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A COST-EFFECTIVE RISK-ASSESSMENT MODEL FOR EVALUATING FIRE SAFETY AND PROTECTION IN CANADIAN APARTMENT BUILDINGS

by

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SUMMARY

A description is given of a stochastic system model that was developed to represent the dynamic interaction between human behaviour, and fire growth and spread in multi-storey apartment buildings in Canada. The effects of the smoke and fire spread are calculated in terms of two performance parameters; namely the expected risk to life and the fire-cost expectation. These performance parameters are used to appraise the cost-effective provisions of fire safety and property protection in apartment buildings. The system model can be used to appraise (1) whether existing code provisions provide consistent levels of risk and (2) the cost-effectiveness of both existing code provisions and possible alternative design strategies.

INTRODUCTION

In recognition of the potentially severe consequences of fire in buildings, communities have decided to control the design and use of buildings through the promulgation of rules and laws. Building codes have undergone a continual revision process in an attempt to reflect advanced techniques in construction technology and in safety, health and welfare requirements. The evolutionary nature of the development of building codes has tended to result in excessive conservatism with evidence suggesting that such codes are not optimal in the interest of the society they serve.

The objective of absolute protection of life and property from fire in the built environment is realistically unattainable or prohibitively expensive. Alternatively, little expenditure on fire prevention will result in levels of life loss that will be unacceptable to the community. Between these extremes will exist a set of cost-effective solutions, in which the expenditure on fire safety and protection measures will produce levels of life safety and property loss that are acceptable to the community.

The broad objective of the research reported herein was to develop a methodology that could be used to rationally appraise the cost-effective provisions of fire safety and property protection in Canadian apartment buildings. This methodology would be used by code authorities and other users of building codes to appraise both current building code provisions, and alternative code provisions. This information can also be used as the basis for future code revisions.

The system model described here is based on a similar model that was developed to appraise the cost-effective provisions of fire safety and property protection in Australian office buildings[1, 2]. The details of the system model and the subsidiary models were described in Reference 1, whereas the results of the application of the model to office buildings were described in Reference 2. In this paper, the details of the complete system model and the subsidiary models will not be repeated. To show how some of the subsidiary models work, only those related to the evaluation of the life safety performance will be described.

For this research, major consideration was given to those factors which are currently the subject of

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regulatory control or which could be readily incorporated within the ambit of regulatory control. Consideration was given to expected occupant mobility and familiarity of buildings as they affect the evacuation of occupants from apartment buildings. The level of manually operated fire services within buildings, and the availability of fire department services was assumed to reflect the current level of services provided.

SYSTEM MODEL

Modelling Approach

The precise level of protection afforded to occupants and property from fire spread in apartment buildings is difficult to quantify because of the complexity of, and interaction between, fire growth and spread, fire detection and warning, fire suppression and protection techniques, and human behaviour. To represent these interactions for multi-storey apartment buildings, a system model was developed. The system model is composed of a number of subsidiary models which are of the stochastic state-transition type; deterministic models were employed only in those cases where the factor being modeled was considered to have little, or no, or common influence on existing or potential design factors that were investigated. The structure of the system model will permit subsequent updating of the individual subsidiary models should additional information or data become available.

It should be pointed out that, as in many risk assessment models, certain assumptions and approximations were made in the mathematical modelling due to the lack of a sufficient data base or information. Because of this, the results obtained from the present apartment model can be regarded only as estimates of reality. Under such circumstances, the proper use of the apartment model is for code equivalency comparisons of alternative fire protection designs. Until such time as the model is further developed, it is not suitable for risk assessments where the design criterion is based on achieving an acceptable level of risk on an absolute basis.

Decision-making Parameters

For this research it was decided to consider the level of safety afforded to occupants of buildings and to the associated costs of providing for such safety. That is, a study based on the cost-effectiveness approach was adopted.

To facilitate the decision-making process, the performance of any building design was characterized in terms of two decision-making parameters, namely expected risk to life, and fire-cost expectation.

The risk to life resulting from fire in apartment buildings was quantified in terms of the "expected risk to life" parameter for occupants of the building over the life of the building. This approach, which avoided difficulties associated with assigning monetary value to human life, provided a more explicit estimate of the expected number of deaths resulting from fire in apartment buildings.

