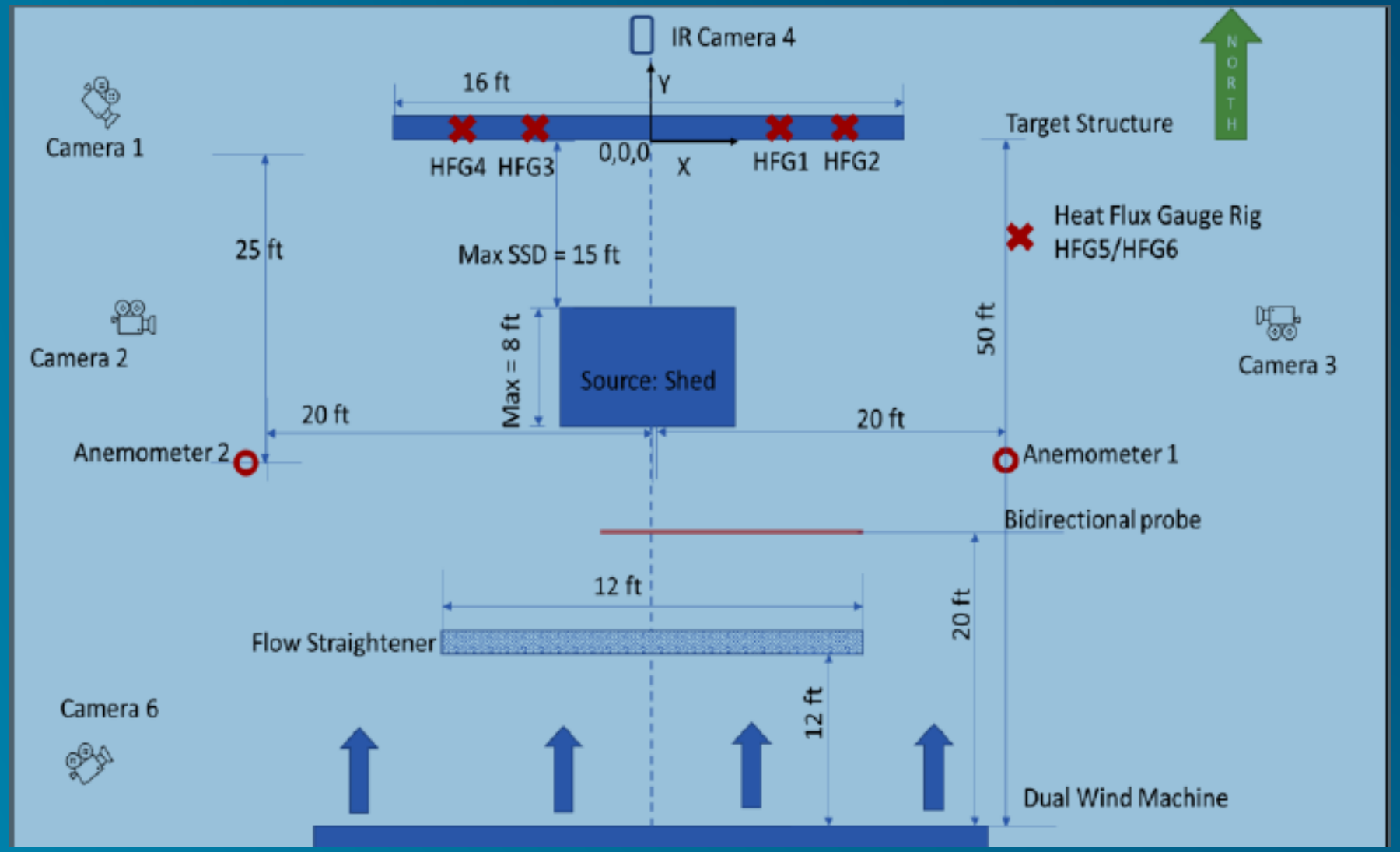


Types of Sheds

Combustible Wood Sheds

Non-Combustible Steel Sheds

Instrumentation and Data Acquisition



NIST TN 2253, Figure

Experimental Matrix

Table 7. Shed and fuel loading specifications for the sheds tested at NIST. (1ft = 0.305 m, 1 kg = 2.2 lbs)

Serial number	Test ID	Shed Type	Fuel Loading, (number of 1-A cribs)	Mass, kg			Fuel Density*, (MJ/ft²)
				Shed	Cribs	Total combustible	
NOSSE1	O-WVSh0-10	Very Small	6	76	128	203	151
NOSSE2	O-SVSh0-10	Very Small	6	42	131	131	126
NOSSE 3	O-WVShw-10	Very Small	6	72	131	203	150
NOSSE 4	O-SVShw-10	Very Small	6	42	138	138	132
NOSSE 5	O-SChw-5	Closet	4	24	95	95	122
NOSSE 6	O-WChw-10	Closet	4	50	96	146	175
NOSSE 7	O-SShw-15	Small	12	110	287	287	112
NOSSE 8	O-WShw-15	Small	12	261	283	544	156
NOSSE 9	O-SVShw-10-90° Door opening:90°	Very Small	6	42	140	140	134
NOSSE 10	O-WVShw-10-R1	Very Small	6	47	144	191	141
NOSSE 11	O-WShw-15-R1 Door opening:180°	Small	12	268	290	558	160
NOSSE 12	O-WShw-10 Door opening: 180°	Small	12	261	285	546	156
NOSSE 13§	O-WVShw-10-R2	Very Small	6	47	147	194	143

§Non-fire hardened target structure was used for this test.

