NIST Technical Note 1953

Propane Gas Fire Experiments in Residential Scale Structures

Joseph M. Willi

This publication is available free of charge from: https://doi.org/10.6028/NIST.TN.1953



NIST Technical Note 1953

Propane Gas Fire Experiments in Residential Scale Structures

Joseph M. Willi Fire Research Division Engineering Laboratory

This publication is available free of charge from: https://doi.org/10.6028/NIST.TN.1953

February 2017



National Institute of Standards and Technology Kent Rochford, Acting NIST Director and Under Secretary of Commerce for Standards and Technology Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

National Institute of Standards and Technology Technical Note 1953 Natl. Inst. Stand. Technol. Tech. Note 1953, 42 pages (February 2017) CODEN: NTNOEF

This publication is available free of charge from: https://doi.org/10.6028/NIST.TN.1953

Contents

Contents	i
List of Figures	ii
List of Tables	iii
List of Acronyms	iv
1 Introduction	1
2 Experimental Setup 2.1 Test Structures 2.1.1 Construction 2.1.2 Layout 2.2 Instrumentation 2.2.1 East Structure 2.2.2 West Structure 2.2.3 Measurement Uncertainty	2 2 5 7 8 14 21
3 Experimental Procedure 3.1 East Structure Tests 3.1.1 Tests 2–4 3.1.2 Tests 5 & 6 3.2 West Structure Tests 3.2.1 Tests 22 & 23 3.2.2 Tests 24 & 25	 23 23 23 25 28 28 28 28
4 Summary	31
Acknowledgments	32
References	33

List of Figures

2.1	North side of the East and West Structures.	3
2.2	Ceiling support of the West Structure.	4
2.3	Dimensioned floor plan of the East Structure.	5
2.4	Dimensioned floor plans of the West Structure.	6
2.5	Instrumentation legend.	7
2.6	Three propane burners used as the fuel source.	8
2.7	Locations and labels of instrumentation in the East Structure	9
2.8	Bi-directional probe plus solid thermocouple arrays in East Structure	0
2.9	Locations and labels of instrumentation in the West Structure.	20
3.1	Tests 2–4 layout and event times	24
3.2	Test 5 layout and event times.	26
3.3	Test 6 layout and event times.	27
3.4	Tests 22–23 layout and event times.	29
3.5	Tests 24–25 layout and event times.	30

List of Tables

2.1	East Structure Channel List	11
2.2	West Structure Channel List	14
3.1	Heat Release Rates for Tests 5 and 6	25

List of Acronyms

PPA	Positive Pressure Attack
PPV	Positive Pressure Ventilation
NIST	National Institute of Standards and Technology
OSB	Oriented Strand Board
TJI	Truss Joist I-beams
UL FSRI	Underwriters Laboratories Firefighter Safety Research Institute

Abstract

Nine full-scale fire experiments were conducted in two residential-scale structures to measure the effect of passive and forced ventilation on the fire conditions. The fires were fueled by three propane burners. Five of the experiments were conducted in a single-story structure, and four were conducted in a two-story structure. The structures were instrumented to measure temperature, gas velocity, heat flux, and oxygen, carbon dioxide, and carbon monoxide concentrations. Various doors and vents were opened and closed during the experiments to provide passive horizontal and vertical ventilation. A fan was used to provide forced ventilation. This report contains detailed descriptions of the setup and procedure used for each of the nine experiments.

Section 1

Introduction

The Fire Fighting Technology Group of the Fire Research Division at the National Institute of Standards and Technology (NIST) develops and applies technology, measurements, and standards to improve the understanding of fire behavior, prevention and suppression, which ultimately enables advances in fire fighting operations, firefighter equipment, fire suppression, fire investigations, and disaster response. One function of the group is to conduct research to enhance the understanding of fire fighting tactics and how they affect the fire environment.

The development and behavior of compartment fires, such as a fire inside a residential structure, depend greatly on the ventilation conditions within the compartment. There are a variety of tactics used by firefighters that can affect the ventilation of a fire environment. For example, firefighters may open different doors and windows within a structure or cut holes in the roof to remove hot gases and smoke. Additionally, firefighters sometimes employ a tactic known as "positive pressure attack" (PPA) or "positive pressure ventilation" (PPV) in an attempt to improve the tenability of the fire environment. PPA/PPV involves using a fan aimed at an opening of a structure and is intended to force fresh air into the structure and force hot gases and smoke out through a separate exterior vent.

Nine full-scale fire experiments were performed to study how the tactics described above affect ventilation and the fire environment within a structure. The experiments were conducted in two structures designed to replicate typical residential dwellings. During each experiment, propane was provided to three diffusion flame burners. Local measurements of temperature, gas velocity, heat flux, and gas concentrations were collected at various locations throughout the structure while the ventilation within the structure was varied by opening and closing certain doors and vents. During a number of the tests, a PPV fan was used in conjunction with the opening and closing of vents to further affect the ventilation conditions within the fire environment. This report contains in-depth descriptions of the setup and procedure used for each of the nine experiments.

Section 2

Experimental Setup

The series of field experiments described in this report were conducted in two structures of similar design located at the Delaware County Emergency Services Training Center in Sharon Hill, Penn-sylvania. Three propane burners were used to fuel the fire for all experiments, and various sensors were used to collect gas temperature, gas velocity, heat flux, and gas concentration measurements throughout the structure.

2.1 Test Structures

2.1.1 Construction

Each test structure was built on a concrete slab as shown in Fig. 2.1. The East Structure was designed to simulate a single-story residential structure, and the West Structure was designed to simulate a two-story residential structure.