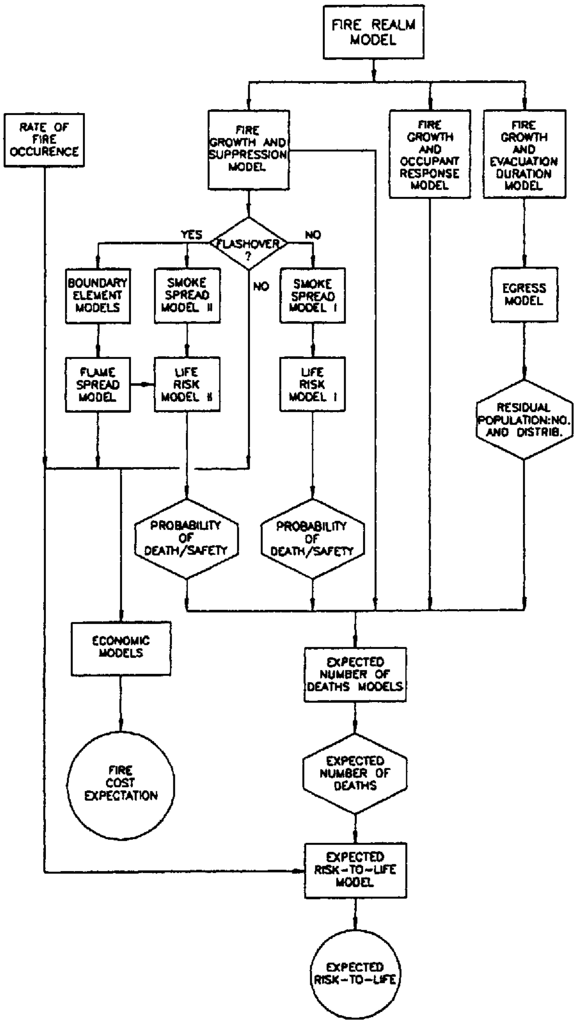


Figure 1. Cost-effective System Model.

The fire-cost expectation decision-making parameter incorporates various direct costs and losses which are listed below:

- Capital cost for the provision of active and passive fire safety and protection facilities,
- Maintenance and inspection costs associated with active fire safety and protection facilities,
- Expected monetary losses resulting from fire spread in apartment buildings.

The present worth of the sum of these components is referred to as the "fire-cost expectation."

System Model Description

A brief description of each of the subsidiary models of the system model (shown in Figure 1) is given in Table 1.

As noted in Table 1, only some of the subsidiary models of the system model are described in detail in this paper. This is because the details of the complete system model and the subsidiary models have been described earlier in Reference 1. To show how some of the subsidiary models work, only those related to the evaluation of the life safety performance will be described. These include the fire growth and occupancy response model, the smoke spread models, the life risk models, and the expected number of death models.

The system model is based on the proposition that prior to the occurrence of the critical event, which is defined to be flashover in the apartment of fire origin, evacuation of the building is possible. The evacuation process is evaluated using the Egress Model. The durations available for occupant evacuation are determined from the Fire Growth and Evacuation Duration Model. It was assumed that the time-dependent evacuation process occurs unimpeded by the effects of fire. That is, prior to the critical event of flashover in the apartment of fire origin, fire is contained within the apartment of fire origin. At the occurrence of the critical event, it was assumed that the time-dependent evacuation process ceases, and that the residual population remaining in the building at flashover is then subject to the effects of instantaneous smoke spread, and possible flame spread, conditions throughout the building. Thereafter, a time-independent evacuation process can occur, depending on the states of smoke spread and flame spread. The probability of death and safety for the residual population remaining at the critical event is calculated using Life Risk Models I and II.

CODE EQUIVALENCY APPROACH

There are many difficulties in attempting to compare the estimated risks for a particular hazard derived from mathematical models, with absolute levels of risk that are deemed to be acceptable. As a consequence, it was decided to undertake a process of code equivalency. Using this approach, the mathematical system model is initially applied to building designs that are in conformity with the National Building Code of Canada (NBCC). The resultant risk-to-life values derived from such an analysis are used to provide benchmark values for the purpose of comparing the predicted performance of possible alternative design strategies. These benchmark values are referred to as "code-imputed expected risk-to-life" values.