* Fuel density is defined as energy per unit area of shed floor space and has units of MJ/ft².

Variables

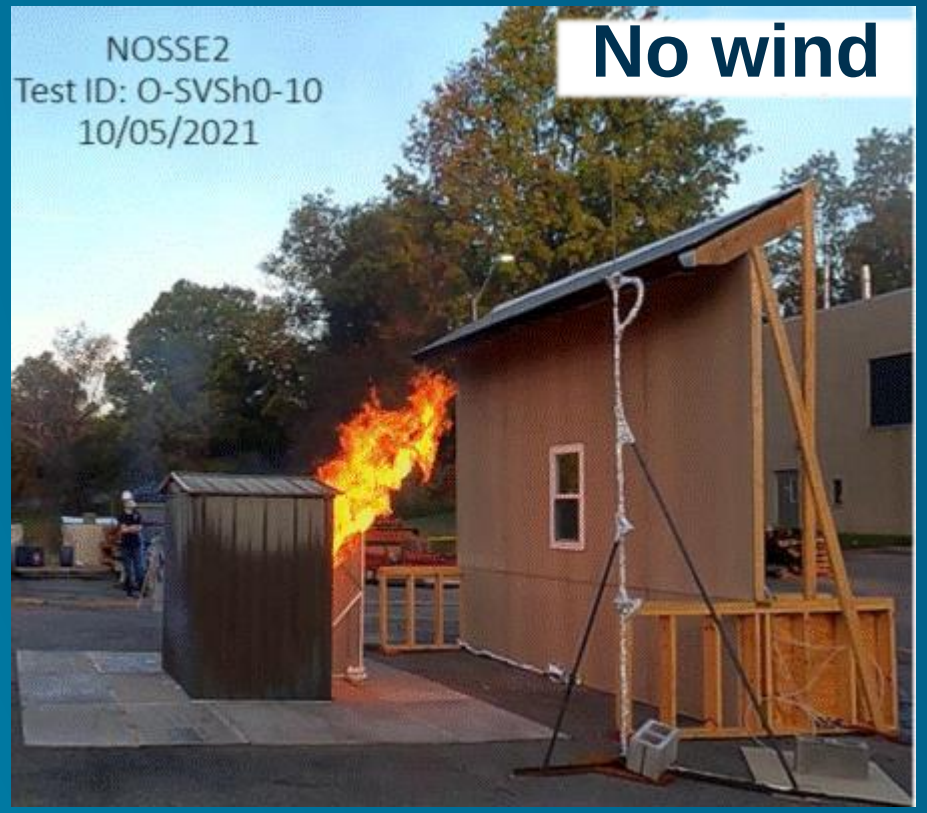
- ✓ **Wind**
- ✓ **Shed Types:**
  - **Combustible wood**
  - **Non-Combustible Steel**
- ✓ **Shed Sizes:**
  - **Very Small Shed**
  - **Small Shed**
- ✓ **Shed Orientation, Door facing**
  - **Target wall**
  - **90° to target wall**
  - **Wind machine**
- ✓ **Exterior Wall:**
  - **Code compliant**
  - **Non-compliant**

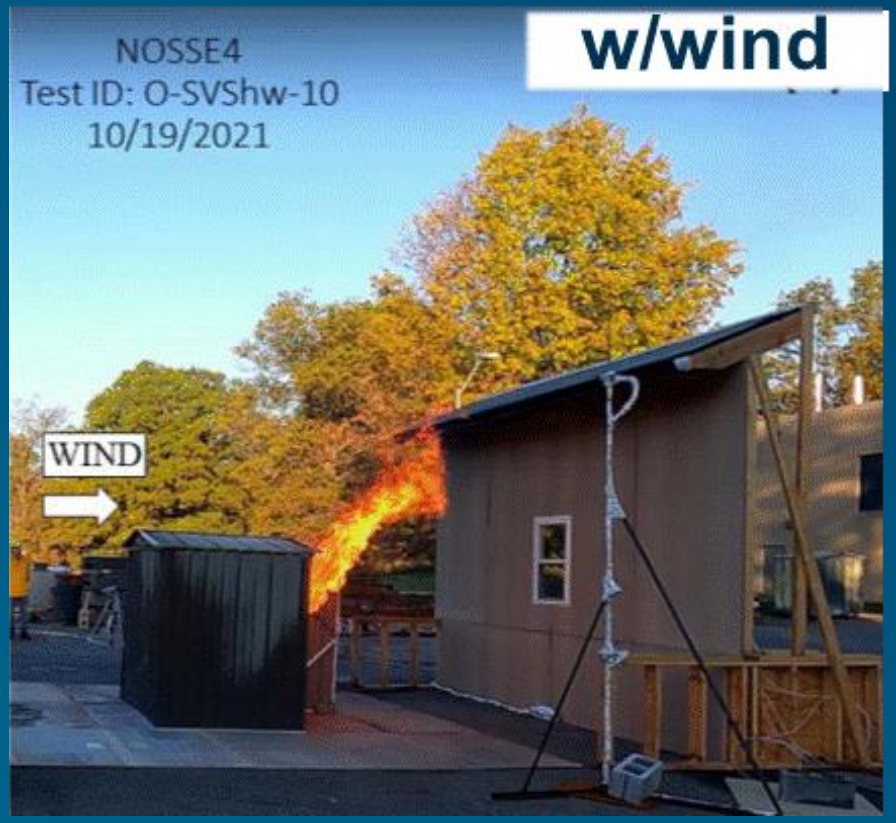
NIST TN 2253, Table 7.

