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THE ST. LAWRENCE BURNS

By

G. W. SHORTER, J. H. McGUIRE, N. B. HUTCHEON and R. F. LEGGET

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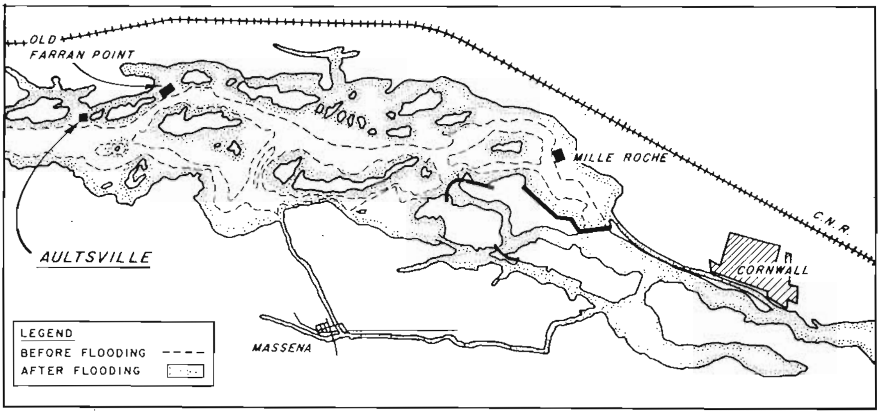


The St. Lawrence Burns

By G. W. Shorter, J. H. McGuire, N. B. Hutcheon, and R. F. Legget
National Research Council, Canada, Division of Building Research

When it became known that the St. Lawrence Power Project would result in the flooding of a large area on the Canadian side of the St. Lawrence River, which included a number of small towns, the Division of Building Research of the National Research Council (Canada) realized that this would provide an excellent opportunity to carry out fire research experiments on derelict buildings. Through the cooperation of the Hydro-Electric Power Commission of Ontario, the Federal Civil Defence authorities arranged that a number of buildings in the Village of Aultsville would be made available for experiments and the Division of Building Research was given the opportunity of selecting suitable buildings for carrying out controlled experiments.

An invitation to assist in the experiments was accepted by the British Joint Fire Research Organization. Assistance was given in planning the operation and in the provision of certain instruments and a senior scientific officer was sent to participate in the tests.

The studies, conducted in January and February of 1958, concerned only the development of fire in buildings; they did not include any investigation of the extinguishment of fire. The studies were limited to the development of fire as it affects (a) survival of the occupants, (b) spread of fire by radiation, and (c) ventilation rates. It was thought that instrumentation installed to study these phenomena might also provide further evidence as to the validity of the "time-temperature" curves that are used in standard fire resistance tests.

As the number of buildings that could be instrumented and burned had to be limited, it was decided that major variables in the experiments with dwellings would be limited to the types of interior linings and exterior claddings. These were classified broadly as combustible and noncombustible. A search was made for a series of dwellings which in all other respects were similar. With this restriction, six two-story dwellings were selected for the experiments. Three had noncombustible linings and, after minor modifications, three were considered to have combustible linings, at least on the ground floor. One dwell-

NOTE: The first portion of this article is based on a paper presented by Mr. Legget at the May 1958 NFPA Annual Meeting.

ing in each of these categories had timber exterior cladding; all dwellings had wood floors and subfloors.

The interest in burning larger buildings came, in the first instance, from the British Joint Fire Research Organization. Information was desired on the influence of large compartment size on the nature of the fire, and on the ventilation rate provided by the induced air flow through openings during a fire. The choice of larger buildings was limited to two, a two-story school and a two-story community hall, both of brick construction.

Wall construction details for all eight buildings are given in Table I. Studies concerned with the survival of the occupants in buildings were restricted to the dwellings. Those related to the spread of fire by radiation were carried out at all eight buildings; those dealing with ventilation rates were restricted to the two large structures, apart from a preliminary trial at the first house burn.

Table I
Construction Details of Walls

Building No.	Exterior Wall	Interior Linings
1*	brick	plaster
2*	brick and 1 inch rough boards	fiberboard downstairs (except kitchen wainscot which was wood)
3*	cavity brick	fiberboard
4*	frame, brick infilling, 1 inch boards, clapboard	plaster
5*	frame, 1 inch boards, cedar shingles, clapboard	pressed paper
6 (Community Hall)	brick	plaster, wood wainscot
7*	brick	plaster
8 (School)	brick	plaster

*Dwellings

Specific Objectives

The specific experimental objectives for determining the effects of the development of fire on the survival of the occupants, the spread of fire by radiation, and ventilation rates were as follows:

Survival of the Occupants

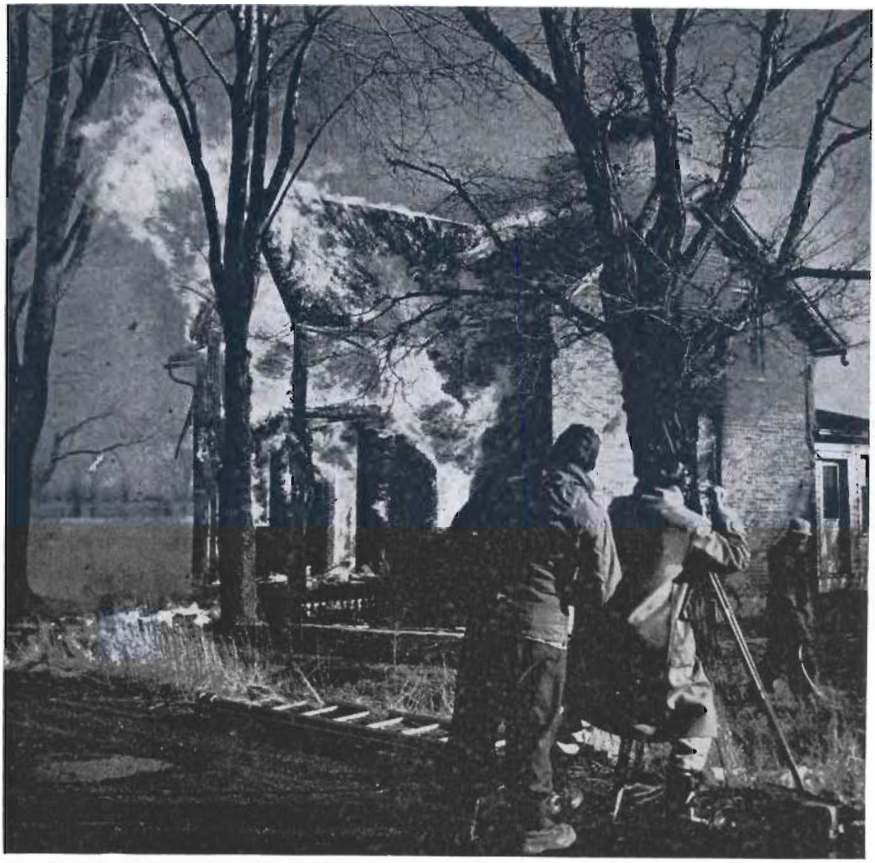
The main objective was to determine the times at which survival of occupants became impossible in two upstairs bedrooms (one with the door closed and one with the door open) and in the basements of the dwellings.