The code-imputed expected risk-to-life values may be considered as both a convenient and approximate measure of what the community perceives as being reasonable levels for risk-to-life. However, the code-imputed expected risk-to-life values cannot be taken as implying that the present levels of risk they represent are acceptable, as either reduced or higher levels of risk may be justified or sought. Accordingly, the code-imputed values for expected risk-to-life values provided a convenient reference or benchmark for which to compare the performance of other designs.

DECISION-MAKING CRITERIA

On the basis of the previous discussion, and for the purpose of appraising the performance of alternative design strategies, the following criterion was used to identify those alternative design strategies which are considered equivalent to, and more cost-effective than, the current code provisions. The decision-making criterion is that for an alternative design to be considered accept-

Table 1. Subsidiary models of the system model

(a) **Fire Realm Model**
A Multi-realm, Fire Realm Model is used for the purpose of defining the various states of fire growth.

Associated Models are:
- Fire Growth and Suppression Model
- Fire Growth and Occupancy Response Model
- Fire Growth and Evacuation Duration Model.

(b) **Fire Growth and Suppression Model**
This model is used to calculate the probability of fire extinguishment, or containment, at various states of fire growth; consideration is given to the effects of intervention by various suppression techniques.

(c) **Fire Growth and Occupancy Response Model**
This model is used to calculate the probabilities of the occurrence of events at which occupants become aware of, and decide to respond to the presence of fire by attempting evacuation from the building. The Fire Growth and Occupant Response Model is described later in this paper.

(d) **Fire Growth and Evacuation Duration Model**
This is a deterministic model which is used to calculate the durations that are available for occupants to attempt evacuation following their decision to respond to the presence of fire.

(e) **Flame Models**
Two flame models are used, namely:

Boundary Element Models. These models are used to calculate the probability of failure of structural and non-structural boundary elements of construction when subject to fully-developed fires.

Flame Spread Model. This model is used to calculate the probability of flame spread between any two separated volumes in a building. Data for this model is obtained from the boundary element models.

(f) **Economic Models**
These models are used to calculate the fire-cost expectation. The fire-cost expectation consists of the summation of the expected monetary loss, which is the monetary loss caused by fire spread in buildings, and the capital and annual costs associated with passive and active fire protection facilities.

(g) **Life-safety-performance Model**
Collectively, the Life-safety-performance Model is used to calculate the expected risk-to-life value for occupants of apartment buildings. This model is composed of a number of interrelated models, namely:
- Fire Growth Models
- Egress Model
- Smoke Spread Models
- Life Risk Models
- Expected Number of Deaths Models
- Expected Risk-to-life Model.

(h) **Egress Model**
The Egress Model is a deterministic model used to calculate the number of occupants that are safely evacuated from a building, and also the residual population (and distribution thereof) remaining in the building at the occurrence of a critical event. The critical event is defined in relation to the Fire Realm Model.

(i) **Smoke Spread Models**
The Smoke Spread Models are used to calculate the probability of smoke spread from the apartment of fire origin to other volumes in the building. Smoke Spread Models I and II are applicable to pre-flashover and post-flashover fires respectively. The Smoke Spread Models are described later in this paper.

(j) **Life Risk Models I and II**
The Life Risk Models are time-independent stochastic, state-transition models that are used to calculate the probabilities of death (and safety) for the residual population. Life Risk Models I and II are applicable to pre-flashover and post-flashover fires respectively. The Life Risk Models are described later in this paper.

(k) **Expected Number of Deaths Models**
These models are used to calculate the expected number of deaths in a building. The models are based on consideration of the calculated probability of death, for pre-flashover and post-flashover fires, and apply to the residual population remaining in the building at the occurrence of the critical event. The Expected Number of Deaths Models are described later in this paper.

(l) **Expected Risk-to-life Model**
This model is used to calculate the expected risk-to-life value for occupants of apartment buildings.

able, the fire-cost expectation shall be minimized subject to the constraint that the expected risk-to-life value shall be similar to, and preferably lower than, the code-imputed expected risk-to-life value for a particular apartment building configuration under consideration.

It is recognized that procedural and non-technical considerations can, and do, have a significant role in the decision-making process. Accordingly, it is intended that whilst the results developed by the research will assist in the identification of cost-effective alternative design strategies which are considered equivalent to the code provisions, the results must be regarded only as an aid to the decision-making process.