Effect of Wind on Burning Behavior of Combustible Wood Shed

Significant plume lean is noted in presence of wind

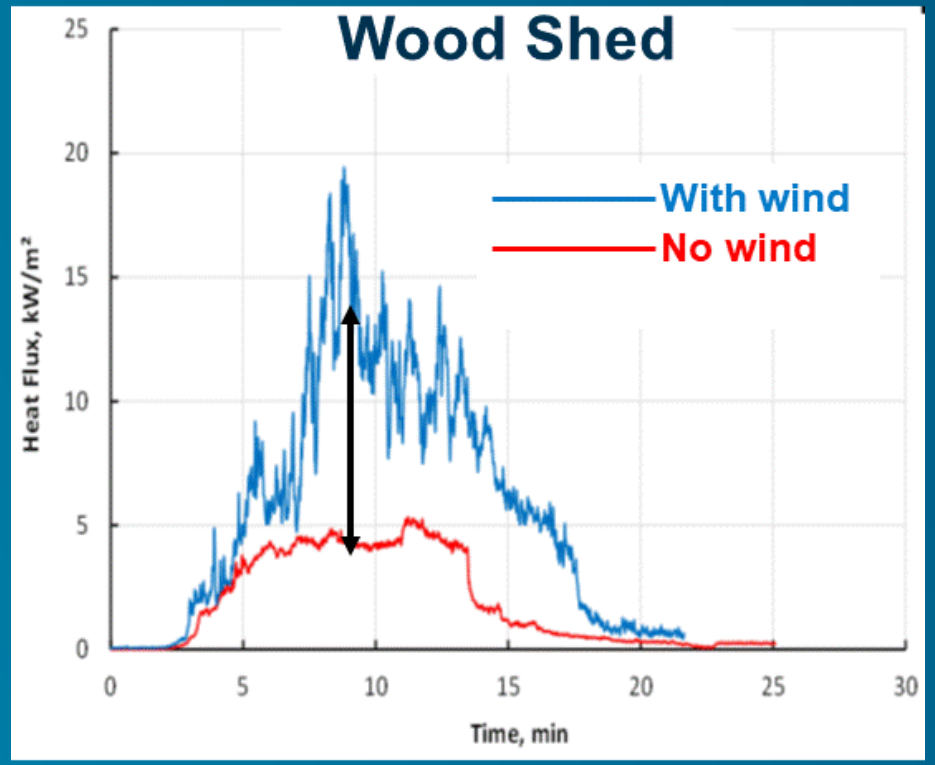
Effect of Wind on Burning Behavior of Non-Combustible Steel Shed

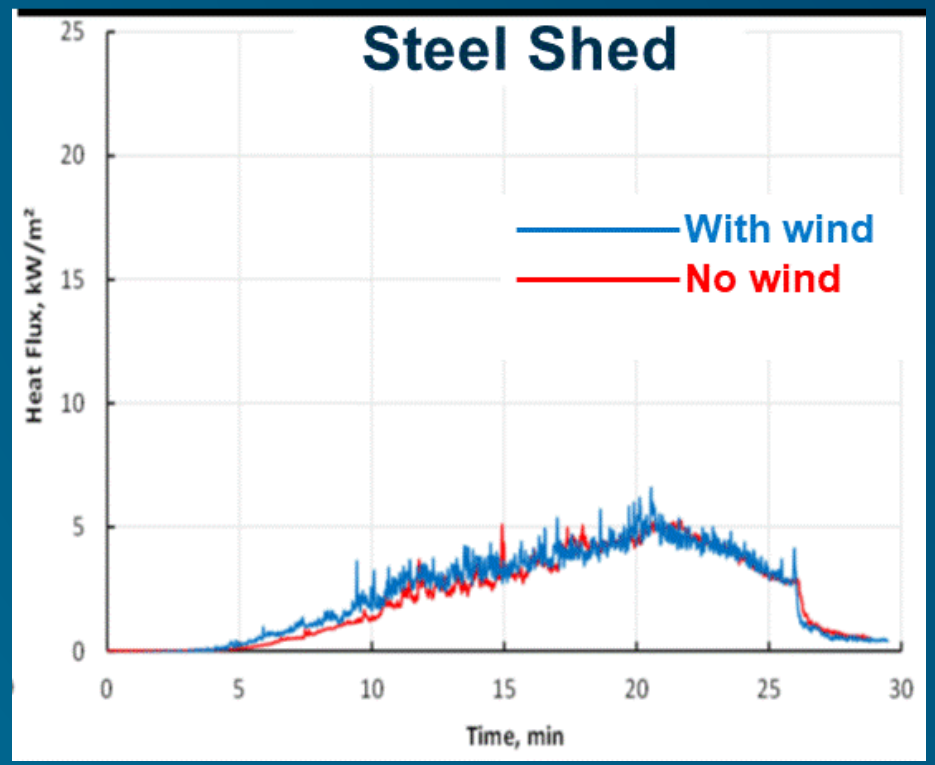




Flame jetting is a function of door opening, wind has minimal effect on flame jetting