First Floor of Both Structures

The first floor of each structure had outer walls composed of interlocking concrete blocks measuring 0.6 m (2.0 ft) wide, 0.6 m (2.0 ft) high, and 1.2 m (4.0 ft) long. The joints and gaps between the blocks were filled with high temperature insulation. All doors along the outer walls were composed of steel.

The first floor interior walls of each structure were framed with steel studs set to 400 mm (16 in) centers and track. Two layers of 16 mm (0.63 in) Type X gypsum board lined the steel studs, and a layer of 13 mm (0.5 in) thick Durock cement board covered the gypsum board. The interior ceiling of each structure was covered by two layers of 13 mm (0.5 in) thick Durock cement board.



Figure 2.1: North side of the East Structure (top) and West Structure (bottom).

The first floor ceiling support of each structure was composed of wood truss joist I-beams (TJIs). Each TJI had a depth of 298 mm (11.75 in) and contained laminated veneer lumber flanges with a cross section of 29 mm (1.13 in) by 44 mm (1.75 in) and an 11 mm (0.43 in) thick oriented strand board (OSB) web as shown in Fig. 2.2. A layer of 18.3 mm (0.72 in) thick tongue and groove OSB was attached to the top of the TJIs.



Figure 2.2: First floor ceiling support of the West Structure composed of wood truss joist I-beams. View is of the southeast corner of the structure.

Second Floor of West Structure

The second floor of the West Structure was built on the structure's first floor wood ceiling support. The two floors were connected by an interior stairwell. A door made of lauan plywood was located at the top of the stairwell. The walls on the second floor were of wood-frame with 51 mm (2 in) by 102 mm (4 in) studs set to 400 mm (16 in) centers. Two layers of 16 mm (0.63 in) Type X gypsum board lined the interior side of the wood studs, and a layer of 13 mm (0.5 in) thick Durock cement board covered the gypsum board. The interior ceiling of the second story was covered by two layers of 13 mm (0.5 in) thick Durock cement board. The exterior sides of the outer walls on the second floor were protected by 11 mm (0.44 in) thick OSB and 8 mm (0.31 in) fiber cement lap siding.

Leakage

An air leakage measurement system was used to measure the leakage area associated with each structure. The leakage area in the East Structure was measured as 0.024 m^2 . For the West Structure, the leakage was measured as 0.027 m^2 when the stairway door was fully closed, 0.054 m^2 when the stairway door was fully closed, 0.054 m^2 when the stairway door was in the "closed" position (having a 152 mm (6 in) gap between the door and the frame) used Tests 24 and 25.

2.1.2 Layout

Dimensioned floor plans of the East and West Structures are presented in Figs. 2.3 and 2.4, respectively.



Figure 2.3: Dimensioned floor plan of the East Structure. Structure dimensions are symmetric across horizontal centerline.



Figure 2.4: Dimensioned floor plan of the second floor (top) and first floor (bottom) of the West Structure.

The exterior doors of both structures, the stairwell door in the West Structure, and the square roof vent with a depth of 320 mm (12.75 in) in the East Structure were opened and closed at certain instances during the experiments to change the ventilation patterns within the structures.

2.2 Instrumentation

The structures were instrumented for temperature, gas velocity, heat flux, and gas concentration measurements. Gas temperatures in the burn rooms were measured with bare-bead, Chromel-Alumel (type K) thermocouples. Additional single thermocouples were installed in conjunction with bi-directional probes for gas velocity measurements. The single thermocouples were bare-bead, Chromel-Alumel (type K) thermocouples with a 1.0 mm (0.04 in) nominal diameter. The thermocouple wire was protected with a 3.2 mm (0.13 in) diameter inconel sheath. Schmidt-Boelter gauges were used to measure both total heat flux and radiant heat flux (radiometer). A radiometer is a total heat flux gauge with a zirconium window to prevent contributions from convective heat transfer. Calibrated pumps pulled gas samples through a sample conditioning system to eliminate moisture in the sample. Then, the dry gas samples were piped to a series of gas analyzers and the concentrations of oxygen, carbon monoxide, and carbon dioxide were measured. A legend is presented in Fig. 2.5 to clarify the instrumentation schematics presented in the follow sections.



Figure 2.5: Legend used for schematics of instrumentation locations.

Three diffusion flame burners, pictured in Fig. 2.6, were used as the fuel source in each experiment. Each burner had a square opening of side length 0.6 m (2 ft) located 0.14 m (5.5 in) above the floor and were positioned 0.6 m (2 ft) from the south and west walls on the first floor of each structure. Propane was supplied to the burners during all experiments. The flow of propane to each burner was controlled by a high-precision turn valve, and the total displaced gas volume was measured using a rotary gas meter.



Figure 2.6: Three propane burners located 0.6 m (2 ft) off the south and west interior walls on the first floor that provided the fire source for the experiments.

2.2.1 East Structure

The East Structure was instrumented with five bare-bead thermocouple arrays, four bi-directional probe plus solid thermocouple arrays, five total heat flux plus radiometer sensor pairs, and two gas sample inlet pipes at the locations shown in Fig. 2.7.



Figure 2.7: Locations and labels of instrumentation in the East Structure.

