Reducing Fire Hazards in Small Buildings

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Each year in Canada, building fires cause hundreds of deaths, thousands of injuries and billions of dollars worth of property damage. Canada has the second highest fire death rate among 15 industrialized countries (Figure 1).[1] In Canada in 1988, about 72% of fire deaths and 40 percent of fire property losses occurred in small buildings, such as one- and two-family homes, apartment buildings and hotels/motels.[2] The 1989 fire statistics for Alberta indicate that about 70% of fire deaths and 51 percent of fire property losses occurred in small buildings.[3]

What can we learn from these numbers? If we are really interested in reducing fire deaths and property losses, we must focus our efforts on fire safety in small buildings. This paper addresses four main aspects of reducing fire hazards:

- controlling fire within a compartment,
- controlling the spread of fire between compartments through interior separations,
- controlling the spread of fire between compartments through openings in exterior walls,
- providing early warning to building occupants.

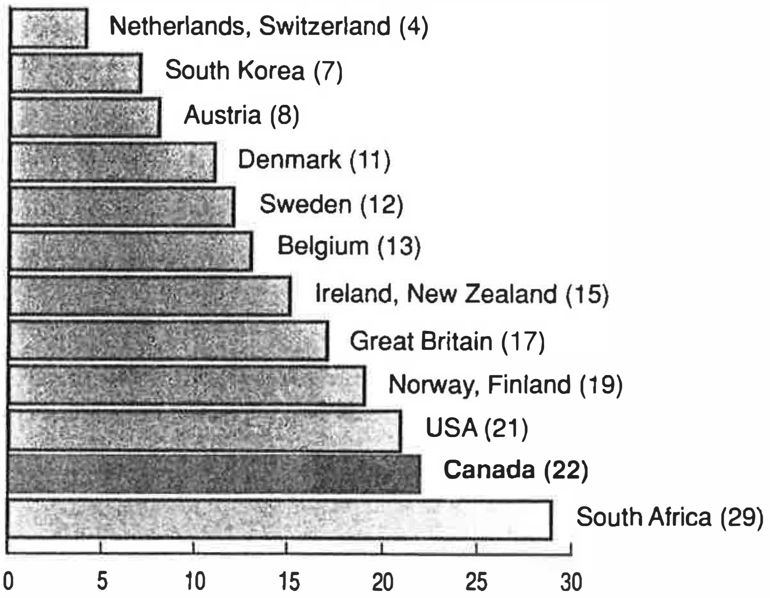
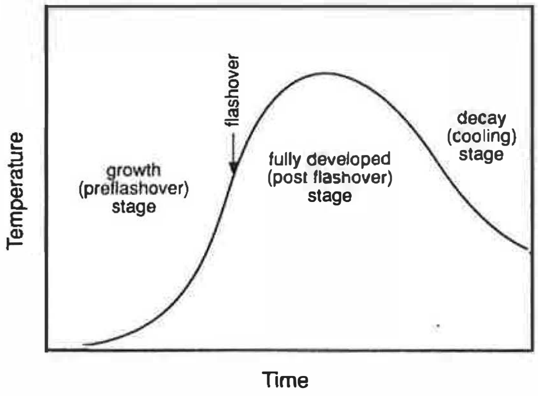


Figure 1 Fire deaths per million population in 15 industrialized countries (1986)

Fire Life Cycle



Typical time / temperature curve

There are four stages in the life of a fire:

- ignition,
- fire growth period (pre-flashover),
- fully developed fire (post-flashover),
- decay.

Combustion requires heat, fuel and oxygen. Fire growth is a function of the fuel itself, with little or no influence from the compartment configuration. Given sufficient fuel and oxygen, the fire will continue to grow, causing an increase in the compartment temperature. When substantial heat is generated (500° to 600°C) flashover occurs and the fire becomes fully developed, engulfing the whole compartment. Decay follows when all the fuel or oxygen within the compartment is totally consumed.

Controlling Fire within a Compartment

A fire compartment is defined as an area of a building which is totally separated from the remainder of the building by continuous fire rated construction. This area can be a single room, a series of rooms or an entire floor. It can be a vertical service space, such as a shaft, or a horizontal service space, such as a crawl space below a floor.

Based on US fire statistics,[4] 85% of fires do not spread beyond the compartment of origin. Thus, if we increase the fire safety measures within a compartment, fire losses will be reduced.

Fire in a compartment can be controlled by either passive or active fire protection measures. Passive fire protection measures include:

- the use of materials which are difficult to ignite or have low surface flame spread ratings,
- the use or storage of fewer combustible items and materials in our buildings.

One active fire protection measure is the use of a fast response sprinkler system.

Low Surface Flame Spread Ratings

Most walls and ceilings of buildings constructed under the National Building Code of Canada (NBC) require a surface flame spread rating of no more than 150. Less stringent ratings apply to bathrooms and doors while more restrictive ratings apply to public corridors and exits. For comparison, the flame spread rating for non-combustibles is 0, for gypsum wallboard, 25, for red oak, 100, and for many carpets, 300. The maximum flame spread rating acceptable under the NBC should not, however, be considered optimum. Specification of surface materials with flame spread ratings lower than the Code limit will help to reduce the fire hazard.