Effect of Wind on Thermal Exposure from Combustible and Non-combustible Sheds

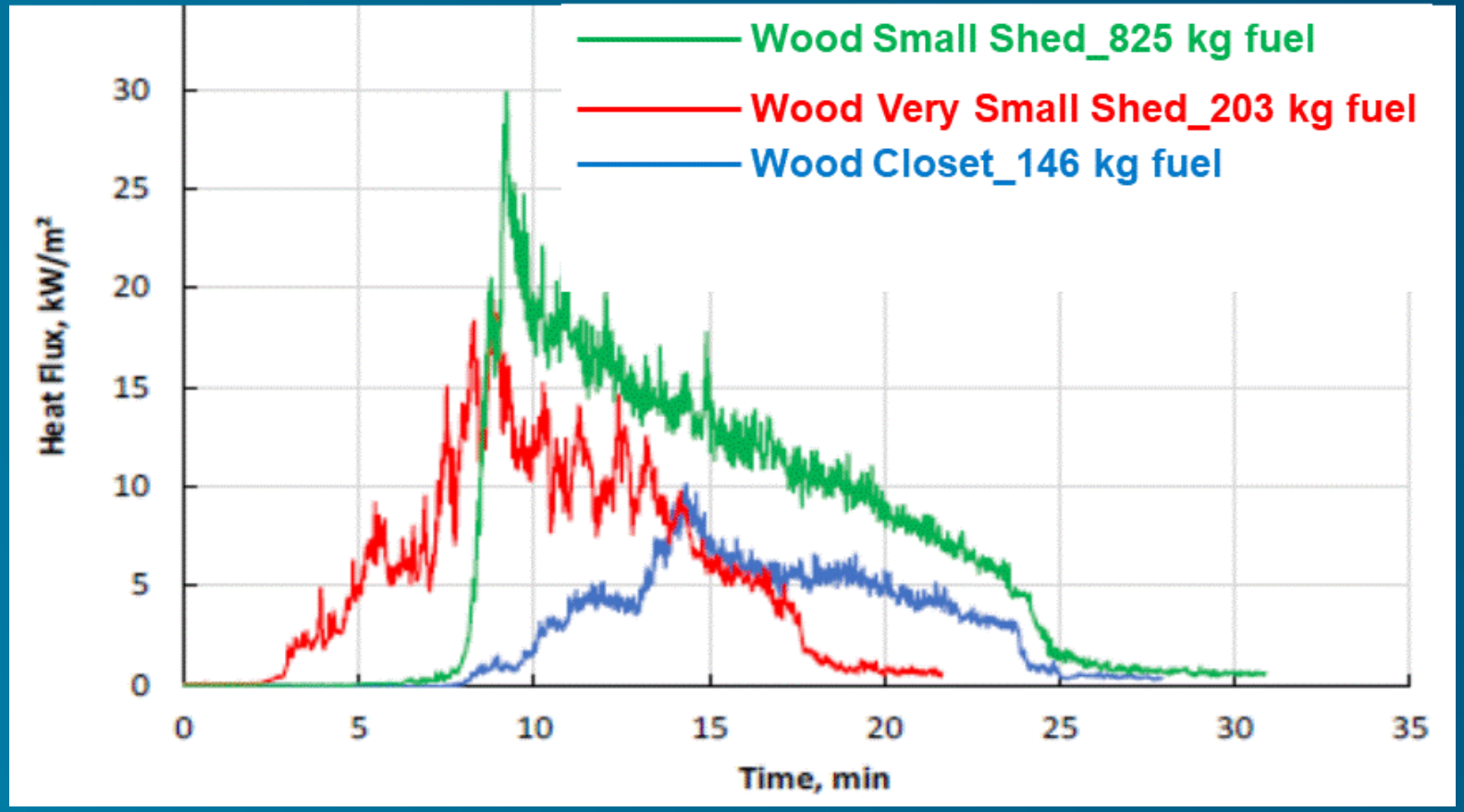




Thermal exposure from non-combustible steel shed is not affected by wind

Effect of Shed Size on Thermal Exposure to the Target Structure (SSD =10 ft)

Effect of Shed Size on Thermal Exposure to the Target Structure



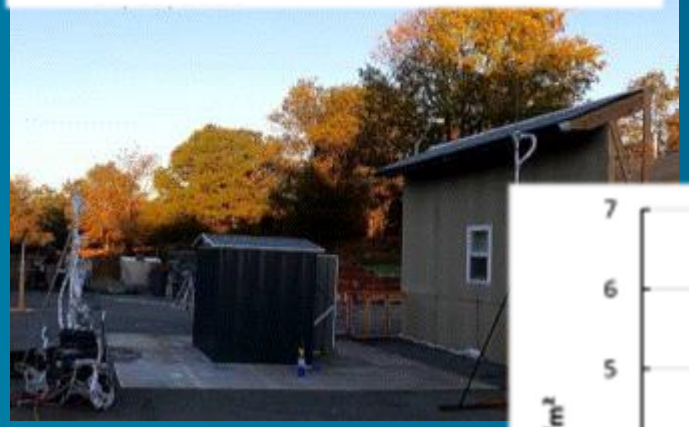
Peak thermal exposure increases with the fuel loading