Instrumentation was provided for determining the concentrations of carbon monoxide and oxygen, smoke density, and the rise in temperature in each area. In addition, microphones were installed to determine if the noise that a fire makes prior to the time at which survival is impossible offers any warning to the occupants of upstairs bedrooms.

Spread of Fire by Radiation

When determining separations between buildings to reduce the hazard of the spread of fire from one building to another, a major factor to be considered is the spread of fire due to radiation. An objective, therefore, was to determine at what distances intensities of radiation would be sufficient to ignite combustible materials in adjacent structures. Small portable radiometers mounted on movable standards were used for measuring radiation intensities. When estimating space separations between buildings, it is necessary to assume a limiting intensity of radiation from a burning building.

Another objective was to measure the intensity of radiation at the window openings. A thermopile radiometer was mounted on a tripod in front of a window of the room where the fire was set. The window completely filled the field of view of the radiometer.



Malak, Ottawa

One of the dwelling house "burns" being filmed by the National Film Board.

To determine to what distance the flames extended from the building on the leeward side, standard motion pictures were taken during periods of peak radiation from a point in line with the leeward wall.

Ventilation Rates

A factor in the development of fire, which is of great interest to those engaged in fire research, is the effect of ventilation, particularly in large single compartments. As there is little information on this subject, a study was made of the rate of ingress of air during the development of the fires in the two large buildings. For these measurements two small specially fabricated anemometers were installed in window openings.

Outline of Operations

The detailed survey of the buildings included taking photographs and measuring all rooms so that floor plans could be drawn. Small plot plans were prepared showing the location of the several buildings. Arrangements were made for heating the buildings for approximately one week prior to the actual fire, with portable space heaters loaned by the Ontario Hydro.

Few modifications to the buildings were necessary. These consisted merely of adding small amounts of lining materials in ground-floor rooms and in the stairways leading to the upper floors, where necessary, in order to have combustible finishes in three of the houses and noncombustible finishes in the other three. The second floors of the two larger structures were removed to convert them into large single compartments.

All recording and indicating instruments were installed in a trailer which was located approximately 100 feet from any structure. This trailer was heated and provided shelter from the cold weather for both instruments and staff and also facilitated the movement of the instruments from one location to another. The main equipment installed in the trailer was the apparatus for gas analysis and a number of recording instruments.

Arrangements were made with the Ontario Hydro to supply power on poles near the various buildings to be burned. In two cases a 20-kva portable generator was provided where no power lines were conveniently available.

Fire protection provided by staff from the Ontario Fire Marshal's Office and by the Ontario Hydro ensured that the fires did not spread to adjacent properties. Except on one or two occasions, it was not necessary to use the fire-fighting equipment and personnel provided so far as the safety of life or property was concerned, but they performed a useful function in keeping the fires from spreading from the buildings proper to attached sheds, the burning of which would have influenced the results of the tests.

It was known that one of the most important results of such an operation should be a pictorial record, and the services of the National Film Board of Canada were obtained to take motion pictures during the operation. These movies consist of approximately ½ hour of film for each fire, taken from a fixed position and a number of random shots used for the preparation of a 20-minute documentary film of the operation.*

Equipment was also provided for obtaining necessary weather records during the fires. The most important item was wind speed and direction, because of its effect in projecting the flame front some distance from the window openings of the burning building.

Prior to the tests, all lines leading from instrument installations in the buildings were connected by leads to the trailer. Moisture content of the wood in the cribs and ground-floor interior finish materials was measured. The space heater was then removed from the building, a door or window left open to provide ventilation, and a final inspection of the premises carried out immediately before the cribs were ignited. Even though measurements were being recorded, one member of the team was assigned to make visual observations during the fires. Once the cribs were ignited, the staff of the NFB began filming, using both a static and a mobile camera.

Five of the residences were burned in the middle of January 1958 and the sixth residence and the two larger structures early in February. In spite of considerable variation in weather during this period both as to wind and temperature, the instrumentation functioned satisfactorily. A good deal of equipment was specially designed so that it could be recovered before damage occurred. In general, this phase of the operation was successfully carried out except in the case of the largest structure where

*Available on loan from N.R.C. Liaison Officer, B.C.S.O., K Street N.W., Washington (for U.S.A.); or from Director, Division of Building Research, National Research Council, Ottawa.

