fire protection planning report

BUILDING CONSTRUCTION INFORMATION FROM THE CONCRETE AND MASONRY INDUSTRIES

Is One-Hour Fire-Rated Compartmentation of Dwelling Units Adequate in Low-Rise Multifamily Housing?

INTRODUCTION

Fire fatalities in North America remain unacceptably high and the situation is not improving. Although fire deaths generally declined from 1977 to 1983, Canada and the United States had the second and third worst fire death rate, respectively, among the developed nations of the world in 1983.[1] Since then, fire deaths have reached a plateau. Table 1 summarizes U.S. and Canadian fire losses with respect to deaths and death rates over a 10-year period.

Although the primary emphasis of building codes today is on lifesafety, some attention needs to be refocused on a structure's ability to resist fire, even after the occupants have safely vacated the premises. The destructive impact of fire on property in the United States and Canada has become a serious economic burden for both countries.

Direct property loss attributed to fire in the United States is estimated at costing the American public between $6 and $7 billion a year.[4] When indirect costs are considered, annual cost estimates approach $30 billion![5]

Canada, on the other hand, has suffered a direct property loss from fire in the range of $0.9 and $1 billion* in each of the last four years.[3] While the magnitude of Canada's property damage isn't as great, the problem is more severe from the standpoint of per capita loss. In 1987, Canada's per capita loss in U.S. dollars was $30.60

*Dollar amount indicated is in Canadian dollars.

Table 1. Fire Deaths and Death Rates in the United States and Canada

| Year | Deaths [1] | | Death rates per 100,000 population | |
	U.S.[2]	Canada[3]	U.S.[2]	Canada[3]
1977	7473	811	3.40	3.47
1978	7791	844	3.51	3.58
1979	7658	733	3.41	3.07
1980	6578	833	2.89	3.48
1981	6774	694	2.95	2.87
1982	6085	675	2.62	2.74
1983	5978	539	2.55	2.17
1984	5299	598	2.24	2.38
1985	6247	550	2.61	2.17
1986	5896	553	2.44	2.18
1987	5863	516	2.41	2.01

[1] Numbers include civilians and firefighters.
[2] Source: Reference 2.
[3] Source: Reference 3.

Boarded up windows tell the tale as fire spread from one compartment to the next, destroying all eight units of this apartment building. Increased structural fire resistance and compartmentation would certainly have reduced the amount of damage.

(based on $37.32 Canadian dollars[5] and an average rate of currency exchange for the years 1987–1989), compared to $25.58 for the United States.[4] Canadian indirect losses in 1987 were estimated at $2.5 billion.*[6]

PURPOSE

This report shows why one-hour fire-rated separation of dwelling units in multifamily housing represents an inadequate level of property protection. Model building code requirements for fire resistance of dwelling-unit separations are also examined, along with the methodology used in establishing these requirements. Finally, a balanced design approach to firesafety is proposed for multifamily housing, identifying concrete and masonry construction as the primary component in a system comprised of compartmentation and automatic suppression and detection elements.

FIRE LOSSES IN MULTIFAMILY OCCUPANCIES

Although the largest percentage of fire losses occurs in one- and two-family residences, a significant portion also occurs in multifamily dwellings. This information is shown in Table 2.

In 1988, approximately 286,000 low-rise multifamily housing starts were reported in the United States,[7] and 65,555 units were built in Canada.[8] Increased construction of low-rise multifamily housing is forecast for the early 1990's in the United States,[7] and there is no reason to believe that a similar trend will not develop in Canada as well. If building codes continue to permit multifamily housing to be built with dwelling separations of minimal fire resistance, the fire problem in North America will continue to stagnate for years to come. Changes must be implemented today if there is any hope of improving this situation in the future.

AN OVERVIEW OF CODE REQUIREMENTS FOR DWELLING-UNIT SEPARATIONS

In general, multifamily buildings are subjected to stricter building code provisions than those classified as one- and two-family residences. The fire-endurance requirements pertaining to dwelling-unit separations in low-rise multifamily buildings and one- and two-family (attached) buildings, however, are virtually the same. Model codes in the United States require dwelling-unit separations to be one-hour fire-rated construction.[9 10 11 12] In Canada, as little as ¾-hour separations are required.[13]

Considering multifamily buildings as a series of single-family homes in a side-by-side or back-to-back configu-

*Dollar amount indicated is in Canadian dollars.