Effects of Shed Orientation on Thermal Exposures (1 of 2)

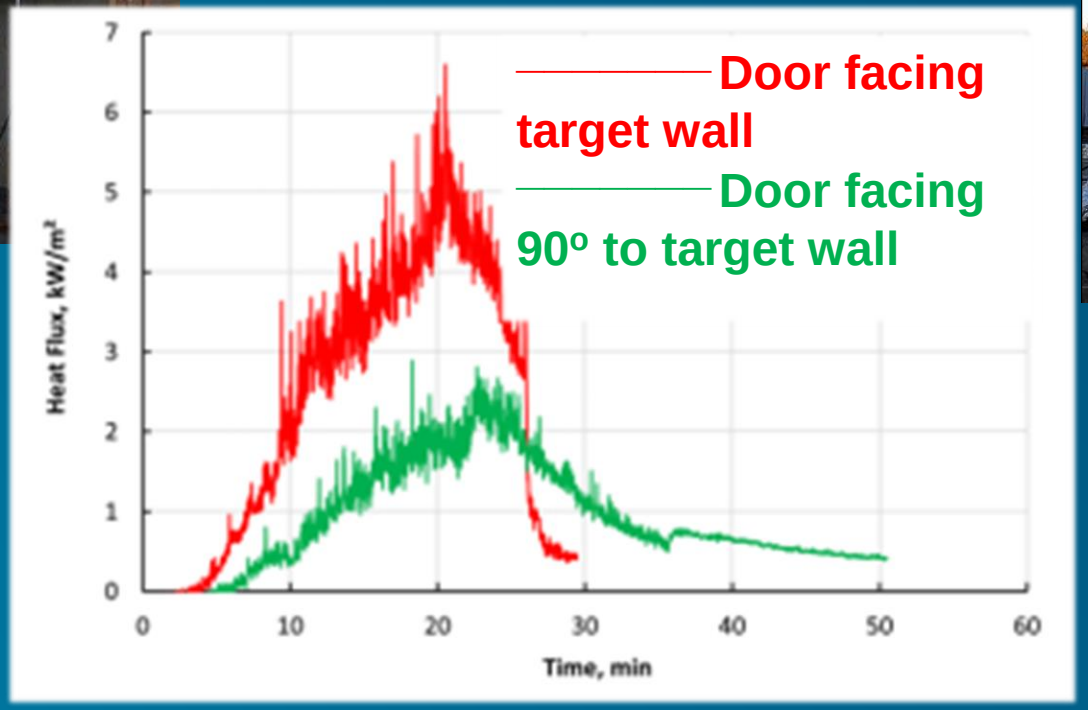
Exposure to the target structure is not affected by combustible shed orientation

Effects of Shed Orientation on Thermal Exposures (2 of 2)