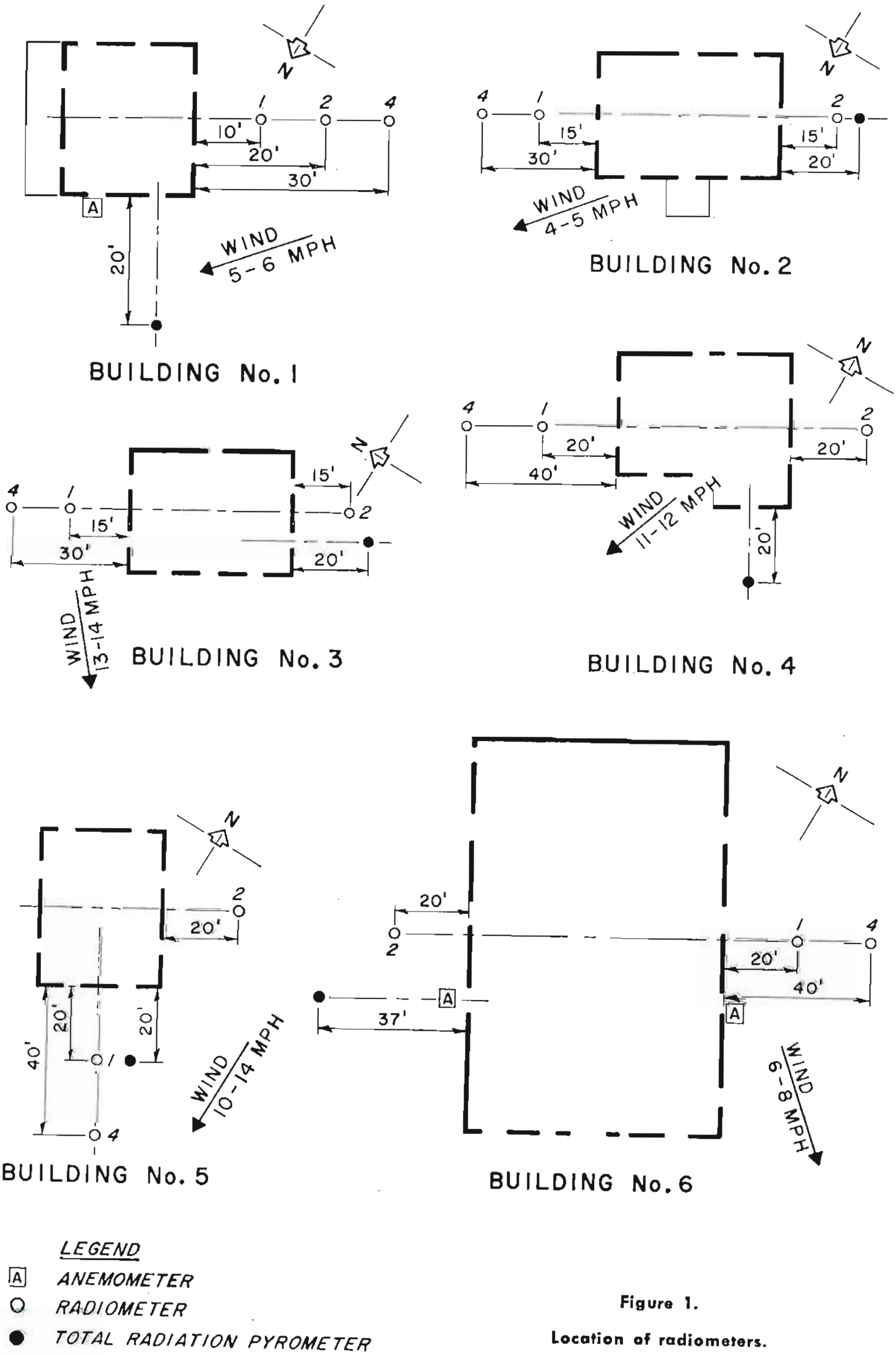
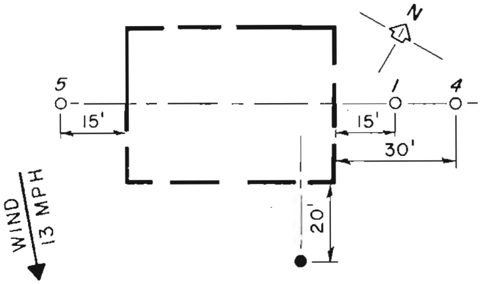


Figure 1.

Location of radiometers.



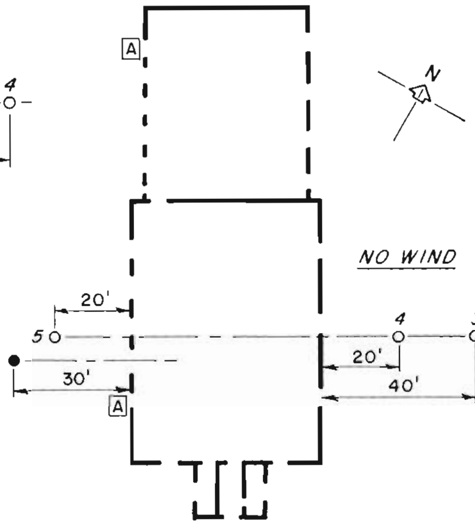
BUILDING No. 7

LEGEND

[A] *ANEMOMETER*

○ *RADIOMETER*

● *TOTAL RADIATION PYROMETER*



BUILDING No. 8

Figure 1 (cont'd).
Location of radiometers.

the collapse of a wall did some damage to instrumentation.

Ignition and Fuel

It was decided that a fire capable of rapid growth should be set at each burn. Accordingly, since the buildings were without furniture, two identical cribs of new wood in sizes from ½ by ½ inch, to 2 by 4 inches and each weighing about 340 pounds were constructed in the room of origin in each house. This weight of wood corresponded to a fire load in the room of origin of about 3 pounds per square foot, which is typical of the fire load due to furnishings in ground-floor rooms.

The fire was always started in the crib, all time measurements being made from the minute the crib was well alight. The fuel load in the two larger structures was formed by the wood flooring which had been removed from the upper floors and piled on the ground floor. The fires were started in these piles of fuel.

Instrumentation

Instrumentation was required to provide information on (a) the limiting times at which life could be sustained in the bedrooms of the dwellings and (b) the levels of radiation outside the dwellings that might give rise to fire in neighboring buildings.