Each bare-bead thermocouple array was composed of eight thermocouples. Three bi-directional probe and solid thermocouple arrays (A7, A8, and A9) were centered in the exterior doorways of the structure and contained eight probes as shown in Fig. 2.8. The fourth bi-directional probe and solid thermocouple array (A10), also presented in Fig. 2.8, was located at the opening of the roof vent, 320 mm (12.75 in) above the compartment ceiling. The array contained three probes centered between the east and west sides of the vent. The position of each probe and thermocouple pair relative to the south wall of the vent is listed in the channel list presented in Table 2.1. The total heat flux gauge/radiometer pairs were aimed to view the ceiling. Gas samples were pulled through 9.5 mm (0.38 in) diameter stainless steel tubing. The height of each individual sensor in the sensor arrays is listed in Table 2.1.



Figure 2.8: Bi-directional probe plus solid thermocouple array at the south exterior doorway (top) and roof vent (bottom) of the East Structure.

Device Location	Channel Name	Channel Location	Measurement Type
	TC_A1_1	0.03 m below ceiling	Temperature
	TC_A1_2	0.30 m below ceiling	Temperature
	TC_A1_3	0.61 m below ceiling	Temperature
	TC_A1_4	0.91 m below ceiling	Temperature
	TC_A1_5	1.22 m below ceiling	Temperature
	TC_A1_6	1.52 m below ceiling	Temperature
A1	TC_A1_7	1.83 m below ceiling	Temperature
	TC_A1_8	2.13 m below ceiling	Temperature
	HF_A1	0.15 m above floor	Total heat flux
	RAD_A1	0.15 m above floor	Radiative heat flux
	CO_A	1.22 m above floor	CO concentration
	CO2_A	1.22 m above floor	CO ₂ concentration
	02_A	1.22 m above floor	O ₂ concentration
	TC_A2_1	0.03 m below ceiling	Temperature
	TC_A2_2	0.30 m below ceiling	Temperature
	TC_A2_3	0.61 m below ceiling	Temperature
	TC_A2_4	0.91 m below ceiling	Temperature
12	TC_A2_5	1.22 m below ceiling	Temperature
AZ	TC_A2_6	1.52 m below ceiling	Temperature
	TC_A2_7	1.83 m below ceiling	Temperature
	TC_A2_8	2.13 m below ceiling	Temperature
	HF_A2	0.15 m above floor	Total heat flux
	RAD_A2	0.15 m above floor	Radiative heat flux
	TC_A3_1	0.03 m below ceiling	Temperature
	TC_A3_2	0.30 m below ceiling	Temperature
	TC_A3_3	0.61 m below ceiling	Temperature
	TC_A3_4	0.91 m below ceiling	Temperature
13	TC_A3_5	1.22 m below ceiling	Temperature
AJ	TC_A3_6	1.52 m below ceiling	Temperature
	TC_A3_7	1.83 m below ceiling	Temperature
	TC_A3_8	2.13 m below ceiling	Temperature
	HF_A3	0.15 m above floor	Total heat flux
	RAD_A3	0.15 m above floor	Radiative heat flux

Table 2.1: East Structure Channel List

Device Location	Channel Name	Channel Location	Measurement Type
	TC_A4_1	0.03 m below ceiling	Temperature
	TC_A4_2	0.30 m below ceiling	Temperature
	TC_A4_3	0.61 m below ceiling	Temperature
	TC_A4_4	0.91 m below ceiling	Temperature
	TC_A4_5	1.22 m below ceiling	Temperature
	TC_A4_6	1.52 m below ceiling	Temperature
A4	TC_A4_7	1.83 m below ceiling	Temperature
	TC_A4_8	2.13 m below ceiling	Temperature
	HF_A4	0.15 m above floor	Total heat flux
	RAD_A4	0.15 m above floor	Radiative heat flux
	CO_B	1.22 m above floor	CO concentration
	CO2_B	1.22 m above floor	CO ₂ concentration
	O2_B	1.22 m above floor	O ₂ concentration
	TC_A5_1	0.03 m below ceiling	Temperature
	TC_A5_2	0.30 m below ceiling	Temperature
	TC_A5_3	0.61 m below ceiling	Temperature
	TC_A5_4	0.91 m below ceiling	Temperature
A 5	TC_A5_5	1.22 m below ceiling	Temperature
AJ	TC_A5_6	1.52 m below ceiling	Temperature
	TC_A5_7	1.83 m below ceiling	Temperature
	TC_A5_8	2.13 m below ceiling	Temperature
	HF_A5	0.15 m above floor	Total heat flux
	RAD_A5	0.15 m above floor	Radiative heat flux
	TC_A7_1	0.08 m below soffit	Temperature
	TC_A7_2	0.34 m below soffit	Temperature
	TC_A7_3	0.61 m below soffit	Temperature
	TC_A7_4	0.88 m below soffit	Temperature
	TC_A7_5	1.15 m below soffit	Temperature
	TC_A7_6	1.42 m below soffit	Temperature
	TC_A7_7	1.68 m below soffit	Temperature
17	TC_A7_8	1.95 m below soffit	Temperature
A/	BDP_A7_1	0.08 m below soffit	Velocity
	BDP_A7_2	0.34 m below soffit	Velocity
	BDP_A7_3	0.61 m below soffit	Velocity
	BDP_A7_4	0.88 m below soffit	Velocity
	BDP_A7_5	1.15 m below soffit	Velocity
	BDP_A7_6	1.42 m below soffit	Velocity
	BDP_A7_7	1.68 m below soffit	Velocity
	BDP_A7_8	1.95 m below soffit	Velocity

Table 2.1: East Structure Channel List (continued)