Table 2. Estimated Multifamily Fire Losses in the United States and Canada in 1987

		Property		Deaths		Injuries	
Country	Dollar loss	Percentage of total residential losses	Number[3]	Percentage of total residential losses	Number[3]	Percentage of total residential losses	
U.S.[1]	$.521 billion (U.S.)	14.1	790	17.0	4765	23.3	
Canada[2]	$78.8 million (Canadian)	20.6	98	22.3	1053	40.4	

[1] Source: Reference 4.
[2] Source: Reference 3.
[3] Quantities for the United States pertain to civilians only. Canadian totals include civilians and firefighters.

ration, stacked on top of one another, it's easy to see the difference in hazard potential associated with each. Clearly, more occupants and property are at risk in a multifamily building. In addition, multifamily residents are exposed to the careless actions of their neighbors without the benefit of separation distance inherent in single-family housing. Comparative levels of risk versus protection in multifamily and single-family buildings are not equal, and they should not be treated as such.

STANDARD FIRE TESTING PROCEDURES FOR BUILDING CONSTRUCTION AND MATERIALS

Fire-resistance ratings of building assemblies are based on an assembly's ability to meet test criteria contained in the ASTM E 119 test standard. The standard fire condition these assemblies are subjected to is shown in Fig. 1.[14] Canada uses an almost identical test curve published in the ULC CAN4-S101 standard.[15]

The dawn of modern-day testing dates back to the 1918 edition of ASTM E 119.* Prior to this, building codes

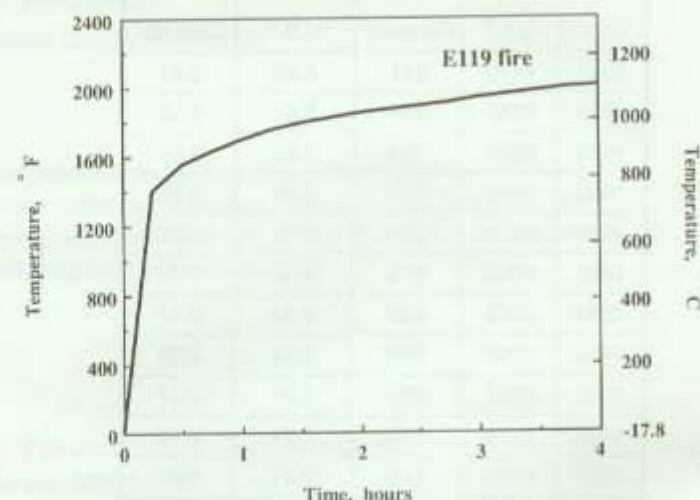*Where E 119 is mentioned, the text also applies to the time-temperature relationship used in Canada.

Fig. 1.   ASTM E 119 time-temperature curve.

were prescriptive in nature, requiring that specific materials and assemblies be installed. With the adoption of the E 119 time-temperature (T-T) relationship, codes have become more performance oriented, leading to the current practice of specifying minimum fire-resistance requirements of various building elements.

Advancements in fire technology over the years, however, have given birth to a strong interest in computer modeling of real-world fires. Such activity has raised questions as to the appropriateness of basing the level of fire protection required by codes on the E119 T-T relationship. Several limitations of using E 119 for this purpose, in lieu of time-temperature relationships of real-world fires, are discussed below:

1. E 119 does not permit a performance evaluation of a compartment or building as a whole, since test specimens are fire tested as individual building elements.
2. E 119 cannot provide a basis for evaluating a building element's performance in the field under actual fire conditions. It can only compare the ability of one assembly to resist the standard fire exposure in relation to another.
3. E 119 was developed at a time when wood was the most common combustible material in building construction. Many of today's combustible materials have much more severe burning characteristics than wood.
4. E 119 is based mainly on fire loading and does not consider several important factors that influence fire behavior. These concerns are addressed in the section that follows.