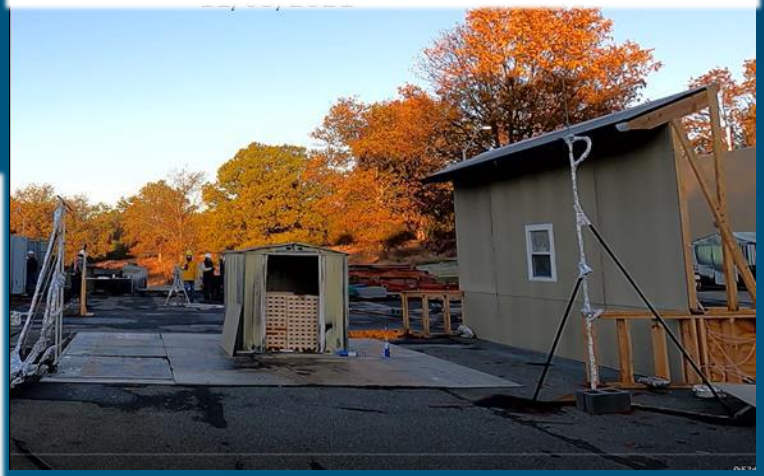
Door opening facing target wall



- ✓ Non-combustible shed
- ✓ Same SSD
- ✓ Same fuel loading

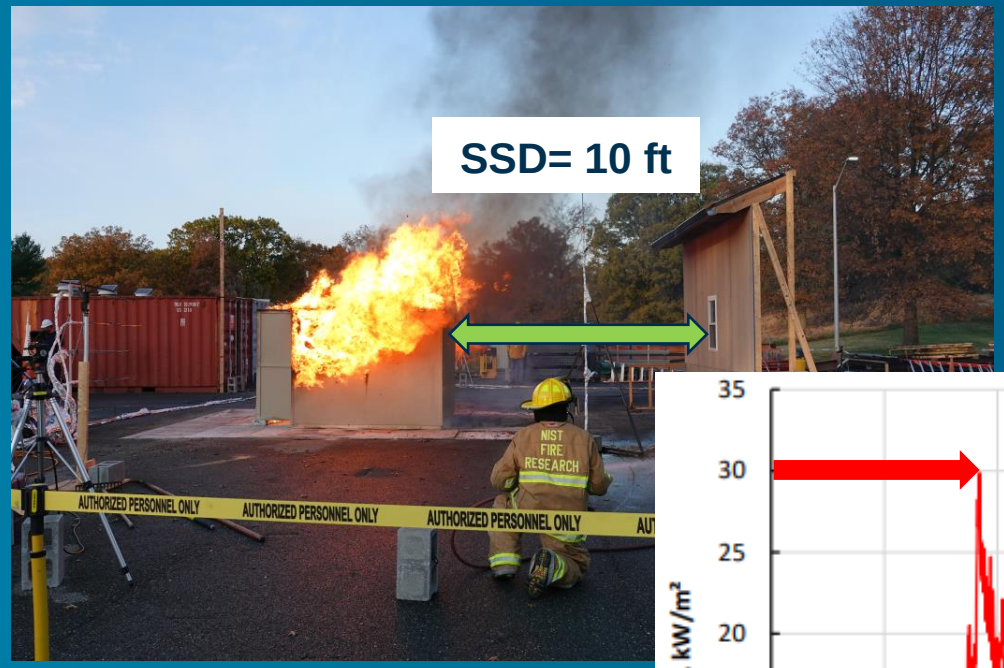


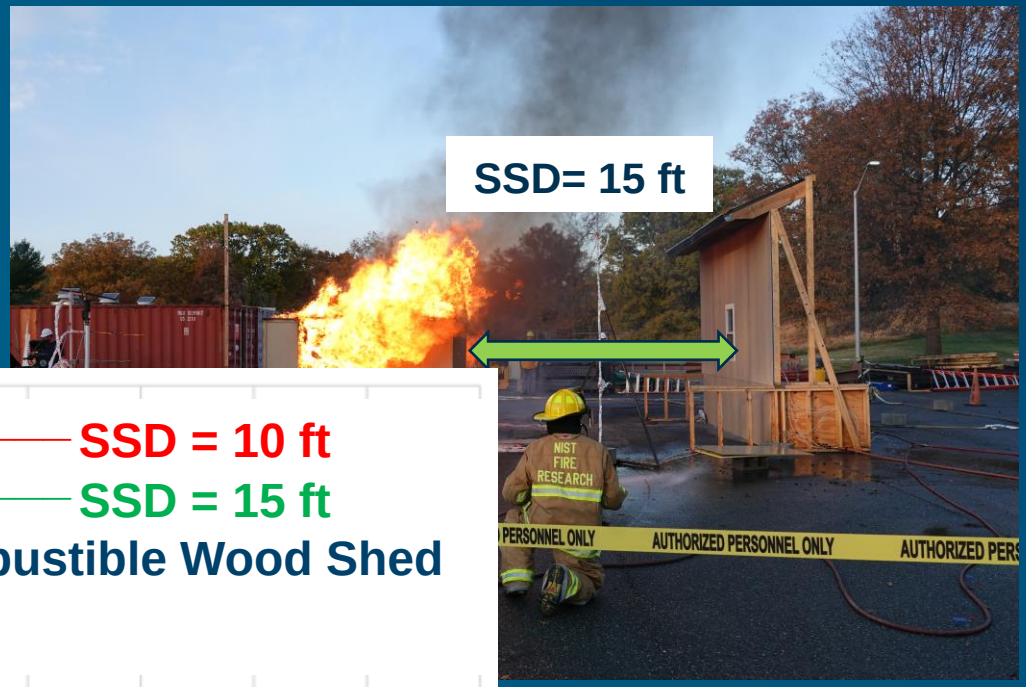
Door opening at 90° to target wall

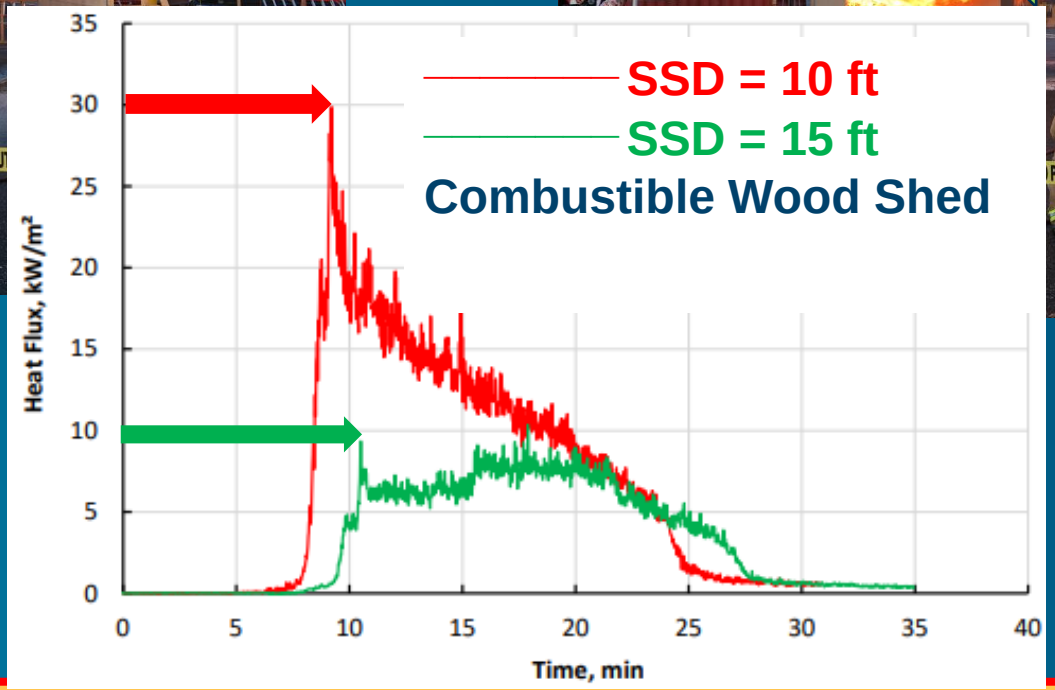


With non-combustible steel shed, exposure to the target structure can be reduced by 1/2 by changing the shed orientation

Effects of SSD on Thermal Exposures







Extra 5 ft reduced thermal exposure to the target structure by 1/3rd

Effect of Target Structure Construction Materials on Ignitability

Same exposure different outcome

Summary of target structure performance for various exposures

Serial number	Test ID	Shed Type	Target Structure Performance			
			Window	Wall	Eaves	Vent
NOSSE1	O-WVSh0-10	Very Small	Thermal deformation of vinyl frame, screen fell off	ND	ND	ND
NOSSE2	O-SVSh0-10	Very Small	ND	ND	ND	ND
NOSSE 3	O-WVShw-10	Very Small	Thermal deformation of vinyl frame, screen fell off	ND	ND	ND
NOSSE 4	O-SVShw-10	Very Small	ND	ND	ND	ND
NOSSE 5	O-SChw-5	Closet	Melting and charring of vinyl frame, screen fell off, cracking of window pane forming an opening	Cracking of cement board	ND	ND
NOSSE 6	O-WChw-10	Closet	ND	ND	ND	ND
NOSSE 7	O-SShw-15	Small	ND	ND	ND	ND
NOSSE 8	O-WShw-15	Small	ND	ND	ND	ND
NOSSE 9	O-SVShw-10-90° Door opening: 90°	Very Small	Thermal deformation of vinyl frame, screen fell off	ND	ND	ND
NOSSE 10	O-WVShw-10-R1	Very Small	Thermal deformation of vinyl frame, screen fell off	ND	ND	ND