Device Location	Channel Name	Channel Location	Measurement Type
	TC_A8_1	0.08 m below soffit	Temperature
	TC_A8_2	0.34 m below soffit	Temperature
	TC_A8_3	0.61 m below soffit	Temperature
	TC_A8_4	0.88 m below soffit	Temperature
	TC_A8_5	1.15 m below soffit	Temperature
	TC_A8_6	1.42 m below soffit	Temperature
	TC_A8_7	1.68 m below soffit	Temperature
18	TC_A8_8	1.95 m below soffit	Temperature
Ao	BDP_A8_1	0.08 m below soffit	Velocity
	BDP_A8_2	0.34 m below soffit	Velocity
	BDP_A8_3	0.61 m below soffit	Velocity
	BDP_A8_4	0.88 m below soffit	Velocity
	BDP_A8_5	1.15 m below soffit	Velocity
	BDP_A8_6	1.42 m below soffit	Velocity
	BDP_A8_7	1.68 m below soffit	Velocity
	BDP_A8_8	1.95 m below soffit	Velocity
	TC_A9_1	0.08 m below soffit	Temperature
	TC_A9_2	0.34 m below soffit	Temperature
	TC_A9_3	0.61 m below soffit	Temperature
	TC_A9_4	0.88 m below soffit	Temperature
	TC_A9_5	1.15 m below soffit	Temperature
	TC_A9_6	1.42 m below soffit	Temperature
	TC_A9_7	1.68 m below soffit	Temperature
٨٥	TC_A9_8	1.95 m below soffit	Temperature
Α,	BDP_A9_1	0.08 m below soffit	Velocity
	BDP_A9_2	0.34 m below soffit	Velocity
	BDP_A9_3	0.61 m below soffit	Velocity
	BDP_A9_4	0.88 m below soffit	Velocity
	BDP_A9_5	1.15 m below soffit	Velocity
	BDP_A9_6	1.42 m below soffit	Velocity
	BDP_A9_7	1.68 m below soffit	Velocity
	BDP_A9_8	1.95 m below soffit	Velocity
	TC_A10_1	0.91 m from S side of vent	Temperature
	TC_A10_2	0.61 m from S side of vent	Temperature
A 10	TC_A10_3	0.30 m from S side of vent	Temperature
A1 V	BDP_A10_1	0.91 m from S side of vent	Velocity
	BDP_A10_2	0.61 m from S side of vent	Velocity
	BDP_A10_3	0.30 m from S side of vent	Velocity

Table 2.1: East	Structure	Channel	List ((continued))

2.2.2 West Structure

The first floor of the West Structure was instrumented with three bare-bead thermocouple arrays, two bi-directional probe plus solid thermocouple arrays, and one gas sample inlet pipe. The second floor was equipped with three bare-bead thermocouple arrays, four bi-directional probe plus solid thermocouple arrays, two total heat flux sensor pairs, and one gas sample inlet pipe. The location of the instrumentation in the West Structure is shown in Fig. 2.9.

The thermocouple arrays and the bi-directional probe plus solid thermocouple arrays contained eight sensors per array. Gas samples were pulled through 9.5 mm (0.38 in) diameter stainless steel tubing located 1.2 m (4 ft) above the floor. Each pair of total heat flux sensors was located 1.0 m (3.3 ft) above the floor. The pair at A16 contained one sensor facing the ceiling and another facing the north side of the room, and the pair at A17 contained one sensor facing the ceiling and another facing the stairway door. The height of each individual sensor in the sensor arrays is listed in the channel list found in Table 2.2.

Device Location	Channel Name	Channel Location	Measurement Type
	TC_A1_1	0.03 m below ceiling	Temperature
	TC_A1_2	0.30 m below ceiling	Temperature
	TC_A1_3	0.61 m below ceiling	Temperature
	TC_A1_4	0.91 m below ceiling	Temperature
	TC_A1_5	1.22 m below ceiling	Temperature
A1	TC_A1_6	1.52 m below ceiling	Temperature
	TC_A1_7	1.83 m below ceiling	Temperature
	TC_A1_8	2.13 m below ceiling	Temperature
	CO_A	1.22 m above floor	CO concentration
	CO2_A	1.22 m above floor	CO ₂ concentration
	O2_A	1.22 m above floor	O ₂ concentration
	TC_A2_1	0.03 m below ceiling	Temperature
	TC_A2_2	0.30 m below ceiling	Temperature
	TC_A2_3	0.61 m below ceiling	Temperature
	TC_A2_4	0.91 m below ceiling	Temperature
A 7	TC_A2_5	1.22 m below ceiling	Temperature
A2	TC_A2_6	1.52 m below ceiling	Temperature
	TC_A2_7	1.83 m below ceiling	Temperature
	TC_A2_8	2.13 m below ceiling	Temperature

Device Location	Channel Name	Channel Location	Measurement Type
	TC_A3_1	0.03 m below ceiling	Temperature
	TC_A3_2	0.30 m below ceiling	Temperature
	TC_A3_3	0.61 m below ceiling	Temperature
	TC_A3_4	0.91 m below ceiling	Temperature
13	TC_A3_5	1.22 m below ceiling	Temperature
AJ	TC_A3_6	1.52 m below ceiling	Temperature
	TC_A3_7	1.83 m below ceiling	Temperature
	TC_A3_8	2.13 m below ceiling	Temperature
	TC_A5_1	0.08 m below soffit	Temperature
	TC_A5_2	0.34 m below soffit	Temperature
	TC_A5_3	0.61 m below soffit	Temperature
	TC_A5_4	0.88 m below soffit	Temperature
	TC_A5_5	1.15 m below soffit	Temperature
	TC_A5_6	1.42 m below soffit	Temperature
	TC_A5_7	1.68 m below soffit	Temperature
۸ 5	TC_A5_8	1.95 m below soffit	Temperature
AJ	BDP_A5_1	0.08 m below soffit	Velocity
	BDP_A5_2	0.34 m below soffit	Velocity
	BDP_A5_3	0.61 m below soffit	Velocity
	BDP_A5_4	0.88 m below soffit	Velocity
	BDP_A5_5	1.15 m below soffit	Velocity
	BDP_A5_6	1.42 m below soffit	Velocity
	BDP_A5_7	1.68 m below soffit	Velocity
	BDP_A5_8	1.95 m below soffit	Velocity