Reduction of Combustibles

This fire protection measure is beyond the control of building designers and owners, unless they also happen to be the building occupants. Many countries maintain strict control over the quantities and types of combustibles that may be stored or used in small buildings. This appears to significantly reduce fire losses; however, it is extremely difficult to impose and enforce.

Quick Response Sprinkler Systems

Quick response sprinkler systems, an active fire protection measure, are not required by the NBC for small buildings, but have sometimes been used to relax other Code requirements, such as the fire resistance of the fire separations.

Sprinklers do a good job fighting fires in their early stages and also play a significant role in detecting the fire and informing the fire department. Although sprinklers are primarily used to control fires until fire department personnel arrive, in the majority of fire incidents involving actuation of an automatic sprinkler system, the fire is fully extinguished without the fire fighters' intervention. Figure 2 shows the results of two tests[5] conducted with and without sprinkler protection. One test involved the ignition of upholstered furniture placed in the corner of a room; the other, a 6-foot-high fuel package of plastic commodities. With the use of sprinklers, in less than 3 minutes the fires were already in the decay period and about to extinguish. In the same interval, the unsprinklered fires continued to grow and to increase the temperature of the compartment.

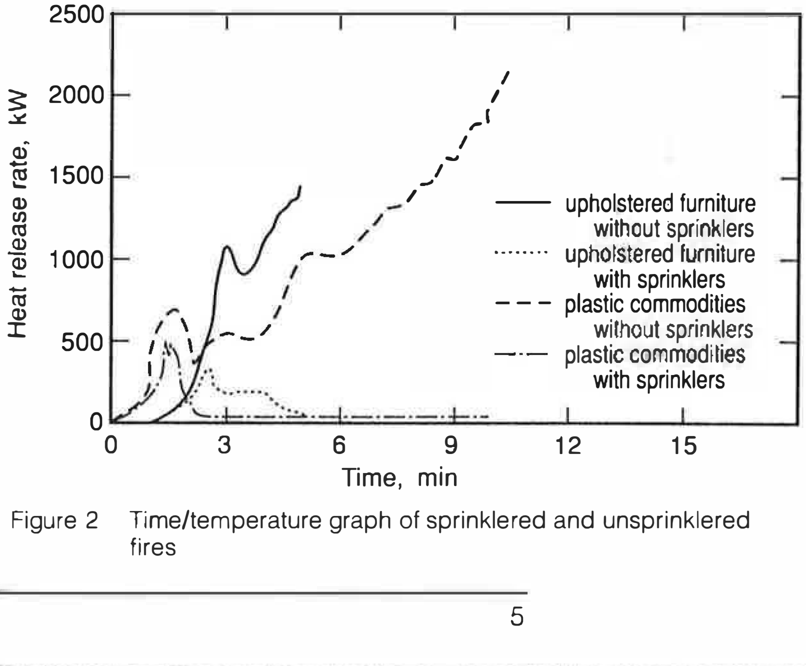


Figure 2 Time/temperature graph of sprinklered and unsprinklered fires

Despite the major role that can be played by sprinklers in fighting fires, sprinkler systems in many small buildings have one disadvantage, the cost of installation.

A joint task group for the NBC considered mandatory sprinklers in residential occupancies. The group has recommended[6] to the Standing Committee on Housing and Small Buildings that the installation of automatic sprinkler systems not be made mandatory in houses, except for houses that are intended to accommodate persons with special needs.

In the opinion of the joint task group and based upon the information available at present, the projected number of lives that would be saved does not justify the expenditure required to install these systems in all new houses.

Control of Fire Spread between Compartments through Interior Separations

Two issues are addressed:

- the effect of sound absorbing material on the performance of fire separations,
- sprinklered glazing as an alternate fire separation measure.

Effect of Sound Absorbing Material on the Performance of Floor and Wall Assemblies

To meet more stringent sound transmission specifications in multi-family residential buildings and small commercial and industrial buildings, designers often propose to install glass fibre sound absorbing batts in the cavities of conventional floor and wall assemblies. Previously, fire resistance data for floors were based on tests of assemblies without glass fibre batts. It was assumed the addition of glass fibre would increase the temperature of the ceiling below and lead to earlier failure of the assembly. In the case of wood frame walls, low density (up to 0.6kg/m^2) glass fibre sound absorbing batts have been installed for a number of years, but their effect on fire resistance was not established. IRC conducted two studies[8,9] to answer the question of how sound absorbing batts affect the fire performance of floor and wall assemblies.

Floors

The first study considered wood truss and wood joist floor assemblies (Figure 3). In several assemblies involving wood trusses with sound absorbing batts, early failure did occur following substantial deflection of the truss under fire exposure. Where the furring channels supporting the gypsum board were wired to the truss chords and when additional channels were provided to support the batts, however, the assembly accommodated the truss deflection without affecting the integrity of the gypsum board ceiling membrane.