NOSSE 11	O-WShw-15-R1 Door opening:180°	Small	ND	ND	ND	ND
NOSSE 12	O-WShw-10 Door opening: 180°	Small	Melting and charring of vinyl frame	Cracking of cement board	ND	ND
NOSSE 13	O-WVShw-10-R2	Very Small	Melting and charring of vinyl frame	Exterior wood ignited	Ignited	Failed

ND = No Damage

NIST TN 2253, Table 10

Minimum SSD estimated from shed burn experiments with applied wind (only for hardened construction)

Shed/SSD for hardened structure	0 ft	5 ft	10 ft	15 ft
Wood Closet and Very Small (up to 26 ft²)			Minimum SSD	
Wood Small shed (26 ft² to 64 ft²)				Minimum SSD
Steel Closet* and Very Small shed* (up to 20 ft²)			Minimum SSD	
Steel Small* shed (20 ft² to 64 ft²)				Minimum SSD

* Place door opening away from primary residence and neighboring residence.

NIST TN 2253, Table 11.

NOSSE Limitations

Source Structure Limitations

- Sheds were tested with representative “high” equivalent fuel loading using standard 1-A wood cribs.
- Experiments were conducted on flat ground; effects of topography on flame spread or thermal exposures to the target structure were not considered.
- Limited shed orientations with respect to target structure and wind direction were tested.
- Non-flame retarded plastic sheds that can melt and burn as pool fires have not been studied.
- Presence of ladder fuels or vehicles between the source structure and the target structure were not considered.
- Experiments do not reflect the ignition hazard associated with embers generated by the burning shed.
- Few repeated tests to confirm the minimum SSDmin.