Table 2.2: West Structure Channel List (continued)

Device Location	Channel Name	Channel Location	Measurement Type
	TC_A6_1	0.08 m below soffit	Temperature
	TC_A6_2	0.34 m below soffit	Temperature
	TC_A6_3	0.61 m below soffit	Temperature
	TC_A6_4	0.88 m below soffit	Temperature
	TC_A6_5	1.15 m below soffit	Temperature
	TC_A6_6	1.42 m below soffit	Temperature
	TC_A6_7	1.68 m below soffit	Temperature
16	TC_A6_8	1.95 m below soffit	Temperature
AU	BDP_A6_1	0.08 m below soffit	Velocity
	BDP_A6_2	0.34 m below soffit	Velocity
	BDP_A6_3	0.61 m below soffit	Velocity
	BDP_A6_4	0.88 m below soffit	Velocity
	BDP_A6_5	1.15 m below soffit	Velocity
	BDP_A6_6	1.42 m below soffit	Velocity
	BDP_A6_7	1.68 m below soffit	Velocity
	BDP_A6_8	1.95 m below soffit	Velocity
	TC_A7_1	0.03 m below ceiling	Temperature
	TC_A7_2	0.30 m below ceiling	Temperature
	TC_A7_3	0.61 m below ceiling	Temperature
۸7	TC_A7_4	0.91 m below ceiling	Temperature
	TC_A7_5	1.22 m below ceiling	Temperature
	TC_A7_6	1.52 m below ceiling	Temperature
	TC_A7_7	1.83 m below ceiling	Temperature
	TC_A7_8	2.13 m below ceiling	Temperature
	TC_A8_1	0.03 m below ceiling	Temperature
	TC_A8_2	0.30 m below ceiling	Temperature
	TC_A8_3	0.61 m below ceiling	Temperature
18	TC_A8_4	0.91 m below ceiling	Temperature
AU	TC_A8_5	1.22 m below ceiling	Temperature
	TC_A8_6	1.52 m below ceiling	Temperature
	TC_A8_7	1.83 m below ceiling	Temperature
	TC_A8_8	2.13 m below ceiling	Temperature

Table 2.2: West Structure Channel List (continued)

Device Location	Channel Name	Channel Location	Measurement Type
	TC_A9_1	0.03 m below ceiling	Temperature
	TC_A9_2	0.30 m below ceiling	Temperature
	TC_A9_3	0.61 m below ceiling	Temperature
4.0	TC_A9_4	0.91 m below ceiling	Temperature
Ay	TC_A9_5	1.22 m below ceiling	Temperature
	TC_A9_6	1.52 m below ceiling	Temperature
	TC_A9_7	1.83 m below ceiling	Temperature
	TC_A9_8	2.13 m below ceiling	Temperature
	TC_A10_1	0.08 m below soffit	Temperature
	TC_A10_2	0.34 m below soffit	Temperature
	TC_A10_3	0.61 m below soffit	Temperature
	TC_A10_4	0.88 m below soffit	Temperature
	TC_A10_5	1.15 m below soffit	Temperature
	TC_A10_6	1.42 m below soffit	Temperature
	TC_A10_7	1.68 m below soffit	Temperature
	TC_A10_8	1.95 m below soffit	Temperature
	BDP_A10_1	0.08 m below soffit	Velocity
A10	BDP_A10_2	0.34 m below soffit	Velocity
	BDP_A10_3	0.61 m below soffit	Velocity
	BDP_A10_4	0.88 m below soffit	Velocity
	BDP_A10_5	1.15 m below soffit	Velocity
	BDP_A10_6	1.42 m below soffit	Velocity
	BDP_A10_7	1.68 m below soffit	Velocity
	BDP_A10_8	1.95 m below soffit	Velocity
	CO_B	1.22 m above floor	CO concentration
	CO2_B	1.22 m above floor	CO ₂ concentration
	O2_B	1.22 m above floor	O ₂ concentration