The study concluded that both assemblies shown in Figure 3 had similar fire resistance ratings. Since wood joist systems deflect less in a fire than wood truss systems, the use of steel channels rigidly fastened to the joists to support the insulation and gypsum board ceiling will lead to similar performance. These findings are incorporated in Chapter 2 of the 1990 Supplement to the NBC and in Part 9 of the NBC.

Walls

In a second study, the installation of glass fibre batts with a density of 0.6 kg/m^2 in gypsum board wood stud non-bearing wall assemblies increased the fire resistance rating by 5 minutes. These findings have also been incorporated into Chapter 2 of the 1990 Supplement and Part 9 of the 1990 NBC.

Effect of Sprinklered Glass on Fire Resistance

The use of glazing in fire separations is strictly regulated by building codes. Glazing is limited to vertical installations using wired glass in steel frames. Individual panes must not exceed 0.84 m^2 in area and must have a maximum dimension of 1.4 m. To the designer, these limits impose severe restrictions on the design of interior and exterior fire-rated assemblies where glazing is desirable.

The IRC Risk – Cost Assessment Model

IRC is developing a risk-cost assessment model for assessing the cost effectiveness of NBC fire safety provisions such as sprinklers, higher reliability alarms and stairwell pressurization. These models are computer-based tools that can be used to evaluate the changes in risk and cost of various designs and features for fire protection of buildings, compared to a design in direct compliance with the NBC. The two major parameters in assessing cost effectiveness are:

- Expected Risk to Life (ERL) – the expected number of deaths over the life of the building divided by the total population and the design life of the building,
- Fire Cost Expectation (FCE) – the expected direct cost, capital and maintenance, and fire losses, divided by the total cost of the building.

An alternative design is considered to be cost-effective if the ERL and/or the FCE are lower than the corresponding values for the design in compliance with the NBC.

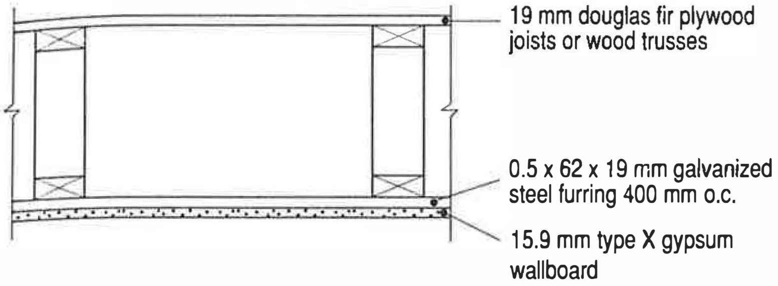
In a recent study,[7] a model for a 3 storey apartment building was developed for different fire protection options. The model was not intended to answer whether sprinklers should be mandatory but to provide design options. The most cost-effective design for the test case used a higher reliability central alarm but no sprinkler; it achieved a 25% lower risk to life for the same cost as the Code-complying design (see table). Adding sprinklers also reduces the risk to life, but increases the cost.

	No Stairwell Pressurization		With Stairwell Pressurization	
	No Sprinklers	With Sprinklers	No Sprinklers	With Sprinklers
No Alarm				
Expected Risk-to-Life	1.66	0.79	1.66	0.79
Fire Cost Expectation	0.76	1.36	1.03	1.63
Central Alarm				
Expected Risk-to-Life	1.00	0.57	1.00	0.57
Fire Cost Expectation	1.00	1.60	1.16	1.77
Higher Reliability Central Alarm				
Expected Risk-to-Life	0.75	0.52	0.75	0.52
Fire Cost Expectation	1.00	1.60	1.16	1.77

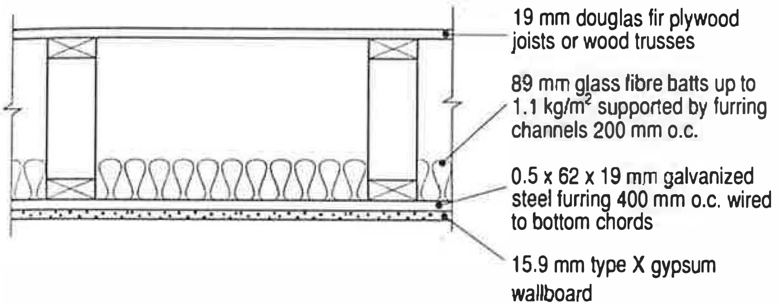
Relative costs and benefits of various fire protection measures in the test case

☐ Code complying design ▣ Most cost effective design

The test case makes a great number of assumptions concerning the building, its design and its occupancy patterns. Costs and risks for other buildings will vary depending on occupancy, suppression systems, evacuation/egress, flame and smoke spread, economics, and risk to life.