It was assumed that death generally results from a high concentration of carbon monoxide, a low concentration of oxygen, or a high temperature. High smoke density would result in poor visibility, making escape difficult. Measurements of all these quantities were made. Carbon monoxide and oxygen were measured at 30-second intervals with continuous sampling equipment; the sampling locations were two bedrooms, one with the door open and the other with the door closed. Measurements of smoke density were made by an optical attenuation method in the two bedrooms. Temperature was measured by chromel-alumel thermocouples of which between ten and sixteen were distributed throughout each dwelling. Tape recordings were made of the sounds created by the fire in the two bedrooms.

The intensities of radiation near the burning buildings were measured by totally enclosed, gold disc radiometers specially designed for this series of experiments. In general two radiometers were located at different distances from the leeward side of a building and one on the windward side (Figure 1). The nearer radiometers, in the case of the house burns, were mounted at a height of 15 feet at which, it was estimated, the radiation level would be a maximum. During the burning of the larger buildings the nearer radiometers were mounted at a height of 20 feet which was the maximum possible with the mounting systems used. It was estimated that the intensity of radiation might have been slightly greater at a level some 5 feet higher than this. In all burns the most distant radiometer was mounted at the more convenient height of only 10 feet because, with the ranges involved, no great variation of intensity with height, up to about 30 feet, was expected.

The total radiation at a window in the room of origin of the fire was measured with a thermopile radiometer to provide a basis for comparison of the radiation from the window openings alone with that from windows plus the flames issuing from them as measured by the gold disc radiometers. Since the thermopile radiometer was arranged so that the window occupied completely its field of view, it could also be regarded as a pyrometer for purposes of calculating the black body temperature of the fire within, as seen through the window. This instrument will subsequently be referred to as the pyrometer to distinguish it from the others.

No smoke, gas, or sound measurements were made in the two large buildings. Radiation and temperature were measured as for the dwellings. A deflection-type anemometer was designed so as to be rugged and to function over a wide range of temperature in order to obtain the air speeds through open windows during the fire. Measurements were made by reading the instrument through a telescope.

Survival of the Occupants

For oxygen concentration, a lower limit of 10 per cent was assumed, based on the report of the National Fire Protection Association Committee on Fire Gas Research.[1] The limit for carbon monoxide concentration has been found to be a function both of concentration itself and of total dosage. Hamilton and Johnstone[2] have reported that, at a concentration of 1.28 per cent carbon monoxide by volume, there is an immediate effect and consciousness is lost. For lower concentrations it is generally agreed that consciousness is lost when 40 to 50 per cent of the blood haemoglobin is converted to carboxy-haemoglobin. This effect will be more nearly a function of total dosage rather than concentration. Minchin[3] reports that collapse will occur when the product of the carbon monoxide concentration, K_{CO} (per cent), and time of exposure, t (minutes), equals 4.5. This law has been assumed valid where K_{CO} has been a function of time and has thus been taken as:

$$\int_0^t K_{CO} dt = 4.5$$

The limiting value of temperature adopted was 300°F following the example set by other workers.[4]

All temperatures used in considerations of survival times were taken from thermocouples located 4 feet above the floor. This level was at the approximate midheight of the room and, in addition was considered a satisfactory compromise between breathing levels for standing, sitting and sleeping positions.

The criterion for impaired visibility is that used by Kingman and others.[5]

This depends on the assumption that when visibility falls to 4 feet, a room is smoke-logged to a degree that would seriously impede the escape of the occupants. From the data given by Kingman and others[5] it can be inferred that the 4-foot visibility limit can be considered to have been reached when the light transmitted through the 2-foot smoke path of the instrument used was reduced to 5 per cent of the intensity obtained in the absence of smoke.

The resulting times of survival, based on these several criteria, are given in Table II. Except in one instance the times based on the 4-foot visibility criterion are substantially less than the others. The carbon monoxide, oxygen, and temperature criteria relate to loss of consciousness (or in the last instance, death) whereas the smoke criterion relates to a substantial limitation in the visual powers of the occupant. Accordingly, the important results, considering the mean curves only, are those given in Table III. The difference in time resulting from the use of noncombustible instead of combustible linings, when the door is closed, is clearly critical since a period of 10 minutes is typical of the time it might take a fire appliance to respond to an alarm and effect a rescue.

Table II
Limiting Times of Survival (Minutes)

Type of Wall Lining	Building No.	Closed Bedroom $K_{CO} \times t = 4.5$	1.28% CO	10% O_2	300°F	4-ft. visibility
Noncombustible	1	12.0	13	13	11.8	3.9
	4	14.8	14.8	21.0	16.5	5.2
	7	16.2	18.6	19.2	11.3	5.7
Noncombustible (mean curve)	1, 4 & 7*	14.5	18.6 (b)	20.2 (a)	11.7	4.4
Combustible	2	10.0	5	5	7.8	—
	3	7.5	5.6	12.9	—	4.4
	5	7.0	4.8	8	9.1	3.4
Combustible (mean curve)	2, 3 & 5*	7.5	5.6 (b)	12.9 (b)	8.7 (b)	3.4 (a)

Type of Wall Lining	Building No.	Open Bedroom $K_{CO} \times t = 4.5$	1.28% CO	10% O_2	300°F	4-ft. visibility
Noncombustible	1	4.5	1.8	2.5	2.8	—
	4	7.0	12.1	3.6	11.5	2.4
	7	10.0	8	7.7	2.1	2.0
Noncombustible (mean curve)	1, 4 & 7*	8.0	12.1 (b)	4.2	2.5	2.1
Combustible	2	4.2	1.5	2.4	1.5	1.9
	3	5.0	2.5	2.3	1.7	1.5
	5	5.5	2.9	2.7	2.2	2.2
Combustible (mean curve)	2, 3 & 5*	5.0	2.9 (b)	2.5	1.8	1.6

*these values are taken from the curves of the means of the quantities
(a) indicates that only two results were available at the time considered
(b) indicates that only one result was available at the time considered

Table III
Critical Times for Survival
(neglecting visibility criteria)

Type of Wall Lining	Closed Bedroom	Open Bedroom
Noncombustible	11.7 min. (300°F)	2.5 min. (300°F)
Combustible	5.6 min. (1.28% CO)	1.8 min. (300°F)

Radiation Levels

During the first burn the three radiometers were located at different distances from the same side of the dwelling, in order to record the relation between radiation level and distance from the house. The direction of the wind greatly affected radiation levels, those on the leeward side being the greater because of the larger volume of flame issuing from the windows on this side. It was therefore decided that measurements should be taken on both sides of the buildings; for subsequent burns one radiometer was therefore located on the windward side and two on the leeward side. The peak radiation levels recorded are listed in Table IV.