APARTMENT BUILDINGS CONSIDERED

Generic Building Configuration

It was decided to simplify the layout of apartment buildings and consider common or generic apartment buildings which have two categories of floor-plan layouts, namely level of fire origin, and levels other than level of fire origin. On the level of fire origin it was further decided to consider two types of apartments, namely the apartment of fire origin; this is denoted as *AF*, and the remaining apartments on the level of fire origin, which were aggregated into a single apartment; this is denoted as $\overline{AF}$.

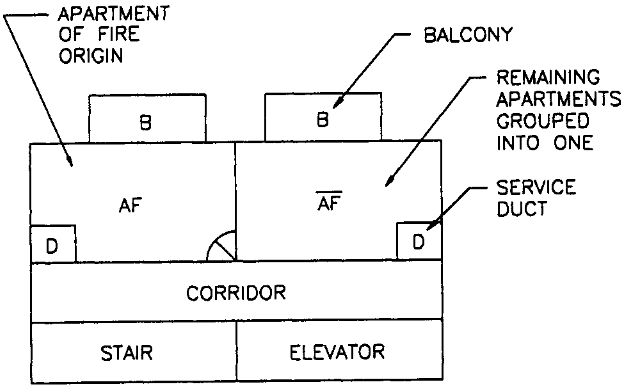
The assumed floor plan layout of the generic apartment building is shown in Figure 2.

Building Design Features

The system model is used to define the cost-effective performance of generic apartment buildings that are characterized by various design features. It is necessary to specify the design features included in Table 2.

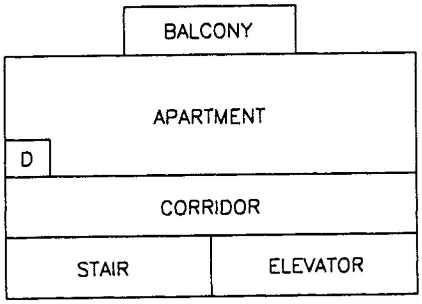
FIRE GROWTH AND OCCUPANT RESPONSE MODEL

The Fire Growth and Occupant Response Model is used to develop estimates of the probability of events at which occupants decide to evacuate a building before the assumed arrival of the fire in occupied apartments. In recognition of the difficulties associated with modelling human response to fire, it was decided to develop a simple model for occupant response to fire. The decision by occupants to evacuate a building was assumed to be uniquely related to the occurrence of various states of fire growth in the apartment of fire origin (see Figure 3), and the detection of fire (by various devices), and the issue and receipt by occupants of various warning signals. Occupant response models were developed for occupants located in the apartment of fire origin, an apartment of non-fire origin on the level of fire origin, and apartments not on the level of fire origin. Further, models were developed for states defined as "occupants awake" and "occupants asleep" at the commencement of a fire.



A) ASSUMED PLAN ON LEVEL OF FIRE ORIGIN

NOT TO SCALE



B) ASSUMED PLAN ON LEVELS OTHER THAN LEVEL OF FIRE ORIGIN

Figure 2. Generic Apartment Building Layout.

The Fire Growth and Occupant Response Model is based on the assumption that for occupants to respond to fire by evacuating a building, three consecutive events must occur: fire detection,

Table 2. Building Design Features

(a) Geometric Factors
- Number of storeys
- Floor area per storey
- Number of apartments per storey
- Size of openings in the apartments
- Presence or absence of balconies
- Number and dimensions of stairwells.

(B) Passive Fire Protection of Elements of Construction
- Fire-resistance rating of
  - floors
  - service ducts
  - stair and elevator shafts
  - apartment entrance door.

(c) Active Fire Protection
- Sprinkler system
- Stairwell pressurization system
- Smoke ventilation system.

(d) Fire Detection

Possible models of detection are
- Smoke detectors
- Sprinkler system
- Manual alarm system.

(e) Type of Alarm

Two general types of alarms can be considered, namely:
- Local alarm - Installed in each apartment and giving an alarm in the apartment of fire origin only (applies to smoke detection only).
- Central warning system - If a central warning system is installed, does this system issue
  - alarm only, or
  - voice communication

  throughout the building.