a) Uninsulated floor assembly



b) Insulated floor assembly

Figure 3 Floor systems tested as fire separations

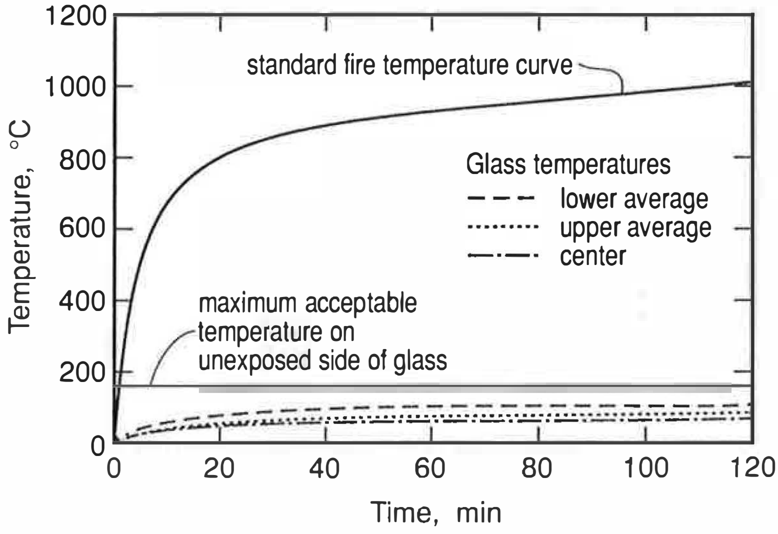


Figure 5 Test curve for tempered glass assemblies protected by sprinklers

In an attempt to give designers more flexibility, the National Fire Laboratory of IRC conducted research to determine whether different types of glass, larger areas and dimensions, and different framing materials could be assembled in such a way as to provide equivalent fire resistance. These experiments examined tempered and wired glass, and single and double glazing, in conjunction with automatic sprinklers[10] (Figure 4).

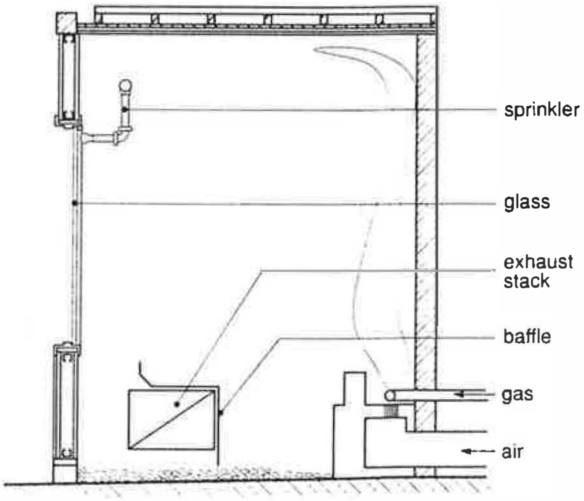


Figure 4 Setup for testing sprinklered glass

The results for tempered glass are presented in Figure 5. Conclusions were drawn from the test series as follows:

- single glazed assemblies protected by sprinklers will withstand a fire for at least two hours, double glazed assemblies for at least 90 minutes;
- temperatures measured on the unexposed surface are within the range permitted by CAN4-S101 (Standard Methods of Fire Endurance Tests of Building Construction and Materials);
- tempered glass assemblies with more than 5 times the permitted area and dimensions greater than 1.8 times those specified for wired glass withstood the fire for at least two hours.

The performance of these assemblies exceeded that required by the Code, indicating that fire resistant assemblies that incorporate sprinkler protected glazing are a feasible design option.

Controlling Fire Spread between Compartments through Openings in Exterior Walls

Flames issuing from a broken window or a door opening tend to curl back and touch the wall and window above (Figure 6). The flow and intensity of the heat is often high enough to be a fire hazard to the compartment above.

The objective is to prevent the flame from attacking the wall above the opening. Two factors which affect this are:

- window size and shape,
- horizontal and vertical baffles.

Window Size and Shape

The effect of window size on fire spread on an exterior wall was studied by IRC's National Fire Laboratory. Tests[11] indicate that large windows allow more fuel to be burned inside the fire compartment than do small windows, thus decreasing the temperature of the exterior fire plume and the height of the flaming portion of the plume. The test results (Table 1) show that heat flow was lowest above the largest window (C).

Window dimensions W x H (m)	Height above window (m)	Heat flow measured on wall (kW/m^2)	
		5.5 MW source	8.6 MW source
A 0.94 x 2.00	0.5	43.9	75.5
(1.88 m^2)	1.5	12.4	25.9
	2.5	7.7	15.9
	3.5	3.9	8.1
B 0.94 x 2.70	0.5	19.2	53.2
(2.54 m^2)	1.5	6.3	15.9
	2.5	3.5	9.8
	3.5	1.7	4.8
C 2.60 x 2.70	0.5	6.5	17.4
(7.02 m^2)	1.5	2.9	8.1
	2.5	2.0	5.7
	3.5	1.4	3.6
D 2.60 x 2.00	0.5	10.5	29.5
(5.2 m^2)	1.5	5.2	14.8
	2.5	4.5	12.6
	3.5	2.9	8.2
E 2.60 x 1.37	0.5	24.5	104.3
(3.56 m^2)	1.5	22.9	58.6
	2.5	13.2	51.2
	3.5	11.5	28.3

Table 1 Heat flow measured above windows of various dimensions

The ratio of the window height to its width controls the shape of the plume. Table 1 shows that tall narrow windows present a lesser hazard than short wide ones. Tall windows tend to project flame away from the facade, decreasing the thermal coupling of the flames with the facade and keeping thermal exposure relatively low. Maintaining width and increasing height (windows A and B) decreases the heat transfer to the wall above the window though the effect may be partly due to increased area. Window B, however, is tall and narrow and presents less of a hazard than window E even though it has a smaller area.