Canada's situation is different. The level of fire protection required by the Canadian code for the separation of dwelling units is not *directly* influenced by the standard T-T relationship. However, use of the standard fire conditon in the testing procedure still affects the fire-resistance ratings of assemblies that will ultimately be installed to meet the code requirements. Consequently, a dicussion concerning the implications of real-world fire curves versus the standard T-T relationship, with regard to Canadian code applications, is still within the scope of this report.

FACTORS INFLUENCING FIRE SEVERITY

Unlike the E119 test fire, real-world fires do not occur in a controlled environment. They are affected by a number of variables that determine the fires' severity. In order to better understand these correlations, T-T relationships for real-world fires that reflect conditions present during a fire must be examined. Parameters that directly influence a fire's time-temperature relationship include fire load, fire compartment size and configuration, height and area of ventilation openings, and heat sink characteristics of the fire compartment.

Figs. 2a-2d[16] show the independent effect each of these parameters has on time-temperature relationships when the other parameters are kept constant. The "real fire" curves represent the gas temperatures that exist within the compartment during the course of the fire.
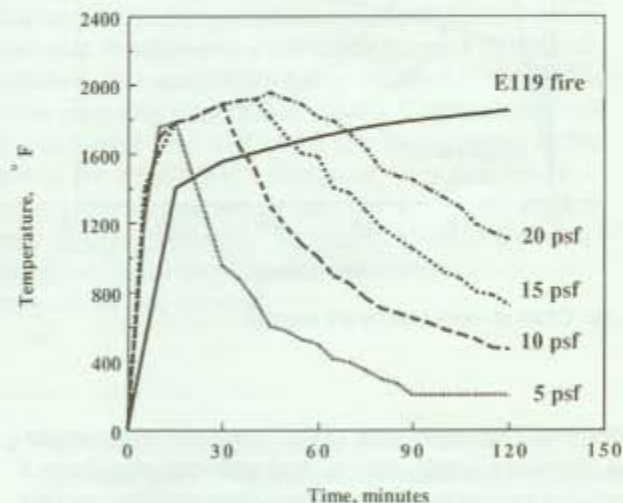

Fig. 2a. Effect of fire load on the severity of real fires.

Changing the amount of ventilation (opening factor) has a dramatic impact on the duration and intensity of fire.
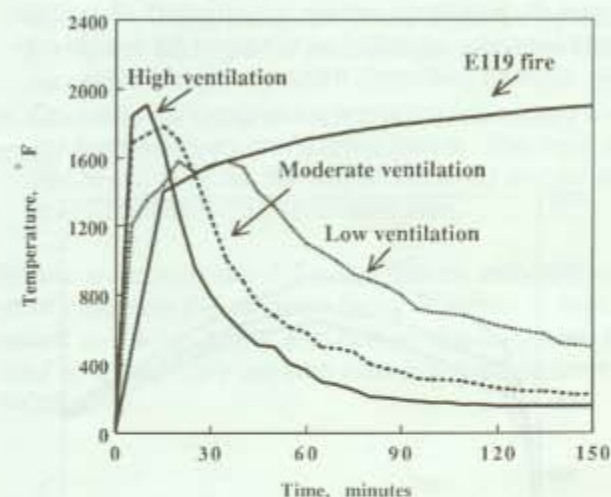

Fig. 2b. Effect of ventilation on fire severity.

Compartment size also affects the fire time-temperature relationship. Opening factors have been adjusted to maintain a moderate amount of ventilation, relative to the room sizes shown. Fire loading and type of enclosure remain constant.
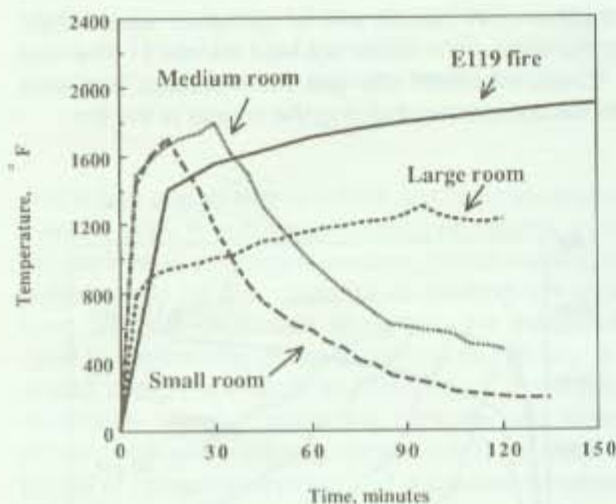
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Fig. 2c. Effect of room size on fire severity.