The measured radiation levels for the various burns are difficult to compare directly, since they apply to the particular window and flame patterns viewed by the instruments for each building. They have been converted to another

Table IV
Maximum Radiation Intensities

Burn and Bldg. No.	Exterior Cladding	Interior Lining	Radiometer Nos.	Max Intensity I (cal/cm²/sec)	Config. factor of openings	I/F (cal/cm²/sec)
1	Brick	Plaster	1	0.12*	‡	‡
			2	0.15	‡	‡
			4	0.09	‡	‡
2	Brick	Downstairs — fiberboard and plywood	1	0.47	0.05	9
			4	0.18	0.016	11
		Upstairs — plaster	2	0.08	0.04	2
3	Brick	Fiberboard	1	1.25	0.034	37
			4	>0.18	0.013	>14
			2	0.46	0.034	14
4	Clapboard	Plaster	1	0.56	0.032	18
			4	0.17	0.011	15
			2	0.46	0.028	16
5	Clapboard	Pressed paper	1	1.05	0.027	39
			4	0.32	0.008	40
			2	0.35	0.012	29
6 (Community Hall)	Brick	Plaster; wooden ceiling	1	0.9	0.075	12
			4	>0.41	0.031	>13
			2	0.42	0.075	6
7	Brick	Plaster	1	0.9	0.058	16
			4	0.38	0.018	21
			5	0.08	0.044	2
8 (School)	Brick	Plaster; wooden ceiling	4	0.83	0.049	17
			3	0.17	0.019	9
			5	>0.5	0.088	> 6

*Radiometer removed before peak level attained
‡Not calculated

Ontario Hydro

First house to be burned about 13 minutes after ignition. Note radiometers in position.

basis for comparison, however, which is considered to be revealing and useful, on the assumption that the radiation level produced by a window plus its flame pattern can be represented by a hypothetical radiation intensity effective from the window area alone. The measured radiation intensities have therefore been divided by the configuration factor F as normally used in radiant energy transfer equations, calculated for the window openings alone with respect to the radiometer location. This approach not only permits a direct comparison between burns to be made but it may also be extended to the prediction of radiation levels at points other than those at which measurements were made, by multiplying the hypothetical window radiation intensities by other appropriate configuration factors relating the window areas to the points in question.

Some justification for this basis of comparison is provided by the reasonable agreement for the house burns between the results expressed in these terms from the two radiometers on the same side of the building. In the case of the school burn, however, the agreement is poor, because the windows of the school annex contributed substantially to the configuration factor F for the more distant radiometer but not for the nearer one. When the radiation from the main body of the building was a maximum, the fire in the annex was not yet fully developed.

Values of I/F were not derived from the results of the first burn because the more distant radiometers were also irradiated by a shed which ignited earlier than was expected. In later experiments ignition of sheds was suppressed and the buildings were stripped of porches and verandas that would have substantially influenced radiation measurements, thus eliminating a highly variable, complicating factor.

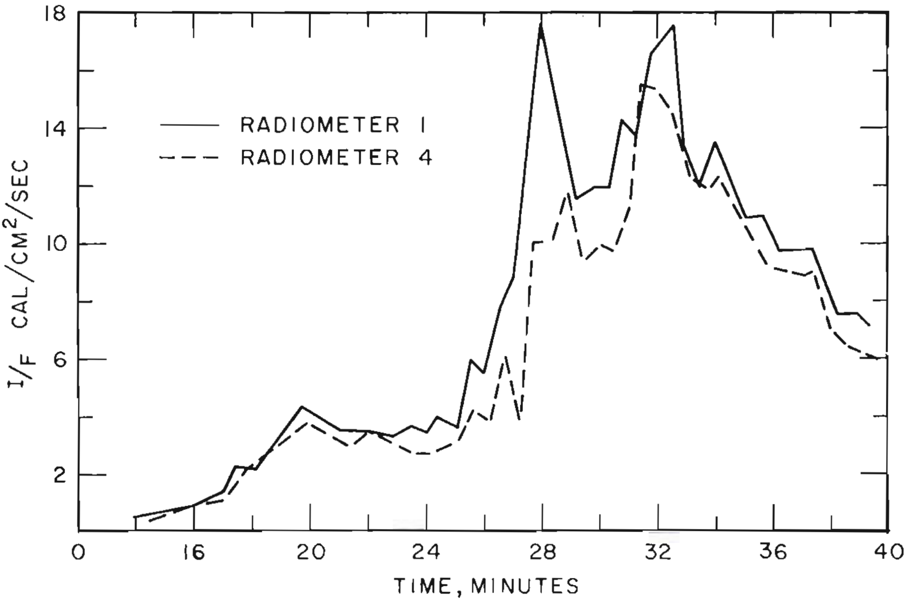


Figure 2.

Normalized radiometer results: Burn No. 4.