Horizontal and Vertical Projections

Functional and aesthetic considerations can affect the form of a building's facade. If the form of the facade protects the wall above the window from flame and heat feedback, we will reduce the likelihood of the flame spreading rapidly up the exterior wall. A recent National Fire Laboratory study[12] on the effect of facade geometry measured heat transfer to the facade from a flame issuing from a 1.13 m^2 window.

A horizontal panel called a "flame deflector," 1.22 m deep and 2.44 m wide, was attached at the top of the window. Figure 7a shows how the fire plume was pushed away from the window; the heat feedback to the

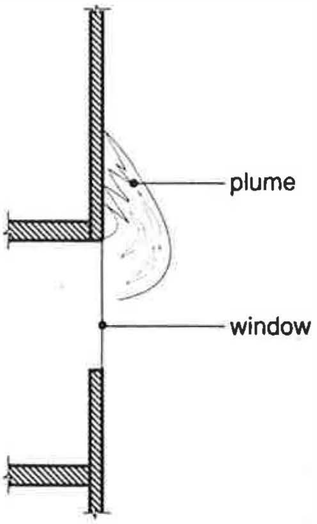
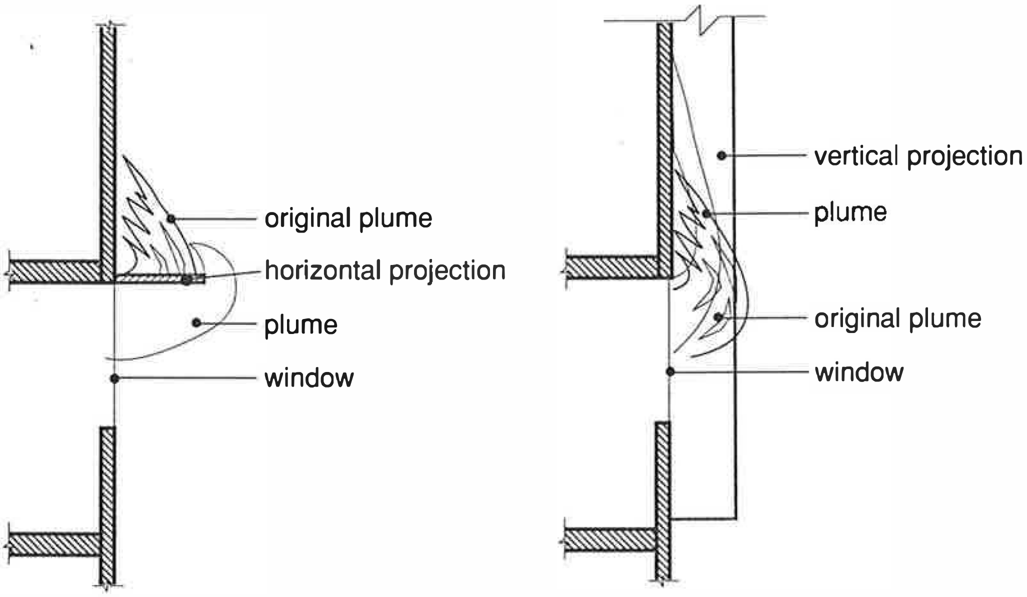


Figure 6 Flame and heat plume from window



a) Horizontal projection

b) Vertical projection

Figure 7 Effects of horizontal and vertical projections on a flame and heat plume

facade dropped suddenly (Figure 8). The horizontal projection offers substantial protection for the wall above the window. Balconies are natural flame deflectors often used in small buildings.