Thermal characteristics of the compartment's enclosure elements (walls, floors, and ceilings) also have a significant impact on compartment temperatures and fire duration.

A description of the enclosing construction for various compartments is provided below:

Type A—Enclosed space constructed of a combination of building materials having thermal properties equivalent to that of structural lightweight concrete.

Type B—Enclosed space constructed entirely of normal-weight concrete.

Type E—Enclosed space constructed of normal-weight concrete, insulating nonstructural lightweight concrete, gypsum wallboard, mineral wool, and brick.
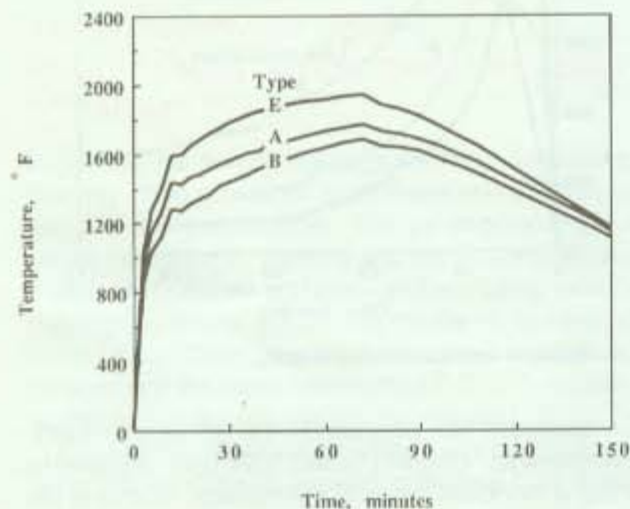

Fig. 2d. Effect of enclosure material on fire severity.

These figures illustrate that fire load is not the only parameter to consider in determining fire-endurance requirements. Under actual fire conditions, the amount of ventilation, thermal characteristics of boundary elements, and geometrical configuration are all key factors in the development of fire. In the real world, these parameters change from one fire scenario to the next. Conditions during standard fire testing remain constant.

FIRE-ENDURANCE REQUIREMENTS BASED ON REAL FIRE CURVES

When code proposals have been introduced to increase the fire-resistance requirements of dwelling-unit separations from one to two hours, opponents have argued that a one-hour separation is sufficient. Their arguments are largely based on an assumed fire loading in residential occupancies of 10 lb per square foot and the common belief that this fire load represents a one-hour exposure of the ASTM E 119 standard fire condition.

The major flaw with this concept, however, is that the E 119 test method is not meant to simulate actual fire conditions. Considering the E 119 method's limitations discussed previously, it is clearly more appropriate that the necessary level of fire separation between multifamily dwelling units be based on real fire curves. To examine this further, a comparison is made between a real fire curve and the E 119 T-T relationship. In producing the real fire curve, two main components are needed (1) an appropriate fire-load design for a multifamily residence and (2) an established calculation method that will handle the complexities of compartment fire behavior.

Recent studies conducted by the National Institute of Standards and Technology (formerly National Bureau of Standards) found that the mean fire load in both single-family attached and detached dwellings is 13 lb per square foot.[17] Because of similarities within single-family and multifamily units, it is reasonable to assume that the fire loading within a multifamily dwelling unit will be just as great. In fact, a case can be made that the fire loading will possibly be higher due to typically smaller room sizes.

Provisions contained in the Swedish Building Code[18] provide the tools for analyzing compartment fire behavior. Sweden's code-accepted procedures in use since 1967 allow structural members to be designed for fire resistance based on the development of T-T relationships of real fires.