_

Device Location	Channel Name	Channel Location	Measurement Type
	TC_A11_1	0.08 m below soffit	Temperature
	TC_A11_2	0.34 m below soffit	Temperature
	TC_A11_3	0.61 m below soffit	Temperature
	TC_A11_4	0.88 m below soffit	Temperature
	TC_A11_5	1.15 m below soffit	Temperature
	TC_A11_6	1.42 m below soffit	Temperature
	TC_A11_7	1.68 m below soffit	Temperature
A 1 1	TC_A11_8	1.95 m below soffit	Temperature
AII	BDP_A11_1	0.08 m below soffit	Velocity
	BDP_A11_2	0.34 m below soffit	Velocity
	BDP_A11_3	0.61 m below soffit	Velocity
	BDP_A11_4	0.88 m below soffit	Velocity
	BDP_A11_5	1.15 m below soffit	Velocity
	BDP_A11_6	1.42 m below soffit	Velocity
	BDP_A11_7	1.68 m below soffit	Velocity
	BDP_A11_8	1.95 m below soffit	Velocity
	TC_A13_1	0.08 m below soffit	Temperature
	TC_A13_2	0.34 m below soffit	Temperature
	TC_A13_3	0.61 m below soffit	Temperature
	TC_A13_4	0.88 m below soffit	Temperature
	TC_A13_5	1.15 m below soffit	Temperature
	TC_A13_6	1.42 m below soffit	Temperature
	TC_A13_7	1.68 m below soffit	Temperature
A 1 3	TC_A13_8	1.95 m below soffit	Temperature
AIJ	BDP_A13_1	0.08 m below soffit	Velocity
	BDP_A13_2	0.34 m below soffit	Velocity
	BDP_A13_3	0.61 m below soffit	Velocity
	BDP_A13_4	0.88 m below soffit	Velocity
	BDP_A13_5	1.15 m below soffit	Velocity
	BDP_A13_6	1.42 m below soffit	Velocity
	BDP_A13_7	1.68 m below soffit	Velocity
	BDP_A13_8	1.95 m below soffit	Velocity

Table 2.2: West Structure Channel List (continued)

_

Device Location	Channel Name	Channel Location	Measurement Type
	TC_A14_1	0.08 m below soffit	Temperature
	TC_A14_2	0.34 m below soffit	Temperature
	TC_A14_3	0.61 m below soffit	Temperature
	TC_A14_4	0.88 m below soffit	Temperature
	TC_A14_5	1.15 m below soffit	Temperature
	TC_A14_6	1.42 m below soffit	Temperature
	TC_A14_7	1.68 m below soffit	Temperature
A 1 <i>1</i>	TC_A14_8	1.95 m below soffit	Temperature
A14	BDP_A14_1	0.08 m below soffit	Velocity
	BDP_A14_2	0.34 m below soffit	Velocity
	BDP_A14_3	0.61 m below soffit	Velocity
	BDP_A14_4	0.88 m below soffit	Velocity
	BDP_A14_5	1.15 m below soffit	Velocity
	BDP_A14_6	1.42 m below soffit	Velocity
	BDP_A14_7	1.68 m below soffit	Velocity
	BDP_A14_8	1.95 m below soffit	Velocity
A 16	HF_2_H	1 m above floor, facing N wall (horizontal)	Total heat flux
A10	HF_2_V	1 m above floor, facing ceiling (vertical)	Total heat flux
A17	HF_1_H	1 m above floor, facing doorway (horizontal)	Total heat flux
	HF_1_V	1 m above floor, facing ceiling (vertical)	Total heat flux

Table 2.2: West Structure Channel List (continued)

This publication is available free of charge from: https://doi.org/10.6028/NIST.TN.1953



Figure 2.9: Locations and labels of instrumentation in the second floor (top) and first floor (bottom) of the West Structure.

2.2.3 Measurement Uncertainty

This section lists the uncertainties in the reported length, mass, temperature, heat flux, gas concentration, gas velocity, and heat release rate measurements. Uncertainty estimates are based either on manufacturer literature or analyses performed by others for similar measurement devices and techniques. In accordance with NIST guidelines [1], measurement accuracy is reported as an *expanded uncertainty* or 95 % (2σ) confidence interval. Most manufacturer specifications express accuracy in terms of a *standard uncertainty* or 68 % (1σ) confidence interval.

Compartment Dimensions

Room dimensions and instrumentation array locations were made with a hand held laser measurement device with a standard uncertainty of $\pm 6.0 \text{ mm} (0.25 \text{ in})$ over a range of 0.6 m (2.0 ft) to 15 m (50.0 ft) according to the manufacturer [2]. Steel measuring tapes with a resolution of $\pm 0.5 \text{ mm}$ (0.02 in) were used to locate measurement devices. The steel measuring tapes were manufactured in compliance with NIST Manual 44, which specifies a tolerance of $\pm 1.6 \text{ mm} (0.06 \text{ in})$ for 9.1 m (30 ft) tapes and $\pm 6.4 \text{ mm} (0.25 \text{ in})$ for 30.5 m (100 ft) tapes [3]. These uncertainties are all well within the precision of the reported dimensions, which are typically rounded to the nearest 10 cm (4 in).

Thermocouples

The standard uncertainty in the temperature of the thermocouple wire itself as determined by the wire manufacturer, OMEGA Engineering, Inc., is ± 2.2 °C at 277 °C and increases to ± 9.5 °C at 871 °C [4]. The variation of the temperature in the environment surrounding the thermocouple is known to be much greater than that of the wire uncertainty. Expanded uncertainties as high as 20 % for upper layer temperatures measured by a 1 mm bare-bead type K thermocouple have been reported by NIST researchers [5, 6]. Small diameter thermocouples were used during these experiments to limit the impact of radiative heating and cooling. The estimated expanded uncertainty associated with the temperature measurements is ± 15 %.

Heat Flux Gauges

Total heat flux measurements were made with water-cooled Schmidt-Boelter gauges. The manufacturer, MEDTHERM Corporation, reports a ± 3 % calibration expanded uncertainty for these devices [7]. Results from an international study on total heat flux gauge calibration and response demonstrated that the expanded uncertainty of a Schmidt-Boelter gauge is typically ± 8 % [8].

Gas Sampling

A gas sampling system from California Analytical Instruments, Inc. (model 602P) having a relative expanded uncertainty of ± 1 % when compared to span gas volume fractions [9] was used to make gas concentration measurements. However, according to a study by Lock et al. [10], the non-uniformity and movement of exhaust gases contribute to an estimated expanded uncertainty of ± 12 %.