(f) Occupant Loading Density

Average number of occupants per apartment during those times when all occupants are defined to be either awake or asleep.

warning, and response. The transition probability model that is used to define whether occupants decide to evacuate the building is as follows:

$$\text{P(Detection, Warning and Response)} = \text{P(Detection)} \times \text{P(Warning)} \times \text{P(Response)}$$

It was further assumed that:

(a) at any particular state of fire growth, g, detection by a given detection system is independent of other methods of detection at that same state of fire growth,

(b) the process of detection, warning, and response can only occur at defined states of fire growth, and not at any point in the realm of fire growth between adjoining states of fire occurrence (for example, the process can only occur in one of the four states as shown in Figure 3 but not in between),

(c) the process of detection, warning, and occupant response is an instantaneous event, and

(d) the process of detection, warning, and response can only occur at States I, II and III. Occupant response at State IV is not considered as it was assumed that there is instantaneous spread of smoke and possibly flame at the critical event which is State IV.

SMOKE SPREAD MODELS

The smoke spread models are used to calculate the probability of smoke spread to different parts of apartment buildings. The calculated probabilities of smoke spread form part of the input to the other life-safety-performance models which calculate the expected risk-to-life parameter. Two smoke spread models are used. Smoke Spread I is for pre-flashover fires in the apartment of fire origin, whereas Smoke Spread II is for post-flashover fires.

There are no simple mathematical models available that can calculate the probability of smoke spread to a large number of compartments. Instead, simple probabilistic models, developed at

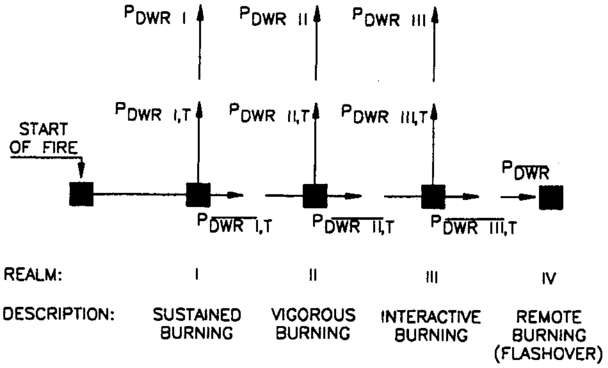


Figure 3. Fire-growth and Occupant Response Model - General.

the National Research Council of Canada (NRCC), were used. These models were deduced from smoke spread test data conducted in a 15-storey hotel[3] and on a study of elevator shaft pressurization at NRCC's ten-story smoke tower[4].

The series of tests conducted at the hotel simulated various building conditions and fire types, including pre-flashover or post-flashover fires, door open or closed, corridor ventilation on or off. The tests, however, were all conducted during the winter months when there was stack effect due to heating. To compensate for the effect of air movement, as a result of heating in the winter or cooling in the summer, a correction factor is used. The correction of ±10% to the probability values is used depending on whether the air movement enhances or suppresses the smoke spread.

Better smoke spread models may be available in the future, and the present system model allows easy replacement of the current sub-models. In the meantime, the smoke spread models are considered adequate.

LIFE RISK MODELS

The Life Risk Models are time-independent stochastic state-transition models which are used to calculate the probabilities of death (and safety) for the residual population. The residual population is calculated using the Egress Model. Life Risk Models I and II are applicable to pre-flashover and post-flashover fires respectively. Results obtained from Life Risk Models I and II form input to the Expected Number of Death Models which are described later in this paper.

The Life Risk Models (LRM) provide for the inclusion of two general categories of smoke control systems: smoke ventilation systems (denoted as SV) include a variety of means that attempt to control (prevent) the movement of smoke in a building and stair pressurization system (denoted as SP). Examples of ventilation systems include centralized or individual floor-by-floor air-handling plant (used in a fire mode) to ventilate smoke to atmosphere.

Various smoke control systems are described in the National Building Code of Canada. If no smoke ventilation facilities are incorporated in a building, then the variable SV is set at zero. If no stair pressurization facilities are incorporated in a building, then the variable SP is set to zero.

When a stair pressurization system is deemed not be effective $\overline{SP_{EF}}$, it was assumed for these models that this is equivalent to those situations where either there is no stair pressurization system installed in the building, or alternatively, where an installed stair pressurization system does not operate; this latter condition is denoted by $\overline{SP}$.