Using the referenced fire load of 13 lb per square foot and the Lund Institute's (Swedish Building Code method) rational design procedure for determining fire resistance,[19] a time-temperature curve can be selected that represents a complete burnout in a typical garden apartment. This curve, shown in Fig. 3, is based on assumptions and calculations indicated in Example 1.
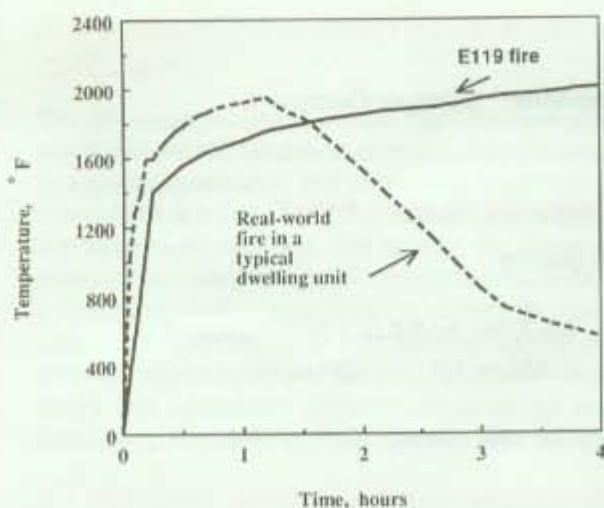
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Fig. 3. Comparing the time-temperature relationship of a real-world fire in a typical apartment to the standard fire curve.

Note that the temperatures of the real fire curve exceed those of the E 119 curve well beyond the one-hour mark. Since the time-temperature relationship of the real fire representing the complete burnout of the contents within the apartment is more severe than the standard fire curve, it is logical that one-hour fire-rated compartmentation is not adequate to resist the total burnout of a typical apartment.

Canadian code requirements do not contemplate that separation elements between dwelling units will be sufficient to withstand a complete burnout of the unit. However, the assemblies being installed to satisfy the code are being rated based on a T-T relationship that is less severe than that which can be expected under actual fire conditions. Therefore, in a real fire, it is expected that they would fail prior to the duration of their assigned ratings. Requiring greater fire-resistance ratings for dwelling-unit separations would compensate for this shortfall.

SELECTING APPROPRIATE T-T CURVES FOR COMPARTMENT FIRE SCENARIOS

Example 1

Given: Three-bedroom plan below, fire load of 13 lb per square foot of floor area, glazing areas equal to 8% (CABO, SBC, BOCA) or 10% (UBC) of the habitable floor area, 5.5-ft window height, 8-ft ceiling height, floor area equal to 1220 sq ft, and boundary surface area equal to 3660 sq ft.
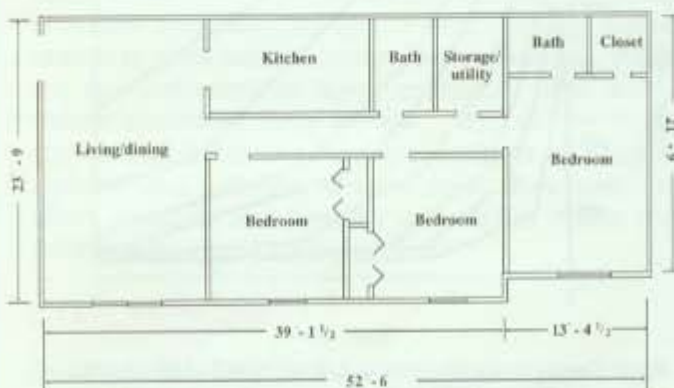

Fig. 4. Floor plan for three-bedroom apartment unit.

1. A Type E enclosure is chosen for boundary conditions, as described in the paragraphs preceding Fig. 2d. Of the several enclosure possibilities, Type E best represents the behavior of a combustible compartment subjected to the given fire conditions.

2. Floor area calculations are based on the entire compartment area, as if the interior walls are not present. Partitions within the apartment are ignored because they are generally nonrated and contain nonrated doors without automatic door closers.