NOSSE Limitations

Target Structure Limitations

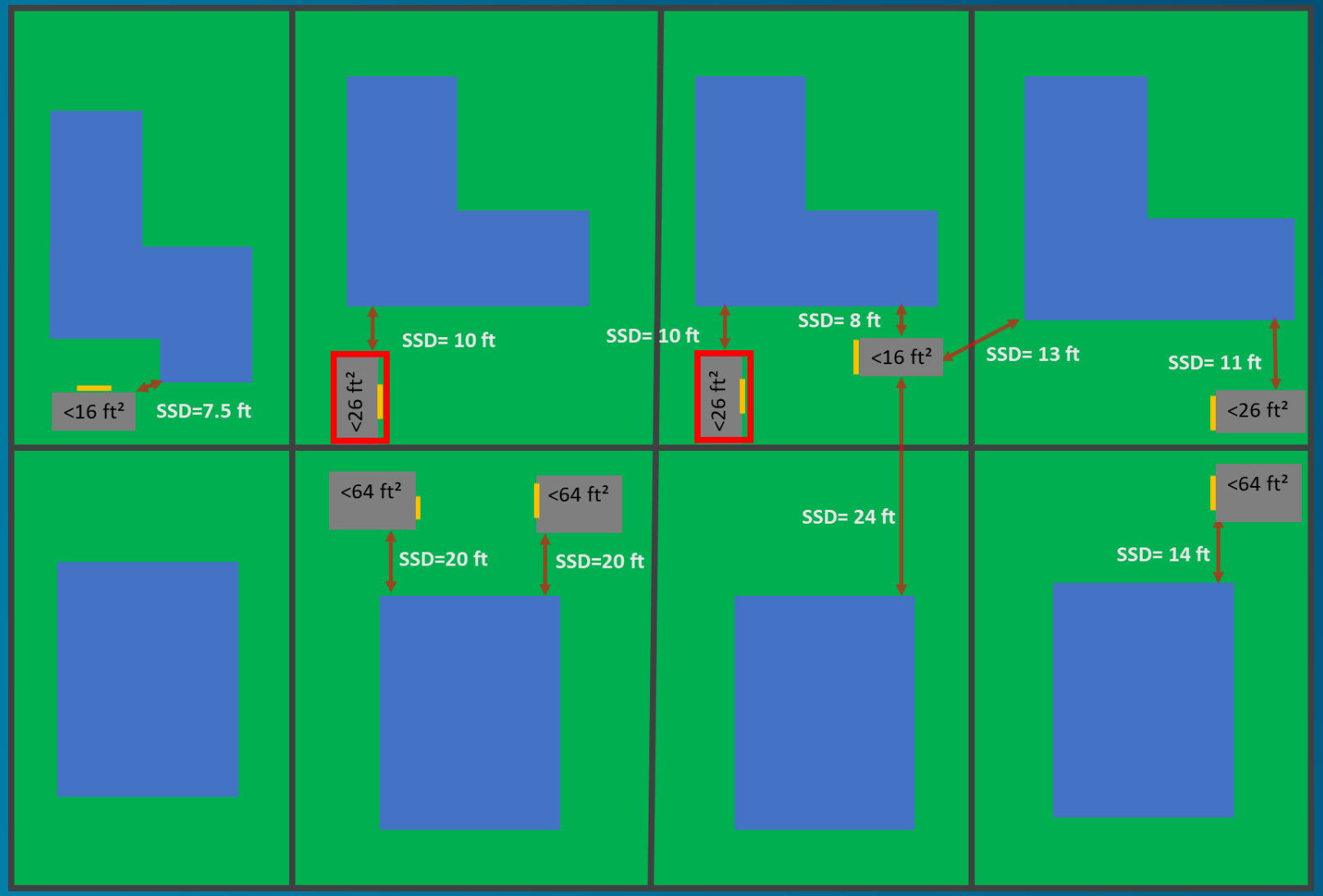
- Assumes structure hardened for ember exposures.
- Fire hardened in compliance with Chapter 7A of the California Building Code requirement (for all but one experiment).
- Single story target structure.
- Perpendicular to wind flow (limited data on various orientations).
- Simplified geometry. Corner configuration NOT tested.
- No weathering, cracking, or other deterioration of the target structure.

Implementation of Technical Findings

Case Study 1

- ✓ Reduce
- ✓ Relocate
- ✓ Remove

Case Study 1



- ✓ Reduce
- ✓ Relocate
- ✓ Remove

Case Study 2

Thank You

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Direct links to SSE reports

NISSE test plan: https://doi.org/10.6028/NIST.TN.2161

NISSE report: https://doi.org/10.6028/NIST.TN.2235

NOSSE test plan: https://doi.org/10.6028/NIST.TN.2199

NOSSE report: https://doi.org/10.6028/NIST.TN.2253

Technical Findings

- Repeat experiment showed good reproducibility of the measured quantities.
- Combustible wood sheds:
  - consumed in the fire, resulting in higher thermal exposure to the target structure as opposed to noncombustible sheds.
  - thermal exposure is not affected by orientation (i.e., door opening facing downwind or upwind).
  - wind had complex effects on the burning behavior causing turbulence and eddies.
- Noncombustible sheds:
  - applied wind had minimal or no effect on thermal exposure to the target structure.
  - contained the fire effectively, thus reducing, but not eliminating, the thermal exposure to the target structure.
  - thermal exposure to the target structure can be reduced by half by changing the orientation of the door opening 90° away from the target structure.
- Increasing the SSD from 10 ft to 15 ft reduces thermal exposure to the target structure by 1/3rd.
- The SSD_{min} for both combustible and noncombustible sheds
  - with floor area < 26 ft^2 (Closets and Very Small Sheds) was determined to be 10 ft.
  - with floor area between 26 ft^2 and 64 ft^2 (Small Sheds) was determined to be 15 ft.
- A non-fire hardened target structure ignited within 6 mins, the fire hardened target structure exhibited minimal thermal damage and significant ignition resistance when exposed to similar thermal exposure.

Case Study 3