Provision is made in the LRM for balcony refuge for occupants in the event of fire. If no balconies are incorporated in the building design, then the smoke spread to the balconies, at all levels, is set equal to unity; that is, $SS_B = 1.0$.

There are a number of similarities between Life Risk Models I and II; for example, both models consider the effects of smoke spread on life safety. However, LRM II has been structured to consider the effects on life safety of flame spread in addition to smoke spread effects.

In addition to the above two generalized LRM, separate sub-models were developed for occupant conditions denoted as awake or as asleep.

The LRM's are used to calculate the probabilities of occupant safety and death for the residual population remaining in the building at the critical event, for fire scenarios that are classified as pre-flashover fires, and post-flashover fires.

EXPECTED NUMBER OF DEATHS MODEL

The Expected Number of Deaths (END) Models are used to calculate the expected number of deaths for the residual population in the building at the occurrence of the critical event (flashover) for the case of fire starting in a given apartment. The Expected Number of Deaths Model consists of two sub-models; namely END Model I, and END Model II.

END Model I is the basic model which is used to calculate the expected number of deaths by using, as input, the results obtained from other models in the system model. There are two END Models I; i.e., occupants awake at the commencement of the fire, and occupants initially asleep at the commencement of the fire.

Further, models were developed for both apartment occupants and stairway occupants. The equation which was developed for the expected number of deaths has been defined previously[1].

The Expected Number of Deaths (END) Model II represents an application of END Model I to each of the following cases:

- Opened or closed door of apartment of fire origin to corridor
- External environmental conditions
  - Winter
  - Summer
  - Fall/Spring.

Consideration is given to the apartment-corridor door being open or closed, as each condition has a significant effect on both smoke spread and flame spread through the apartment building, and also the times of occurrence of the various states of fire growth (which will therefore control the evacuation duration). Consideration is given to different external environmental conditions as they can also have a significant effect on smoke spread through the building.

RESULTS

The present risk-cost assessment model is still in the development stage and is therefore not yet fully operational. As an example to show its potential application in the assessment of cost effectiveness of fire safety provisions, a simple case of a three-storey apartment building is considered.

The three storey apartment building is assumed to have six apartments on each floor and have two stairwells. In the present system model, the apartments and stairwells are grouped, as was discussed earlier under Apartment Buildings Considered, into a simple layout of Figure 2. It is also assumed that there are 54 people living in the building. For such a building, the present National Building Code of Canada requires the installation of a central alarm system, but not sprinklers or stairwell pressurization. To determine the cost effectiveness of these various fire protection measures, twelve cases were considered encompassing all possible combinations of these three fire protection options plus the option of a higher reliability central alarm system (higher detection and warning reliabilities). The results are tabulated in Table 3.

In Table 3, the expected risk-to-life (ERL) is defined as the expected number of deaths over the lifetime of the building divided by the population of the building and the design life of the building. The fire cost expectation (FCE) is the expected fire cost divided by the total cost of the building. In Table 3, the numbers have been normalized by ERL = 1.9×10^{-4} and FCE = 4.62×10^{-2}, which are the computed results for the reference building code option (no stairwell pressurization, no sprinklers but with central alarm). The results in the Table show that, first of all, stairwell pressurization in such a low-rise building does not reduce the risk, but will increase the protection cost. This is probably because in such a low-rise building with a low evacuation time, the chance of being trapped in the stairwell is very low. The effect of stairwell pressurization may be more pronounced in taller buildings.

For the case of no stairwell pressurization in Table 3, the option of a central alarm only is the reference option as required by the building code. The Table shows that this reference option will reduce the risk from the no alarm option but will increase the protection cost. Comparing with this reference option, both the option of sprinklers only and the option of a central alarm and sprinklers will reduce the risk but will incur higher protection costs. The option of a higher reliability alarm only is the most cost effective. This option will reduce the risk but will not increase the cost compared with the reference option (in the present system model, the cost for a higher reliability central alarm is assumed to be about the same as that of a regular central alarm). The option of both a higher reliability central alarm and sprinklers will reduce the risk further, when compared with the option of a higher reliability central alarm only. The option of a higher reliability central alarm system and sprinklers has little effect on the risk to life compared with the option of a central alarm system and sprinklers. This is because the risk has already been reduced substantially in buildings containing regular central alarms and sprinklers. The Table shows how different options can provide various levels of risks, but at different costs.