The best agreement was for building No. 4 as is illustrated in Figure 2. The levels of radiation differed by a factor of the order of three but the two curves of I/F almost coincide. The maximum values of I/F for the 4th and 7th burns correspond quite closely, as do those for the 3rd and 5th burns (Table IV). It would therefore appear that the use of clapboard exterior cladding does not appreciably increase the maximum radiation levels from a house. Where the dwellings had combustible interior linings, as in burns Nos. 3 and 5, values of I/F of up to 40 calories per square centimeter per second ($cal/cm^2/sec$) were obtained. Where the linings were noncombustible, as in burns Nos. 4 and 7 and the two larger buildings, the maximum values were no more than half this. Building No. 2 gave a maximum value of only 11 $cal/cm^2/sec$ although it included fiberboard and plywood linings downstairs. It is thought that this was due partly to the absence of combustible linings upstairs and partly to the low speed of the prevailing wind.

Comparison may usefully be made between the values of I/F just cited and the pyrometer measurements of internal temperatures discussed later. At no time was a black-body temperature higher than 1000°C (1832°F) recorded, although it is possible that a slightly higher temperature might have developed in the Community Hall about 32 minutes after the start of the fire. The radiation level corresponding to a black-body temperature of 1000°C is 3.6 $cal/cm^2/sec$. It therefore follows that the window openings themselves only made a small contribution to the peak levels of radiation as recorded by the radiometers, with the major contribution being from the large volume of flame spreading out from the windows.

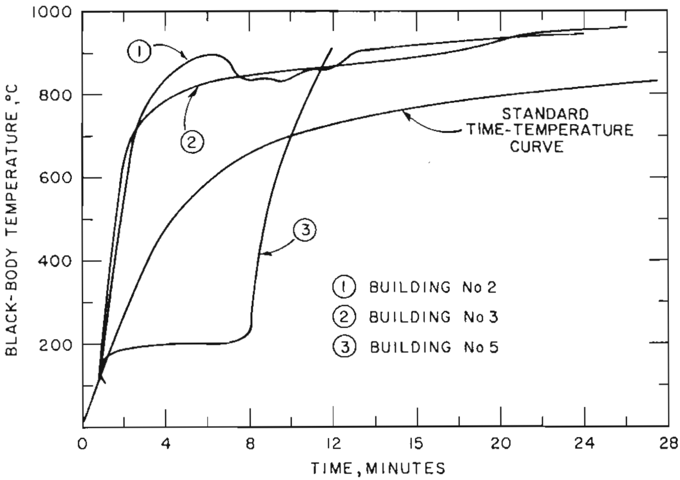


Figure 3. Black-body temperatures, combustible linings.

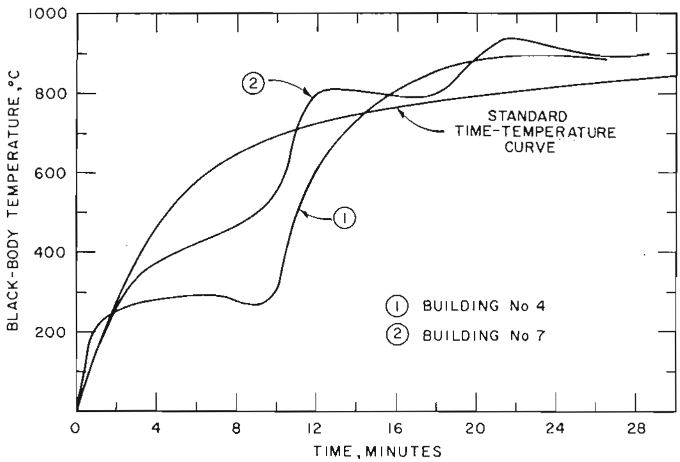


Figure 4. Black-body temperatures, noncombustible linings.

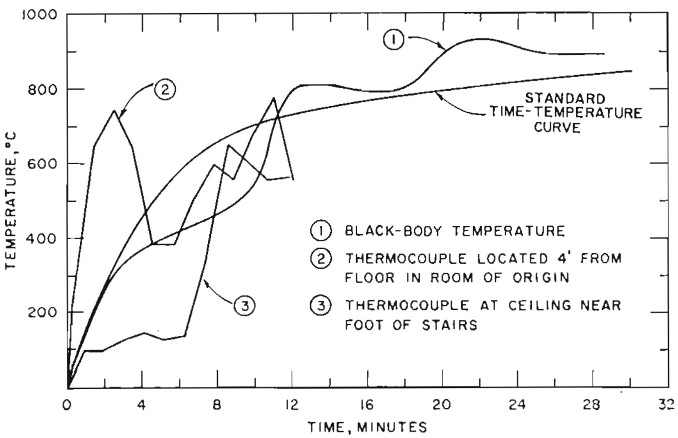


Figure 5. Black-body and thermocouple temperatures, Building No. 7.

Figure 2 gives an indication of the typical behavior of the radiation levels with time. The level of radiation for the buildings with noncombustible linings expressed in terms of I/F never exceeded one quarter of the maximum value of 20 cal/cm²/sec until after 16 minutes from the start of the test. Only in one of the buildings with combustible linings, for which the maximum value of I/F was about 40 cal/cm²/sec, did the radiation level rise above the quarter value within 16 minutes; in house No. 5 with pressed paperboard lining, a quarter of the maximum value was attained in 10 to 11 minutes.

Conclusions from Radiation Measurements

The conclusions to be drawn from the radiation measurements are as follows:

1. The radiation levels from buildings completely lined internally with combustible materials were double those where noncombustible linings were used, the peak levels being about 40 cal/cm²/sec and 20 cal/cm²/sec respectively, when expressed as hypothetical radiation intensities, I/F, over the window areas alone.

2. The hypothetical window radiation intensity, I/F, is a convenient and useful factor by which the radiation levels from different buildings can be compared.

3. The contribution of radiation directly from the openings in the exterior walls (at the periods of peak radiation) was substantially less than that from the flames above and surrounding the windows, the former being no more than about 3.6 cal/cm²/sec, compared to the maximum hypothetical window radiation levels, I/F, of 20 cal/cm²/sec, and 40 cal/cm²/sec.