3. Since the habitable spaces shown in Figs. 4 and 5 occupy approximately 75% of the respective total floor areas and glazing areas are assumed to represent about 70% of the window assembly, these factors offset one another when calculating areas of the vertical openings (A) in the opening factor (O.F.) equation. Thus, the quantity A is obtained by multiplying the glazing-area percentage by the compartment floor area.

4. Calculation of the opening factor only considers venting from windows and sliding doors. The main entrance-exit door for the unit is assumed closed and is not considered as ventilation area.

Before an appropriate T-T curve can be selected, one must calculate the opening factor in terms of meters raised to the $\frac{1}{2}$ power and convert the floor-area fire load to a boundary surface-area fire load in units of MCal/sq m.

Calculating the Opening Factor

The opening factor (O.F.) is defined as $(A \times H^{1/2})/A_t$

where A = area of vertical openings in the enclosed space

H = height of window openings
A_t = total bounding surface area of the compartment

In this example, glazing areas of 8% and 10% are shown, based on model code requirements.

For 8% glazing:

$$O.F. = 8\% \times 1220 \text{ sq ft} \times (5.5 \text{ ft})^{1/2}/3660 \text{ sq ft}$$
$$\times .555 \ m^{1/2}/ft^{1/2} = .035 \ m^{1/2}$$

Similarly for 10% glazing: O.F. = .043 $m^{1/2}$

Converting the Fire Load, Q

From: 13 lb/sq ft of floor area
To: MCal/sq m of boundary surface area

$$Q = [8000 \text{ Btu/lb} \times 252.4 \times 10^{-6} \text{ MCal/Btu}$$
$$\times 10.56 \text{ sq ft/sq m}] \times (\text{fire load in lb/sq ft})$$
$$\times (\text{floor area/boundary area})$$
$$= [21.32] \times (13) \times (1220/3660)$$
$$= 92.4 \text{ MCal/sq m}$$

Repeating these steps for a two-bedroom plan:

Example 2

Given: Two-bedroom plan, shown in Fig. 5, fire load of 13 lb per square foot of floor area, glazing areas equal to 8% (CABO, SBC, BOCA) or 10% (UBC) of the habitable floor area, 5.5-ft window height, 8-ft ceiling height, floor area equal to 954 sq ft and boundary surface area equal to 2937 sq ft.
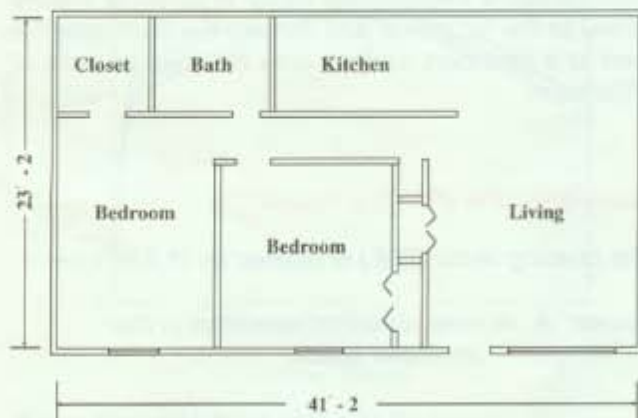

Fig. 5. Floor plan for two-bedroom apartment unit.

Assumptions: Same as Example 1.

Calculating the Opening Factor

For 8% glazing:

$$O.F. = 8\% \times 954 \text{ sq ft} \times (5.5 \text{ ft})^{1/2}/2937 \text{ sq ft}$$
$$\times .555 \ m^{1/2}/ft^{1/2} = .034 \ m^{1/2}$$

Similarly for 10% glazing: O.F. = .042 $m^{1/2}$

Converting the Fire Load, Q

$$Q = [8000 \text{ Btu/lb} \times 252.4 \times 10^{-6} \text{ MCal/Btu}$$
$$\times 10.56 \text{ sq ft/sq m}] \times (\text{fire load in lb/sq ft})$$
$$\times (\text{floor area/boundary area})$$
$$= [21.32] \times (13) \times (954/2937)$$
$$= 90.0 \text{ MCal/sq m}$$