Bi-Directional Probes

Bi-directional probes with Setra 264 pressure transducers from Setra Systems, Inc. were used to measure gas velocity in doorways. Bryant [11] calculated an expanded uncertainty ranging from ± 14 % to ± 22 % for bi-directional probes of similar design.

Heat Release Rate

A positive displacement rotary gas meter was used to measure the volume flow rate of propane into the gas burners. The manufacturer, Romet Limited, reports a relative standard uncertainty of $\pm 2 \%$ [12] for this type of meter (model RM-3000). A volumetric flow rate was calculated from the gas meter volume readings and used in conjunction with the heat of combustion of propane to calculate the heat release rate of the fire. The total expanded uncertainty for the heat release rate obtained from this method is estimated to be $\pm 8 \%$.

Section 3

Experimental Procedure

A similar procedure was followed for all experiments described in this report. First, three propane burners were ignited in sequential order. Next, various actions, such as opening and closing doors and roof vents or turning on a fan, were performed to change the ventilation pattern within the structure. Finally, the burners were turned off and the fire was extinguished. The nine tests were conducted in series with a variety of other experiments. In order to be consistent with the original test numbering, the gas burner experiments presented in this report are referred to as Tests 2–6 and Tests 22–25.

3.1 East Structure Tests

Five different tests, Tests 2–6, were conducted in the East Structure. Table 3.1 lists the heat release rates for Tests 5 and 6. The time between the ignition of each gas burner for Tests 5 and 6 was on the order of seconds. As a result, a single heat release rate, one for all three burners ignited, is reported. The heat release rates for Tests 2–4 are not reported because they were not able to be accurately measured during the tests.

3.1.1 Tests 2-4

Tests 2–4 followed a nearly identical order of events. Fig. 3.1 includes a floor plan schematic and table of event times corresponding to the data files for each test. A 0.61 cm (2.0 ft) diameter PPV fan located 1.6 m (5.2 ft) away from the south exterior door was aimed at the center of the doorway and used during Tests 2–4. During these experiments, the south exterior door was not able to completely close due to an obstruction caused by the hoses used to transport the propane to the burners. So, when the south door was in the "closed" position, a 133 mm (5.25 in) opening was present between the door and its frame. For all other experiments, however, the south exterior door was not used and the doorway remained closed for the entirety of the test. To fully close the doorway during these tests, the hinged door was removed, and gypsum board was used to cover the doorway.

Test 2	Test 3	Test 4	
0	0	0	
181	181	179	
361	361	360	
418	416	415	
538	536	535	
604	597	597	
720	778	778	
840	898	897	
961	1018	1019	
1256	1316	1319	
1892	N/A	1380	
N/A	N/A	1487	
	Test 2 0 181 361 418 538 604 720 840 961 1256 1892 N/A	Test 2Test 3001811813613614184165385366045977207788408989611018125613161892N/AN/AN/A	

Event Times (s) for Tests 2-4 Data Files



Figure 3.1: Tests 2–4 layout and event times.

3.1.2 Tests 5 & 6

The procedures for Tests 5 and 6 are outlined in Figs. 3.2 and 3.3, respectively. Both tests involved repeating a specific set of events three times in a row. To avoid listing the identical actions three separate times in the "event" column of the tables, each repetition of events is denoted as a "sequence" (abbreviated as "seq."), and each table contains three columns of times—one for each sequence.

Test	Heat Release Rate (kW) All Burners On
Test 5 - Seq. 1	1190
Test 5 - Seq. 2	1190
Test 5 - Seq. 3	1190
Test 6 - Seq. 1	1190
Test 6 - Seq. 2	1190
Test 6 - Seq. 3	1180

Table 3.1: Heat Release Rates for Tests 5 and 6

Event	Seq. 1	Seq. 2	Seq. 3
(1) All burners on	0	1225	2425
(2) Roof vent opened	154	1345	2545
(3) West double door opened	175	1432	2632
(4) East double door opened	361	1524	2730
(5) Roof vent closed	445	1723	2852
(6) All burners off	576	1840	2997
(7) Roof vent opened	720	1890	3086
(8) East double door closed	1148	2311	N/A
(9) West double door closed	1164	2330	N/A
(10) Roof vent closed	1179	2387	N/A

Event Times (s) for Test 5 Data File



Figure 3.2: Test 5 layout and event times.

Event	Seq. 1	Seq. 2	Seq. 3
(1) All burners on	0	565	1075
(2) West double door opened	116	685	1195
(3) Roof vent opened	207	747	1287
(4) All burners off	327	868	1387
(5) East double door opened	369	911	1446
(6) Roof vent closed	494	1040	N/A
(7) East double door closed	522	1012	N/A
(8) West double door closed	538	1025	N/A



Figure 3.3: Test 6 layout and event times.

3.2 West Structure Tests

Four different tests, Tests 22–25, were conducted in the West Structure. Table 3.2 lists the calculated heat release rate for each test. Similar to Tests 5 and 6, Tests 22–25 had a duration on the order of seconds between the ignition of each burner, so only the heat release rate for when all three burners were ignited is reported.

Heat Release Rate (kW)		
Test	All Burners On	
Test 22	1240	
Test 23	1290	
Test 24	1270	
Test 25	1270	

Table 3.2: Heat Release Rates for West Structure Tests

3.2.1 Tests 22 & 23

Tests 22 and 23 followed a nearly identical procedure. The starting configuration for Test 22 had the second story south exterior door in the opened position, while the starting configuration for Test 23 had the same door in the closed position. Fig. 3.4 includes a floor plan schematic and table of event times corresponding to the data files for Tests 22 and 23. A 0.61 m (2.0 ft) diameter PPV fan located 2.3 m (7.5 ft) away from the first level double doors and aimed at the center of the two doors was used during the tests to change the ventilation pattern within the structure.