4. A period of at least 16 minutes elapsed before maximum radiation levels were attained.

5. Maximum radiation levels were not greatly affected by the type of exterior covering.

6. Radiation levels were affected by wind conditions, but the results obtained were not adequate to allow a quantitative analysis of the effects.

Internal Temperature Conditions

The black-body temperature records of the dwelling tests are given in Figures 3 to 5. It is useful to compare these results with the furnace time-temperature curve prescribed in the Standard Methods of Fire Tests of Building Construction and Materials (NFPA No. 251; ASTM E119-58) for the fire resistance testing of structures.[6] Two of the curves relating to houses with combustible linings (Figure 3) are almost identical in form but lie about 150°C (270°F) higher than the standard time-temperature curve. In the case of building No. 5 there was a slight delay before the curve rose sharply; shortly after this, measurements had to be discontinued. From the trend of the curve, it would appear that high black-body temperatures were later attained. For the two houses with noncombustible linings (burns Nos. 4 and 7, Figure 4) the black-body temperatures remained substantially below the standard time-temperature curve values for about 10 minutes and then rose above them.

Considering only the heat transfer to the interior walls of the dwellings, the radiation intensity within the building as defined by a black-body temperature is probably the most appropriate quantitative measurement of the "intensity" of the fire that is capable of simple definition. This presupposes that for walls in the dwellings the heat transfer by convection was very much smaller than that by radiation. For the ceilings, however, it is probable that the heat transfer by convection was very much greater than for the walls, and so the black-body temperature alone may not give such an adequate measure of the fire intensity for them.

A number of thermocouples were installed throughout the houses. A typical set of temperature records is given in Figure 5. One of the curves (2) refers to a thermocouple located 4 feet from the floor in the room of origin and the other (3) refers to a thermocouple at ceiling level at the foot of the stairs. It will be seen that the temperatures are not directly related to time.

The results for the larger buildings are given in Figure 6. This shows that there was considerable delay, particularly in the case of the Community Hall, before substantial black-body temperatures were attained. During the course of the Community Hall test, the pyrometer measurement was faulty; unfortunately the only results obtained were for the period from zero to 18 minutes when the black-body temperature was still very low and for the period 34 to 35 minutes. In each building two thermocouples were installed 15 feet apart on a beam which had originally constituted a first-floor joist. The thermocouple temperature records for each test were in quite close agreement; one curve only has been drawn for each case. The rapid drop in temperature in each burn after about 18 minutes is believed to be due to the collapse of the supporting beam; these sections of the records should not necessarily be taken as indicating that there was a sharp drop in temperature at the original level of the thermocouples.

Ventilation

The anemometer readings were taken to provide information upon which estimates might be made of the air supplied to the fire, that is, the ventilation rate. One of the specially constructed instruments was placed in the opening formed by partially raising the lower sash in the first house burn. The back

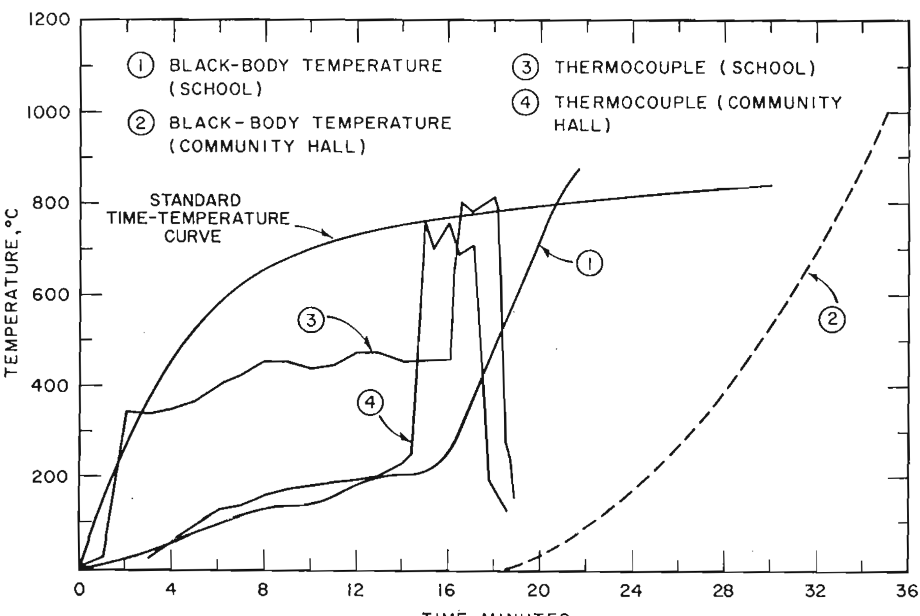


Figure 6. Black-body and thermocouple temperatures, large buildings.

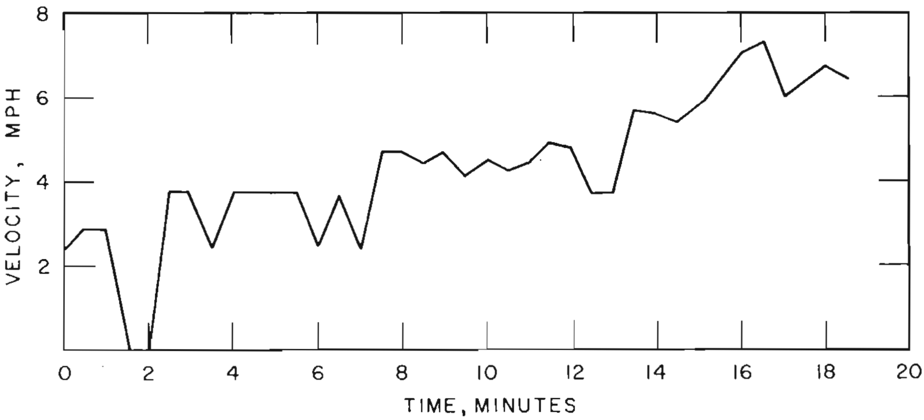


Figure 7. Inlet air velocities: school, main building.

door of the house was also open. The results obtained during the burn were inconclusive since it was possible to leave the instrument in place only for the first 10 minutes of the fire. The readings ranged from negative values to a maximum velocity of 4.5 miles per hour. Other measurements indicated that the fire did not reach its peak until at least 20 minutes had elapsed.