Interpolating from the family of curves in Fig. 6 below, using an average fire load of 91 MCal/sq m, the real fire curve in Fig. 3 is obtained.
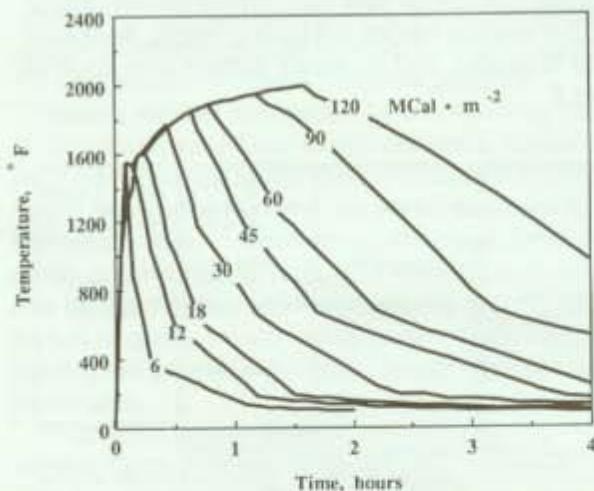

Fig. 6. Family of real-world fire curves for Type E enclosures having an opening factor of 0.04 $m^{1/2}$.

HOW MUCH FIRE PROTECTION IS ENOUGH?

The preceding analysis shows that one-hour compartmentation will not be able to contain a fully developed fire in a typical apartment. But even if two-hour construction is provided, it is only a single component of a fire protection system design. For this reason, the Concrete and Masonry Industry Firesafety Committee recommends that a balanced design approach be utilized for multifamily construction, consisting of compartmentation in conjunction with suppression and detection systems. All components are necessary if progress is to be made in decreasing the fire loss of life and property in future years.

A FIRESAFE ALTERNATIVE IN LOW-RISE MULTIFAMILY CONSTRUCTION

The first element of balanced design should be two-hour fire-rated concrete and masonry construction. Since this form of protection is not dependent upon water, mechanical or electrical systems, or human response, it is described as passive protection, staying in place even when other systems fail. The structure should then be supplemented with properly designed and installed automatic suppression and detection systems. If the suppression system should fail, the structural fire resistance is still available as a last line of defense.

Studies indicate concrete and masonry compartmentation should be used instead of other types of construction, because of its long-term economical benefits.[20, 21] It is the key to insurance savings, since the insurance industry does not recognize gypsum wallboard assemblies in the same favorable rating category as concrete and masonry. Other factors such as reduced maintenance costs, increased durability, and greater equity buildup further contribute to the concrete and masonry advantage. There are also indications of higher occupancy rates, which means maximized rental income. Cumulatively, these savings over the life of a building can offset initial costs of sprinkler and detection systems many times over. In effect, concrete and masonry construction makes the balanced design concept work.

CONCLUSIONS

1. Loss of life to fire in North America still remains unacceptably high. Previous gains in reducing fire losses in the United States and Canada have now reached a plateau.
2. Building codes must make a stronger statement for property protection by requiring buildings to be constructed with increased structural fire resistance.
3. Rational design procedures, using real-world fire curves, provide evidence that one-hour dwelling-unit separations in multifamily housing are inadequate.

4. A balanced design concept of fire protection consisting of two-hour fire-rated concrete and masonry compartmentation and automatic suppression and detection systems is needed if the future North American fire-loss record is to improve.
5. Concrete and masonry compartmentation between multifamily dwelling units should be the first consideration in a balanced design approach to firesafety because (1) it provides passive protection, staying in place even when other systems fail and (2) its long-term savings can offset the initial costs of suppression and detection systems necessary to complete the balanced design.

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Organizations represented on the CONCRETE AND MASONRY INDUSTRY FIRESAFETY COMMITTEE

BIA	Brick Institute of America
ESCSI	Expanded Shale, Clay and Slate Institute
NCMA	National Concrete Masonry Association
NRMCA	National Ready Mixed Concrete Association
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