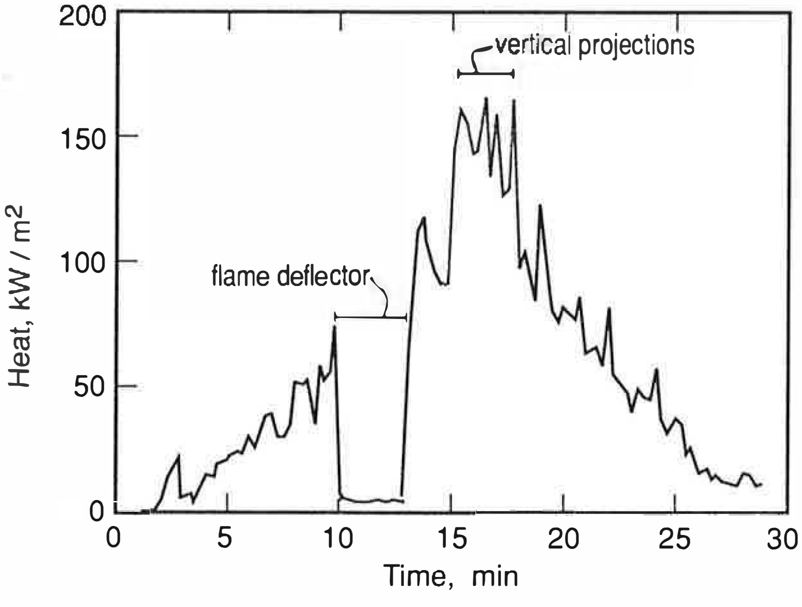


Figure 8 Effects of projections on heat feedback to a wall

Vertical projections are often used on buildings to provide visual screens, sunshades or simple articulation of the facade These projections increase heat feedback to the facade. They restrict the supply of air to the sides of the plume, causing the combustion zone within the plume to extend further up the wall (Figure 7b), and increasing heat feedback to the wall (Figure 8).

Early Warning

In today's society, builders and regulators must respond to demands from occupants for quieter accommodation. Designers achieve this by specifying sound absorbing material in floors and walls to minimize sound transmission between living units or work spaces. As discussed previously, this does not have any adverse effect on the fire performance of the assemblies. It can, however make a fire alarm less audible.

Fire alarms can save lives in fire emergencies only if people hear them. Furnishings, surface treatments and sound insulation in intervening walls reduce the sound level between the alarm and the building occupants. Studies on the audibility of smoke and fire alarms have been conducted at

IRC, to enable practitioners to determine the optimum location of sounding devices.

For non-residential buildings where the occupants are assumed to be awake, the sound level at the occupant must be 5 dBA above any other sound likely to persist for longer than 30 seconds, or 65 dBA, whichever is greater. (dBA is the sound pressure level in decibels weighted to approximate the response of the human ear, which is not equally sensitive at all frequencies.)

For residential buildings, where occupants may be asleep, a sound level of 75 dBA is required in the bedrooms. It is common practice in apartment buildings to locate alarm-sounding devices in the corridor outside the apartments. There are a number of reasons for doing this, including the security of the device, ease of maintenance and cost.

IRC investigated the problem of significant attenuation (reduction of sound level) between the common corridor and bedrooms[13,14] in an apartment building. The sound attenuation between the common corridor and the apartment hallway (Figure 9) was about 32 dBA, and between the common corridor and bedroom was about 55 dBA. Given that the minimum sound level required to waken a sleeping person is 75 dBA, the alarm sounding device needs to produce 130 dBA in the common corridor. This is not a reasonable level; not only is it difficult to achieve, it is above the threshold for permanent hearing damage. Thus if adequate waking potential for fire emergencies is to be provided for sleeping residents, an alarm-sounding device must be located within each apartment.

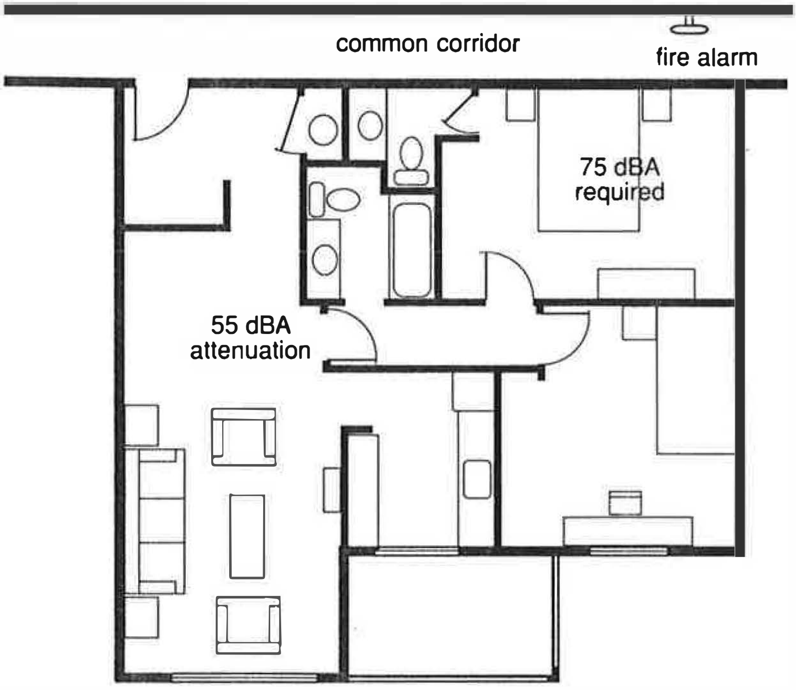


Figure 9 Apartment layout indicating sound attenuation between fire alarm and bedroom

The appendix shows how to determine the optimum location for both a fire alarm in an apartment building and a smoke alarm in a single family home. The same procedure may be applied to non-residential buildings.