The results were also complicated by the existence of a variable wind up to 6 miles per hour, the effects of which could not be separated from the inlet air speed induced by the fire alone. A somewhat similar situation existed in the case of the burn of the Community Hall.

When the school was burned there was little wind and it was possible to leave the anemometers in position until the fire was fully developed. One anemometer was located in an open window of the main hall and another in an open window of the annex. Both were on the west side of the building. The lower sash of each window was opened about one-third and at the start of the fire there were no other windows or outside doors open; windows were progressively broken as the fire developed. The results are given in Figure 7. On the assumption that the gas temperature within the building was 1000°C, an application of Bernoulli's Theorem gives approximate values of 7.8 miles per hour and 16 miles per hour for the cases where the areas of open or broken windows at the inlet and outlet levels are respectively equal and much greater at outlet than inlet. When the measurements had to be discontinued all the upstairs windows and most of the downstairs windows had fallen out. The higher theoretical value was then not directly applicable; some value between the two was appropriate to the conditions then obtaining. The maximum value recorded, about 7 miles per hour, is in good agreement with the theoretical value. Having thus established that air speeds through openings, and thus ventilation rates, might be predicted from simple theory for at least some of the cases of major interest, no further analysis of the anemometer readings was made.

Miscellaneous Measurements

The noise recordings were compared with the level of the sound emanating from a ringing alarm clock situated 3 feet from the sound level meter. The

Table V
Noise Levels

	Frequency range cps 60 to 20,000 cps	Frequency range cps 600 to 20,000 cps
Fire noise, open door, average	69 db	67 db
Fire noise, open door, peak	72 db	72 db
Fire noise, closed door, average	65 db	55 db
Fire noise, closed door, peak	67 db	58 db
Alarm clock, ringing	—	63 db

results are listed in Table V. The last column has been included because it is believed that it is the noises in the higher frequency range that will most probably awaken a sleeping person. Table V shows that the higher frequencies are attenuated much more than the lower frequencies by the closing of the bedroom door. If the noise of an alarm clock would arouse a sleeper, the fire noise would have awakened the occupant of a room with the door open. There is some doubt whether a person would have been awakened in a bedroom with the door closed. The sharp crackling sounds produced from the start of these fires may not be typical of a dwelling fire but may have been associated with the nature of the igniting cribs.

The film records of some of the burns were studied to provide information on the pattern of flame from windows and on the horizontal and vertical distances to which flame patterns extended. Flames extended up to 18 feet horizontally in the case of burn No. 5, the maximum distance outward being reached at about the height of the house. The maximum extension horizontally was about the same, 17 feet, in the case of burn No. 7, occurring at a level just below the eaves. The extreme limit of flame in the case of the Community Hall was about 25 feet, at a height of about half that of the building itself. During the School burn, flames extended to a distance of 18 feet at about eave level.

Conclusions

The tests had three major objectives, the conclusions regarding each of which can be summarized as follows:

1. With reference to the survival of occupants, it was found that all dwellings became smoke-logged within 6 minutes of the ignition of the cribs. In all but one case the criterion for decrease of visibility was exceeded before the other criteria for survival — the carbon monoxide concentration, reduction of oxygen, and temperature. The smoke criterion relates principally to possible unaided escape of occupants in contrast to the lethal effects of carbon monoxide and high temperatures, upon which survival depends more directly and without regard for subsequent rescue. The relation between the limiting times, according to the respective criteria, is shown in Table II, and, excluding the visibility criterion, is summarized in Table III.

2. Extensive studies of radiation were a major feature of the test and valuable information on radiation levels was obtained. The conclusions are listed in the section dealing with radiation levels (see page 11).

3. Limited information on air speeds through open windows was obtained in the case of one of the larger buildings. The maximum value obtained provides a reasonable check on estimates based on simple theory.

Time-temperature relationships were obtained for the fires in all buildings. These provided an interesting comparison with the standard time-temperature curve. In the case of two of the three dwellings lined with combustible materials, the black-body temperatures developed in the room of origin of the fire exceeded for about 30 minutes the values given by the standard time-temperature curve.

Interesting information was obtained on the noise level in a bedroom produced by a fire downstairs which would not necessarily rouse a sleeping occupant of an upstairs bedroom with the door closed.

A useful photographic record of all fires from the time of ignition has been obtained, and from this it has been possible to estimate the projection of flame fronts from the windows.

Acknowledgments

The success of the operation was made possible by the very valuable cooperation of a number of organizations including the Hydro-Electric Power Commission of Ontario, the Ontario Fire Marshal's Office, the National Film Board, and the Ontario Provincial Police. Grateful acknowledgment is due to all the members of the Fire Section and to other members of the Division for untiring efforts, often under extremely difficult circumstances.

References

(1) Fire Gas Research Report, National Fire Protection Association, Committee on Fire Gas Research, NFPA QUARTERLY, *45*, 280 (1952).

(2) Hamilton, A. and R. T. Johnstone, Industrial Toxicology, Oxford University Press, 1945.

(3) Minchin, L. T., Mild Carbon Monoxide Poisoning as an Industrial Hazard, Ind. Chem *30*, 381 (1954).

(4) Corson, R. C., and W. R. Lucas, Life Hazard Tests on Wood Interior Finish, Factory Mutual Laboratories Report No. 11975, Boston, Mass., Oct. 1, 1951.

(5) Kingman, F. E. T., E. H. Coleman and D. J. Rasbash, The Products of Combustion in Burning Buildings, Jour. App. Chem., *3*, 1953, p. 463–468.

(6) Standard Methods of Fire Tests of Building Construction and Materials. NFPA No. 251. ASTM E119–58.