3.2.2 Tests 24 & 25

Like Tests 22 and 23, Tests 24 and 25 followed a nearly identical procedure. The starting configuration for Test 24 had the south exterior door on the second level in the opened position, while the starting configuration for Test 25 had the same door in the closed position. During both tests, the stairwell door was unable to completely close. When it was in the "closed" position at the beginning of each test, there was a 152 mm (6.0 in) gap between the door and its frame. Fig. 3.5 includes a floor plan schematic and table of event times corresponding to the data files for Tests 24 and 25. A 0.61 m (2.0 ft) diameter PPV fan located 2.3 m (7.5 ft) away from the first level double doors and aimed at the center of the west double door was used during the tests to change the ventilation pattern within the structure.

Event	Test 22	Test 23
(1) All burners on	0	0
(2) 2nd floor west double door opened	194	130
(3) 1st floor west double door opened	314	252
(4) 1st floor east double door opened	450	371
(5) 2nd floor south exterior door closed	511	N/A
(6) 2nd floor east double door opened	585	498
(7) PPV fan on	652	612
(8) PPV fan off	798	761
(9) All burners off	829	794
(10) 2nd floor south exterior door opened	899	849
(11) PPV fan on	1065	940
(12) 2nd floor south exterior door closed	1176	N/A

Event Times (s) for Tests 22–23 Data Files



Figure 3.4: Tests 22–23 layout and event times.

Event	Test 24	Test 25
(1) All burners on	0	0
(2) Interior stairwell door opened	144	112
(3) 1st floor west double door opened	265	244
(4) 2nd floor west double door opened	383	353
(5) 2nd floor south exterior door closed	452	N/A
(6) 2nd floor south exterior door opened	502	474
(7) PPV fan on	624	594
(8) All burners off	746	721
(9) 2nd floor east double door opened	877	N/A
(10) 1st floor east double door opened	N/A	836

Event Times (s) for Tests 24–25 Data Files



Figure 3.5: Tests 24–25 layout and event times.

Section 4

Summary

Nine full-scale fire tests were conducted in two residential-sized structures to examine how changing ventilation patterns within a structure affects the fire environment. The fire source for each experiment was provided by a set of three diffusion flame burners with propane as the fuel. Various doors and vents were opened and closed during each test to change ventilation within the structure. A PPV fan was also used during some of the experiments to change the ventilation patterns. Local measurements of temperature, gas velocity, heat flux, and gas concentrations were collected at various locations throughout the structure during the experiments. The total volume of propane delivered to the burners was measured by a positive displacement rotary gas meter and was used to calculate the heat release rate of the fire during each test.

Acknowledgments

The author would like to thank Daniel Madrzykowski, Roy McLane, Kristopher Overholt, Keith Stakes, and Craig Weinschenk for their contributions in preparing and conducting these experiments.

References

- B.N. Taylor and C.E. Kuyatt. Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results. NIST Technical Note 1297, National Institute of Standards and Technology, Gaithersburg, Maryland, 1994.
- [2] Stanley Hand Tools, New Britain, Connecticut. User Manual TLM 100, 2013.
- [3] T. Butcher, S. Cook, L. Crown, and R. Harshman. NIST Handbook 44: Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices. *National Institute of Standards, Gaithersburg, MD*, 2012.
- [4] Omega Engineering Inc., Stamford, Connecticut. The Temperature Handbook, 2004.
- [5] L.G. Blevins. Behavior of bare and aspirated thermocouples in compartment fires. In *National Heat Transfer Conference, 33rd Proceedings*, pages 15–17, 1999.
- [6] W.M. Pitts, E. Braun, R. Peacock, H. Mitler, E. Johnson, P. Reneke, and L.G. Blevins. Temperature uncertainties for bare-bead and aspirated thermocouple measurements in fire environments. *ASTM Special Technical Publication*, 1427:3–15, 2003.
- [7] Medtherm Corporation, Huntsville, Alabama. 64 Series Heat Flux Transducers, 2003.
- [8] W.M. Pitts, A.V. Murthy, J.L. de Ris, J. Filtz, K. Nygård, D. Smith, and I. Wetterlund. Round robin study of total heat flux gauge calibration at fire laboratories. *Fire Safety Journal*, 41(6):459–475, 2006.
- [9] M. Bundy, A. Hamins, E.L. Johnsson, S.C. Kim, G.H. Ko, and D.B. Lenhart. Measurements of Heat and Combustion Products in Reduced-Scale Ventilated-Limited Compartment Fires. NIST Technical Note 1483, National Institute of Standards and Technology, Gaithersburg, MD, 2007.
- [10] A. Lock, M. Bundy, E.L. Johnsson, A. Hamins, G.H. Ko, C. Hwang, P. Fuss, and R. Harris. Experimental study of the effects of fuel type, fuel distribution, and vent size on full-scale underventilated compartment fires in an ISO 9705 room. NIST Technical Note 1603, National Institute of Standards and Technology, Gaithersburg, MD, 2008.
- [11] R.A. Bryant. A comparison of gas velocity measurements in a full-scale enclosure fire. *Fire Safety Journal*, 44:793–800, 2009.
- [12] Romet Limited, East Mississauga, Ontario. Rotary Gas Meter RM3000 Technical Specification, 2014.