In the case of a smoke alarm, the optimum location for audibility may not necessarily be the optimum location for smoke detection. A smoke alarm should be located on each level; it is wise to have them interconnected so that if one sounds, all will sound. In this way, you can put smoke alarms in their optimum positions for both smoke detection and audibility.

Summary

Sprinklers provide an effective tool in fighting fire in its early stages. Cost factors generally restrict their use.

Risk-cost assessment models provide designers with design options.

Not only are designers permitted to use sound insulation in the cavities of fire-resistant wall and floor assemblies, this practice actually improves fire performance in walls.

The use of sprinklers gives designers more freedom in their use of glazing in fire-resistant wall assemblies.

Tall windows and flame deflectors significantly reduce the flame spread over walls and windows from fire plumes issuing from the storey below.

A procedure has been developed that allows designers to determine the optimum location for fire and smoke alarms in small buildings.

Appendix

Determining Sound Attenuation between Fire Alarms and Building Occupants

The appendix consists of two parts:

- The first part presents the general steps to follow to determine sound level at the recipient. The procedure may be applied to any type of building.
- The second is a worked example for a residential row unit, addressing the worst case (sleeping occupants).

For non-residential occupancies, where the occupants are presumed to be awake, the sound level at the receiver must be 5 dBA above any other sound level that is likely to persist for longer than 30 s or 65 dBA, whichever is greater. For residential occupancies, the sound level at the location of a sleeping occupant must be no less than 75 dBA.

Table A1 is the form to be filled out in the process of doing the calculation. Tables A2 to A4 provide values used in the calculation. Table A5 presents the worked-out example.

General Procedure

Step 1

Assume a location for the smoke alarm and define the path, in terms of rooms, that the sound will follow between the smoke alarm and the room in which the sound level is to be determined (the receiver). Hallways should be considered as rooms. Assume that the sound path is the same as that which a person would follow in walking between the two locations. List in Table A1 each portion of the sound path, starting with the room where the alarm is located.

Step 2

Determine the floor area of each room. Enter these values in Table A1.

Define the sound absorption characteristics (soft, normal, or hard) of each portion of the sound path (room), according to the descriptive factors in Table A2. Record in Table A1 the absorption characteristics for each portion of the sound path (room).

Step 3

Obtain the sound level correction factor for each room on the sound path. Use Table A3 for the room in which the alarm is located and Table A4 for other rooms. (Table A4 gives the sound correction factor for moving from one room to another via a typical open doorway.) Pay close attention to the sign (positive or negative) of the correction factor. It is usually negative, except in small corridors with "hard" absorption features, where the intensity of the alarm sound level may be increased. An additional reduction in sound level of 10 dBA must be included for each door along the sound path that could be closed. Record the correction factors for each portion of the sound path (room) and each door in Table A1.

Step 4

Compute the sum of the correction factors in Table A1, paying close attention to sign (positive or negative). Add the value obtained in this calculation to the stated sound power level of the alarm device to obtain the sound level in the room at the end of the sound path.

If the calculated sound level in the room at the end of the sound path is equal to or greater than the sound level required in the room, the assumed location for the smoke alarm is adequate. If not, assume another location for the smoke alarm and repeat the procedure until the required sound level is achieved in the bedroom.

Example

Given

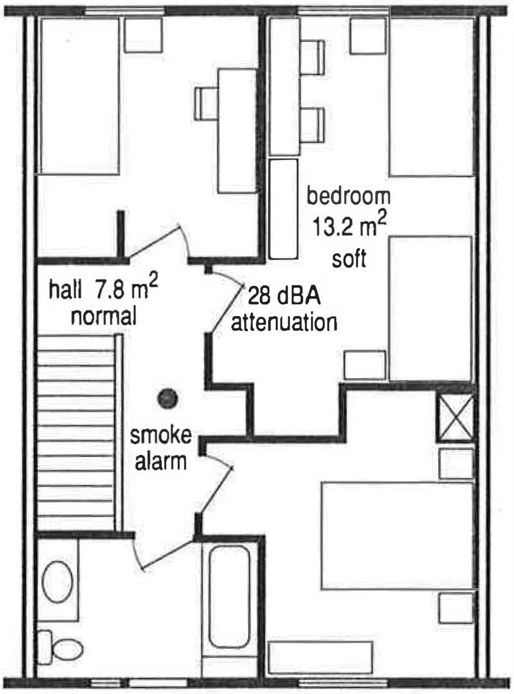
Assume a 2-level home as shown in Figure A1. The predicted alarm sound level in the bedroom indicated (Level 2) is to be determined with a smoke alarm located in the adjacent upstairs hallway. The hall has a floor area of 7.8 m^2, wall-to-wall carpeting and light drapes ("normal" absorption characteristics in Table A2). The bedroom has an area of 13.2 m^2, deep carpets, heavy drapes and a bedspread (a "soft" room in Table A2). The smoke alarm has a sound power level of 95 dBA.