It is interesting to note from the present results that the effectiveness of fire protection measures in reducing fire risk is not as dramatic in apartment buildings as in office buildings. The present results show that various active fire protection measures can reduce the risk from no active protection in a three-storey apartment building by a factor of about 1.7 to 3.2. A previous study[2] shows that in an office environment, similar fire protection measures can reduce the risk by one to two orders of magnitude. This apparent difference is the result of the fact that in apartment buildings there is inherently more compartmentation and fewer people exposed to the fire in the zone of fire origin.

CONCLUSIONS

To represent the complex interactive process between human behaviour and fire dynamics in apartment buildings, a series of stochastic state-transition models, and inter-related deterministic models were developed. These models were integrated into a system model which is used to calculate the effects of smoke and flame spread in multi-storey apartment buildings. The effects of fire spread are calculated in terms of two performance parameters; namely the expected risk to life (ERL), and the fire-cost expectation (FCE).

The use of mathematical models to calculate the expected effects of fire spread in buildings necessarily involves the introduction of many assumptions, both of a conceptual and numerical nature. The present system model is classified as being intermediate between a simplistic model and an overly complex model. The system model was developed cognizant of the data that is available or which could be readily obtained; statistical data is used where appropriate.

The net effect of the assumptions is expected to give rise to a conservative estimate for the calculated expected risk-to-life value for a particular building design. However, the significance of this is diminished because the decision criterion that was adopted is based on the establishment of equivalency of expected risk-to-life values, rather than isolated consideration of an absolute value for the risk to life.

The system model can be used to:

- Appraise existing code requirements and proposals to change code requirements and to investigate whether consistent cost-effec-

Table 3

Normalized* results for a three-storey apartment building
with various combinations of fire protection measures

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

*The numbers have been normalized by ERL = 1.91×10^{-4} and FCE = 4.62×10^{-2}, which are the computed results for the reference building code option (no stairwell pressurization, no sprinklers but with central alarm).

tive performance is provided by the various code requirements.

- Identify alternative design configurations that give equivalent performance to the existing code requirements (in terms of ERL values), but at a lower net cost (FCE value); that is, the alternative designs are more cost-effective.
- Provide a performance-based approach to design for fire. For example, designers can be permitted to use any design configuration, provided the design can be shown to provide the life safety performance (ERL values) which are not greater than obtained for the code-specified design requirements.
- Guide future research efforts into those areas which are identified as having a significant impact on the cost-effective provision of fire safety and protection.

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NOMENCLATURE

AF	Apartment of fire origin
$\overline{AF}$	Apartment of non-fire on the level of fire origin.
DWR	Detection, Warning and Response
EF	Effective-used for stair pressurization
g	The realm of occurrence in the Fire-growth and Suppression Model; I, II, III, IV, V or VI
$P[x]$	Denotes the probability of an event, x, occurring
SP	Stair Pressurization System, or the system is working and operating according to design requirements
SS_x	Probability of Smoke Spread from the apartment of fire origin to a destination volume, x
SV	Smoke Ventilation System, or the system is working according to design requirements, and exhausting smoke from the building
T	Transition, to indicate transitional probability

Notes:

(1) I, II, III, IV, V, VI States in Fire-Growth and Suppression Model.

(2) Bar over a probability symbol, such as DWR, indicates complement of the probability term.

REFERENCES

1. Beck, V.R., "A Cost-Effective Decision-Making Model for Building Fire Safety and Protection," *Fire Safety Journal*, **12(2)**, 1987, pp. 121-138.
2. Beck, V.R. and Poon, S.L., "Results from a Cost-Effective Decision-Making Model for Building Fire Safety and Protection," *Fire Safety Journal*, **13(2-3)**, 1988, pp. 197-210.
3. Tamura, G.T. and Manley, P.J., "Smoke Movement Studies in a 15-Storey Hotel," *ASHRAE Transactions*, **91**, Part 2B, 1985, pp. 1237-1253.
4. Tamura, G.T. and Klote, J.H., "Experimental Fire Tower Studies on Mechanical Pressurization To Control Smoke Movement Caused by Fire Pressures," *2nd International Symposium on Fire Safety Science*, Hemisphere Publishing Co., 1989.