Calculation

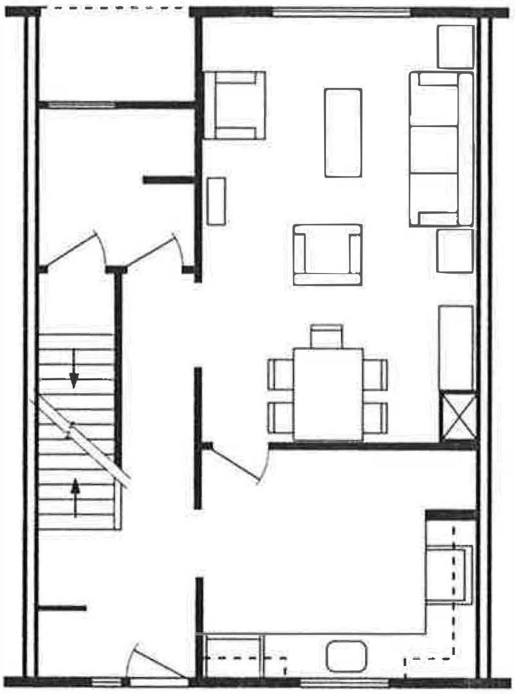
The sound path consists of a hallway and the bedroom. Starting with the hallway, 7.8 m^2 floor area and "normal" characteristics, the sound power level correction factor is -3 dBA from Table A3. Moving to the bedroom and using Table A4, the 13.2 m^2 "soft" bedroom contributes a reduction in sound pressure level (in passing through the door opening) of -15 dBA. Since the door can be closed, an additional reduction of 10 dBA is required. The total sound level correction factor is -28 dBA and thus the predicted sound level in the bedroom is 67 dBA.

Outcome

This is inadequate to ensure that a sleeping person will be wakened. Solutions include modification of sound path characteristics, increasing the power level of the alarm or moving the alarm into the bedroom.



Level 2



Level 1

Figure A1 Floor plan of residence

Room	Floor area m²	Absorption characteristics	Sound correction factor dBA	Door correction factor dBA	Total sound reduction dBA

Total sound level correction factor, dBA

Stated sound power level of alarm device, dBA

Predicted sound level at end of sound path, dBA

Table A1 Computation of alarm sound level at end of sound path

Room Characteristic	Sound Absorption Features
Hard	No carpet, drapes or upholstered furnishings (kitchen, bathroom)
Normal	Carpets, light drapes, upholstered furnishings (living/dining rooms, halls)
Soft	Thick carpets, heavy drapes, soft furnishings (bedrooms)

Table A2 Room sound absorption characteristics

Area of room where alarm is located, m²		Correction to be added to the sound power level of alarm device, dBA		
greater than	to	Soft	Normal	Hard
2.4	3.0	0	2	4
3.0	3.7	-1	1	3
3.7	4.7	-2	0	2
4.7	5.9	-3	-1	1
5.9	7.4	-4	-2	0
7.4	9.3	-5	-3	-1
9.3	11.7	-6	-4	-2
11.7	14.8	-7	-5	-3
14.8	18.6	-8	-6	-4
18.6	23.4	-9	-7	-5
23.4	29.5	-10	-8	-6
29.5	37.1	-11	-9	-7
37.1	46.7	-12	-10	-8
46.7	58.8	-13	-11	-9
58.8	74.1	-14	-12	-10
74.1	93.3	-15	-13	-11
93.3	117.5	-16	-14	-12

Table A3 Sound power level correction factor to determine the sound level in the room where the alarm is located

Area of room into which sound is moving, m²		Correction to be added to the sound power level of alarm device, dBA		
greater than	to	Soft	Normal	Hard
1.9	2.3	-7	-5	-3
2.3	2.9	-8	-6	-4
2.9	3.7	-9	-7	-5
3.7	4.7	-10	-8	-6
4.7	5.9	-11	-9	-7
5.9	7.4	-12	-10	-8
7.4	9.3	-13	-11	-9
9.3	11.7	-14	-12	-10
11.7	14.7	-15	-13	-11
14.7	18.5	-16	-14	-12
18.5	23.3	-17	-15	-13
23.3	29.4	-18	-16	-14
29.4	37.0	-19	-17	-15
37.0	46.6	-20	-18	-16
46.6	58.6	-21	-19	-17
58.6	73.8	-22	-20	-18
73.8	92.9	-23	-21	-19
92.9	116.9	-24	-22	-20

Note: Add an additional -10 dBA if the door can be closed.

Table A4 Reductions in sound level as sound passes from one room to the next via a typical open doorway

Room	Floor area m^2	Absorption characteristics	Sound correction factor dBA	Door correction factor dBA	Total sound reduction dBA
Hallway	7.8	Normal	–3	nil	–3
Bedroom	13.2	Soft	–15	–10	–25
Total sound level correction factor, dBA					–28
Stated sound power level of alarm device, dBA					95
Predicted sound level at end of sound path, dBA					67

Table A5 Sample computation of alarm sound level at end of sound path

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